Appendix A

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Reverse Engineering using Close Range Photogrammetry for Additive Manufactured Reproduction of Egyptian Artefacts and other O*bjets d'art.*

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ABSTRACT

Photogrammetry has been in use for over one hundred and fifty years. This research considers how digital image capture using a medium range Nikon Digital SLR camera, can be transformed into 3D virtual spatial images, and together with additive manufacturing (AM) technology, geometric representations of the original artefact can be fabricated. The research has focused on the use of photogrammetry as opposed to laser scanning (LS), investigating the shift from LS use to a Digital Single Lens Reflex (DSLR) camera exclusively.

The basic photogrammetry equipment required is discussed, with the main objective being simplicity of execution for eventual realisation of physical products. As the processing power of computers has increased and become widely available, at affordable prices, software programs have improved, so it is now possible to digitally combine multi-view photographs, taken from 360°, into 3D virtual representational images. This has now led to the possibility of 3D images being created without LS intervention.

Two methods of digital data capture are employed and discussed, in acquiring up to 130 digital data images, taken from different angles using the DSLR camera together with the specific operating conditions in which to photograph the objects. Three case studies are documented, the first, a modern clay sculpture, whilst the other two are 3000 year old Egyptian clay artefacts and the objects were recreated using AM technology. It has been shown that with the use of a standard DSLR camera and computer software, 2D images can be converted into 3D virtual video replicas as well as solid, geometric representation of the originals.

KEYWORDS: photogrammetry; reverse engineering; additive manufacturing; 123D Catch; PhotoScan; Studio Pro4.

INTRODUCTION

In 1860 Lenticular invented the Stereoscope, a device through which a 2D picture or photograph could be viewed as a 3D image. Thus the idea of using photographs to create 3D images is not new. Since the invention of the first digital camera in 1975 by Sasson, an engineer working for Eastman *Kodak*® [1], these cameras have developed from the 0.01 pixel of the first camera to 80+ megapixels at the top end of today's professional range. The notion of stitching digital images together has become a reality. Since the late 1990's obtaining digital images from laser scanners (LS) has become the predominant non-invasive method of 3D replication of both large and small buildings as well as objects and artefacts [2]. From the mid 1970's techniques have evolved to *stitch* images to produce photo-mosaics [3, 4] and by the late 1990's commercial computer programs such as Adobe's *Photoshop Elements*® [5] were widely available, being able to *stitch* full colour [3] 2D digital captured photographs together, creating panoramic views of city, sea or landscapes [6]. However, within the last few years, software has become available capable of stitching 70 or more high resolution digital images together to form a virtual 3D representation.

Photogrammetry has been defined by the American Society for Photogrammetry and Remote Sensing (ASPRS) as:

"*the art, science, and technology of obtaining reliable information about physical objects and the environment through processes of recording, measuring and interpreting photographic images and patterns of recorded radiant electromagnetic energy and other phenomena*" [7].

In this paper, it is shown that with the use of photogrammetry, virtual 3D models can be created, without a high level of computer expertise and without the use of relatively expensive or complicated 3D LS equipment. With the use of Autodesk's *123D Catch*® [8] and Agisoft's *PhotoScan Pro*® [9] as primary processing software, high resolution point cloud image data files are

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created, and are then converted by additional software programs such as Netfabb's *Studio Pro4®* [10] to the files needed for additive manufacturing (AM) machines to replicate the photographed item and produce geometric representational models. The use of this technique could contribute to the reproduction, restoration or repair of damaged or broken antiquities by non-invasive methods at modest cost and by lay persons, who are computer literate but not necessarily expert in the use of specialised software or complex laser based scanning technologies.

Barsantia *et al* [11] investigated the different techniques and characteristics of both photogrammetry and LS, but the advantage of photogrammetry is that expensive LS equipment is not used and experienced technicians are no longer required to operate this equipment, since by using a relatively modest DSLR camera, 3D virtual images are obtainable.

MOTIVATION and *RAISON D'ETRE* of RESEARCH

There are 40 software programs claiming to be able to convert 2D digital photographs into 3D virtual images [12]. Several commercial computer software programs are available with a proven and reliable record to "stitch" multi-view photographs together to produce a 3D image. The primary research task investigates how well these software programs convert the digital 2D image into 3D CAD models and ultimately physical AM enabled models, and the results obtained are compared with the original photographed object.

There has been a trend of "hands on" exhibits in museums over the last few years, in order that all members of the public might more readily engage with the collections normally housed behind glass cabinets [13]. To fulfill this need, institutions such as Kendal Museum are interested in exploring potential opportunities from emerging technologies so as to replicate artefacts within their collection, in line with their mission statement:

> *"To safeguard and enhance all of the collections for the benefit of all Museum users, improve the visitor experience, to increase learning opportunities and ensure that the Museum has a sustainable future".*

The Kendal collection was established in 1796, as a *'Cabinet of Curiosities'* While the museum's value is in its collection of original objects, replicas of specific objects have their place. Due to the delicate nature of most objects, they are unable to be handled by the public. Replicas are very useful for handling sessions, especially for school sessions and loan boxes. Loan boxes are often used by rural schools where it is difficult to arrange actual visits to the museum. The school can hire a box of material for a term and undertake practical activities on the school premises using museum resources.

Loan boxes and handling collections often comprise of un-accessioned objects (not in the main museum collection), or if there are large amounts of the same type of material some original material can be used. The loan boxes contain original Medieval and Roman material, but in the case of Egyptian collections it is rare to have an original handling collection. At present the Egyptian schools' loan box is made up of general replicas (not items in the collection), and photocopies of documents and photos. Being able to replicate actual museum collection objects would be of great benefit to teaching in local schools about the Egyptians and the material held in the collection. Replicas, if exact, give the handler a chance to experience the size, texture and weight of objects if they are not able to handle the original object directly.

The relatively cheaper and simpler use of a DSLR camera, at the end of 2013 costing under £400.00, is a great attraction, as with a little training the museum's own staff will be able to replicate many of their artefacts.

Fig.1 **Clay Vase**

Fig.2 **Sobekhotep**

Two objects from the Kendal Egyptian collection were initially chosen: a small vase, about 120mm high x 100mm diameter, (Fig.1), and a solid statuette of Sobekhotep, son of Nehesy, (Fig.2), about 195mm high, which dates to around 1500BC, and is a very important and rare figurine within the Kendal Museum collection.

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 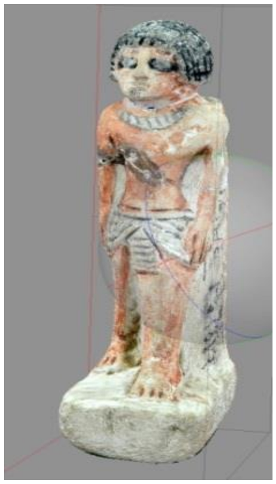

Fig. 3
Textured High Resolution

Fig. 4
Point Cloud Data Images

Figures 1 and 2 are photographs of the actual objects whilst Fig. 3 and 4 are screen shots of the textured high resolution point cloud data images created using Agisoft's *PhotoScan Pro*®, as described in the next section. Photogrammetry can be used as a non-invasive method of image capture for AM geometric representation of *objets d'art*, limited only by the size of the AM machine, but in some cases, if the original model is too big for an AM machine, the CAD models can be sectioned and joined after physical fabrication.

DATA CAPTURE PROCESS

One of the main objectives of the research is concentrating on the ease of reproducing artefacts without complex hardware or software. A mid-range Nikon *D3100*® [14] DSLR camera was used, the digital data obtained being in *.jpg format. A standard fixed focus prime 50mm lens, which has a wide f1.4 or f1.8 aperture and minimum lens distortion and very good depth of field was considered, but a Nikon *18/55mm DX*® auto focus lens was chosen, being directly compatible with the camera and able to automatically refocus around the subject from the many positions and angles encountered. Minimum lens distortion is achieved by keeping to the higher focal length end of 35/55mm on the lens. The disadvantage of this lens as opposed to a fixed lens is that the depth of field is not as good and slower shutter speeds are required as the aperture is not as wide. A resolution of 3456 x 2304 pixels equates to just under 8 megapixels.

The method of lighting and camera positioning for the artefacts were different in each case study, the common factor being that shadowless, flat lighting was required to illuminate all the artefacts as any shadow distorted the image captured and processed by the software. The same was true for any highlights or reflections that the lighting might have caused.

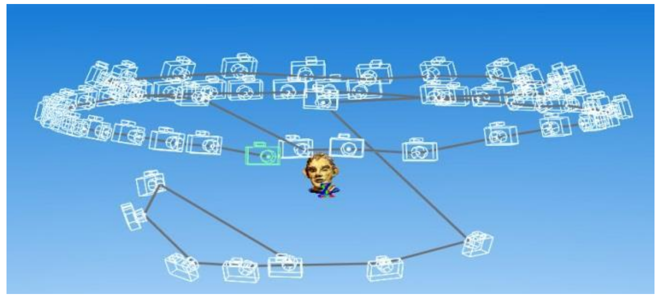

Fig.5 **Multi Camera positions around Clay Head**

The first study, a small modern clay head sculpture, has been included to show a comparative method in both AM printing and data capture. This is a semi glazed painted head measuring 105mm x 95mm, was placed in the centre of a room on a pedestal whilst the camera was moved in a full circle around the object and a digital image captured every 20^{o}. A second and third circle of data images, at a higher and lower elevation of 20^{o} to 30^{o} to the horizontal, was obtained, ensuring that every part of the head was recorded and that a good overlap of images was obtained (Fig.5). The head is seen, arrowed, in the center of Fig. 6.

In addition to the natural daylight, which was softened by translucent window blinds, so as to cut out any glare, two overhead recessed ceiling fluorescent lights, each containing 36watt mini tubes plus two *bip*® fluorescent floodlight units on telescopic stands were used. Each of these had three separate switched 100watt bulbs and white defusing front covers to balance the strong daylight, (Fig.6). It can be seen in Fig.6, that all reflective surfaces in the room were covered. Each tube was "Cool White" equating to Kelvin scale 4000K, whilst the floodlights equated to 5000K. This small difference in colour temperature, known as White Balance in camera terms, was automatically adjusted by the *D3100* camera *"as digital cameras have a far greater capacity to compensate for the varying colours of light"* [15]. Two smaller additional lights were used when a Light Tent was used, these having 100 watt, 5000K fluorescent bulbs.

Fig. 6 **Indoor Open Room setup**

The second method of digital data capture used a collapsible Light Tent, (Fig.7). This was constructed

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specifically for this purpose, from 20mm plastic tubing and suitable angle corners to make a metre square enclosure, covered in white poplin fabric with a front opening. So as to obtain strong contrast between the subject matter that was being photographed, interchangeable Chroma Key [16] backdrops were used, either white or green, depending on the colour of the subject, this contrast can be seen in Fig.2. As seen in Fig.7, the lights were placed outside the tent allowing the fabric to soften the lighting and disperse any shadows.

Fig.7 ***Light Tent*** **set up in Museum workshop**

The artefacts were placed upon a revolving turntable as the camera was static in the horizontal plane, only moving up and down by approx. 30^o in the vertical plane to capture all faces of the artefacts. Depending on the complexity of the artefact the turntable was revolved either 15^o, or for complex or detailed objects, 10^o at a time per exposure, resulting in up to 130 or more digital images.

Of the three case studies discussed in this paper, the first is of the digital data capture of a clay head, which was processed using AutoDesk's *123D Catch*®, a freeware software program, and the high resolution point cloud image data was processed via AutoDesk's internet cloud technology. The returned file was then processed by using Netfabb's *Studio Pro4*® to produce the *.stl file which the Stratasys' *Dimension* ® Fused Deposition Modelling (FDM) machine could accept and use to fabricate the model.

The other two studies used the light tent to digitally capture images from the artefacts from the Kendal Museum, and to process them using the primary processing software Agisoft's *PhotoScan Pro*®. Netfabb's *Studio Pro4*® was then used to produce the *.stl file which the AM machine software read in order to print the replications. The models that were made using this technique were processed on a 3D Systems *DTM* Selective Laser Sintering (SLS) machine, in a plain white Nylon 12 polyamide. Using Mcor's Selective Deposition Lamination (SDL) *IRIS* machine, an additional replication of the figurine, Sobekhotep, was processed in full colour, showing the hieroglyphics that were written on the back and side of the original object.

3D RECONSTRUCTION METHODOLOGY

Method 1 – open room set-up

In 2011, Verhoeven [17] using stereoscopic photography and processing the digital images with *PhotoScan*®, produced a series of virtual 3D images. Because of the many output formats this software can produce, including PDFs, file/image sharing is made easy. It was noted that although *PhotoScan*® claim to be able to process, in theory, a very large number of photographs, in practical terms there is a maximum of approximately 1024 images. Verhoeven records that the relationships between the processing time, speed, quantity and high resolution data, are all interlinked. The more detailed the photogrammetric data, the greater the speed of processor needed with a computation time penalty.

With this research in mind and as described above in the Data Capture section, the first part of the process was the acquisition of the digital data images using the DSLR camera. For the clay head, three attempts were made, gradually increasing the number of images from 40 to 60, which were taken from different angles, encircling and arcing around the object from above and below. This ensured that there was an image overlap of about 15-20%. The images were taken using a mid-range resolution of 4608 x 3074 pixels.

The images were then used to generate three point cloud data sets, in this instance using, *123D Catch*® as the primary data processor. This program used internet web-based cloud services provided by Autodesk to turn the *.jpg processed data, taken from the camera, into either a *.3dp data file, or exported as *.obj or *.dwg files, these being the most common file type for importing into third party software programs. By using *123D Catch*®, a video could be created by selection or rejection of the 60 photographic images in the path the images had taken. The software seamlessly converted the images selected into a moving 3D virtual representation. The returned point cloud image, as seen with another example, (Fig.8), had to be filtered, or cleaned, to eliminate background noise that had been captured along with the original subject, such as other objects or furniture that were in the line of focus when the image was recorded by the DSLR. The data image having been cleaned, it was then exported as an *.obj file and, using a secondary software, *Studio Professional 4*®, a 3D textured mesh was created. This *.stl file was solid, but by hollowing the model, using *Studio Professional 4*®, the amount of material, and therefore its weight, was reduced; this could be in the region of 80% of the mass, making a great difference to the final material cost of AM manufacture.

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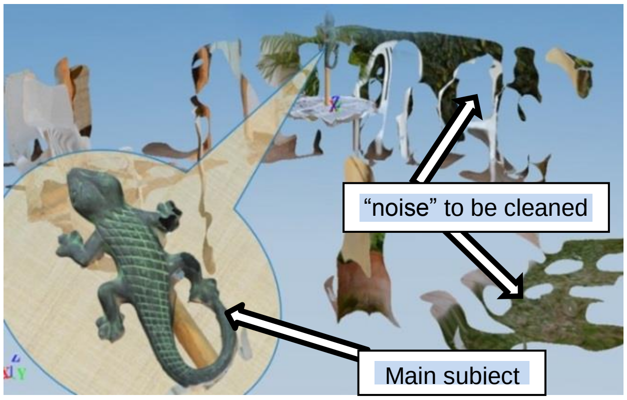

Fig. 8. **Processed Digital Image ready to be cleaned**

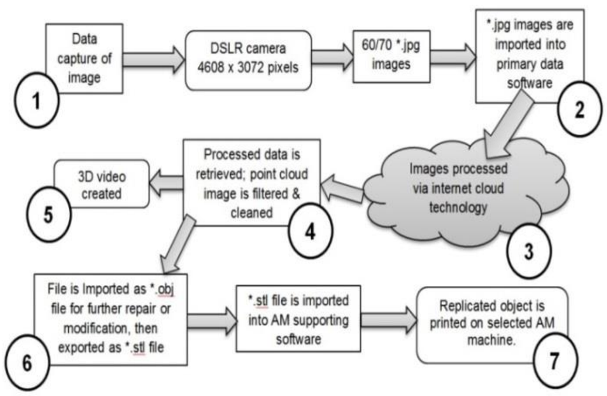

Fig 9. **Digital Process from Image Capture to AM Geometric Representation**

The flow chart, shown at Fig.9, details the seven major processes, in capturing digital data by the use of a DSLR camera, to produce between 60 and 70 *.jpg images, which were then imported into the primary digital software. The individual images could then be checked for quality and sent via internet cloud technology to be processed. As Verhoeven [17] points out, the time taken for this process is dependent on the quantity and quality of the images, (as well as internet speed) but a reduction in either can result, as Nguyen *et al* show [18], in processed image data which is badly degraded.

Method 2 – Light Tent

As seen from Fig.3, in the “open room” system of data capture, the main subject to be photographed was in a static position and the camera was rotated at a distance of approximately 1.2 to 1.5 metres away, as each image was captured. Suitable shadowless lighting was required from all directions ensuring that there was no light spill into or onto the camera lens. With the light tent system of data capture, depending on the artefact’s size, the camera was placed much nearer the subject, which was then rotated on a turntable as each frame was shot. This method allowed for small objects to be photographed with the use of close-up ring lenses which screwed onto the front of the camera’s prime or zoom lens. The screw-on rings should not be confused with macro-lenses, but were used in order to capture more detail. Close-up lens rings were usually labelled +1 to +10 giving a magnification of +0 diopter to +10 diopter.

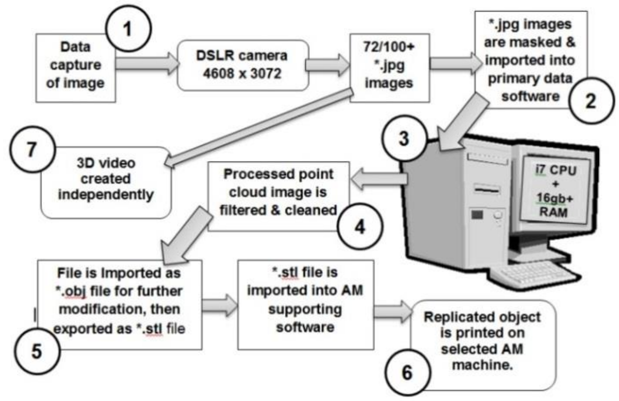

Fig.10
Alternative method of Data Capture using Light Tent

But being much nearer the subject increased the criticality of the focusing and the depth of field became far more critical; the closer the lens to the subject, the shallower the depth of field became. Shooting at f/5.6 to f/9 in an open room became f/18 to f/22+ in a close up light tent. These smaller apertures required increased illumination on the subject or required longer timed exposures.

There were some similarities between the two methods employed, (Fig.10), but the main difference was that the primary processing software used in this method was Agisoft’s *PhotoScan*®, rather than *123D Catch*®. Instead of processing the data via the internet, as long as the host computer had an i5 or preferably i7 CPU with a minimum 12GB memory [19], the data could be processed on the same computer. The software also allowed for a certain amount of control, by the operator, over how the data was processed. Unfortunately the software did not have the facility to convert the captured images into a video. If required, this could be done using a proprietary video processing program.

Before the data was processed each image was masked from the surrounding background with a built in tool in the software (Fig.11). A faint white line can be seen (arrowed in Fig.11) that was added by the software to mask out the background colour.

Experimentation with inter-changeable Chroma Key backdrops was undertaken; this type of backdrop provided a very good contrast between the main subject matter and its surroundings. It was found that the time taken to mask each digital image was considerably speeded up with the use of a Chroma Key and in one instance masking was not used at all as the software was able to process the images automatically without the masking process being activated.

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Fig. 11 **Green background has been masked out of Warrior Figurine**

Once the *.obj file had been obtained the process was the same as for the Open Room method as described above, and the same secondary software was used to produce this type of *.stl file.

CASE STUDY 1. – The Clay Head

The data capture method for the clay head was obtained as described in the previous section using *123D Catch*® software, (Fig.5 and Fig.6), to process the data to obtain the point cloud image. It was then cleaned so as to remove any background noise or clutter, as shown in Fig.8. The resulting processed textured 3D mesh showed minor flaws or distortion which had to be corrected, (Fig. 12). The processed photo-textured 3D mesh image head could have been repaired using *Studio Pro 4*® but by adding and increasing the number of images, with more angled shots and greater image overlap, complex repairs to the point cloud and textured mesh were eliminated. The additional images, once added to the original images, were reprocessed and cleaned.

By selecting the appropriate control in the editing section of *123D Catch*®, a wire frame, wire frame and texture, or texture only model can be obtained. This would facilitate in the model repair if required.

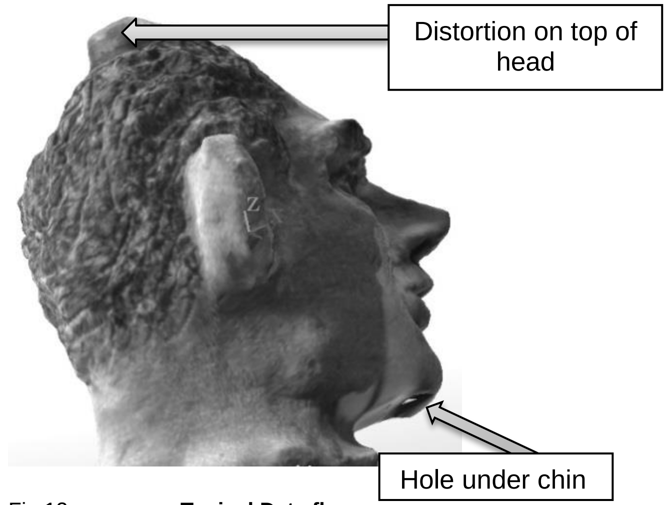

Fig.12 **Typical Data flaws**

The final data file of the head (Fig. 14.) was processed to create an *.stl file using *Studio Pro4*® and then hollowed using the same program. Finally the file was sent to the Stratasys' *Dimension*® FDM machine to create the physical model.

Fig.13 **Original Clay Head** Fig.14 **Final Textured Digital Image**

The model was instantly recognisable as a copy of the original and although the FDM reproduction is a little smaller than the original; (approx. 80%), the tactile surface finish was much smoother than the rough, prickly feel of the original. This could be attributed to similar geometric errors caused by the size of the extrusion nozzle and tool path of the *Dimension*® machine on which it was made, as described by Brooks *et al.*[20].

The Egyptian Collection

The following two objects from the Kendal Museum's collection were both processed in the same way using Agisoft's *PhotoScan Pro*® and the light tent as shown in Fig. 7. The only difference was in the use of the backdrop

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or Chroma Key, and the amount of masking required depending on how complex or simple the shape of each object was.

CASE STUDY 2 and 3.

The Egyptian Vase and Sobekhotep son of Nehesy

There was little difference between these two items in their processing, except that the Chroma Key background for the vase was white and for the figurine it was green. It was thought that the contrasting background would facilitate the masking of each object, preprocessing, by speeding up the time taken to do this manual process; however no conclusive results were obtained. The contrast was perhaps not great enough between the white background and vase, (Fig.15 and 16), and the green background and Sobekhotep, as for the Warrior figurine in Fig.11.

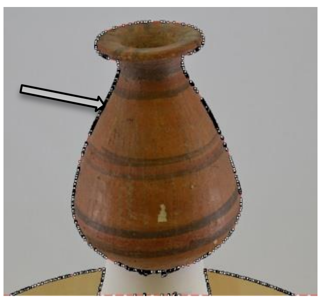


Fig.15 **Pre Masking**

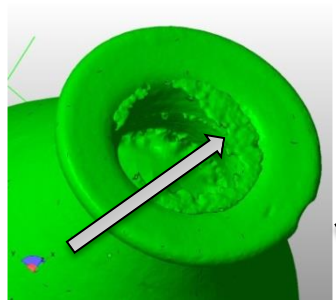
Fig.16 **Post Masking**

However, when a comparison was made between the digital images taken in the light tent (Fig.15 and 16), and the open room set up, there was a significant increase in the time taken to completely mask the main object, because the background of the open room was so cluttered with irrelevant objects and light reflections, (Fig. 17 and 18). The dotted black lines in Fig. 15 and 18, indicate the outlining of the images requiring to be masked (see arrows), a far more complex operation in Fig. 18 than in Fig.15.

Fig. 17 **Pre Masking**

Fig.18 **Complex Masking**

In the case of the vase, there was an amount of cleaning required to the mesh that had been created, inside the neck of the opening as seen in Fig. 19. The small triangulated mesh as seen in the enlargement screen shot in Fig. 20 is deleted using *Studio Pro4*®, and the final process on both objects was the hollowing out or *shelling*, so as to use less material and reduce their weight. A small hole was made in the base of Sobekhotep so that any unsintered powder could be released, on completion, if it was fabricated on a SLS machine. As the original figurine of Sobekhotep was solid with very little indentations or orifices the processing of the object was much simpler.



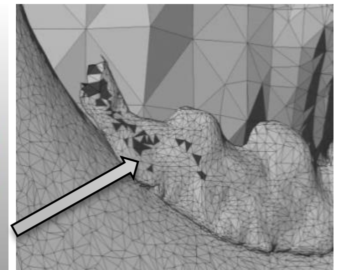


Fig. 19 Fig.20

Wire Mesh to be cleaned

RESULTS & DISCUSION

Although only three case studies are discussed in this paper, they come from a series of over 40 objects, all of which were digitally captured using the Nikon DSLR camera, with the data recorded shown in Table 1. The shutter speeds were in fact averages, as the camera was set to aperture priority, leaving it to automatically adjust the shutter speed. The final resolution of each image was 4608 x 3072 megapixels.

The ultimate objective was to turn the original artefact through the use of a data image file, processed by primary and secondary software, into an *.stl file, which AM machines could read without the loss of definition.

Item		No. of attempts	No. of images	f/ aperture	Focal length mm	Shutter speed
Head	Glazed clay	4	60	f/5.6	55	1/60
Vase	Painted clay	2	143	f/10	48	1/15
Figurine	Painted clay	1	126	f/18	55	1/3

Table 1. **Camera Exposure Data**

The objective was to simplify a process of duplication and replication, to make it more affordable so that it became accessible to a wide range of participants, who until that time had needed much more expensive laser based

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equipment, and complex computer software, to achieve good results. It is hoped this photogrammetrical method will eliminate the need for a high level of specialist CAD knowledge in order to process the data obtained from a midrange DSLR camera, to produce virtual 3D images and physical geometric representational models.

CONCLUSIONS & FUTURE WORK

The three models were manufactured using three different types of AM machines, but these models were processed with the minimum of computation, and there was no CAD reconstruction or alteration to the point cloud image or the photo-textured mesh, only minor cleaning; this eliminated the need for software experts, one of the main objectives of the research. If the point cloud image was too badly distorted or holes in the mesh were present, either a new set of images were taken or manual photo stitching of additional photographic images was undertaken. There are obvious exceptions in which the DSLR camera cannot compete, since it can only capture surface images, as in the example of the MRI scanning of the Egyptian mummy by Steele and Williams [21].

Further research is required to investigate how and whether adverse effects can be minimised or eliminated. One of the main problems that was encountered was reflection of highly glazed surfaces or where there was very little surface detail on a very regular shaped item such as a perfectly round, undecorated, highly glazed single colored bowl. In some cases the silhouettes of the objects themselves were so complex that a greater number of images needed to be taken from a greater number of angles. A series of tests using different lighting levels, camera settings such as focal length and depth of field, lens filters, image quantity, and quality and positioning, was required to find a solution, together with the use of the Chroma Key backdrops with greater masking. A suggested starting point might be: less top lighting, a graduated neutral grey filter, perhaps the use of a Polaroid filter or an aperture setting in the region of f/18 to f/21 and slower shutter speeds to compensate for these smaller apertures, but this will mean longer time needed for collecting the data.

By using the same digital image data sets with other primary data processing software, comparisons will be able to be drawn, and a table of pros and cons of the software used, established.

ACKNOWLEDGMENTS

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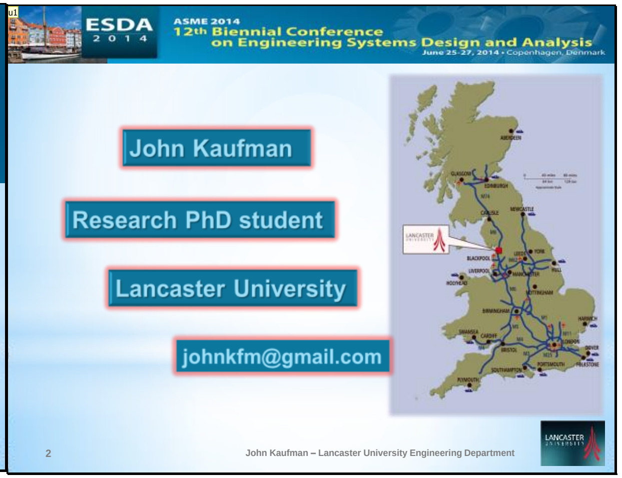

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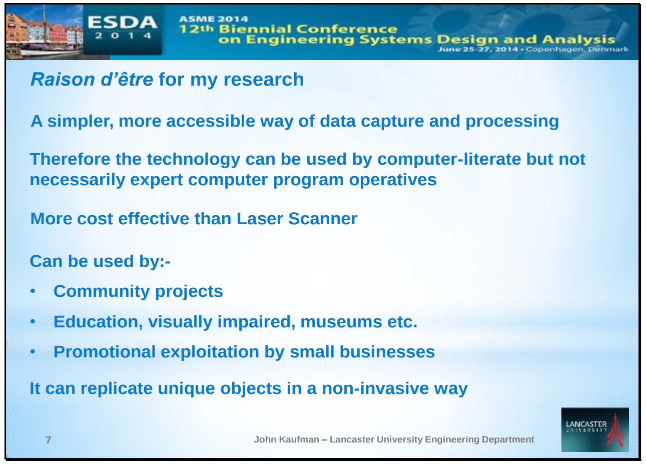

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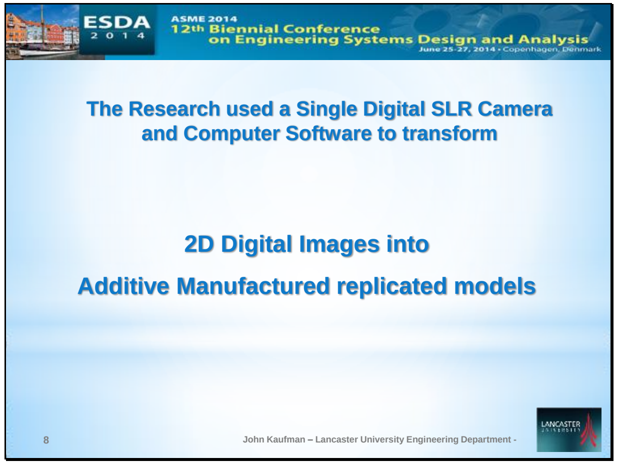

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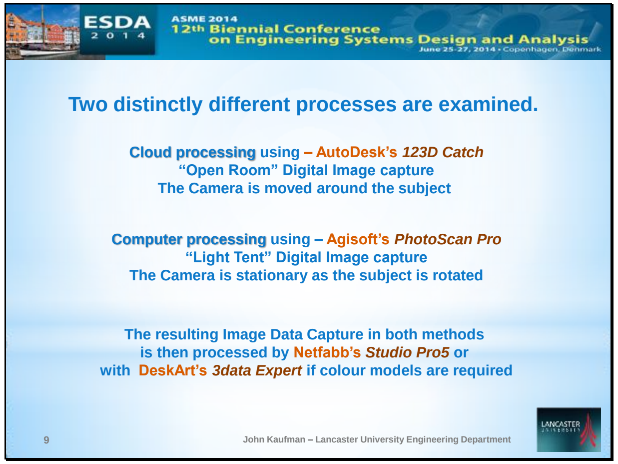

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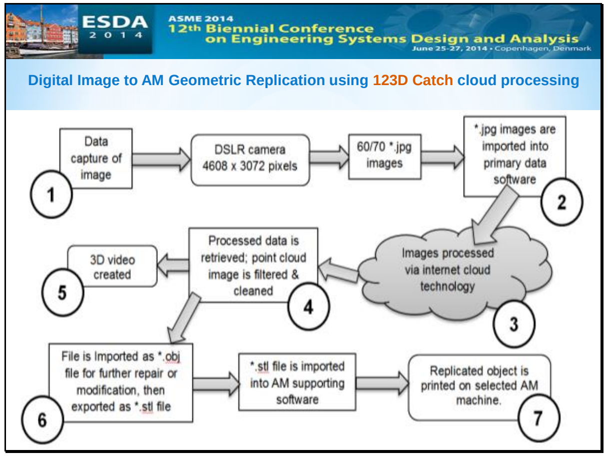

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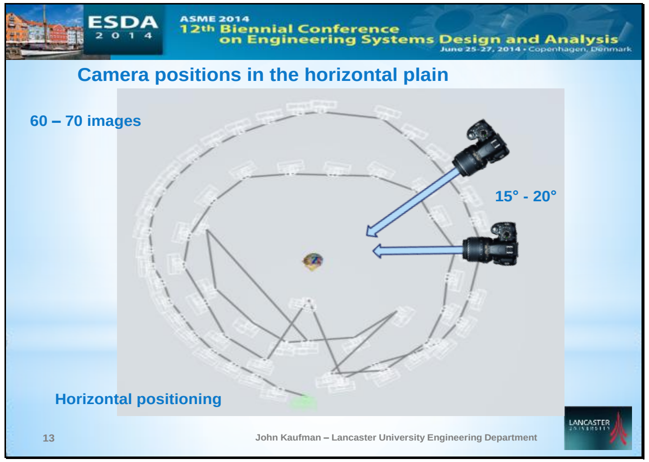

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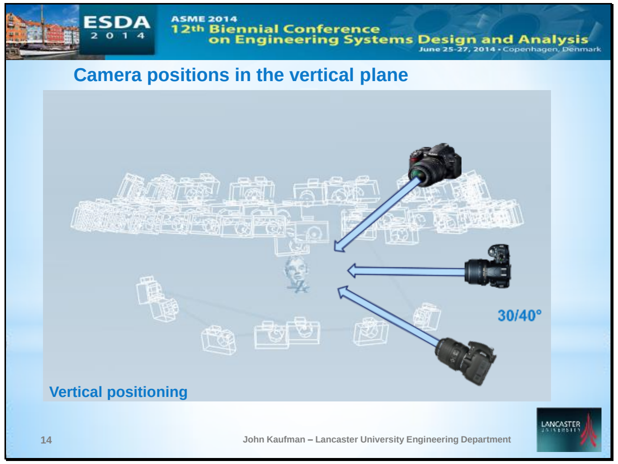

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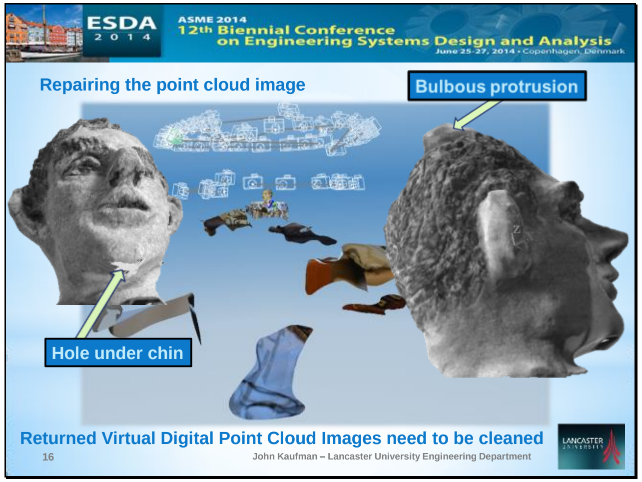

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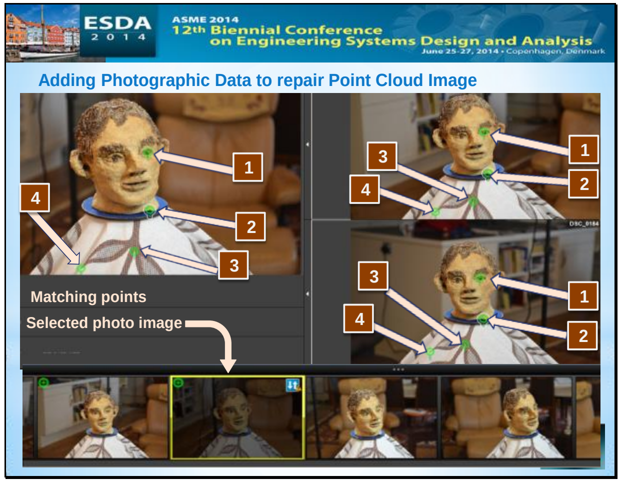

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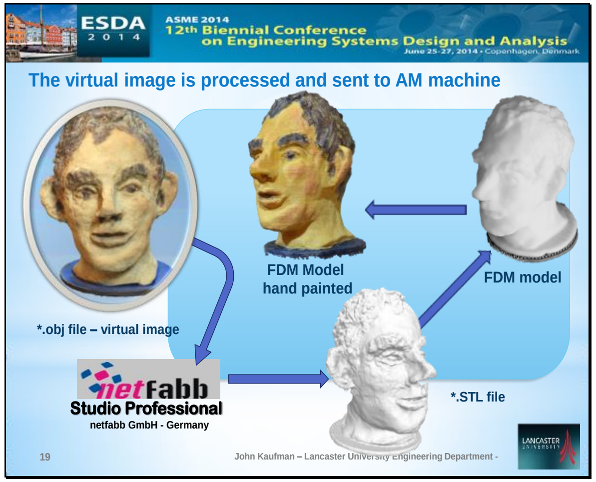

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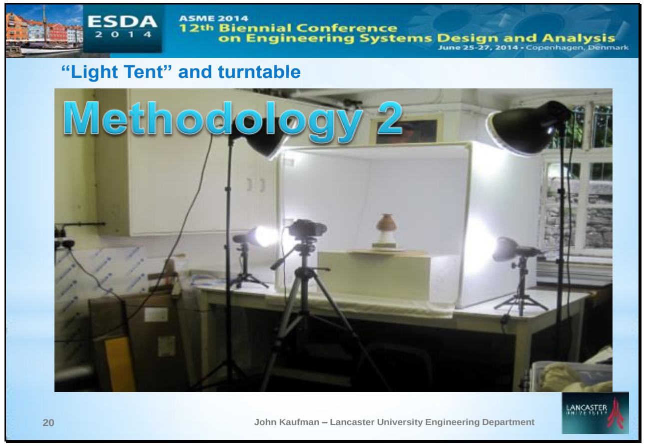

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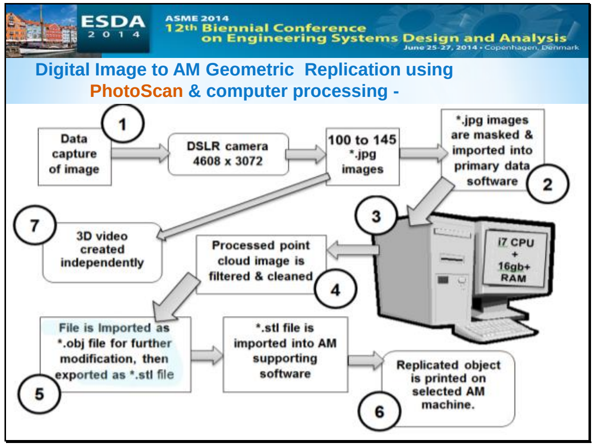

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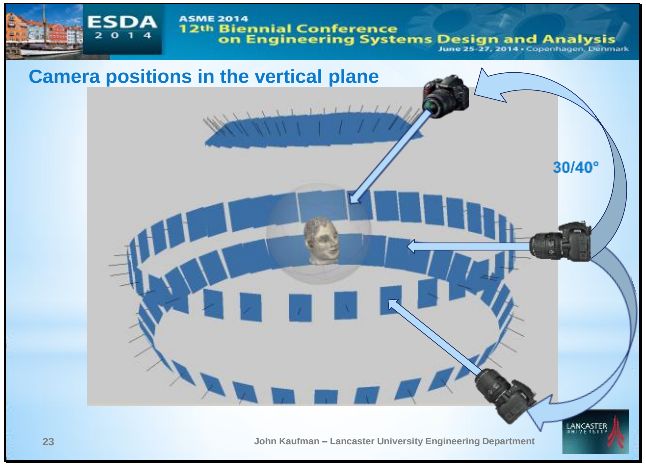

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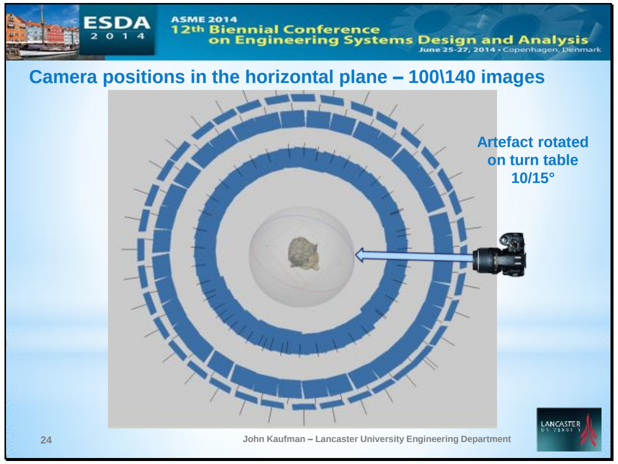

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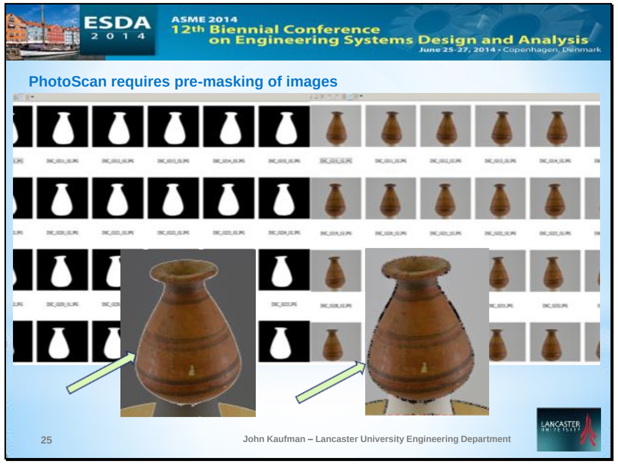

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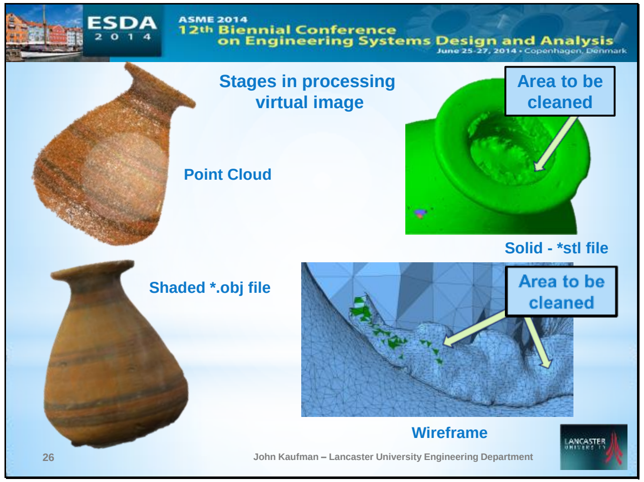

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Appendix B

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Single Camera Photogrammetry for Reverse Engineering and Fabrication of Ancient and Modern Artifacts

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ABSTRACT:

Photogrammetry has been used for recording objects for well over one hundred and fifty years. Modern photogrammetry, or digital image capture, can be used with the aid of a single medium range digital single lens reflex (DSLR) camera, to transform two-dimensional images into three-dimensional CAD spatial representations, and together with the use of additive manufacturing or 3D Printing technology, geometric representations of original cultural, historic and geological artifacts can be fabricated in a process known as Reverse Engineering. Being able to replicate such objects is of great benefit in education; if the original object cannot be handled because it is too old or delicate, then replicas can give the handler a chance to experience the size, texture and weight of rare objects. Photogrammetry equipment is discussed, the objective being simplicity of execution for eventual realisation of physical products such as the artifacts discussed. As the processing power of computers has increased and become more widely available, and with the use of computer software programs it is now possible to digitally combine multi-view photographs, taken from 360° around the object, into 3D CAD representational virtual images. The resulting Data is then reprocessed, with a secondary computer program, to produce the STL file that the additive manufacturing machines can read, so as to produce replicated models of the originals. Three case studies are documented: the reproduction of a small modern clay sculpture; a 3000-year-old Egyptian artifact; and an Ammonite fossil, all successfully recreated, using additive manufacturing technology.

KEY WORDS: photogrammetry; reverse engineering; DSLR camera; non-invasive reproduction; 123D Catch; PhotoScan; Studio Pro5; cultural heritage; education; additive manufacture.

1. INTRODUCTION

Three-dimensional (3D) imaging has been in existence since the invention of Lenticular's Stereoscope in 1860. Thus, the idea of a two-dimensional (2D) image being converted to a 3D image is not new. Photogrammetry, as it is sometimes referred to, "*is as old as modern photography*" (1) and dates from the mid-nineteenth century. Since the late 1990's, Laser Scanning (LS) has moved to the predominant non-invasive method used to replicate both large and small objects, such as large historic buildings and small statues [1].

The first digital camera was invented in 1975 by Sasson, who was an engineer working for *Eastman Kodak*® (2). These cameras have developed from the low resolution 0.01megapixel early camera to 60 or 80 megapixels at the top end of today's professional range. Photo-manipulating/enhancing computer programs have been able to stitch 2D digital photo images together for a number of years, creating panoramic views of city, sea or landscapes (3). More recently, with the help of i5 and i7 CPUs and the large amount of RAM that modern computers can now accommodate, software is available which is capable of stitching 150 or more, high resolution digital images together to form a virtual 3D representational image (4). The reconstruction of 3D models is semi-automatic due to reconstruction problems and requires user intervention.

2. RESEARCH OBJECTIVES

In this paper, it is shown that with the use of photogrammetry, virtual 3D models can be created, without a high level of computer expertise and without the use of relatively expensive or complicated 3D laser scanning equipment. Many software programs claim to be able to convert 2D digital photographs into 3D virtual images. On investigation, it has been found that many are still in development and are not necessarily available for use except experimentally. Several commercial computer programs are available with a proven and reliable record to "stitch" multi-view digital images together to produce a 3D image.

Two programs were used in this research for the primary software processing of the digital images (4, 5). In addition, the high resolution point cloud images produced were filtered and converted to STL files by a third program (6), ready for additive manufacturing (AM) machines to replicate and produce geometric representational models. The use of this technique could contribute to the reproduction, restoration or repair of damaged or broken antiquities by non-invasive methods at modest cost and by laypersons, who are computer literate but not necessarily expert in the use of specialised software.

By using a relatively modest DSLR camera, expensive LS is not required to capture the data necessary to produce 3D virtual images, and experienced technicians are no longer required to operate such equipment. A comparison between photogrammetry and laser scanning, their techniques and characteristics has been shown in Barsantia *et al* (7). The primary research task investigates how well these software programs convert the digital 2D image into AM models, and compares results obtained with the original object. The research investigates the tactile surfaces of the replicated models and compares them to the original objects; it considers whether those replicated models, when scaled up and down, lose surface detail and whether the AM models created could be substituted for the original.

3. DATA CAPTURE METHODS

One of the main objectives of the research was concentrating on the ease of reproducing artifacts without complex hardware or software. A mid-range *Nikon D3100®* DSLR camera was used, the digital data obtained being in JPG, or common image format. A standard fixed focus prime 50mm lens, which has a wide f1.4 or f1.8 aperture and minimum lens distortion and very good depth of field, was considered, but a *Nikon 18/55mm DX®* auto focus lens was chosen, being directly compatible with the camera and able to automatically refocus around the subject from the many positions and angles encountered. Minimum lens distortion was achieved by keeping to the higher focal length end of 35/55mm on the lens. The disadvantage of this lens as opposed to a fixed lens is that the depth of field is not as good and slower shutter speeds are required as the aperture is not as wide. A resolution of 3456 x 2304 pixels per frame was used throughout, which equates to approximately 8 megapixels.

- **Method 1 – open room set-up**

The method of lighting and camera positioning for the artifacts were different in each case study, the common factor being that shadowless, flat lighting was required to illuminate all the artifacts, as any shadow distorted the image captured and processed by the software. The same was true for any highlights or reflections that the lighting might have caused. In Fig.1 the windows are covered so as to diffuse the natural daylight and help create a shadowless room. The main indoor lighting consisted of two *bip®* fluorescent floodlight control units on telescopic stands, each with three separate switched 50W 5000K bulbs and white defusing front covers and, if needed, two small lamps with 45W 5500K bulbs. Indirect daylight was utilised if available. Any small difference in colour temperature, known as White Balance, was automatically adjusted by the *D3100* camera *"as digital cameras have a far greater capacity to compensate for the varying colours of light"* (8).

The first study, a small modern clay head sculpture, has been included to show a comparative method in both AM printing and data capture. This semi-glazed painted head, measuring 105mm x 95mm x 85mm, was placed in the centre of a room on a pedestal whilst the camera was moved in a full circle around the object and a digital image captured every 20°. The model clay head is seen, arrowed, in the centre of the room (Fig.1).

All reflective surfaces are covered (television and glass coffee table), to stop any light flare or reflection. A second and third circle of data, at a higher and lower elevation of 20° to 30° to the horizontal, was obtained, ensuring that every part of the head was recorded and that a good overlap of images was obtained (Fig.2). The digital data capture of the clay head was processed using *AutoDesk's 123D Catch®*, and the high resolution point cloud image data obtained was processed via *AutoDesk's* internet cloud technology. The returned data image was then cleaned and the file was processed using *Netfabb's Studio Pro4*® to produce the STL file which the *Stratasys' Dimension*® Fused Deposition Modelling (FDM) machine could accept and use to fabricate the model.

Fig. 1 Indoor Open Room Setup

Fig. 2 Multi Camera positioning around Clay Head

- **Method 2 – Light Tent**

The second method of digital data capture used a collapsible Light Tent; (Fig.3). This was constructed specifically for this purpose, from 20mm plastic tubing and suitable angle corners to make a metre square enclosure, covered in white poplin fabric with a front opening. So as to obtain strong contrast between the subject matter that was being photographed, interchangeable Chroma Key [8] backdrops were used, either white or green, depending on the colour of the subject. As seen in Fig.3, the lights were placed outside the tent allowing the fabric to soften the lighting and disperse any shadows. Natural light coming from the window behind (unshaded) helped to counteract any shadows.

Fig 3 Light Tent in Kendal Museum

Fig.4 Green Chroma Key backdrop and open-sided light tents

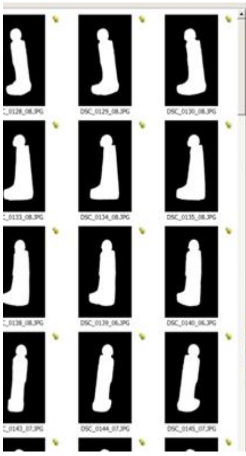
The light tent was used to digitally capture images of the artifacts from antiquity, a 3000 year old Egyptian figurine, and an Ammonite fossil and processed using Agisoft's *PhotoScan Pro*®. Netfabb's *Studio Pro4*® was then used to produce the STL file which the AM machine requires in order to print the replications. The models that were made using this technique were processed on a 3D Systems *DTM Sinterstation*®, Selective Laser Sintering (SLS) machine, in a plain white Nylon 12 (polyamide). The light tent used to capture the Ammonite data was different in that the white linen cover was not used, as the natural light in the indoor environment was very soft and it was felt that only a small amount of "fill in" artificial light was needed. However a contrast green backdrop was used to enhance the contrast with the greyish colored Ammonite (Fig 4). In both Fig. 3 and Fig. 4 a turntable can be seen which was used to revolve the artefact around 360°. The camera was stationary, only being moved once in the vertical plane for every complete revolution of the subject.

- **Data Processing**

In 2011, Verhoeven (9) using stereoscopic photography, and after processing the digital images (4), produced a series of virtual 3D images. It was noted that although the software claimed to be able to process, in theory, a very large number of photographs, in practical terms this is a maximum of approximately 1024 images. Verhoeven records that the relationships between the processing time, speed, quantity and high resolution data, are all interlinked. The more detailed the photogrammetric data, the greater the speed of processor required with a computation time penalty.

For the clay head, three attempts were made, gradually increasing the number of images from 40 to 70, which were taken from different angles, encircling and arcing around the object from above and below. This ensured that there was an image overlap of about 15-20%. Using one of the primary software programs, the images were processed to generate point cloud data sets (5). This program used internet web-based cloud services provided by *Autodesk* to turn the JPG processed data, taken from the camera, into image formats for importing into third party software programs. Using this software, a video could be created by selection or rejection of the 60 photographic images in the path the images had taken. The software seamlessly converted the images selected into a moving 3D virtual representation. The time taken for this process was dependent on the quantity and quality of the images (as well as internet speed), but a reduction in either could result, as Nguyen *et al* show [10], in processed image data which is badly degraded. The data image having been cleaned, it was then exported as an OBJ file and a 3D textured mesh was created.

The other two items were photographed using the light tent: Sobekhotep, the Egyptian figurine and the Ammonite fossil were processed in the same way to each other. As seen from Fig.1, in the "open room" system of data capture, the main subject, in this case the clay head, was in a static position and the camera was rotated at a distance of approximately 1.2 to 1.5 metres away. With the light tent system of data capture, depending on the artifact's size, the camera was placed much nearer the subject. The artifact was then rotated on a turntable between 10^o and 15^o, as each frame was shot (Fig.5).



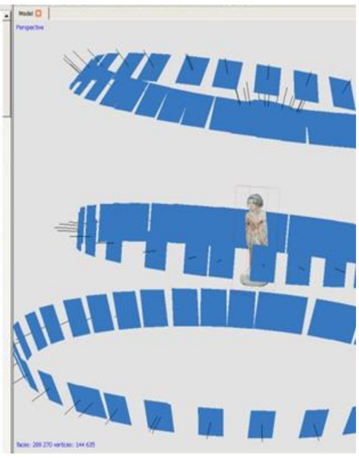


Fig. 5a. Masked Images Fig. 5b. Multi Image positions Fig. 6a Actual model Fig. 6b high resolution point cloud image

This method allowed for small objects to be photographed with the use of close-up ring lenses which screwed onto the front of the camera's prime or zoom lens. In Fig.3, Sobekhotep can be seen on the turntable ready to be photographed using the standard *Nikon 18/55mm DX®* lens. For each object, 130 images were taken. But being much nearer the subject increased the criticality of the focusing and the depth of field became far more important; the closer the lens to the subject, the shallower the depth of field became. Shooting at f/5.6 to f/9 in an open room became f/18 to f/22+ in a light tent. These smaller apertures required increased illumination on the subject or required longer timed exposures.

In this method, the software (4) also allowed for more control, by the operator, over how the data was processed. Instead of processing the data via the internet as with the first example, and as long as the host computer had an i5 or preferably i7 CPU with a minimum 12GB memory the data could be processed on the same machine. Before processing the data, each image was masked from the surrounding background with a built in tool in the software, as can be seen in Fig.5a. The actual original model (Fig.6a) shows no discernable loss of detail compared to the screen shot of the high point cloud data image (Fig.6b).

Experimentation with inter-changeable Chroma Key backdrops was undertaken; this type of backdrop provided a very good contrast between the main subject matter and its surroundings. It was found that the time taken to mask each digital image was considerably quicker with the use of a Chroma Key background. The more RAM that was available, the faster the digital data could be processed, and the more detail that was forthcoming. Unfortunately the software did not have the facility to convert the captured images into a video. If required, this could be done using a proprietary video processing program.

4. REPAIR of NOISY, DISTORTED and INCOMPLETE DATA

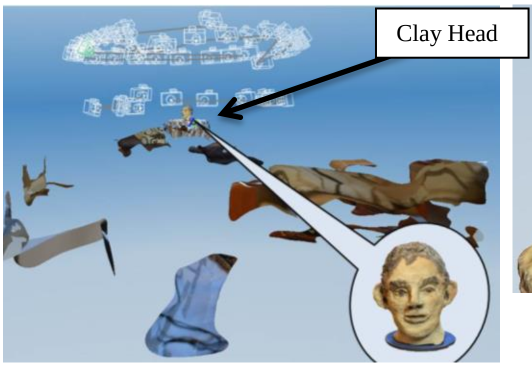


Fig. 7 Processed digital image ready to be cleaned

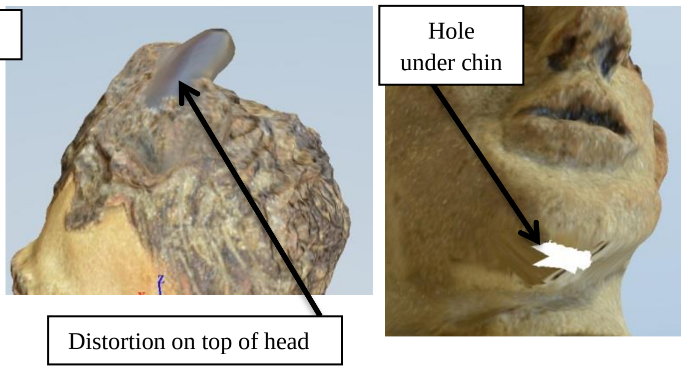


Fig. 8 Typical data flaws requiring correction

The returned processed point cloud image, as seen in Fig.7; (head identified) had to be filtered, or cleaned, to eliminate background noise that had been captured along with the original subject, such as other objects or furniture that were in the line of focus when the image was recorded by the DSLR. The resulting processed textured 3D mesh showed minor flaws or distortion which had to be corrected (Fig. 8). The processed photo-textured 3D mesh image head could have been repaired using software, but by adding and increasing the number of images, with more angled shots and greater image overlap, complex repairs to the point cloud and textured mesh were eliminated. The additional photographic digital images, once added to the original data set of images, were reprocessed and sent by the internet to be cloud processed and returned ready to be recleaned. By selecting the appropriate control in the editing section, a wire frame, wire frame and texture, or texture only model could be obtained. This would facilitate the model repair if required.

5. THE FINAL MODEL

The OBJ file was created as a solid, but by hollowing the model, using this secondary software, the amount of material, and therefore its weight, was reduced; this could be in the region of 80% of the mass, making a great difference to the final material cost of manufacturing using AM. The model that was then made was instantly recognisable as a copy of the original and although the FDM reproduction was a little smaller than the original (approximately 80%), the tactile surface finish was much smoother than the rough, prickly feel of the original clay surface. This could be attributed to similar geometric errors caused by the size of the extrusion nozzle and tool path of the *Dimension*® FDM machine on which it was made, as described by Brooks *et al*. [9].

The quality of build is well known (10) (11), as can be appreciated by the differences between the use of an entry level FDM machine costing a few hundred £/€ to that of a SLS machine costing several hundred thousand £/€, thus resulting in how much detail of the original model was lost or captured.

Fig. 9 Original Clay model

Fig.10 Virtual Point Cloud image

Fig.11 Hand painted FDM model

6. SCALE and PHYSICAL DETAIL of AM MODELS.

It was found that the resulting dimensions of the 3D image obtained from the primary software very rarely matched the original dimensions of the object photographed, being created in a virtual arbitrary scale. For large objects such as buildings or monumental structures, this is a problem, but it is not within the scope of this paper, which only concerns itself with smaller sized artifacts, that can be easily measured. The scaling feature which exists in the Studio Pro 4® software program is of great importance, as the final dimensional accuracy of the finished AM replicated artefact can be fine-tuned. By simply comparing the size of the 3D virtual model with the original, and by adjusting the percentage increase needed to scale up the model within the software, an exact dimensional copy was obtained in all x, y, z planes. The operator has a certain amount of control when using PhotoScan Pro®, for example, to process the final 3D point cloud image; but even this control was limited to the processing capacity of the computer. Guidi, et al, (12) discussed the control that the operator has over this software, a semi-automatic commercial software program

Mesh type	Ultra High	Medium	Ultra Low
Polygons	4,846,416	527,150	460,304
STL file size	236,642 kb	25,740 kb	22,476 kb

Fig. 12 Ammonite Fossil - wire mesh screen shots – Mesh types vs Number of polygons and Number of STL elements

However, in processing a range of artifacts in this research, the following factors played a key role in determining the time taken and quality achieved: the difference in the “Build Dense Cloud” function between *Ultra High* to *Ultra Low* (Fig.12); the fact that a specification of an i7 CPU was being used; and whether the computer had 16MB or 32MB RAM. Only the smallest of objects with a relatively simple profile, could be processed with 16MB RAM using *Ultra High* setting. The processing times in the Ammonite fossil seen in Fig.12, increased from around 30-45 minutes for the *Ultra-Low* build (using16MB RAM) to up to 6 or 8 hours for *Ultra High* (using 32MB RAM), as well as increasing the size of the final STL file: which then was reflected in the quality of the AM build. This ultra-high detail of the build was in itself controlled by the capabilities of the AM machine used, whether the machine could print in layers of say (typically) 100microns or (with recent advances) 16microns..

7. CONCLUSIONS & FUTURE WORK

The digital date for these artifacts, were all captured, using a single mid-range DLSR camera. The models were manufactured using different types of AM machines, but these models were processed with the minimum of computation. There was no CAD reconstruction or alteration to the point cloud image or the photo-textured mesh, only minor cleaning; this eliminated the need for software experts, one of the main objectives of the research. If the point cloud image was too badly distorted or holes in the mesh were present, either a new set of images were taken or manual photo stitching of additional photographic images was undertaken. There are obvious exceptions in which the DSLR camera cannot function, since it can only capture surface images unlike volumetric scanning, or as in the examples of the MRI scanning of an Egyptian mummy by Steele and Williams (12) or the use of CT scanning and computer assisted surgical planning, combined with patient-specific surgical guides for patients with deformed bone structures as in the work of Leong et el (13). But for this research using the DSLR, it is only the surface data which is required to produce the geometric representation artifacts.

Further research is required to investigate how and whether adverse effects can be minimised or eliminated at the data capture stage. One of the main problems that was encountered was reflection of highly glazed surfaces. In some cases the silhouettes of the objects themselves were so complex that a greater number of images needed to be taken, thus slowing down the processing time. A series of tests using lower lighting levels, camera settings, lens filters, data pixel image size, is required to find a solution. A suggested starting point might be: graduated neutral grey filters, perhaps the use of a Polaroid filter, or aperture setting even smaller than f/18 or f/21, compensated by slower shutter speeds, but this means a longer processing time penalty. Ultimately, as stated, monetary budget is a very important factor, as to the final detail and standard of finished product. Both processing and build time will ultimately be reflected in the quality of the final version of the model.

Coloration of the replicated artifacts needs further work, as can be seen in differences between Figures 9 and 11. The original clay head (Fig.9) was painted using pottery glazes, then ‘fired’, producing quite a different look to the brighter pigmentation of the Acrylic paints used on the FDM model (Fig.11). Water colour paints, which are more subtle than oil or acrylic paint, were tried, but would not dry properly on the nylon material from which the FDM model was made. Printing or painting on a sandstone material, in this instance, may have produced a better result. Producing models using a series of different materials, types of paint or inks, including a colour printer, might yield results nearer to the original coloration.

However, it has clearly been shown that simply with the use of a single DSLR camera, user friendly software and AM technology, both modern and ancient artifacts have been reversed engineered and replication models fabricated.

Acknowledgements

The authors have been granted renewable licenses for the use of Agisoft *PhotoScan Pro*® and Netfabb *GmbH’s Studio Pro4*®. The authors are grateful and acknowledge the support of all mentioned companies towards this research. All photographic data copyright of the authors unless cited otherwise.

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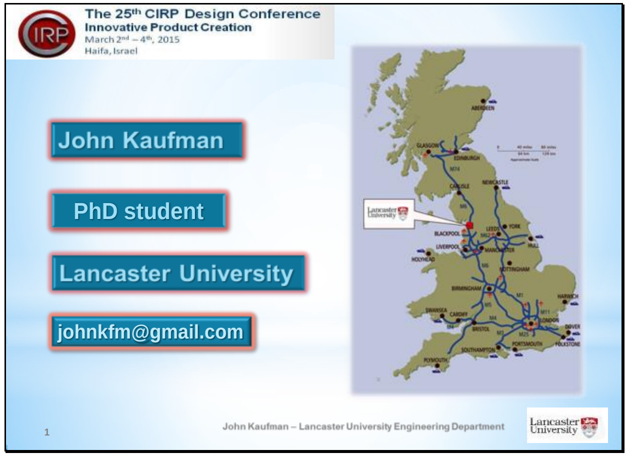

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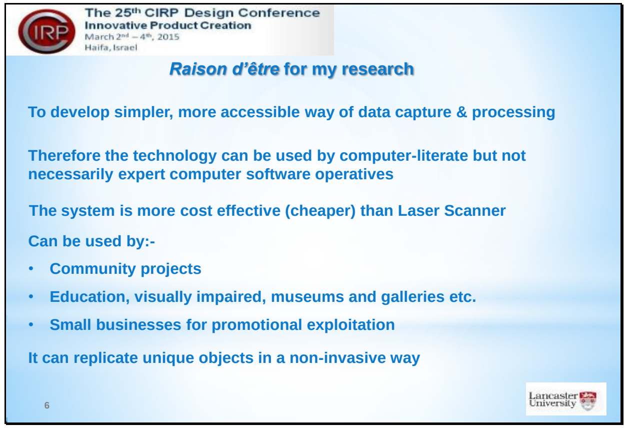

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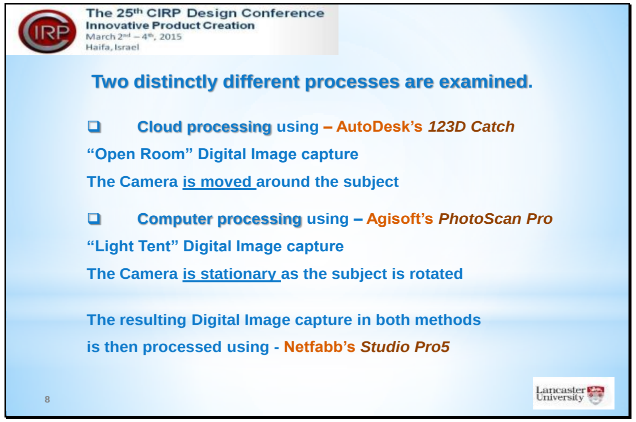

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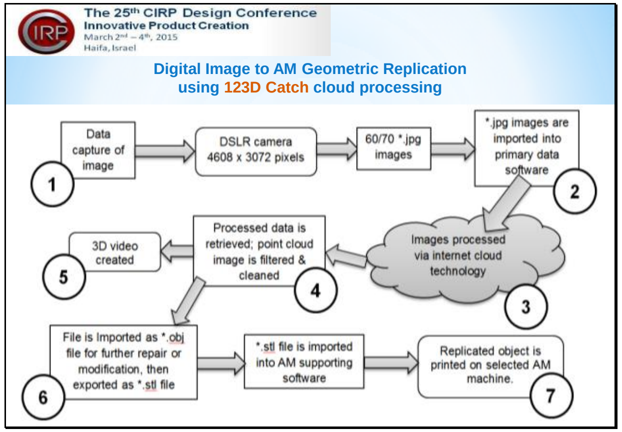

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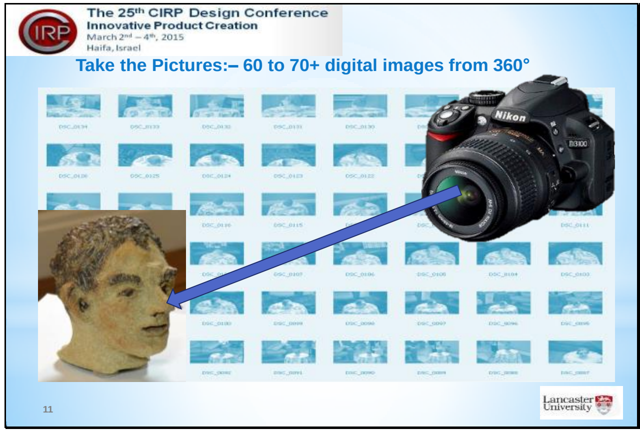

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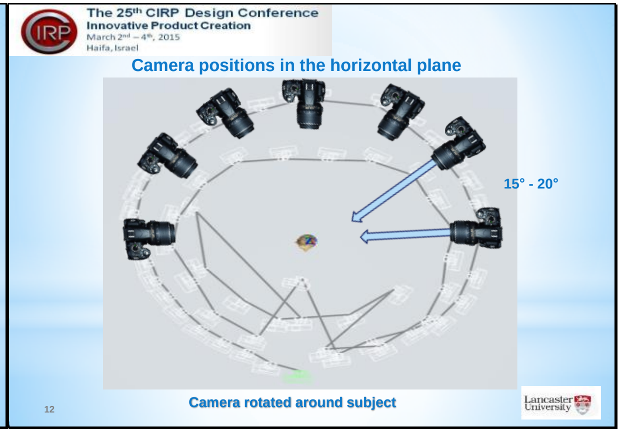

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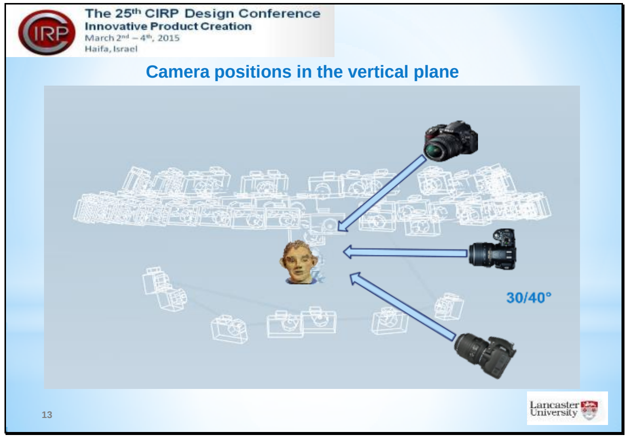

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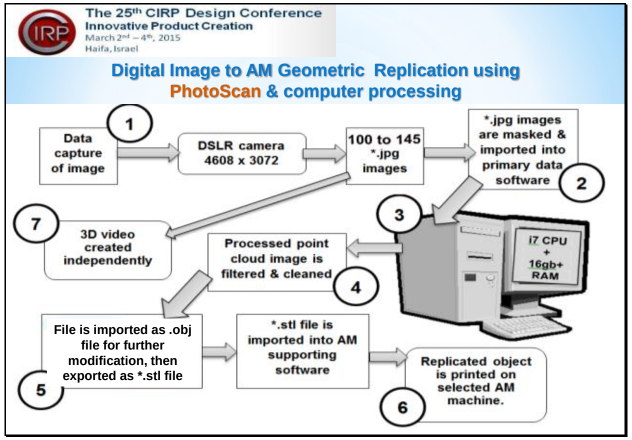

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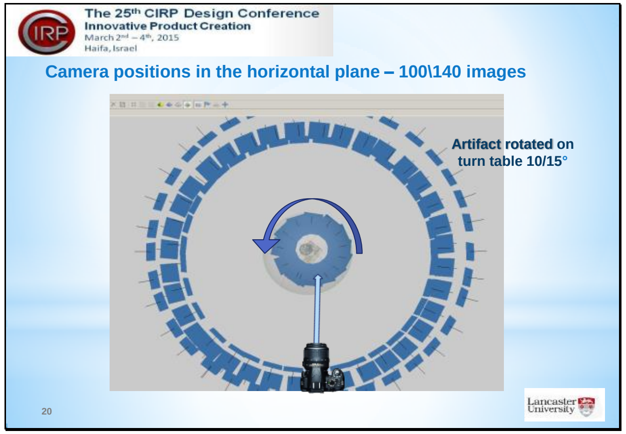

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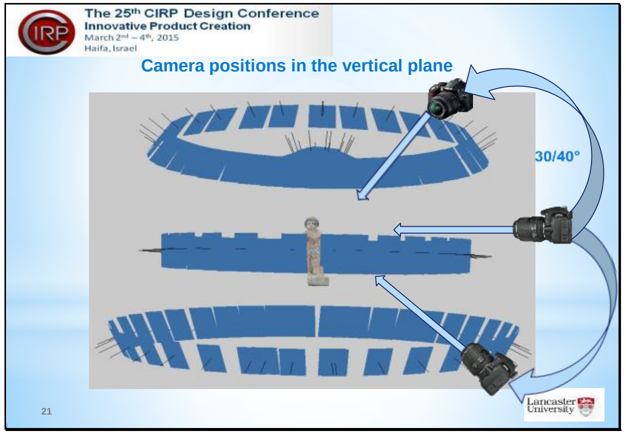

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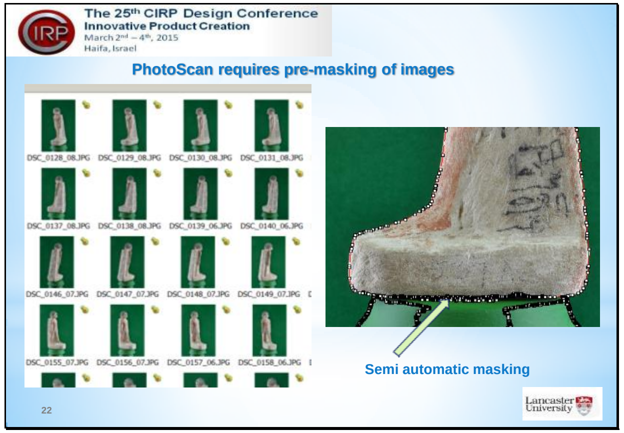

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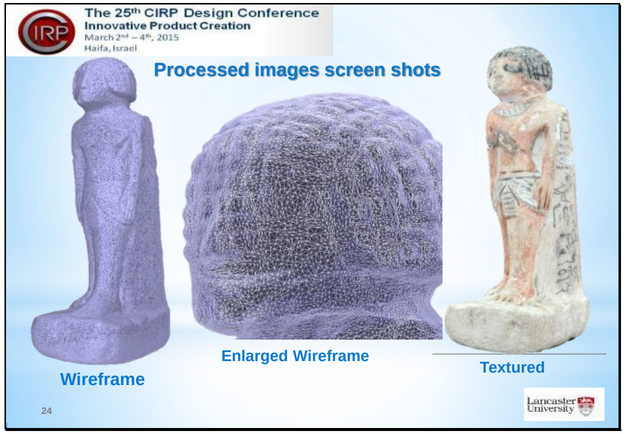

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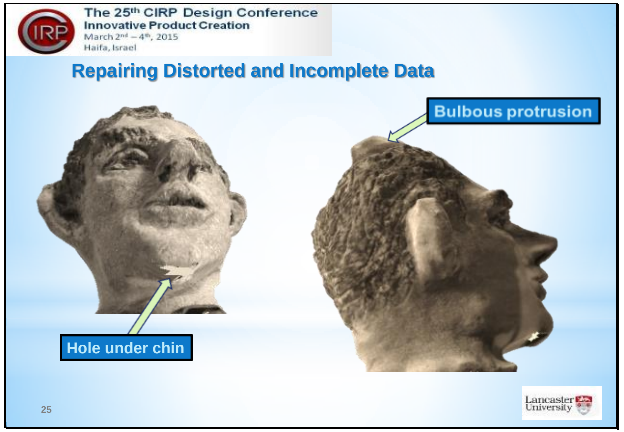

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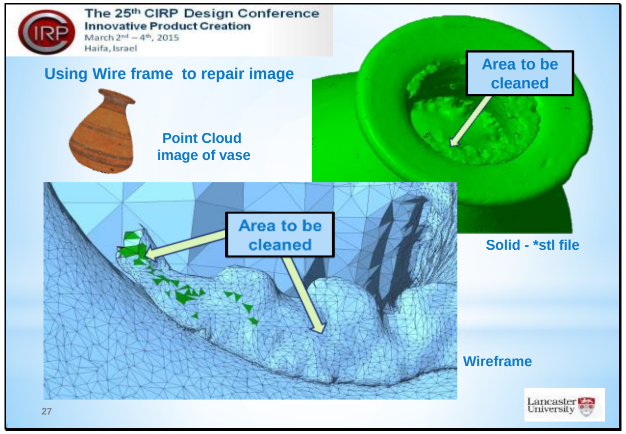

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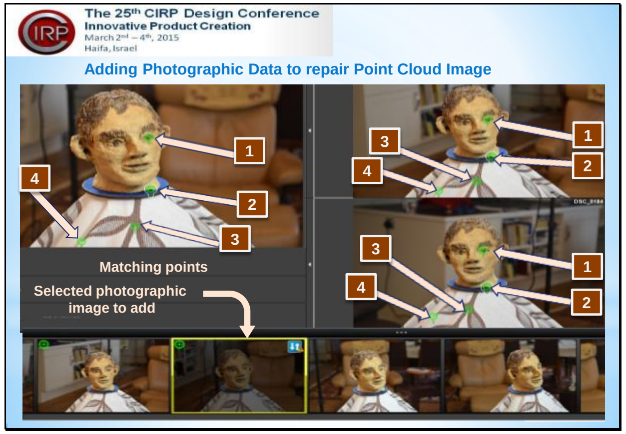

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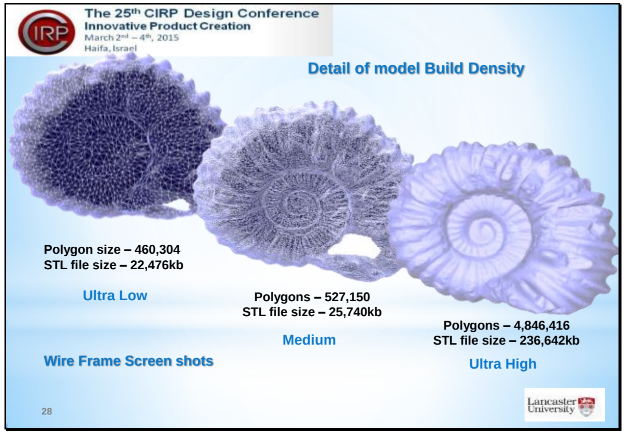

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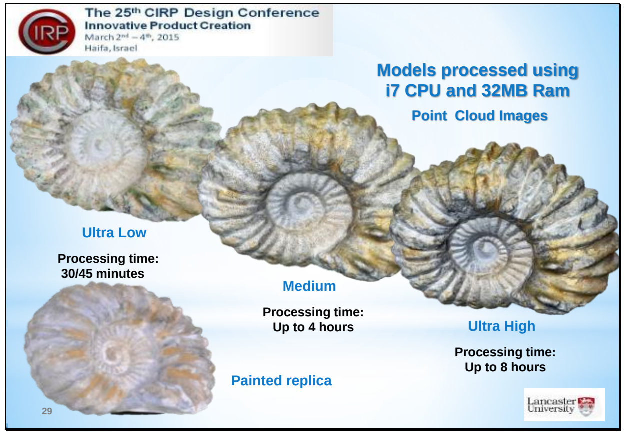

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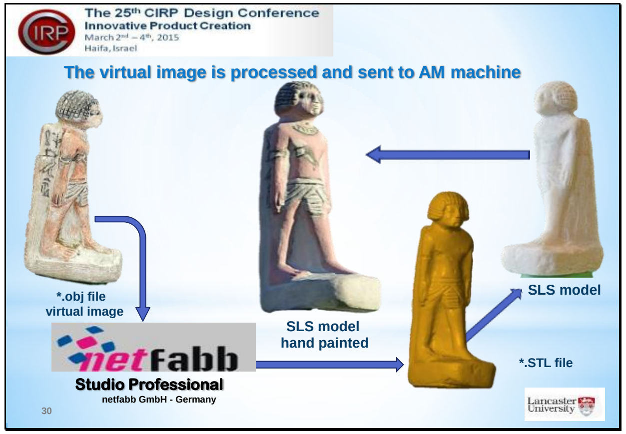

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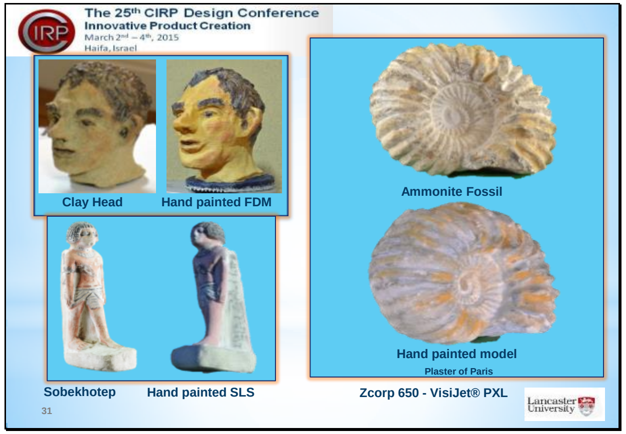

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Appendix C

Media coverage

Ancient Egypt – vol. 15 No. 3 – Dec 2015

Touching History – The Egyptian collection

Chapter 2.13.3 – page 58

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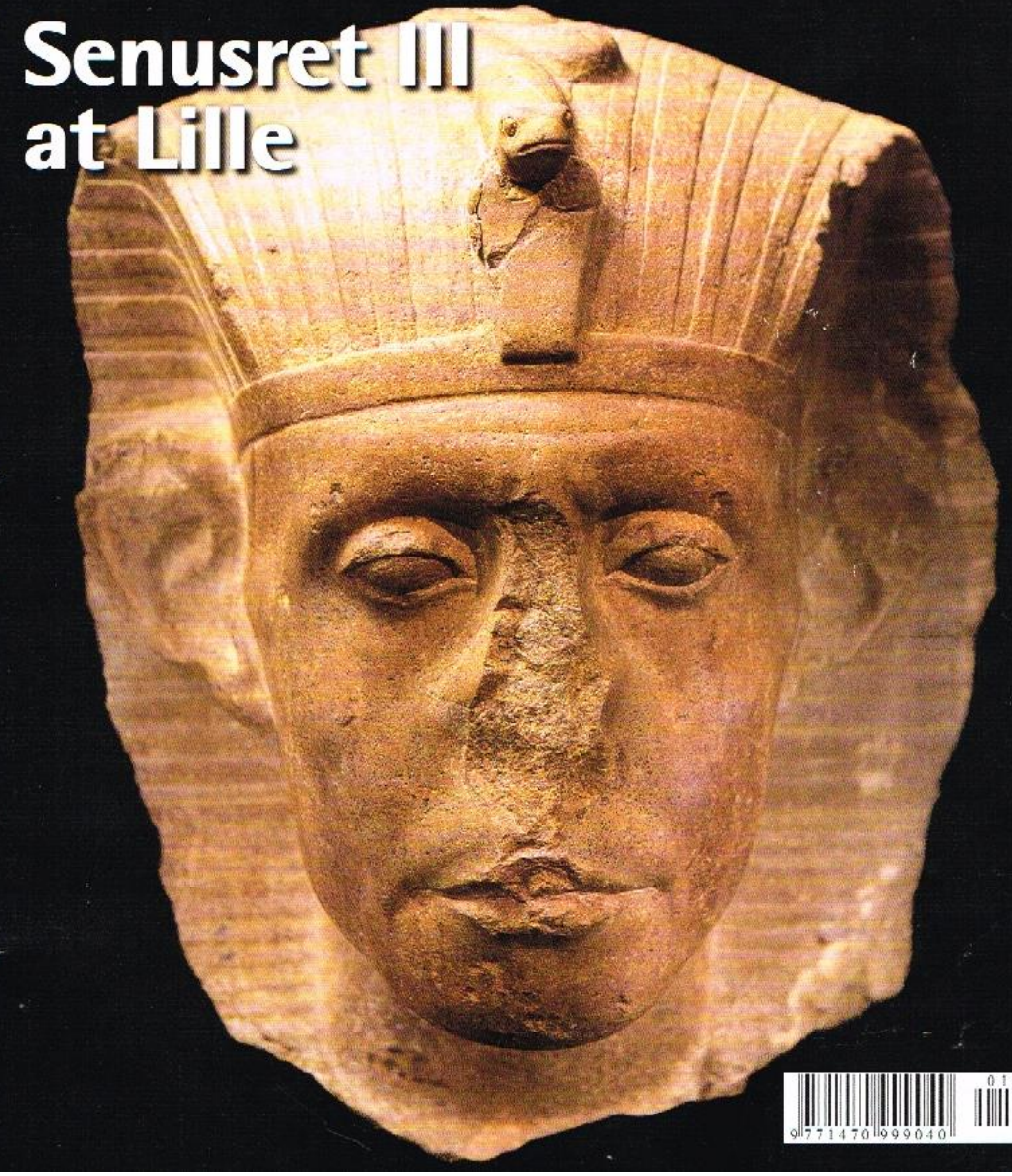
The History, People and Culture of the Nile Valley

Senusret III at Lille



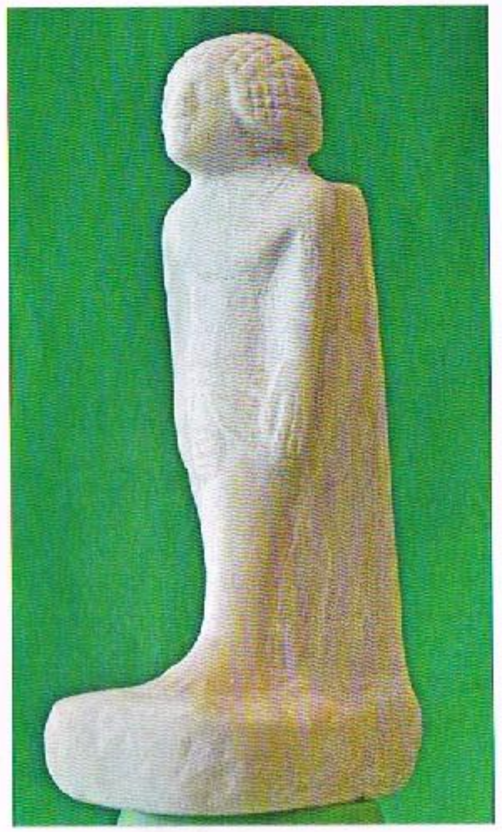
Touching History: 3D Replica Artifacts

Visitors to Kendal Museum will soon be able to handle ancient Egyptian pottery and statues, thanks to a digital camera, a 3D printing machine and Ph.D. student John Kaufmann.

Museums greatly value their collections of original objects but due to the delicate nature of most artefacts, these are unable to be handled by the public. If the original object cannot be touched, then replicas can give people a chance to experience the size, texture and weight of rare objects. Loan boxes may contain original Victorian and Roman material, but in the case of Egyptian collections, it is rare to have an original handling collection. At present at Kendal Museum (in Cumbria), the Egyptian loan box available to schools is made up of general replicas, photocopies of documents and photos.

In September 2012, I began a Ph.D. at Lancaster University under Dr Allen Rennie. I had been trying out the technique of 'reverse engineering by single camera photogrammetry' to replicate some of my own personal artefacts, and as part of my research I thought it might be an idea to see if I could apply this technique to some of the objects held by my local museum. I approached Kendal museum last year and arranged to capture digitally two or three objects over a period of several weeks.

Photogrammetry (making measurements from photographs) has been used for recording objects for well over one hundred and fifty years. In modern photogrammetry, or 'digital image capture', a laser scanner is used to photograph an object from every direction giving a series of two dimensional (2D) images which are then transformed into three-dimensional (3D) spatial representations using CAD (computer-aided design) software. As part of my research, I used a much cheaper digital camera (a single medium range DSLR) to see if I could make this method more accessible, taking up to 150 photos of each object. These were then digitally stitched together to create a 3D virtual image of the original.

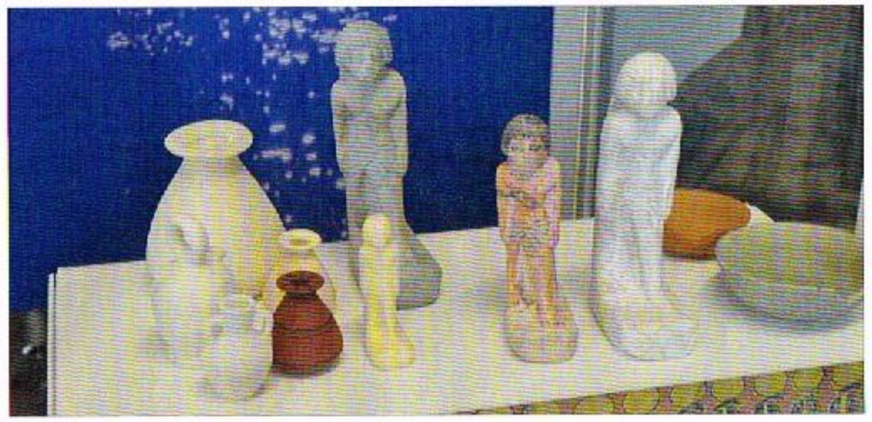


ABOVE
A 3D model of Sobekhotep, son of Nehesy, recreated from a rare statuette at Kendal Museum *(see opposite top)*. Where original objects like this are too fragile to be touched, visitors can learn far more about them by physically handling replica versions. Replicas could also allow museums to take objects out into the local community to reach people who may not have access to the museum itself.

Combining this technique with the use of 'additive manufacturing' (AM) or 3D Printing technology, where layer after layer of material is laid down under computer control, geometric representations or models of original cultural and historic artefacts can be fabricated using a process known as 'reverse engineering'. As the processing power of computers has increased and become more widely available, using software programs such as Agisoft's *PhotoScan Pro* it is now possible to digitally combine multi-view photographs, taken from 360 degrees around the object, into 3D CAD representational images. The resulting virtual data files are then reprocessed with a secondary computer program such as Netfabb's *Studio Pro5* ready for the additive manufacturing 3D printers to produce replicated models of the originals.

The Kendal collection was established in 1796, as a 'Cabinet of Curiosities'. Three objects from the collection were initially chosen: a small dish, approximately 110 mm diameter and 45 mm high, a vase 120 mm high and 100 mm in diameter, and a 162 mm statuette of Sobekhotep, son of Nehesy (an inscribed figurine excavated by Garstang from Tomb 537 at Abydos and donated in 1923 by Ruskin) which dates to around 1500 BC, and is a very important and rare figurine within Kendal Museum.

The method of geometric data capture was the same for all three items. The object was viewed by placing it on a turntable and rotating the platform through 10 degrees per camera shot. The camera was positioned in one of four elevations, for each data set, being higher, lower or on the same plane as the subject being photographed at elevations of 20 to 30 degrees to the horizontal, which ensured that every part of the object was recorded and that a good overlap of images was obtained, the artefact being in the centre always at the same elevation.



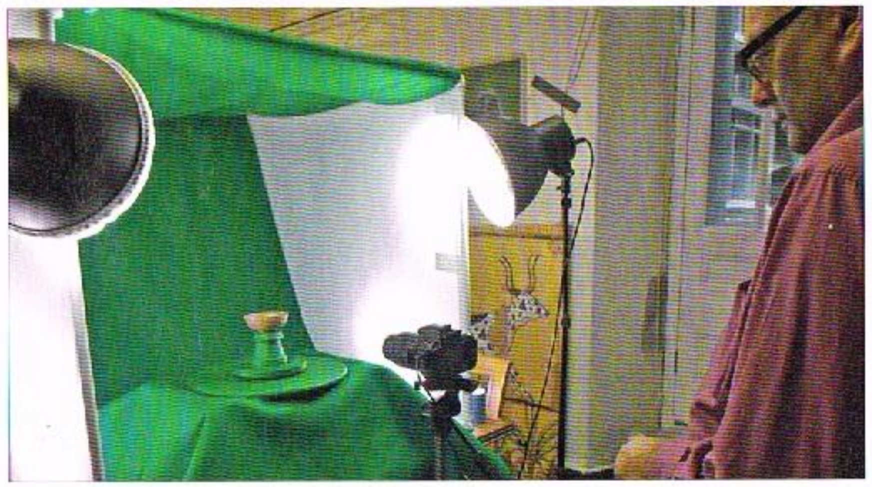
Depending on the additive manufacturing machines used, the models may be printed in a variety of materials, from simple nylon plastic material to the more exotic silver or gold. Full colour printed replications can be fabricated; however, if made from white nylon, the models can be hand-painted to further enhance realism.

Being able to replicate actual museum collection objects would be of great benefit to teaching local school children about their own local culture and heritage as well as other civilisations such as the Roman or Egyptian periods, using the material in the museum's collection. The experience becomes far more tactile than just looking at a 2D colour photograph. By these methods, it is hoped to bring ancient Egypt literally into the hands of the modern world.

John Kaufmann

John is retired and currently working on his Ph.D. in the Department of Engineering at Lancaster University.

All photos by the author.



TOP
Sobekhotep surrounded by 3D printed replicas from the Kendal Museum collection.

CENTRE
A ceramic bowl (right) with its 3D replica (left, in white).

LEFT
Author John Kaufmann in his museum studio, using a camera for data image capture of the ceramic bowl.

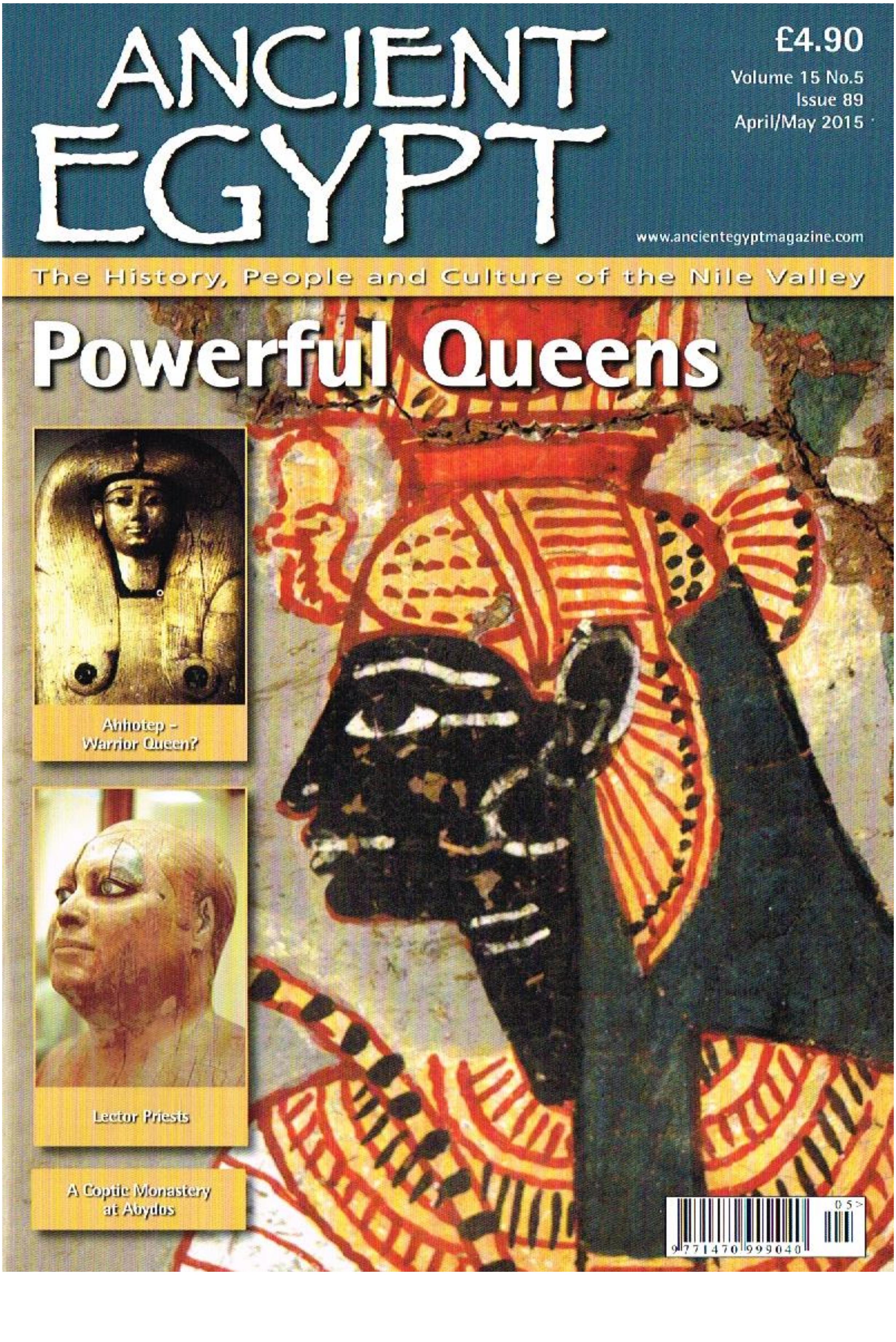
Appendix D

Media coverage

Ancient Egypt – vol. 15 No. 5 – April/May 2015

Touching History – The Lost Crown of Horus

Chapter 6.10 – page 259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Powerful Queens
Ahhotep – Warrior Queen?
Lector Priests
A Coptic Monastery at Abydos

Touching History: THE LOST CROWN OF HORUS

John Kaufman describes how he used modern technology to create a crown for a modern tourist figure of Horus.

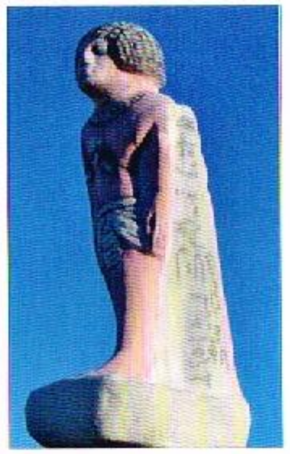

Fig. 1: The hand-painted AM reproduction of Sobekhotep, son of Nehesy.

Fig. 2: The tourist 'Horus' minus his crown.

Fig. 3: Four styles of crown from the large researched range.

Regular readers of *AE* may remember an article that I wrote in *AE* 87 (December 2014/January 2015), about how, with the help of modern technology, I was able to reverse engineer (RE) or copy, amongst other Egyptian artifacts, a 162 mm-high statuette of Sobekhotep, son of Nehesy, dating from around 1500 BC, an important and rare figurine in the collection of Kendal Museum in Cumbria, UK; this figurine was excavated by Garstang from Tomb 537 at Abydos, and donated in 1923 by Ruskin to Kendal Museum.

The replication was achieved by non-invasive methods using Photogrammetry to digitally capture the data. With the use of a DSLR camera and Agisoft's *PhotoScan Pro*®, a computer aided design (CAD) software program, data files containing 3D virtual models could be produced. By converting these files so that additive manufacturing (AM) machines (3D printers) could read the files, a replicated model of the original artefact could be printed in white plastic. This was then painted with acrylic paint to match the original artefact (Fig.1). The *AE* article described part of my Ph.D. research at Lancaster University into "Single Camera Photogrammetry for Reverse Engineering and Fabrication of Ancient and Modern Artefacts".

It was during this 'Egyptian period' of my research, whilst rummaging in a local car boot sale, that I came across a modern statuette, presumably produced for tourists on the Pyramids/Nile trail, of a crownless 'Horus' (Fig. 2). Picking him up, the flattened skull where his crown had been was visible. My mind began thinking about RE and AM techniques to reinstate his majestic status. Using the same techniques as those used to replicate Sobekhotep, a model of Horus could be created – this was not a problem, except that this technique cannot be used on negative space! If the crown was missing it could not be copied. I then thought of another method of recreating the crown using a program by Dassault Systems called *SolidWorks*®. This is a CAD tool used by many disciplines from within the virtual computing world. I like to think of this program as sculpting/modelling with putty or clay, but without getting your fingers sticky.

Not being an Egyptologist, I had to research various books about ancient Egypt and after visiting several internet sites came up with half a dozen versions of the crown of Horus. As there does not seem to be a definitive design for the crown (Fig. 3), two versions of the crown were designed using *SolidWorks*® and then both were fabricated on an additive manufacturing 3D printer. Figures 4 to 8 show the stages in creating the crown within this computer program. The drawing in Fig. 8 was the first crown model to be replicated (Fig. 10). Possibly because it was made in plastic, the curled extrusion, being only 2·5 mm thick, soon broke off at the base. The crown was redesigned, and in the final version, the curled extension was thickened to 3 mm and the horizontal bar was added for strength.

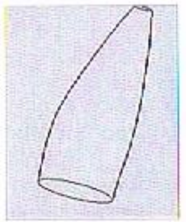

Fig. 4: The first loft of the inner crown.

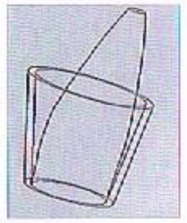

Fig. 5: The second outer crown added.

Fig. 6: The top dome and fillet added to the inner crown.

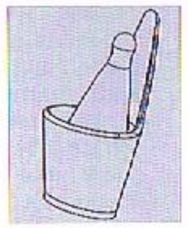

Fig. 7: The top of the outer crown added and the edges smoothed.

Fig. 8: The curled front swept extrusion added.

Fig.9: The secondary support bar added.

Fig. 10: The unpainted 3D printed model of version 1 of the crown.

If fabricated in a stronger material such as steel or bronze, this breakage might not have happened and the added bar could be omitted. The finished virtual 3D Crown was saved as an STL file in *SolidWorks*®.

Fig. 11: A *SolidWorks*® screen shot of version 2 of the crown.

Fig. 12: The final hand-painted 3D model of version 2 of the crown.

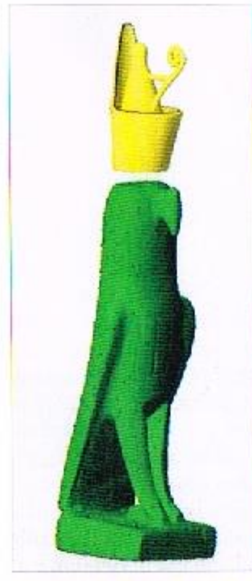

Fig. 13: A *SolidWorks*® screen shot

Having already produced a 3D virtual image of Horus, and having converted the image file to an STL file, all that was left to do was to assemble the crown and body together (Fig. 13). Importing both parts into *Netfabb's Studio Pro4*® computer software, and joining the two parts together, was quite straightforward, adjusting the size of the crown slightly so as to fit the head exactly. Once assembled and joined together, the single artifact was hollowed out with an outer shell of 3 mm. This procedure speeded up printing time and used less material – thus reducing the cost of the whole process. Finally all that was left to do was the printing on an AM Selective Laser Sintering (SLS) machine (Fig. 14) and then painting the white plastic (Fig. 15). Horus could now be crowned again in all his glory, thanks to modern technology.

John Kaufman

This article arises from John's Ph.D. research in the Department of Engineering at Lancaster University.

All images supplied by the author.

Fig 14 (right): The finished SLS model.

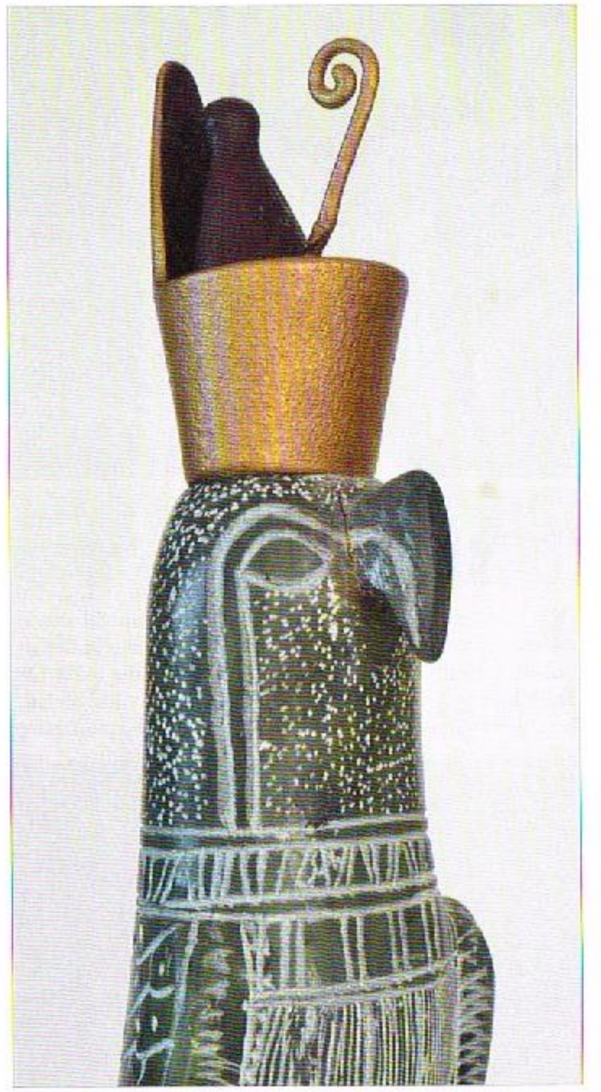

Fig. 15: The hand-painted finished model.

Appendix E

Media coverage

American Scholar – theamericanscholar.org/dept/essays

Oct 2014 by Josie Glausiusz

Ode on a Grecian Replica

Chapter 8.6.3 – page 304

The AMERICAN SCHOLAR

Ode on a Grecian Replica

On simplifying accurate copies of fragile antiquities

Kendal Museum

By Josie Glausiusz   October 8, 2014

On a recent visit to Greece, my three-year-old son reached out and touched The Discus Thrower, a fifth-century B.C.E. statue first executed in bronze by Myron of Eleutherae. "Look, he's throwing a plate," my son said.

The statue he touched is a plaster replica, and so no one reprimanded him. (The Greek original is lost, and we know of its existence from Roman copies in stone.) But the experience reminded me how tactile children are, how they investigate and probe the world through their fingers and hands, touching, squeezing, stroking, molding. Indeed, that sense of touch is crucial to learning and development in children. Building with blocks, for example, has been shown to enhance math skills and spatial abilities.

The average museum exhibits little interest in allowing young visitors to handle ancient artifacts, however. So I was interested to read about the research of John Kaufman, a Ph.D. candidate at Lancaster University in England, who has developed a cheap method to reverse engineer replicas of fragile, 3,000-year-old Egyptian pottery held at the Kendal Museum in the northwest English county of Cumbria. The replicas can be handled by inquisitive children—and, for that matter, by adults.

“It is more and more the fashion in museums and galleries to allow the general public to engage with the artifacts,” Kaufman wrote to me via email. Some museums, he explained, even have “school boxes” that contain fossils or relics such as Roman coins. “But certain items, such as the Egyptian artifacts, are very rare and so cannot be allowed out from their glass cases.”

Kaufman used an inexpensive digital camera to photograph two of the Kendal Museum’s Egyptian treasures: a small, four-inch-high clay vase, and a seven-and-a-half-inch tall statuette of Sobekhotep, son of Nehesy, which dates to 1500 B.C.E. Its hieroglyphic inscription indicates that it served as his sister Kemet’s offering to the god Ptah-Sokar-Osiris. He placed each item on a revolving turntable, and as it rotated 360 degrees photographed the object up to 150 times every 10 to 15 degrees. In contrast, he says, other, more expensive methods employ up to 60 or 80 digital cameras “linked or tethered, positioned around the objects to fire simultaneously.”

With the aid of software called Agisoft PhotoScan Pro, Kaufman transformed this stream of images into one three-dimensional image of the original. The 3D image is converted into a computer file that can be read by 3D printing machines, which can reproduce the original model in materials ranging from sandstone to silver.

Kaufman’s method is so cheap and simple to operate—costing a fraction of the price of laser scanning technology typically used by universities—that it could easily be employed by museum workers with minimal training. The Kendal Museum, he adds, “recently had an open day, and several of my replicated models were available to the general public. Seeing the original in the glass-fronted cabinet, the visitors were intrigued and fascinated to be able to hold the copies.”

Josie Glausiusz has written about every topic known to science, from physics to furry animals, for magazines that include *Nature, National Geographic, Scientific American Mind, Discover, New Scientist,* and *Wired*. She is the co-author of *Buzz: The Intimate Bond Between Humans and Insects*.

The Daily Scholar

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https://theamericanscholar.org/ode-to-a-grecian-replica/#.VagzBMv_GYl

Appendix G

Table G.1: Data Chart – processed using *123D Catch*® - Appendix G

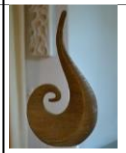
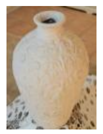
Figure	*Item Name*	*Attempts*	*Material composition and surface finish*	*Artefact size in mm*	*No of Images*	*f/. Aperture*	*Shutter speed*	*Focal length mm*	*Results*
G.02	Clay head	4	Part painted & glazed clay	105 x 95 x 85	60	*A	1/60	55	***** Model made
G.03	Porcelain Figurine	3	High gloss porcelain	25 x 100 x 70	72	f5.6	*A	48	**##** Complex shape - flair
G.04	Dolphins	2	Wood & satin waxed	400 x 250 x 100	72	n/a	n/a	55	**##** Complex shape – flair
G.05	Dog	2	Satin painted clay	90 x 140 x 180	74	f14	*A	55	***** Model made
G.06	Vase	3	Non glazed outer & glazed	180 x 380 x 21	61	*A	1/40	55	**##** Excessive flair - distortion
G.07	Lizard	4	Aged Bronze	350 x 185 x 50	55	*A	1/60	34	****** STL file - Model to be made
G.08	Mollusc	5	Ribbed unglazed dark clay	305 x 85 x 160	68	f8	*A	38	**##** Complex shape – more images
G.09	Square pot & lid	1	High glazed lid, matt pot	140 x 185 x 100	55	f11	1/60	55	**##** Too much flare on lid
G.10	Square pot	2	As above but no lid	95 x 185 x 100	44	f11	1/60	55	****** STL file - Model to be made
G.11	Glass bottle	3	Frosted glass	230 x 295	61	f5.6	*A	45	**##** Distortion – too much flair
G.12	Large clay pot	2	Matt white painted pot	480 x 800/280	65	f8	1/60	40	***** Model made - miniature
G.13	Ceramic pot	2	Unglazed, paint faded clay	200 x 220 x 130	72	f11	*A	32	***** Model made
G.14	Pot with flowers	1	Pot 29 artificial silk flowers	400 x 220 x 200	76	*A	1/60	40	****** Model made - miniature
G.15	Fat clay pot	2	Matt white painted pot	460 x 300/200	70	*A	1/100	35	***** Model made -
G.16	Relief canvas	1	Unvarnished mixed media	400 x 600 x 10	63	*A	1/30	30	****** STL file - Model to be made
G.17	Part Painted Vase	1	Part high gloss clay	300 x 290/200	72	f4	*A	18	**##** Flare on painted section
G.18	Lincrusta - Acanthus	2	Non glazed satin finish	550 x 460 x 3	65	f14	*A	28	# V. good image relief too small
G.19	Lincrusta - Aphrodite	2	Non glazed satin finish	550 x 460 x 3	91	f14	*A	28	# As above
G.20	Unglazed holder	1	Non glazed fire clay	210 x 100 x 120	80	f14	*A	42	****** STL file **-** Model to be made
G.21	Mother & Child	3	Modern ceramic covering	2 x 3 x1 meters	99	f10	*A	28/55	On location – too large
G.22	Concrete heads	1	Modern concrete statues	3x1.5x2 meters	52	f14	*A	24	On location – more top images
G.23	Griffin	1	Medieval Stone	1 x .5 x .5 mtrs.	40	*A	*A	*A	Point cloud image made
G.24	Fish Pot	2	Modern painted clay	130 x 120 diam.	52	f10	*A	28	More images needed
G.25	Egyptian Bowl	2	Ancient Semi Glazed clay	40 x 110 diam.	52	f10	*A	40/44	***** Slightly out of focus – model made
G.26	Egyptian Vase	2	Ancient Semi Glazed clay	120 x 100 x 50	72	f10	*A	40/44	***** V. good image - model made

***** FDM model made -- ****** FDM model waiting to be made -- **#** detail too small to be made -- **##** Too much flare causing distortion on image

Table G.2: Photographic Images, size and material - Capture Log Data *123D Catch*®						Appendix G	1
Number	Original images	Number	Original images	Number	Original images	Number	Original images
G.02		G.03		G.04		G.05	
Name	Clay Head	Name	Figurine	Name	Dolphins	Name	Dog
Size	105 x 95 x 85mm	Size	25 x 100 x 70mm	Size	400 x 250 x 100mm	Size	90 x 140 x 180mm
Material	Semi Glazed Clay	Material	Glazed China	Material	Semi Glazed Wood	Material	Unglazed Clay
G.06		G.07		G.08		G.09	
Name	Vase	Name	Lizard	Name	Mollusc	Name	Square pot & lid
Size	180 x 360 diam. mm	Size	350 x 185 x 50mm	Size	305 x 85 x 160mm	Size	185 x 140 x 100mm
Material	Semi matt outer & Glazed inside	Material	Aged bronze	Material	Ribbed unglazed clay	Material	Part Glazed Clay
G.10		G.11		G.12		G.13	
Name	Square pot	Name	Frosted Bottle	Name	Large Clay Pot	Name	Unglazed Ceramic Pot
Size	185 x 95 x 100mm	Size	230 x 295diam. mm	Size	480 x 800/280 diam. mm	Size	220 x 200 x 130mm
Material	Part Glazed Clay	Material	Glass	Material	Unglazed Clay	Material	Unglazed Clay

Table G.2: Photographic Images, size and material - Capture Log Data *123D Catch*®						Appendix G	2
Number	Original images	Number	Original images	Number	Original images	Number	Original images
G.14		G.15		G.16		G.17	
Name	Pot & flowers	Name	Fat clay pot	Name	Relief canvas	Name	Part Glazed Ceramic Vase
Size	400 x 200 x 220mm	Size	460 x 300/200diam. mm	Size	600 x 400 x 30mm	Size	300 x 290/200mm
Material	Silk and unglazed clay	Material	Unglazed clay	Material	Mixed Media - canvas, paint,	Material	Half glazed clay
G.18		G.19		G.20		G.21	
Name	Lincrusta/Acanthus	Name	Lincrusta/Aphrodite	Name	Unglazed Candle holder	Name	Mother & Child
Size	550 x 460 x 4mm	Size	550 x 460 x 4mm	Size	210 x 100 x 120mm	Size	3000 x 2000 x 1000mm
Material	Unglazed semi matt surface	Material	Unglazed semi matt surface	Material	Unglazed clay	Material	Glazed Mini ceramic tiles
G.22		G.24		G.25		G.26	
Name	Concrete Heads	Name	Fish Pot	Name	Egyptian Vase	Name	Egyptian Bowl
Size	3000 x 1500 x 1000mm	Size	130 x 120diam. mm	Size	120 x 100/50 diam. mm	Size	40 x 120 diam. mm
Material	Polished Concrete	Material	Painted unglazed clay	Material	Painted unglazed clay	Material	Painted unglazed clay

Table G.3: Capture Log for 123D Catch | **Appendix G**

	Item		Version	Download	Video	OBJ	STL	RP Model	Date	Material Composition	Height	Width or circumference/ diameter	Depth/Length	No.Phto's	No. not Stitched	Comments	Resolution	Focal Lenghth	Aperture	Exposure Mode	Shutter Speed V = Varied	Auto ISO	Background
	General Notes															**AP = Aperture Priority: SP = Shutter Speed Priority**							
02	Clay Head		1	✓	X				28/11/12	Clay	105mm	95mm	85mm	52	1	Hole under chin - no distortion	2304x1536	55mm	f/5.6	AP	V	800	Pattern cloth
			1a	✓	X				30/11/12					40	4	Distortion on top of head		55mm	V	SP	1/60		Room
			v2	✓					30/11/12					60	0	**Good image**	3456x2304	55mm				Y	Pattern tablecloth
02a			v2	✓	✓	✓	✓	✓	18/02/13		Redo 123d download			60	0	**Good image**		Data pictures as above					Pattern tablecloth
03	Serenity		1		X				04/12/12	High Glazed china	25	70/100	70	66	13	Small amount of distortion but lot of Flair	3456x2304	55mm	f/5.6	AP	V	100	Pattern table cloth
			v2	✓	X				04/12/12					72	17	good detail but a lot of Flair - **Stitching** pictures back		data not available					Pattern cloth - more showing
			v3	✓	X				17/12/13					59	53	Pictures are **too Dark**		48mm	f/14	AP	V	400	Pattern cloth
04	Dolphins		1	✓	X				08/12/12	Wood	400	250	100	64	2	good detail but a lot of Flair	2265x3300	44mm	f/18	AP	V		Pattern table cloth
			v2	✓	X				16/03/13					72	2	Sharp images	3456x2304						Pattern table cloth
05	Dog		1	X					08/12/12	Clay	90	140	180	56	44	No 3D image - REDO	3456x2304	40mm	f/18	AP	V	100	Pattern table cloth
			v2	✓					15/03/13					71									Pattern cloth
			v3	✓	✓	✓	✓		17/12/13					74	0	**Good** image -		55mm	f/14	AP	V	400	Pattern cloth
06	Vase		1	✓	X				15/01/13	Matt Glazed pot	180mm	230/380/215mm		38	15	**Very distorted**	3456x2304	44mm	f18	AP	V	100	A4 Coloured card
	Vase v4		1a	✓	X				15/01/13					38	16	No 3D image did not stitch by fourth attempted							
	Vase		v2	✓	X				31/01/13					61		Stitched together - a lot of flair distorted image		55mm	V	SP	1/40	400	News Print
07	Lizzy		1	✓	X				27/01/13	Bronze	350mm	185mm	50mm	56	1	Parts missing	3456x2304	45mm	V	SP	1/60	100	Grey card on white table
			2	✓	X				27/01/13					49	17	Not enough points for photo stitching							
			3	✓	X				29/01/13					17	0	More photos needed - bad 3D result		34mm					
			4	✓					03/02/13					55	0	Good result - backgroung left		38mm				400	On pole
	Lizzy v2		4	✓					03/02/13					55	0	**Good result** Background cleaned - images from above							
08	Mollusc		1	✓	X				28/01/13	Unglazed clay	305mm	85mm	160mm	43	8	Part Image	3456x2304	55mm	f/11	AP	V	V	On pole in Garden
			2	✓	X				07/02/13					55	8	Part Image		48mm	f/9	AP	V	200	On pole in Garden
			5	✓	X				28/01/13					68	25	Part Image		48mm	f/5.6	AP	V	V	In Room on Wrought iron table
			6	✓	X				11/02/13					64	21	Best yet - some photos stitched on image		34/44	f4/8	SP	V	800	Plastic spot pattern cover in garden
			7	✓	X				24/02/13					73	47	Holes in body - some photos stitched		38mm	V	SP	1/60	800	Lace table cloth in garden
09	Sq Pot & lid		1	✓	X				29/01/13	Matt Glazed pot	140mm	185mm	100mm	55	1	Not enough overhead pictures - lot of flair on lid	3456x2304	55mm	f/11	AP	V	V	Clay pots & White table
	Sq pot		1a	✓	X				29/01/13		95mm	185mm	100mm	33	0	Good image but hole in side		34mm	f/5	SP	1/60	3200	News Print
			v2	✓	✓				03/02/13					44	0	**Good result** - stitched pictures back		55mm	V	SP	1/60	V	News Print
10	Bottle		1	✓	X				03/02/13	Frosted glass	230mm	295mm diam		34		Distorted shape - stitched pictures back	3456x2304	55mm	f/8	AP	1/30	Y	News Print
			2	✓	X				16/02/13					61	26	Taken indoors v low light photos too dark		35mm	V	SP	1/3	800	Plastic spot pattern cover
			3	✓	X				16/02/13					51	0	taken outside Distorted shape		45mm	f5.3	AP	V	800	Plastic spot pattern cover
11	Large clay pot		1	✓					05/02/13	Clay White painted	480mm	230/800/280mm		59	0	Body good but mouth distorted	3456x2304	40/32m	f/7.1	AP	30/15	Y	Plastic spot pattern cover
			2	✓					17/02/13					65	0	Better than first - mouth a little distorted		24mm	V	SP	1/60	800	Lace table cloth Outside in bright sun in patio tent
	Large clay pot cleanup		v2	✓	✓	✓	✓	✓	18/02/13		Added pictures did not stitch			28		**Good result** Cleaned up image added photos		40mm					Horizontal video
11b	Large clay pot		v3	✓	✓				18/03/13		Check size and remake			65		Photos downloaded as Portrait	Photos as above but portrait						Portrait video - Flare to mouth rim
12	Ceramic pot		v1						17/02/13	Clay Grey non glazed	200mm	150/220	90/130	57	6	Very good outer image	3456x2304	32mm	V	Auto	V	100	Lace table cloth in garden
			v2	✓	✓	✓	✓	✓	17/02/13					57	0	Cleaned good image - all photos stitched		Same photo data but restiched					
	Ceramic pot cleanup								18/02/13		Added pictures			17		**Good result** Cleaned up image added photos							Lace table cloth Outside in bright sun in patio tent

No.	Item	Image	Version	Download	Video	OBJ	STL	RP Model	Date	Material Composition	Height	Width or circumference/ diameter	Depth/Length	No.Phto's	No. not Stitched	Comments	Resolution	Focal Lenghth	Aperture	Exposure Mode	Shutter Speed V = Varied	Auto ISO	Background
12a	Ceramic pot - cleanup		v2	✓	✓	✓	✓	✓	18/02/13	Grey non glazed	Redo 123D			72		**Good result** Cleaned up image	3456x2304						Lace table cloth Outside in bright sun in patio tent
	Ceramic pot & flowers		v1	✓	✓	✓	✓	✓	24/02/13		400mm	800mm	600mm	76		**Good result**		40mm	V	SP	1/60	800	Lace table cloth Outside in bright sun in patio tent
13	Fat pot		v1	✓					18/02/13	Clay White painted	460mm	170/300/200mm		70		**Good result** Cleaned up image	3456x2304	24/35mm	V	SP	1/100	800	Lace table cloth Outside in bright sun in patio tent
			v2	✓	✓	✓	✓	✓	18/02/13					70		**Good result - fully cleaned**		same data as above					above images taken with distance pole on tripod
			v2a	✓	✓	✓	✓	✓	18/03/13							Copied from above but Photos changed to **portrait**	Photos as above but portrait						
14	Relief canvas			✓	✓	✓	✓		24/01/00	Relief wall picture	400mm	600mm	30mm	63		**Good result** Cleaned up image	3456x2304	18/30mm	V	SP	1/30	800	On painted plane inside wall
15	Ceramic Vase			✓	X				27/02/13	Yellow part glazed	300mm	290/200mm		72		stitched 6 picts but still too much flare & distortion	3456x2304	18mm	f/4	AP	V	400	overcast in patio tent
16	Lincrusta - Acanthus			✓	X				20/03/13	cream relief	550mm	460mm	3mm	37		good detail but only half image	3456x2304	18mm	f/8	AP	V	400	
	Acanthus v2			✓	X				21/03/13					65		blurred image		26/34mm	f/14	AP	V	400	Camera tied to 4' distrance from subject
16b	Acanthus v3 - hires			✓	✓	✓			22/03/13							**Good image**	4608x3072						
17	Lincrusta - Aphrodite hrs		v1	✓					21/03/13	cream relief	550mm	460mm	3mm	61			4608x3072	28mm	f/16	AP	V	400	Camera tied to 4' distrance from subject
17b	Aphrodite v2 - hires		v2	✓	✓	✓	✓		22/03/13					34		**Good image - BUT detail lost in making STL file**							As 17b but only first half
18	Candle holder		v1	✓	✓	✓	✓		22/03/13	Terracotta	210mm	100mm	120mm	80		**Good image -** some minor flare	4608x3072	30/42mm	f/14	AP	V	400	Pattern table cloth
			v2													**Smoothed rough edges with MeshMixer 8 - but detail lost**							
																							Change background
19	Mother and Child		v1	✓					04/04/13	Small mosaic tiles	2mtrs	3mtrs	1mtr	51		**High res photos**	4608x3072	28mm	f/14	AP	V	400	open air sea views cloudy day
			v2	✓					05/04/13					60		**More pictures from top view needed**	3456x2304	45/55	f/13	AP	V	200	overcast
			v3						05/04/13					111		**combined photos - top view needed**							
20	Statue								05/02/13	Stone	3000 x 1500 x 2000			52	0	More pictures needed -	3456x2304	24mm	f/14	AP	V	400	Outside in bright sun
21	Fish Pot		v1	✓	X				17/11/2013	Unglazed painted clay				86		Double Image		48	f/8	AP	V	200	
			v2								130	120					4608x3072						
			v3																				
22	Griffin									Victorian Grey Stone	2 mtrs high						Compact						
23	Egyptian Vase		v1	✓					12/9/13	Painted semi clay	120mm	55mm top diam 100mm diam		72		see notes on PhotoScan log	4608x3072	40/44 mm	f/10	AP	V	200	Good result -
			v2	✓	✓	✓	✓	✓	26/09/13														
24	Egyptian bowl		v1	✓			✓		12/9/13	Semi glazed clay	40mm	110mm diam		124		see notes on PhotoScan log		50mm					Good result -
			v2	✓	✓	✓	✓	✓	26/09/13								4608x3072	28mm	f/10	AP	V	200	

General Notes AP = Aperture Priority: SP = Shutter Speed Priority

Appendix H

Table H.1: - Ammonite Data Chart – Triangles (Polygons) size in relation to Kilobyte size of File

Table H.2: - Processing 40 images with *PhotoScan Pro4*®

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Table H.1: Ammonite Data Sheet - Triangles (Polygones) size in relation to Kilobytes size of File	Appendix H

Converted file from *PhotoScan* *.psz to *.obj and imported into *Studio Pro* - Data from Standard Analysis

	Int. Size mm	Adj. Size cm	Hollow adj	shell wall
Width	6.58	112.07	n/a	2.50
Hight	5.37	88.73	n/a	
Depth	3.91	70.87	n/a	
Volume cm	0.06	310.42	64.46	
Area cm	0.95	275.70	515.19	

This file imported to Studio Pro and file is **a.npf

	1 UH	2 H	3 M	4 L	5 UL
Points	2,204,791	518,167	42,365	30,002	5,121
Triangles	4,409,558	1,036,330	84,734	60,000	10 238
Edges	6,614,337	1,554,495	127,101	90,000	15,357
Shells	7	1	1	1	1

Converted and processed (size, hollowed & fixed) fabbproject file to Stl file using Studio Pro

Models have been hollowed and file is **c.nfp

File size in **kilobytes**

	1 UH	2 H	3 M	4 L	5 UL	File size	1 UH	2 H	3 M	4 L	5 UL
Points	2,423,251	738,018	263,499	247,718	230,155	**a.obj	489,651	108,631	8,144	5,694	897
Triangles	4,846,416	1,476,046	527,150	495,432	460,304	**a.nfp	74,558	9,101	767	5,606	190
Edges	726,924	2,214,069	790,725	743,148	690,456	**b.nfp	181,544	18,147	681	6,157	186
Shells	1	1	1	1	1	**c.nfp	261,871	22,130	8,634	12,535	3,983
						**c.stl	236,642	43,000	25,740	24,192	22,476

Hollow & Boolean took 3.5 hours **Hollow & Boolean took 1 minute**

Hollowed Top Half Shells

	File name	kb	Triangles	
1 UH	**d.nfp	58,065	2,570,986	solid
	**e.nfp	60,576	2,897,236	hollow
	**f.nfp	57,559	2,854,466	shell
	**f.stl	139,442		
2 H	**d.nfp	14,087	578,434	solid
	**e.nfp	19,597	891,216	hollow
	**f.nfp	7,433	921,952	shell
	**f.stl	45,018		
3 M	**d.nfp	403	49,776	solid
	**e.nfp	2,829	303,634	hollow
	**f.nfp	2,232	305,126	shell
	**f.stl	14,899		
4 L	**d.nfp	9,133	37,050	solid
	**e.nfp	3,069	347,822	hollow
	**f.nfp	6,709	288,866	shell
	**f.stl	14,105		
5 UL	**d.nfp	147	6,352	solid
	**e.nfp	2,619	321,956	hollow
	**f.nfp	4,192	261,778	shell
	**f.stl	12,783		

Text Letters Hollow
Areal Rounded MT
Bold - Size 12
Text length - 10mm
Text Depth - 3.5mm

Text Letters Relief
Areal Rounded MT
Bold - Size 12
Text length - 10mm
Text Depth - 7.5mm

Colour - Ocher
Hue - 38 Red - 227
Sat - 158 Green - 222
Lum - 163 Blue - 119

Hollowed Top 60mm x 60mm Shells

	File name	kb	Triangles	
1 UH	**g.nfp	42,724	795,364	Sq solid
	**h.nfp	57,100	929,196	shell
	**h.stl	45,371		shell
2 H	**g.nfp	6,156	214,310	Sq solid
	**h.nfp	10,698	470,050	shell
	**h.stl	23,157		shell
3 M	**g.nfp	605	27,426	Sq solid
	**h.nfp	2,832	181,314	shell
	**h.stl	8,854		shell
4 L	**g.nfp	19,900	485	Sq solid
	**h.nfp	3,564	149,706	shell
	**h.stl	7,310		shell
5 UL	**g.nfp	136	6,242	Sq solid
	**h.nfp	1,851	134,048	shell
	**h.stl	6,546		shell

Half Shells
Use **b.nfg and cut in half
Cut from high point on frount
Base point - 0.00 - -34.00 - 22.5mm
0.00 - 7.00 - 22.5mm
Roll - 90
Pitch - 0
Yaw - 180
Size 115 x 115

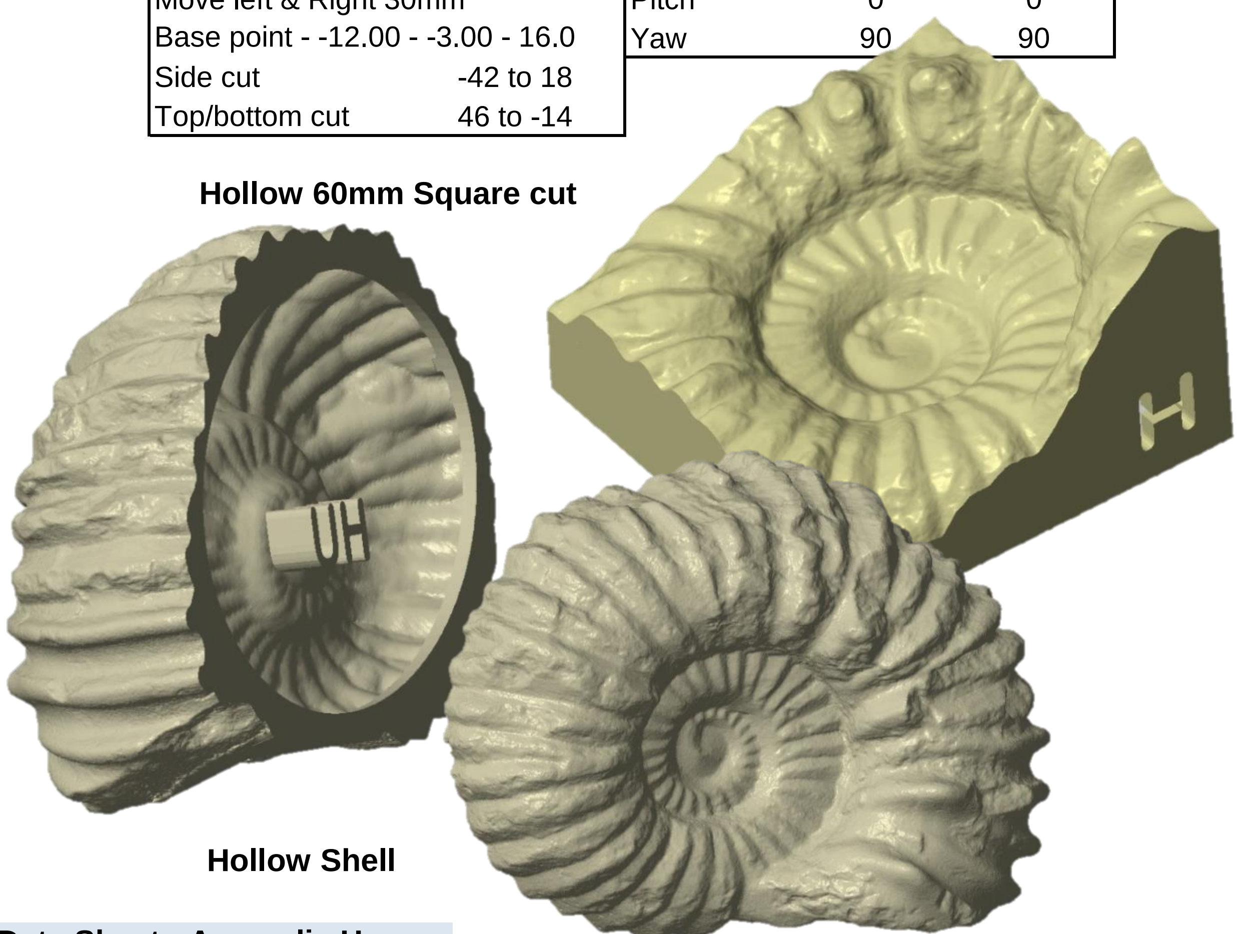
60mm Sq cut Hollow Shell
Use **d.nfg and cut square
Move left & Right 30mm
Base point - -12.00 - -3.00 - 16.0
Side cut -42 to 18
Top/bottom cut 46 to -14

	L/R cut	T/B cut
Roll	90	-180
Pitch	0	0
Yaw	90	90

File name identity

**a.obj	= from PhotoScan	Solid
**a.nfp	= file converted	Solid
**b.nfp	= resize, repair, solid	Solid
**c.nfp	= hollow & drain hole	Hollow
**c.stl	= converted file	
**d.nfp	= cut in half	Half Solid
**e.nfp	= hollowed & fixed	Hollow
**f.nfp	= open back	shell
**f.stl	= converted file	
**g.nfp	= square cut	Sq solid
**h.nfp	= hollow & shell	Shell
**h.stl	= converted file	

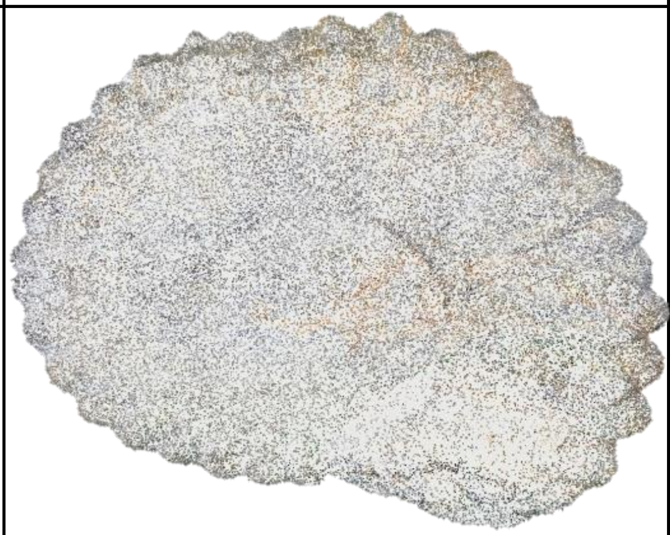
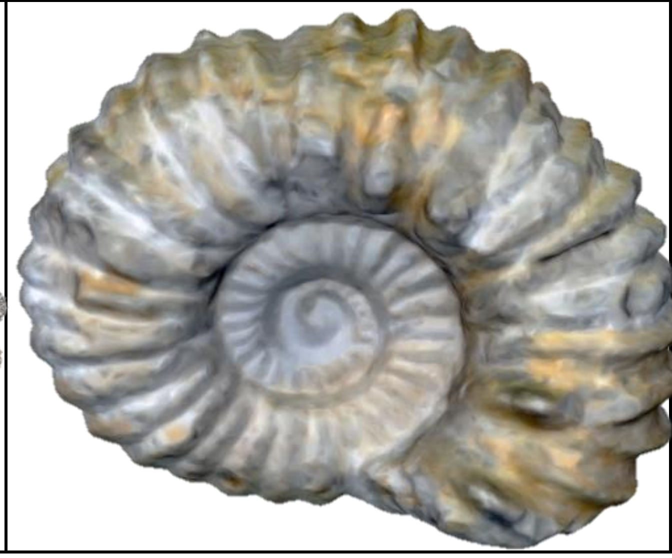
Hollow 60mm Square cut

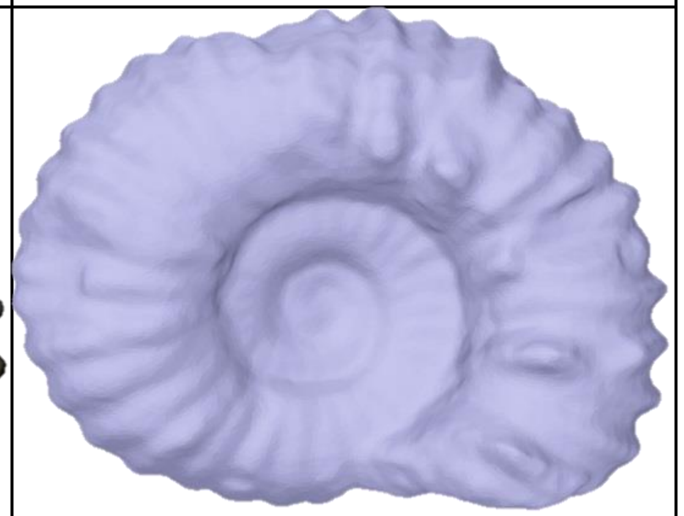
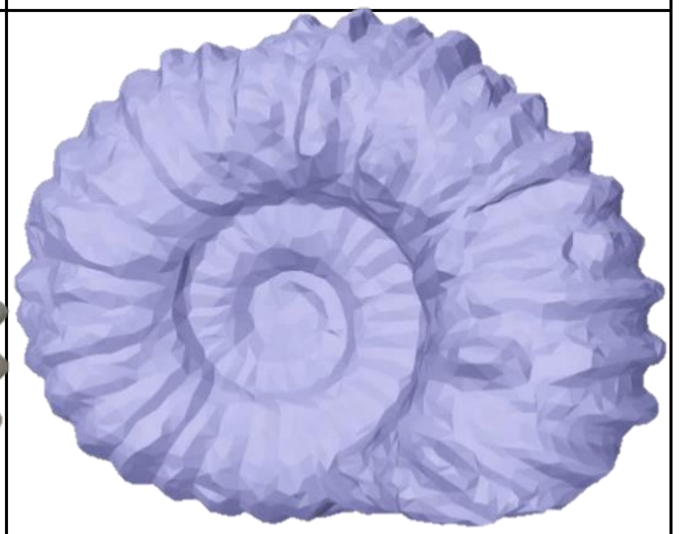


Hollow Shell

Table H.1: Ammonite Size Data Sheet - Appendix H

Table H.2 - Ammonite Data Resolution Statistics - "Processing using 40 images and PhotoScan Pro4" **Appendix H**

	Point Cloud	Dense Cloud	Shaded	Solid
B.D.C Ultra High				
BDC High				
B.Dense Cloud Medium				

	Point Cloud	Dense Cloud	Shaded	Solid
BDC Low				
BDC Lowest				

Align Photos*	DC - Quality	S Points	D Point	Faces	Vertices	Depth Filtering**	B M - Polygon Count**		
High	Ultra High	458,688	21,852,650	4,410,094	2,205,072	Aggressive	D Cloud	H	4,369,093
High	High	458,664	5,125,734	1,035,936	518,167	Aggressive	D Cloud	H	1,025,146
Medium	Medium	91,861	1,270,722	84,713	42,425	Moderate	D Cloud	M	84,714
Low	Low	20,573	313,799	60,000	30,002	Moderate***	D Cloud	M	60,000
Low	Lowest	20,573	74,813	10,192	5,120	Mild	S Cloud	L	10,192

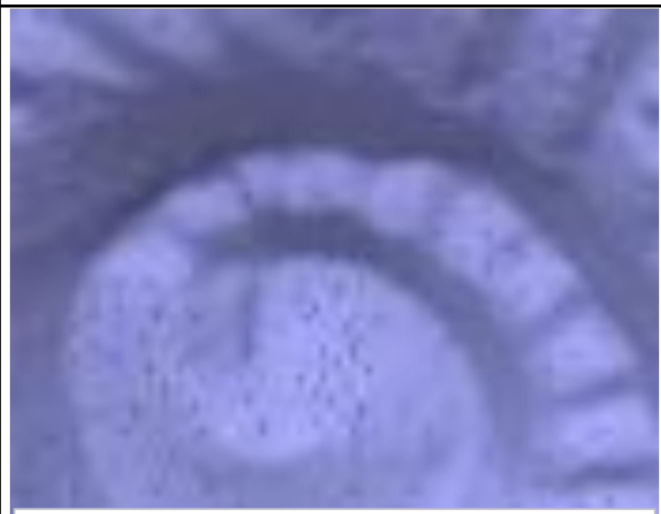
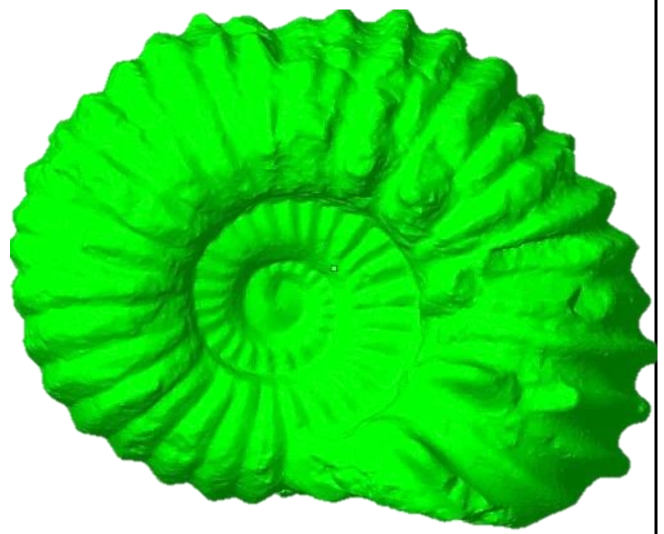
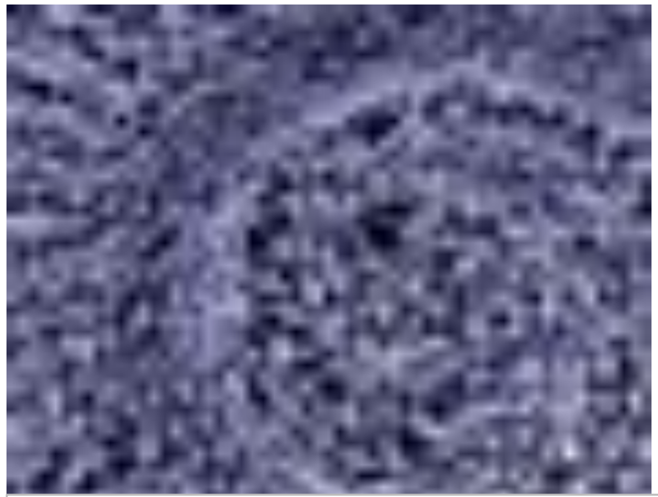
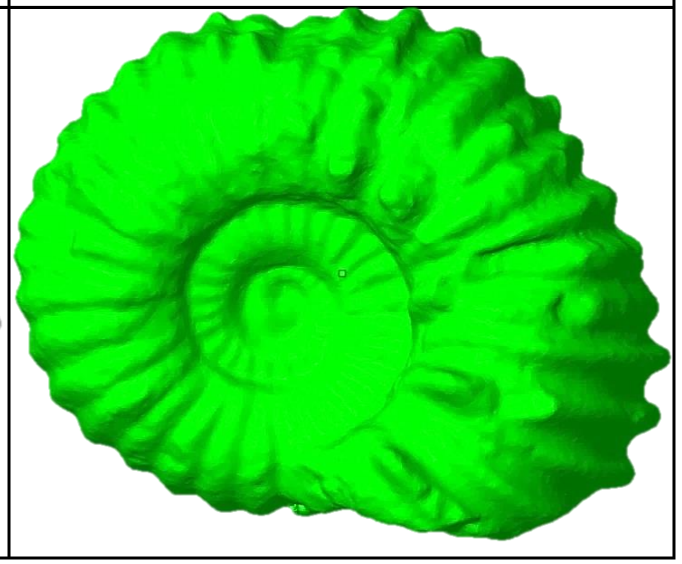
Texture size/count		Build Texture**	
Mosaic - defalt	4096 x1	Maximum Intensity	**U**
Average		Maximum Intensity	**H**
Maximum Intensity		Mosaic	**M**
Minimum Intensity		Average	**L**
		Minimum Intensity	**UL**

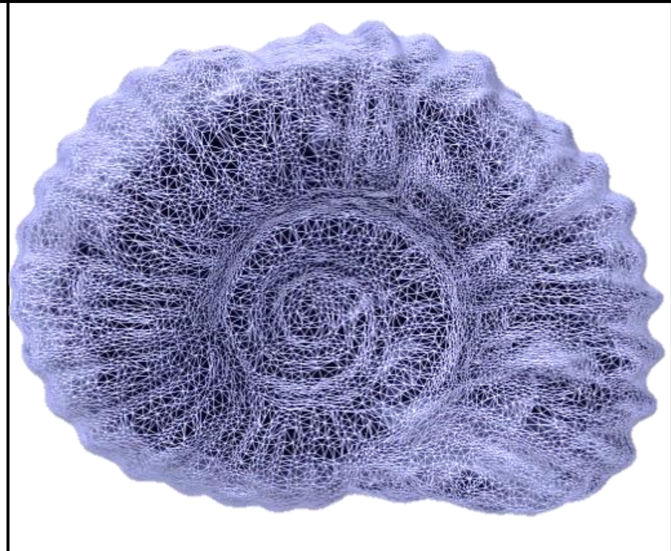
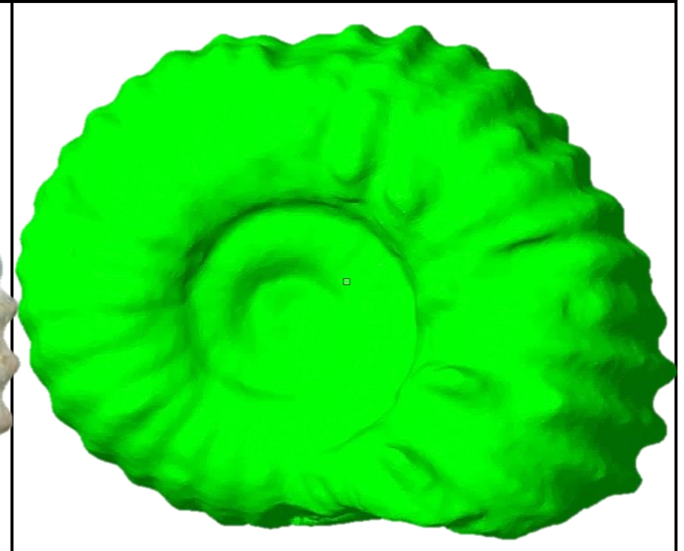
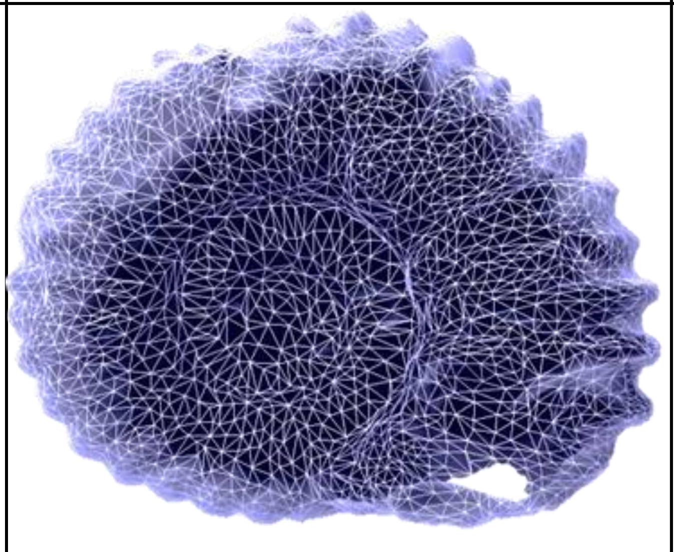
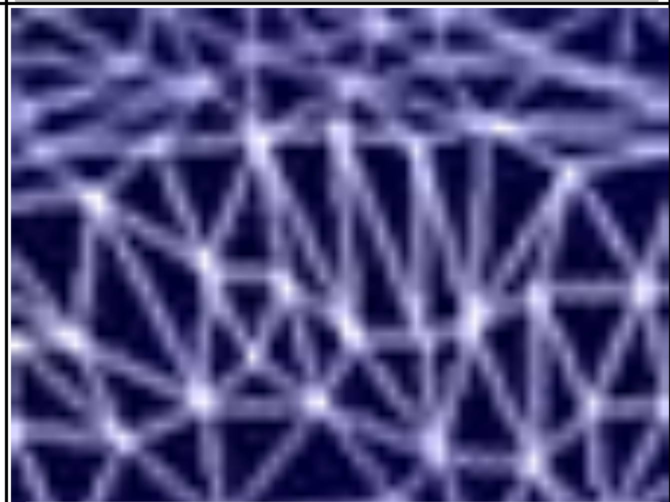
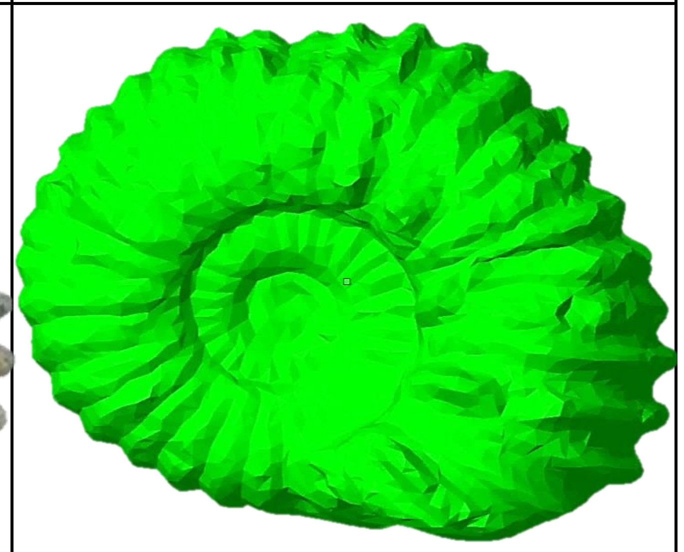
Options	Align Photo Accuracy*
	High
	Medium
	Low

*** = very little difference if Mild and S Cloud - Faces 21,000 and Vertices 10,500

		Filter***	Poly count
BDC = Build Dense Cloud	S = Sparse Point or Cloud	Aggressive	High - 1,035,937
BM = Built Mesh	D = Dense point or Cloud	Moderate	Medium - 345,312
DC = Dense Cloud	** = Slect Option	Mild	Low - 115104

Table H.2- Ammonite processing using 134 images and AgiSoft PhotoScan Pro4 — **Appendix H**

	Wire Frame	Wire Frame - 1:8	Textured	STL file from netfabb Studio Pro
B.D.C Ultra High		 **Ultra High - 4,369,093**		
BDC High		 **High - 1,025,146**		
B.Dense Cloud Medium		 **Medium - 84,714**		

	Wire Frame	Wire Frame - 1:8	Textured	
BDC Low		 Low - 60,000		
BDC Lowest		 Lowest - 10,192		

Converted file from *PhotoScan* *.psz to *.obj and imported into *Studio Pro* - Data from Standard Analysis

	Int. Size	Adj. Size			shell wall
Width	6.58	112.07			2.50
Hight	5.37	88.73			
Depth	3.91	70.87			
Volume cm	0.06	310.42			
Area cm	0.95	275.70			
	UH	**H**	**M**	**L**	**UL**
Points	2,204,791	518,167	42,365	30,002	5,121
Triangles	4,409,558	1,036,330	84,734	60,000	10,238
Edges	6,614,337	1,554,495	127,101	90,000	15,357
Shells	7	1	1	1	1
File *a.obj	489,651	108,631	8,144	5,694	897 kb

Converted and process (size, hollowed & fixed) fabbproject file to Stl file using Studio Pro

Models have been hollowed = *c.nfp

	1 **UH**	2 **H**	3 **M**	4 **L**	5 **UL**
Points	2,423,251	738,018	263,499	247,718	230,155
Triangles	4,846,416	1,476,046	527,150	495,432	460,304
Edges	726,924	2,214,069	790,725	743,148	690,456
Shells	1	1	1	1	1
File *c.nfp	261,871	22,130	8,634	3,960	3,983
*.Stl file	236,642	43,000	25,740	24,192	22,476
	3.5 hours				1 minute

kb

If Halved = *f.nfp

Triangles	2,854,466	921,952	305,126	288,866	261,778
File *f.nf	57,559	7,433	2,232	6,709	4,192
*.Stl file	139,379	45,018	14,899	14,105	12,783

kb

Appendix J

Table J:1	Data Chart - Image processed using *PhotoScan*® -							Appendix J
Figure	Item Name	Attempts	Material composition and surface finish	Artifact size in mm	No of Images	f/. Aperture	Focal length mm	Results
J.24	Painted Fish Pot	2	Non glazed satin finish	130x120 dia.	113	f8	48	Model made and painted
J.27	Painted Clay Vase	2	Part painted, semi glazed clay	150 x 120 dia.	88	f8	40	** Model waiting to be made
H.28	Egyptian Bowl	6	Semi-glazed clay	40 x 110 dia.	124	f11	48	Model made x 2
J.28	Egyptian Bowl	6	Semi-glazed clay	40 x 110 dia.	Digital repair			Model made
J.29	Egyptian Vase	2	Part painted, semi glazed clay	120 x55 x 100	142	f10	48	Model made
J.30	Dog	2	Semi-glazed clay	90x140x180	88	f14	55	Model made
J.31	Clay Head	4	Non glazed clay	105x95x85	120	f14	55	Model made
J.32	Serenity	5	High glazed China	200x100dia.	145	f18	38	## Distortion due to flare – not made
J.33	Dolphins	2	Semi polished Wood	400x250x100	98	f18	44	## Distortion due to flare – not made
J.34	Frosted Bottle	3	High glazed glass	230x295dia.	89	f14	45	## Distortion due to flare – not made
J.35	Aged Pot	7	Unglazed Pot	100x110x60dia	151	f18	48	** STL file - Model waiting to be made
J.36	Pot Shard	1	Unglazed pot	32x85	68	f5.6	50	** STL file - Model waiting to be made
J.37	Clay Bottle	2	Semi-glazed clay	200x100x40	84	f16	48	** STL file - Model waiting to be made
J.38	Warrior	3	Matt Marble	90x35	109	f18	55	Model made and painted
J.39	China Dish	2	High glazed China	115dia.	73	f29	55	## Too distorted due to flare – not made
J.40	Eureka Cat	2	Painted & Semi glazed	35x80x16	76	f25	55	# Model made by *Mcor* & colour printed
J.41	Eureka Man	2	Painted & Semi glazed	64x29x11	75	f18	55	# Model made by *Mcor* & colour printed
J.42	Sobekhotep	2	Unglazed Clay	200x20x40	125	f18	55	Model made and painted x 3
J.43	Roman Jug	1	Unglazed Clay	130 x 82	65	f14	48	Model made
J.45	Long Roman Jug	2	Unglazed Clay - CAD	160 x 50	n/a	n/a	n/a	Model made
J.46	Flat Sided Jug	1	Unglazed Clay - CAD	198 x 113 dia	n/a	n/a	n/a	** STL file - Model waiting to be made
J.47	Spanish Botijo	1	Unglazed Clay	200 x 100 dia	129	f18	42	Model made
J.48	Rock	1	Unglazed natural rock	190 x 170 x 150	139	f22	35	** STL file - Model waiting to be made
J.49	Small Rock	1	Unglazed natural rock	129 x 81 x 93	136	f22	55	** STL file - Model waiting to be made
J.50	Concrete Mix	1	Unglazed stone & concrete	155 x 110 x 42	136	f22	55	Model made and painted
J.51	Ammonite	1	Unglazed natural rock	112 x 65 x 82	134	f22	55	Model made and painted
J.52	Trilobite	1	Unglazed natural rock	87 x 57 x 30	149	f18	55	Model made and painted
J.53	Horus	1	Semi glazed - Clay (crownless)	180 x 54 x 70	148	f22	55	Model made and painted
J.54	Batwing Sea Shell	1	Outer unglazed – inner glazed	57 x 40 x 35	162	f22	55	## Flare on underside – not made
J.55	Thin Sea Shell	1	Unglazed shell	85 x 40 x33	119	f18	36	Model made and painted
J.56	Jug Stand	1	Made in SolidWorks – CAD	78 x 60/70	n/a	n/a	n/a	Model made
J.57	Horus Crown	1	Made in SolidWorks - CAD	58 x 33	n/a	n/a	n/a	Model made and painted
J.58	Horus Egg Crown	1	Made in SolidWorks - CAD	65 x 36 x 54	n/a	n/a	n/a	Model made and painted
J.59	Photo frame	1	Gold painted Wood	205 x 275 x 15	105	f22	34	** Model waiting to be made

2 made of paper by *Mcor* and colour printed
21 Models made
** 8 models waiting to be made

5 Not Made, too much flare causing distortion on image
There was no Shutter speed – as Automatic exposure time

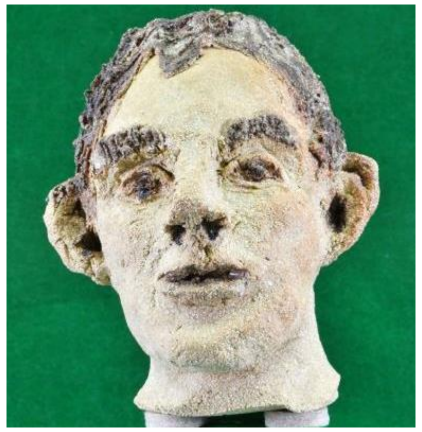
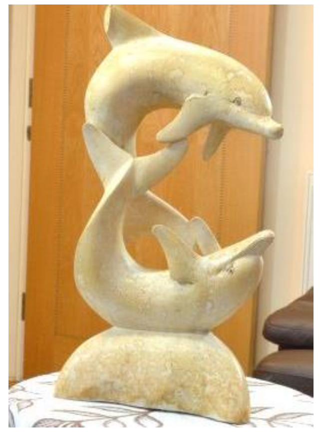
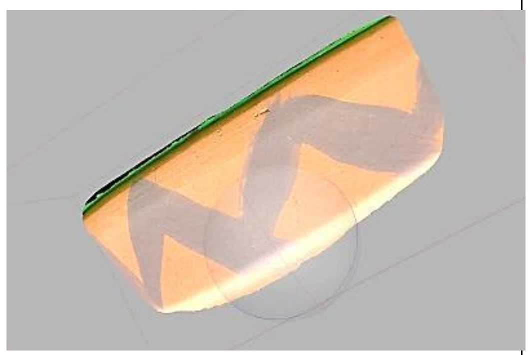
Table J.2: Photographic Images, size and material Capture Log Data *PhotoScanPro4*®							**Appendix J**
Number	Original images	Number	Original images	Number	Original images	Number	Original images
J.24		J.27		J.28		J.29	
Name	Fish Pot	Name	Painted Clay Vase	Name	Egyptian Bowl	Name	Egyptian Vase
Size	130 x 120diam. mm	Size	150 x 120 dia.	Size	40 x 120 diam. mm	Size	120 x 100/50 diam. mm
Material	Painted unglazed clay	Material	Part painted, semi glazed clay	Material	Painted unglazed clay	Material	Painted unglazed clay
J.30		J.31		J.32		J.33	
Name	Dog	Name	Clay Head	Name	Serenity	Name	Dolphins
Size	90 x 140 x 180mm	Size	105 x 95 x 85mm	Size	25 x 100 x 70mm	Size	400 x 250 x 100mm
Material	Unglazed Clay	Material	Semi Glazed Clay	Material	Glazed China	Material	Semi Glazed Wood
J.34		J.35		J.36		J.37	
Name	Frosted Bottle	Name	Aged Pot	Name	Pot Shard	Name	Clay Bottle
Size	230 x 295diam. mm	Size	100 x 110 x 60 dia mm	Size	32 x 85mm	Size	200 x 100 x 40 mm
Material	Glass	Material	Unglazed Pot	Material	Unglazed Pot	Material	Semi-glazed Pot

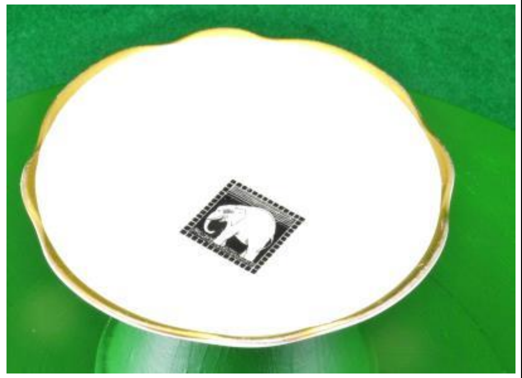
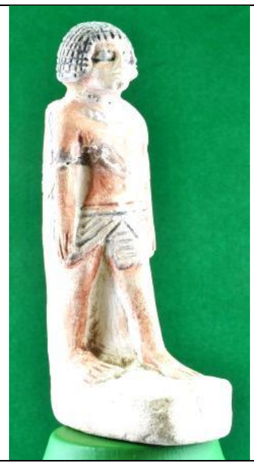
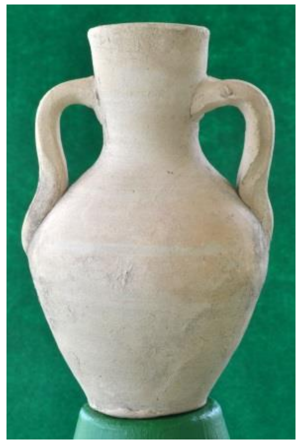
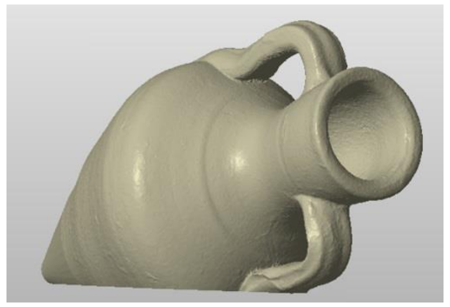
Table J.2: Photographic Images, size and material - Capture Log Data *PhotoScanPro4*®							Appendix J - p2
Number	Original images	Number	Original images	Number	Original images	Number	Original images
J.38		J.39		J.40		J.41	
Name	Warrior	Name	China Dish	Name	Eureka Cat	Name	Eureka Man
Size	90x35	Size	115dia.	Size	35x80x16	Size	64x29x11
Material	Matt Marble	Material	High glazed China	Material	Painted & Semi glazed	Material	Painted & Semi glazed
J.42		J.43		J.44		J.45	
Name	Sobekhotep	Name	Roman Jug	Name	Fish Pot v1	Name	Long Roman Jug
Size	200x20x40	Size	130 x 82 mm	Size	130 x 120diam. mm	Size	160 x 50 mm
Material	Painted Un-glazed Clay	Material	Un-glazed Clay	Material	Painted unglazed clay	Material	SolidWorks
J.46		J.47		J.48		J.49	
Name	Flat Sided Jug	Name	Spanish Botijo	Name	Rock	Name	Small Rock
Size	198 x 113 diam mm	Size	200 x 100dia mm	Size	190 x 170 x 150	Size	129 x 81 x 93
Material	SolidWorks	Material	Un-glazed Clay	Material	Unglazed natural rock	Material	Unglazed natural rock

Table J.2: Photographic Images, size and material - Capture Log Data *PhotoScanPro4*®							Appendix J – p3
Number	Original images	Number	Original images	Number	Original images	Number	Original images
J.50		J.51		J.52		J.53	
Name	Concrete Mix	Name	Ammonite	Name	Trilobite	Name	Horus
Size	155 x 110 x 42 mm	Size	112 x 65 x 82 mm	Size	87 x 57 x 30 mm	Size	180 x 54 x 70 mm
Material	Rough concrete and stone	Material	Unglazed natural rock	Material	Unglazed natural rock	Material	Alabaster
J.54		J.55		J.56		J.57	
Name	Batwing Sea Shell	Name	Thin Sea Shell	Name	Jug Stand	Name	Horus Crown
Size	57 x 40 x 35 mm	Size	85 x 40 x33	Size	78 x 60/70	Size	58 x 33 dia mm
Material	Mother of pearl seashell	Material	seashell	Material	SolidWorks	Material	SolidWorks
J.58		J.59		J.60		J.61	
Name	Horus Egg Crown	Name	Photo Frame	Name		Name	
Size	65 x 36 x 54 mm	Size	205 x 275 x 15mm	Size		Size	
Material	SolidWorks	Material	Gold painted wood/plaster	Material		Material	

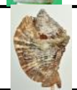
Table J.3: Capture Log Data - *PhotoScanPro4* ® — **Appendix J** — 1

General Notes: OPR = open room; AP = Aperture Priority, V = Variable shutter speed; Accuracy = H/M/L, G = General; All Times* in Minutes, Face count in Thousands; Do not use HDR - only with 32 bit Tiff pics

No.	Item	Image	Background	Photo Data Set	Version	Project file	OBJ	Solid STL	Hollow STL	Zedit - DeskArt	OBJ Screen Shot	Colour Model	AM Model - FDM	AM Model - SLS	AM Model - UO!	Video	Full Text Log	Date	Comments	Mask	Degrees	No. Images
J.27	Clay Vase		White	✓	v1	✓	✓	✓	X								✓	23/09/13	v1 - needed a lot of cleaning around main image	X		88
				✓	M2	✓	✓	✓									✓		**mask - Good result**	✓		
			Green		M3	to be done													**to be done**			
J.28	Egyptian bowl		123D	✓	v1	✓	✓	✓	X							✓		26/09/13	v1 - cleaned in netfabb	X	15	72
			White	✓	v2	✓	✓	X										27/10/13	v2 & M3 - Analysed by Agisoft - top pic blurred	X	10	124
				✓	M3	✓	✓	✓	-				✓	✓				01/10/13	Cleaned and **produced a model** - but lopsided	✓		
				✓	M4	X												10/10/13	Removed top blurred and added photos from 123D			109
				✓	M5	✓	✓	X										15/10/13	Top good but underside needs a lot of cleaning			
				✓	M6	✓	X											16/10/13	As above - needs smaller base to stand on			
			Green	✓	v3	X												28/11/13		X	10	129
				✓	M7															✓		
				✓	M8																	
J.29	Egyptian Vase		White	✓	m1	✓	✓	✓	✓				✓					12/09/13	**very good result - mask used - use Standard 24**	X	15	72
			OPR	✓	M2	✓	✓	✓	✓		✓			✓				26/09/13	**part masked - open room -**	✓	10	143
			Green																			
J.30	Dog		123D	✓	v1	✓	✓	✓	✓					✓				19/03/13	use 123D photos v3	X		74
			White		v2	e done																
			Green	✓	m1	✓	✓	✓										17/10/13	**Mask - very good model**	✓	15	88
J.31	Clay Head		123D	✓	v1	✓	✓											30/11/12	used 123D photos - Requires too much cleaning	X	20	60
			White		v2						✓											
			Green	✓	v3	✓	X										✓	21/11/13	Double image - point cloud mesh not cleaned	X	10	120
				✓	v4	✓	X										✓		cleaned point cloud - needed cleaning before texture - good res	X		
				✓	m1	✓	✓	✓	✓								✓	11/12/13	Fully masked v.good image	✓		
J.32	Serenity		123D	✓	v1	✓	✓											04/12/12	from 123D v2 - quite good result - not as good as M4	X	15	71
			White	✓	v2	✓	X										✓	21/09/13	v2 - White contrast not good enough merged with background	X		75
			Green	✓	m3	✓	X										✓	17/10/13	Total distortion of figure	X		92
				✓	m4	✓	✓	✓									✓		Mask - **good result** perhaps redo at a higher f/stop	✓		
				✓	m5	✓												21/11/13	Reshot @ f/32	✓	10	145
J.33	Dolphins		123D	✓	v1					to be done								08/12/12		X		62
			White		v2					to be done												
			Green	✓	v3	✓	X											17/10/13	Total distortion of figure	X		98
					m1					to be done									**Reshoot** lower & mid shots - no white to show **Mask**	✓		
J.34	Bottle		123D	✓	v1	✓	X				Bad distortion							19/03/13	v1 - from 123D gave worse result	X		51
			Green	✓	v2	✓	X				Bad distortion						✓	05/10/13	No better than first	✓		52
					m3						To Do								**Reshoot in very low light @ f5.6??**			
				✓	m4	✓	X				Bad distortion						✓	21/11/13	as above but @ f22 - **Image but distorted**	✓	15	89
J.35	Aged pot		White	✓	v1	✓	X											05/10/13	use f14 for top shots - no mask -mis-alinenent	X		113
				✓	m2	✓	✓	✓	X										**mask** - fizzy finish some masks not recorded	✓	10	
				✓	m3														**Remask -**	✓		
				✓	v3	✓	X												mask - inside fuzzy - add some top photos	✓	15	76
				✓	v4	✓	X											08/10/13	Need mask - image not complete	X	10	110
			Green	✓	G1	✓	X											17/10/13	**No Mask** - did not align or build	X		151
				✓	G2	✓	✓	✓	-										**added mask - Very good image**	✓		149
J.36	Pot shard		Green	✓	v1	✓	✓	✓	-									08/10/13	**Good result**	X		68
J.37	Clay Bottle		Green	✓	v1	✓	X											17/10/13	2D Flat Model - did not build correctly	X		84
				✓	m2	✓	✓	✓	✓									26/10/13	Reprocesses with mask - **Good result**	✓	15	
			White		m3	to be done																
J.38	Warrior		Green	✓	v1	✓	X										✓	03/11/13	Good image, needs a lot of cleaning - used **Batch** process	X		109
				✓	v2	✓	X												Not Batch - cleaned 1st stage - but as above inside forest	X	10	
				✓	m1	✓	✓	✓	✓		✓			✓			✓		**Very good result -**	✓		

No. / Version	Material Composition	Height in mm	Width or circumference/ diameter in mm	Depth/Length in mm	Wall thickness in mm	Pixel Resolution	Focal Length mm	Aperture	Exposure Mode	Shutter Speed	ISO	Align photo: Accuracy	Align photo: Pair preselect	Align photo: Time*-Align photo	Building geometry: Arbitrary	Building geometry: High	Building geometry: Smooth	Building geometry: Sharp	Building geometry: Face Count K	Time* - Building geometry	Texture mapping: Generic	Texture mapping: Mosaic	Texture mapping: Std (24bit)	Texture mapping: 4096x4096	Texture mapping: 8192x8192	Time* - Building texture	
J.27 v1	Glazed clay	155	120 diam		5	4608x3072	40	f/8	AP	V	200	H	G	90	✓	UH		✓	300	92	✓	✓	✓		✓	30	Clay Vase H27
J.27 M2														69			✓		400	361						5	
J.27 M3																											
J.28 v1	Semi glazed clay	40	110 diam		4	4608x3072	48	f/11	AP	V	200	H	G	200	✓	H	✓		350	300	✓	✓	✓		✓	30	Egyptian Bowl H28
J.28 v2							42	f/10						20	✓	H	✓		400		✓	✓	✓		✓	20	
J.28 v3							55	f/18	AP	V	200	H	G	85.8													
J.29 m1	Painted semi clay	120	55 top diam 100 diam		5	4608x3072	48	f/8	AP	V	200									44							Egyptian Vase H29
J.29 M2							40	f/10				H	G		✓	H	✓		400		✓	✓	✓	✓			
J.30 v1	Semi glazed Clay	90	140	180	solid	3456x2304	55	f/14	AP	V	200	H	G	60						300	✓	✓	✓		✓	10	Dog H30
J.30 v2											100										✓	✓	✓		✓		
J.30 m1						4608x3072	40 - 48	f/14	AP	V		H	G	60	✓	H	✓		350	209	✓	✓	✓		✓	5	
J.31 v1	Semi glazed Clay	105	95mm	85mm	solid	3456x2304	55	f/14	AP	V	200	H	G		✓	H	✓		400		✓	✓	✓	✓			Clay Head H31
J.31 v2											200																
J.31 v3						4608x3072	**50**	f/20			200			35	✓	H	✓		300	250	✓	✓	✓	✓		5	
J.31 v4												H	G	52						120	✓	✓	✓	✓		5.6	
J.31 m1														17					250	130	✓	✓	✓	✓		4.6	
J.32 v1	Painted Bone china on polished wood base	200	100 base			2302x3484	55	f/14	AP	V	100	H	G	60	✓	H	✓		350	72	✓	✓	✓		✓		Serenity H32
J.32 v2							48	f/8				H	G	10	✓	H	✓		400								
J.32 m3						4608x3072	36	f/18			100			29													
J.32 m4																											
J.32 m5							52/45	f/ 32			200																
J.33 v1	Polished Wood	400	250	100	solid wood	2304x3456	44	f/18	AP	V	100									91							Dolphina H33
J.33 v3						4608x3072	36	f/16																			
J.34 v1	Frosted Glass	230	95 diam		3	3456x2304	45	f5.3	AP	V	800				✓	H	✓										Bottle H34
J.34 v2							46	f14			100	H	G	27					400								
J.34 m3						4608x3072																					
J.34 m4							55	f22			200			17					250	26	✓	✓	✓	✓		3	
J.35 v1	Clay pot, broken and painted	100	110mm at top - 60mm bottom		5	4608x3072	48	f/16			200			113	✓	H	✓		400K		✓	✓	✓		✓		Aged Pot H35
J.35 m2																				360							
J.35 m3												H	G	62													
J.35 v3								f/18	AP	V	100									242	✓	✓	✓		✓	24	
J.35 v4							48	f14			200																
J.35 G1							55	f18/ f22			100	H	G	141	✓	`H	✓	-									
J.35 G2														75	✓		✓	-	350	113	✓	✓	✓		✓	7	
J.36 v1	Broken part of Clay Pot	32		85	5	4608x3072			AP	V	100																Shard H36
J.37 v1	Semi Glazed Clay Fire	200 - 210	100	40	6	4608x3072	38/48	f/16	AP	V	100	H	G	64	✓	H	✓			171							Clay Bottle H37
J.37 m2														14.5	✓	H	✓	-	300	49	✓	✓	✓		✓	4.3	
J.37 m3																											
J.38 v1	Matt Marble	90	35		3	4608x3072	55	f/18	AP	V	200				used Batch Processing					157						4.6	Warrior H38
J.38 v2												H	G	340	✓	H	✓		250	311	✓	✓	✓	✓		3.3	
J.38 m1						x3 Close up								59	✓	H	✓		250	280	✓	✓	✓	✓		4	

Table J.3: Capture Log Data - *PhotoScanPro4®* — Appendix J — 2

Item			Background	Photo Data Set	Version	Project file	OBJ	Solid STL	Hollow STL	Zedit - DeskArt	OBJ Screen Shot	Colour Model	AM Model - FDM	AM Model - SLS	AM Model - UO!	Video	Full Text Log	Date	Comments	Mask	Degrees	No. Images	Material Composition	Height in mm	Width or circumference/ diameter in mm	Depth/Length in mm	Wall thickness in mm	Pixel Resolution	Focal Length mm	Aperture	Exposure Mode	Shutter Speed	ISO	Align photo: Accuracy	Align photo: Pair preselect	Align photo: Time*-Align photo	Building geometry: Arbitrary	Building geometry: High	Building geometry: Smooth	Building geometry: Sharp	Building geometry: Face Count K	Time* - Building geometry	Texture mapping: Generic	Texture mapping: Mosaic	Texture mapping: Std (24bit)	Texture mapping: 4096x4096	Texture mapping: 8192x8192	Time* - Building texture	
J.39	China Dish		Green	✓ ✓	v1 m1 m2	X X												03/11/13	V1 - Model **would not build**. - m1 - Total distortion of figure - needs location points & less light use markers??	X ✓	15	73	High gloss china		115/60 diam		3	4608x3072	55	f/29	AP	V	200	H H	G G	128 61	✓	H	✓		250	93	✓	✓	✓	✓		3.6	China Dish H39
J.40	Eureka Cat		Green	✓ ✓	v1 m1	✓ ✓	✓ ✓	✓	✓		✓						✓ ✓	03/11/13	**No Mask** -Good final image but needs cleaning **Very good clear model - very little cleaning needed**	X ✓	15	76	Glazed Clay	35 to ear	80	16		4608x3072	55	f/25	AP	V	200	H	G	83 33	✓	H	✓		200	113 142	✓	✓	✓	✓		3.2 3	Eureka Cat H40
J.41	Eureka Man		Green	✓ ✓	v1 m1	✓ ✓	X ✓	✓	✓		✓						✓	03/11/13	Needs cleaning image part double. **Good clean model**	X ✓	15	75	Glazed Clay	64	29	11	-	4608x3072 x3 Close up	55	f/18	AP	V	200	H	G	104 141	✓ ✓	H H	✓ ✓		200	84.5 94	✓ ✓	✓ ✓	✓ ✓	✓ ✓		3.5 3.2	Eureka Man H41
J.42	Sobekhotep		Green	✓ ✓	v1 m1	✓ ✓	X ✓	✓	✓	✓	✓		✓	✓				28/11/13	**Clear image but needs cleaning & masking** **Good clean model**	✓	10	125	Painted Limestone	total 200	plinth 20 x 40	plinth length 78	4	4608x3072	55	f/18	AP	V	200	H H	G G	90 23	✓ ✓	H H	✓ ✓		300 300	125 156	✓ ✓	✓ ✓	✓ ✓	✓ ✓		4.8 4.4	Sobekhotep H42
J.43	Roman Jug		Green	✓ ✓	v1 m1	✓ ✓	X ✓	✓	✓		✓			✓				29/01/14	**Model would not build** **Good clean model**	✓	10	133	Unglazed Clay	133	82 diam		6	4608x3072					200	H	G	24	✓	H	✓		100	213	✓	✓	✓	✓			Roman Jug H43
J.44	Fish Pot v2		White Green	✓ ✓	v1 m1	✓ ✓	✓ ✓	✓	✓		✓		✓	✓				19/09/13 21/11/13	**no mask - Good result - miniature model made** **SLS model hand painted**	X ✓	10	86 113	Unglazed painted clay	130	120 diam		5	4608x3072	48	f/8	AP	V	200 100	H	G ✓	60	✓	UH H		✓ ✓	300 200	1680	✓ ✓	✓ ✓	✓ ✓	✓	✓	5	Fish Pot H44
J.45	Roman Long Jug		CAD			✓	✓		✓		✓							30/01/14	**Remodeled in Netfabb Studio Pro from H.43**	n/a			Unglazed Clay	200	100mm diam		6		n/a								n/a						n/a						Long Roman Jug H45
J.46	Flat sided Jug		CAD			✓	✓		✓		✓							28/10/15	**Remodeled in Netfabb Studio Pro from H.43**	n/a			Unglazed Clay	160	50		6		n/a								n/a						n/a						Flat sided Jug H46
J.47	Spanish Botijo		Green	✓	m1	✓	✓		✓		✓			✓				26/02/14	**SLS model hand painted**	✓	15	128	Unglazed Clay	200	100 diam		5	4608 x 3072	42	f/18	AP	V	100	H	G		✓	H	✓		446	170	✓	✓	✓	✓		24	Spanish Botijo H47
J.48	Rock		Green	✓	m1	✓	✓		✓		✓							16/03/14	**good textured image**	✓	10	139	Stone	190	170	150	3	4608 x 3072	44	f/25	AP	V	200	H	G		✓	H	✓		200	145	✓	✓	✓	✓			Rock H48
J.49	Small Rock		Green	✓	m1	✓	✓		✓		✓							26/03/14	**good textured image** **Wood prop eliminated**	✓	10	136	Stone	129	81	93	3	4608 x 3072	55	f/22	AP	V	200	H	G		✓	H	✓		705	138	✓	✓	✓	✓			Small Rock H49
J.50	Concrete Mix		Green	✓	m1	✓	✓		✓		✓			✓				26/03/14	**Wood prop eliminated** **SLS model hand painted**	✓	10	135	Mix Stone	155	110	42	3	4608 x 3072	40	f/22	AP	V	200	H	G		✓	H	✓		1,310	134	✓	✓	✓	✓			Concrete Mix H50
J.51	Ammonite		Green	✓	m1	✓	✓		✓		✓		✓	✓				16/03/14	**several versions processed ultra low to ultra high** **SLS model hand painted**	✓	10	134	Sand stone	112	65	82	3	4608 x 3072	55	f/22	AP	V	200	H	G		✓	H	✓			140	✓	✓	✓	✓			Ammonite H51
J.52	Trilobite		Green	✓	h1	✓	✓		✓		✓			✓				23/12/14	**several versions processed ultra low to ultra high** **SLS model hand painted**	✓	10	149	Sand stone	87	57	30	3	4608 x 3072	55	fr/18	AP	V	200	H	G		✓	H	✓			91	✓	✓	✓	✓			Trolobite H52
J.53	Horus crownless		Green	✓	m1	✓	✓		✓		✓			✓				29/06/14	**SLS model hand painted**	✓	10	148	Alabasta?	180	54	70	3	4608 x 3072	44	f/14	AP	V	200	H	G		✓	H	✓			-	✓	✓	✓	✓			Horus H53
J.54	Batwing Sea Shell		White	✓	m1	✓	✓		✓		✓	X						09/07/14	**Very good top dark side -** **too much reflexion on underside**	✓	10	162	Shell	57	40	35	2	4608 x 3072	55	f/22	AP	V	200	H	G		✓	H	✓		628	639	✓	✓	✓	✓			H54 Bat Wing
J.55	Sea Shell		Green	✓	m1	✓	✓		✓		✓			✓				13/10/14	**good model - hand painted**	✓	10	119	Shell	85	40	33	2	4608 x 3072	36	f/18	AP	V	200	H	G		✓	H	✓		500	639	✓	✓	✓	✓			Sea Shell H55
J.56	Jug Stand		CAD			✓	✓	✓			✓			✓				09/10/14	black nylon	n/a			Nylon	78	60/70		S		n/a								n/a						n/a						Jug Stand H56
J.57	Horus Crown		CAD			✓	✓		✓		✓	✓		✓				02/06/14	**SLS model hand painted**	n/a			Nylon	58	33diam		3		n/a								n/a						n/a						Horus crown H57
J.58	Horus Egg Crown		CAD			✓	✓		✓		✓	✓		✓				02/07/14	**SLS model hand painted**	n/a			Nylon	65	36	54	3		n/a								n/a						n/a						Horus Egg crown H58
J.59	Photo Frame		Green	✓	m1	✓	✓	✓			✓							01/09/14	**Model repair on top right corner**	✓	10	105	Wood	275	205	15	S	4608 x 3072	32	f/22	AP	V	200	H	G		✓	H	✓		906	-	✓	✓	✓	✓		6.5	Photo Frame H59

Appendix K

Table K.1: - Capture Log - Failed Artifacts - *123D Catch*																					Appendix K - p1
Item Number	**Item**		**Version**	**Dn load - Project fle cloud image/ Masked**	**OBJ**	**STL**	**Date**	**Material Composition**	**Height in mm**	**Width or circumference/ diameter in mm**	**Degrees rotated**	**No.Phto's**	**No. not Stitched**	**Comments**	**Resolution**	**Focal Lenghth mm**	**Aperture**	**Exposure Mode**	**Shutter Speed V = Varied**	**Auto ISO**	**Background**
	General Notes													**AP = Aperture Priority: SP = Shutter Speed Priority**							
	123D Catch																				
G.03	Serenity		1				04/12/12	High Glazed china	25 x 70/100 x 70			66	13	Small amount of distortion but lot of Flair	3456 x 2304	55	f/5.6	AP	V	100	Pattern table cloth
			v2	✓	X		04/12/12					72	17	good detail but a lot of Flair - **Stitching** pictures back			data not available				Pattern cloth - more showing
			v3	✓	X		17/12/13					59	53	Pictures are **too Dark**		48	f/14	AP	V	400	Pattern cloth
G.04	Dolphins		1	✓	X		08/12/12	Wood	400 x 250 x 100			64	2	good detail but a lot of Flair	3456 x 2304		data not available				Pattern table cloth
			v2	✓	X		16/03/13					72	2								Pattern table cloth
G.06	Vase		1	✓	X		15/01/13	Matt Glazed pot	180 x 230/380/215			38	15	**Very distorted**	3456 x 2304	44	f18	AP	V	100	A4 Coloured card
	Vase v4		1a	✓	X		15/01/13					38	16	No 3D image did not stitch by fourth attempted							
	Vase		v2	✓	X		31/01/13					61		Stitched together - a lot of flair distorted image		55	V	SP	1/40	400	News Print
G.08	Mollusc		v1	✓	X		28/01/13	Unglazed clay				43	8	Part Image	3456 x 2304	55	f/11	AP	V	V	On pole in Garden
			v2	✓	X		07/02/13					55	8	Part Image		48	f/9	AP	V	200	On pole in Garden
			v5	✓	X		28/01/13					68	25	Part Image		48	f/5.6	AP	V	V	In Room on Wrought iron table
			v6	✓	X		11/02/13					64	21	Best yet - some photos stitched on image		34/44	f4/8	SP	V	800	Plastic spot pattern cover in garden
			v7	✓	X		24/02/13					73	47	Holes in body - some photos stitched		38	V	SP	1/60	800	Lace table cloth in garden
G.11	Bottle		v1	✓	X		03/02/13	Frosted glass	230 x 295 diam			34		Distorted shape - stitched pictures back	3456 x 2304	55	f/8	AP	1/30	Y	News Print
			v2	✓	X		16/02/13					61	26	Taken indoors v low light photos too dark		35	V	SP	1/3	800	Plastic spot pattern cover
			v3	✓	X		16/02/13					51	0	taken outside - Distorted shape		45	f5.3	AP	V	800	

G.17	Ceramic Vase		v1 ✓ X	27/02/13	Yellow part glazed	300 x 290/200			stitched 6 picts but still too much flare & distortion	3456 x 2304	18	f/4	AP	V	400	overcast in patio tent
G.18	Lincrusta - Acanthus		v1 ✓	20/03/13	cream relief		37		good detail but only half image	3456 x 2304	18	f/8	AP	V	400	Camera tied to 4' distrance from subject
	Acanthus v2		v2 ✓ X	21/03/13			65		blurred image		26/34	f/14	AP	V	400	
18b	Acanthus v3 - hires		v3 ✓ ✓ X	22/03/13					**Good image - detail lost in STL file**	4608 x 3072						
G.19	Lincrusta Aphrodite hires		v1 ✓	21/03/13	cream relief	550 x 460 x 3	61		**Good image**	4608 x 3072	28	f/16	AP	V	400	Camera tied to 4' distrance from subject
19b	Aphrodite v2 - hires		v2 ✓ ✓ X	22/03/13			34		**BUT detail lost in making STL file**							

Table K.1 - Capture Log - Failed Artifacts - PhotoScan Pro4

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Item Number	Item		Version	Dn load - Project fle	cloud image/ Masked	OBJ	STL	Date	Material Composition	Height in mm	Width or circumference/ diameter in mm	Degrees rotated	No.Phto's	No. not Stitched	Comments	Resolution	Focal Lenghth mm	Aperture	Exposure Mode	Shutter Speed V = Varied	Auto ISO	Background
J.32	Serenity		v1	✓		✓		04/12/12	not masked	200 x 100 dia base		15	71		from 123D v2 - quite good result - not as good as M4				AP	V		White from 1233D - merged with background
			v2	✓		X		21/09/13					75		v2 - White contrast not good enough							White from 1233D
			m3	✓	✓	X		17/10/13	Masked				92		Not masked - total distortion of figure	4608 x 3072						Green
			m4	✓	✓	✓									**good result** perhaps redo at a higher f/stop						100	Green
			m5	✓	✓			21/11/13				10	145		Reshot @ f/32							Green
J.33	Dolphins		v1	✓		X		08/12/12		400 x 250 x 100			62			3456 x 2304	44	f/18	AP	V		White from 1233D
			v2			X																White from 1233D
			v3	✓		✓		17/10/13				15	98		Total distortion of figure	4608 x 3072	36	f/16			100	Green
			m1					to be done with mask							**Reshoot** lower & mid shots - no white to s							Green
J.34	Bottle		v1	✓		X		19/03/13	Semi glazed glass bottle	230 x 95 dia			51		v1 - from 123D gave worse result	3456 x 2304						White from 1233D
			v2	✓		X		05/10/13					52		No better than first							Green
			m3		✓	X			masked						Reshoot in very low light @ f5.6??	4608 x 3072						Green
			m4	✓	✓	X		21/11/13				15	89		Reshoot lower & mid shots - no white to s							Green
J.39	China Dish		v1			X		03/11/13	high gloss	115/60 dia		15	73		V1 - Model **would not build**. -	4608 x 3072	55	f/29	AP	V	200	Green
			m1		✓	X			masked						m1 - Total distortion of figure - needs location points & less light							Green
			m2												use masks ????							Green

AP = Aperture Priority: SP = Shutter Speed Priority

Table K.2: Failed Photographic Artifacts -	Appendix K

Items G.03 and J.32 - Serenity

Figure K. 01 Highly glazed porcelain figurine

Figure K. 01a Textured point cloud image

Items G.04 and J.33 - Dolphins

Figure K. 02 Polished wood

Figure K. 02a Textured point cloud image

Item G.06 - Glazed Vase

Figure K. 03 Inner Glazed vase, outer semi glazed

Figure K. 03a Textured point cloud image

Table K.2: Failed Photographic Artifacts	**Appendix K**

Item G.08 - Mollusc

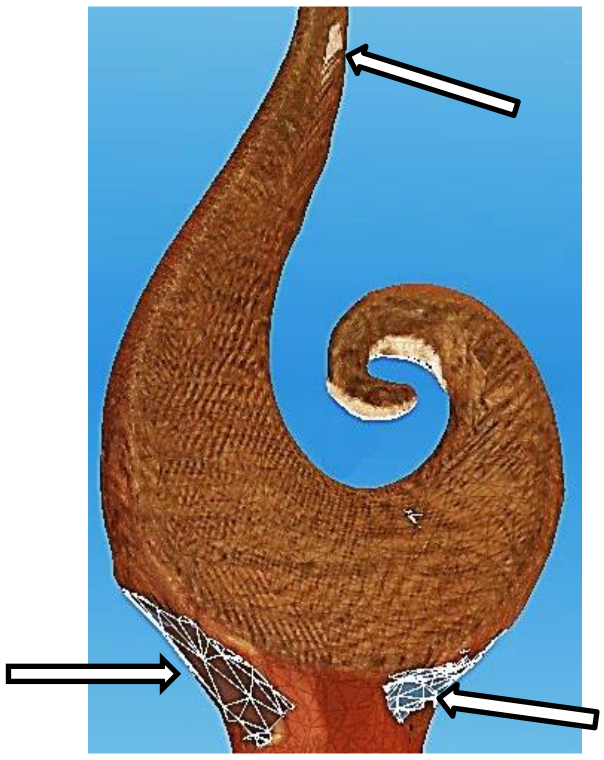

Figure K. 04 Woven unglazed painted clay

Figure K. 04a Textured point cloud image

Items G.11 and J.34 – Frosted Bottle

Figure K. 05 Frosted glass

Figure K. 05a Textured point cloud image

Item G.17 – Ceramic Vase

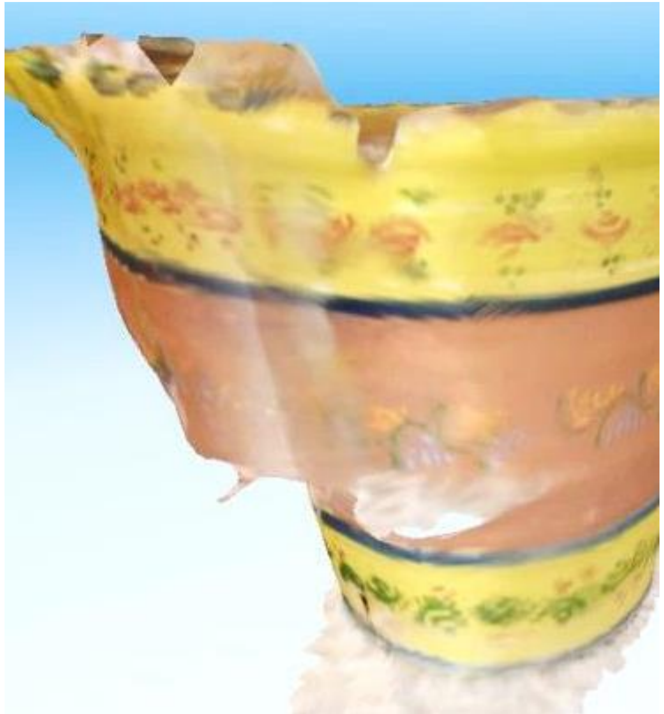

Figure K. 06 Top glazed painted rim flower pot

Figure K. 06a Textured Point cloud image

Table K.2: Failed Photographic Artifacts — **Appendix K**

Item J.39 – China Dish

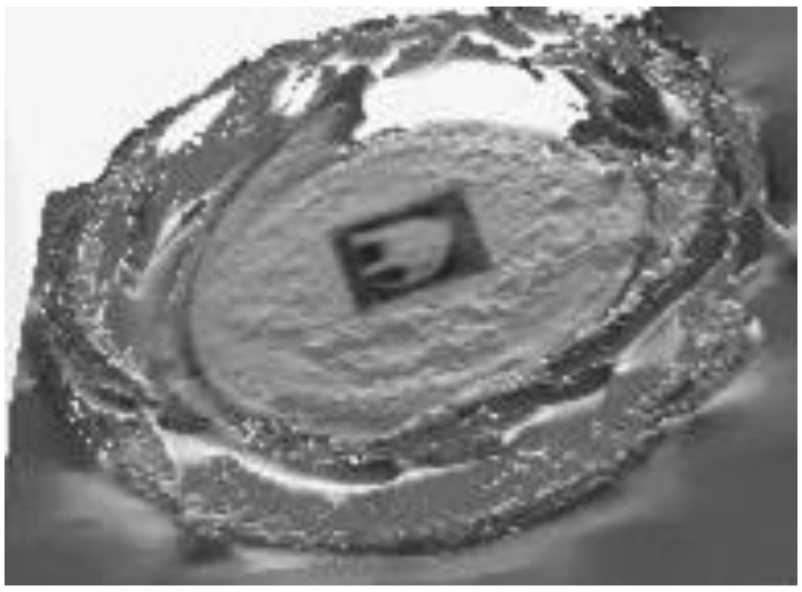

Figure K. 07 High glazed gold edge — Figure K. 07a Textured point cloud image

Item J.54 – Batwing Sea Shell

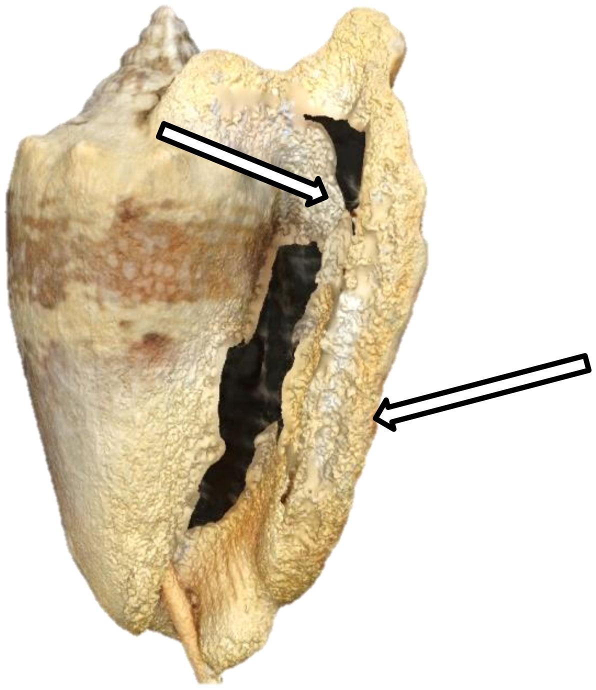

Figure K. 08 Mother of pearl inner shell — Figure K. 08a Textured Point cloud image

Items G.18 and G.19 – Lincrusta

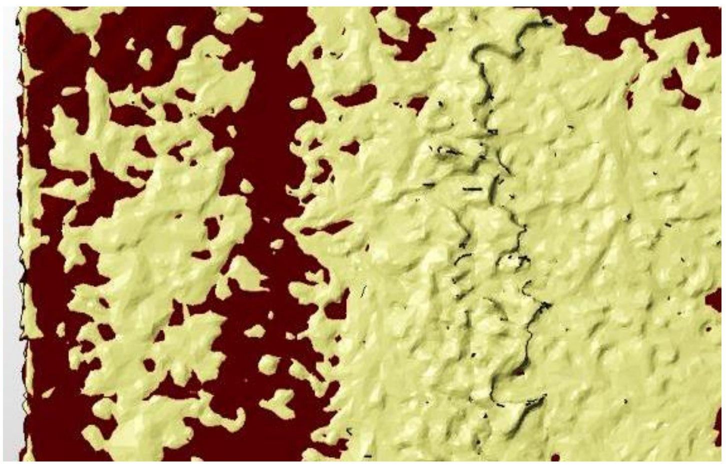

Figure K. 09 Acanthus — Figure K. 09a Textured point cloud image

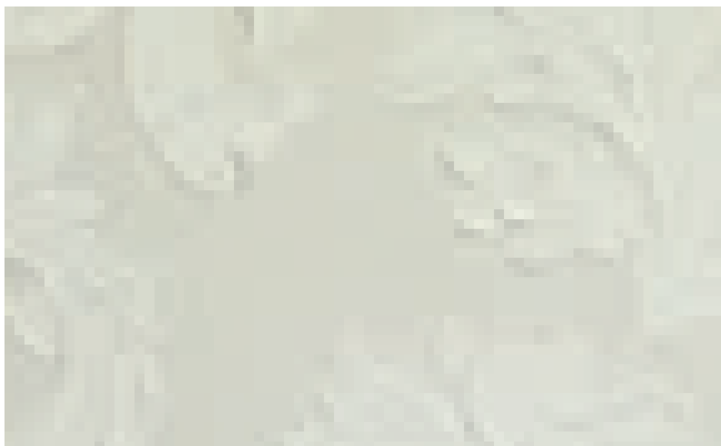

Figure K. 10 Original Aphrodite — Figure K. 10a Textured point cloud image

Appendix L

Table L.1: - Compact v DSLR Digital Data comparison

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Chapter 7.2 – page 277

Table L.1: Compact camera v DSLR Data Comparison -

Appendix L

Camera Data Comparison

Camera		Camera Data						PhotoScan Data*					Imported size of *.obj into *netfabbPro5*				
		No. Images	Aperture f/-	S/Speed second	F/Length	Image size pix	Image File size - kb	Faces	Vertices	Sparse Points	Dense Cloud	*.obj file size kb	Length mm	Width mm	Height mm	Triangles	*.stl file size kb
Nikon D3100	J43 - Roman Jug	130	22	1/2 - 1/5	52 - 48	4608 x 3072	3477 - 3903	1,394,804	697,408	419,501	6,894,939	14,329	1.56	1.49	2.41	199,918	9,800
Canon IXUS	J43a - Roman Jug	95	5 - 5.8	1/60 - 1/80	14.8 - 17.9	3264 x 2448	1518 - 2003	858,646	429,327	95,264	4,247,853	89,333	1.80	1.75	2.79	858,506	41,920
Nikon D3100	J47 - Botijo	118	18 - 22	1/2 - 1/5	26 - 40	4608 x 3072	3143 - 3955	89,058	44,529	445,491	7,432,402	777	1.85	1.88	3.48	89,058	4,349
Canon IXUS	J47a - Botijo	75	2.8 - 3.5	1/60	5.4 - 9.3	1024 x 768	194 - 205	180,146	90,073	23,950	813,059	17,417	1.71	1.66	3.20	180,146	8,790
Nikon D3100	J30 - Dog	88	14	1/2 - 1/4	40 - 48	4608 x 3072	3440 - 4064	1,276,440	638,236	225,985	6,579,104	35,559	1.92	1.31	0.98	313,800	15,323
Canon IXUS	J30a - Dog*	75	3.5	1/40	7.2	640 x 480	81 - 101	177,162	88,581	5,540	225,501	17,192	1.97	2.03	1.45	177,162	8,649
Canon IXUS	Fig.7.7 - Griffin	32	4	1/500-1/1000	8.736	3264 x 2448	1682 - 2547	2,827,950	1,414,053	53,832	14,123,079	307,006	2.36	3.10	4.80	2,742,798	132,933
										123D Catch		50,289	18.34	25.90	37.74	700,618	167,143

*** note for PhotoScan**

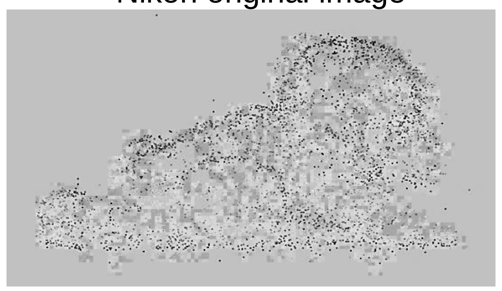
All digital images were Aligned the same way
The Accuracy setting were set to 'High'

Roman Jug was set to 'Aggressive' and 'High'
Build dense Cloud - Botijo, Dog & Griffin
setting were set to 'Aggressive' & 'ultra high'

Nikon original image

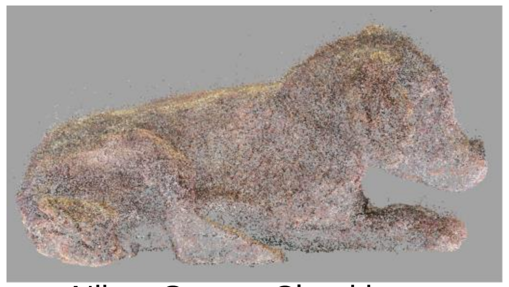
Nikon Mesh

Canon Mesh



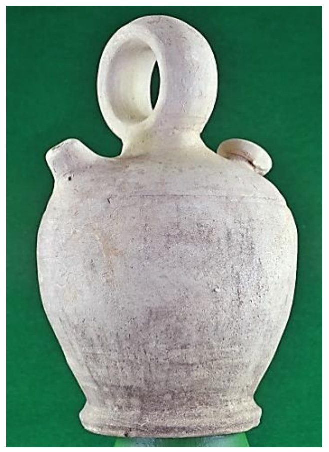
Canon Sparse Cloud image

Canon Mesh



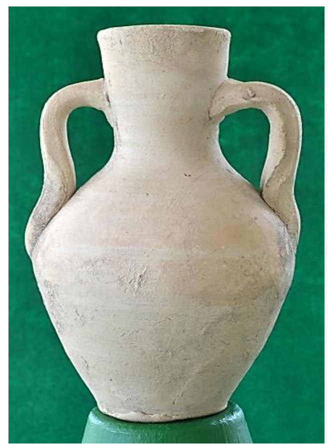
Nikon Sparse Cloud image

Nikon Mesh



Nikon original image

Canon 'Orthophoto'



Nikon original image

Canon 'Orthophoto'

Appendix M

Table M.1 - Warrior Head - NetFabb Data for bench mark models

Chapter 4.12 – page 154
page 158
Chapter 7.2 – page 274
Chapter 9.4 – page 327

Table M.1: Warrior Head - NetFabb Data for bench mark models

Appendix M

Original PhotoScan Obj Data

2.39mm high scaled up to 90mm high

Solid body	U High	High	Medium	Low	U Low
Tiff images					
Volume m^3	44.00	43.86	45.77	45.47	46.64
Area m^2	97.50	93.87	92.60	88.26	86.78
Triangles	4,161,290	913,366	211,744	177,318	117,048
Obj file size kb	459,583	96,497	21,673	17,668	11,597
Stl file size kb	203,187	44,599	10,340	8,659	5,706
Vrml/wri size kb	383,257	81,788	9,327	7,768	5,125

Solid body	U High	High	Medium	Low	U Low
Jpeg images					
Volume m^3	49.88	49.58	49.83	50.12	50.09
Area m^2	105.12	101.79	100.00	94.56	90.96
Triangles	3,678,552	902,020	216,552	175,608	118,428
Obj file size kb	420,501	97,586	21,993	17,569	11,621
Stl file size kb	179,617	44,045	10,575	8,575	5,783
Vrml/wri size kb					

Netfabb processed Tiff Hollow Heads - Stl file

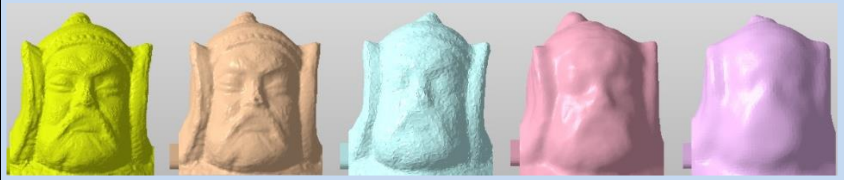
W: 21.2mm D: 24mm H: 25.mm

Tiff Images	U High	High	Medium	Low	U Low
Volume m^3	3.47	3.38	3.40	3.47	3.48
Area m^2	32.09	31.13	31.37	31.86	32.12
Triangles	824,782	185,918	64,980	59,354	47,100
Stl file size kb	40,273	9,079	3,173	2,899	2,300
Vrml/wri size kb	58,397	10,741	4,935	3,411	2,668

U H | H | M | L | UL

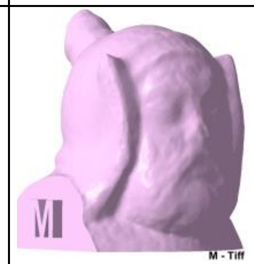
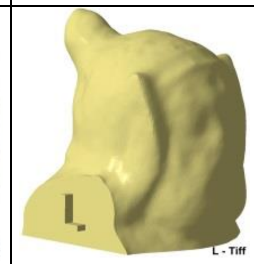
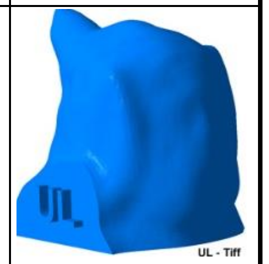
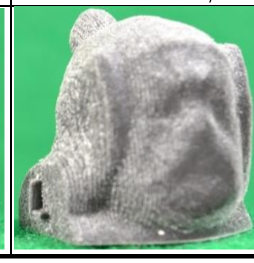
Netfabb processed Jpeg Hollow Heads - Stl file

Jpeg Images	U High	High	Medium	Low	U Low
Volume m^3	3.33	3.35	3.31	3.34	3.43
Area m^2	31.15	31.14	30.85	31.14	32.15
Triangles	694,612	174,676	60,854	55,664	47,588
Stl file size kb	33,917	8,530	2,972	2,719	2,324

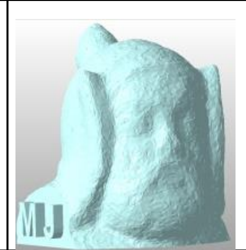
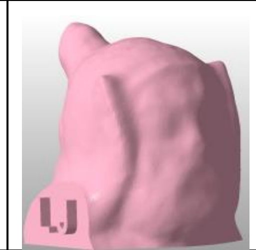
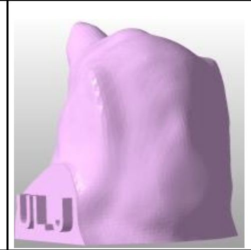


UH | H | M | L | UL

AM machine and fabricated **Tiff** model chart - from **RAW** images

	U High	High	Medium	Low	U Low
Screen shot					
stl kb	43,607	9,079	3,173	2,899	2,300
Triangles	862,720	185,918	64,980	59,354	47,100
vrml/wri kb	58,397	10,741	4,935	3,411	2,668
PolyJet — Fabricated model - photographic image					

AM machine and fabricated **Jpeg** model chart - from **RAW** images

	U High	High	Medium	Low	U Low
Screen shot					
stl kb	33,917	8,530	2,972	2,719	2,324
Triangles	694,612	174,676	60,854	55,664	47,588
PolyJet — Fabricated model - Photographic image					

AM machine fabricated **Jpeg** models - from **Camera Ready (CR)** stl file

Original Image	Original CR Jpeg - screen shot	PolyJet - photographic image	FDM - Ultimaker+2 photographic image	SLS - photographic image
				

Appendix N

Capture Log for PhotoScan

Table N.1: Capture log - RAW & Jpeg - Photographic Image Data																						Appendix N
				Photo Shoot Data													Model details					
	Item		Date Photo Shoot	Background	No. Images	Cir. Polaroid Filter	RAW Photo Data Set	Original Jpeg Data Set	Degrees	Focal Length mm	Aperture	Exposure Mode	Shutter Speed	File Size KB	ISO	Pixel Resolution	Material Composition	Height in mm	Depth/Length	Width or circumference/	Wall thickness in mm	Comments
										AP = Aperture Priority: V = Variable shutter speed: OPR = open room												
	Warrior		03/11/13	Green	109			✓	10	55	f/18	AP	V		200	4608 x 3072	Matt Marble	90 mm		35mm diameter base		Good image, needs a lot of cleaning - used **Batch** process
																						Not Batch - cleaned 1st stage - but as above inside forest
								✓		x3 Close up												**Very good result** -
	Warrior RAW		16/11/16	Green RAW	138		✓		10	55	f/16	AP	V	11,186 to 10,511	100	4608 x 3072 Raw						High and low shot @ 30 degrees horizintal
																						Tiff images - 16 bit
																						Jpeg images
	Serenity		17/10/13	Green	92			✓	15	36	f/18	AP	V		100	4608 x 3072	Painted Bone china on polished wood base	200 mm		100mm dia. base		Total distortion of figure
																						Mask - good result perhaps redo at a higher f/stop
			21/11/13		145			✓	10	52/45	f/ 32				200							Reshot @ f/32
	Serenity RAW		17/11/16	Green RAW	140	✓	✓		10	50	f/16	AP	V	16,383 to 10,627	100	4608 x 3072 Raw						High and low shot @ 30 degrees horizontal
																						Tiff images - 16 bit
																						Jpeg images
	Dolphins		17/10/13	Green	98		✓			36		AP	V		100	4608 x 3072	Polished Wood	400 mm	100mm	250mm	solid wood	Total distortion of figure
																						Reshoot lower & mid shots - no white to show **Mask**
	Dolphins RAW		17/11/16	Green RAW	141	✓	✓		10	55 to 48	f/16	AP	V	12,843 to 10,823	100	4608 x 3072 Raw						
																						Tiff images - 16 bit
																						Jpeg images

Capture Log for PhotoScan

	Item		Date	Background	No. Images	Cir. Polaroid Filter	RAW Photo Data Set	Original Jpeg Data Set	Degrees	Focal Length mm	Aperture	Exposure Mode	Shutter Speed V = Varied	File Size KB	ISO	Pixel Resolution	Material Composition	Height in mm	Depth/Length	Width or circumference/ diameter	Wall thickness in mm	
	China Dish		03/11/13	**Green**	73			✓	15	55	f/29	AP	V		200	4608 x 3072	High gloss china	115/60 diam			3	V1 - Model **would not build**. - m1 - Total distortion of figure - needs location points & less light use markers??
	China Dish			**Green RAW**		✓																

Capture Log for PhotoScan

Table N.2: RAW & Jpeg image Processing log - PhotoScan Data processing Information — Appendix N

For sizes of artifacts see Appendix J - All times in minutes

Original Model images													Align photo				Building Dense Cloud							Texture mapping									Warrior head only					AM Build				
													Accuracy = UH, H, M, L, Lo All Pair Preselect "General"				Depth Filter:- Aggressive, Moderate, Mild, Disable			Build Mesh Tile size 4096																						
Original Model images		Date Photo Shoot	No. Images	Cir. Polaroid Filter	RAW Photo Data Set	Jpeg Photo Data Set	Tiff Photo Data Set	Mask	File name	Version	Project file	Processing Log	Accuracy	No. Alignments	Sparse Point Cloud	Time to Align photos	Quality	Depth Filter	Dense Cloud Count	Faces Triangles	Vertices	Face Count	Time to Building Dense Cloud	Mapping - Generic	Blending - Mosaic	Time taken	Shaded D Cloud Screen Shot	OBJ	Obj file Size in Kb	Solid STL	Hollow STL	Solid body Stl file Size in Kb	Solid Head	Hollow Head	Hollow head stl file size kb	Vrml file	Vrml file size	AM Model - FDM	AM Model - SLS	AM Model - PolyJet	AM Model - DLP	
36R - Warrior RAW		16/11/16	138	No	✓	n/a	✓	✓	Warrior - UH	UH	✓		UH	138	67,063	21.6	UH	A	Out of Memory - 3 attempts old GPU				2,875.0	X			X	X	X	-	-		X	X		-						Bench mark models
									Warrior - UH*	UH	✓	✓	UH				UH	A	Filtering Depth Map error				1,108.6	X			X	X	X	-	-		X	X		-						
									Warrior - UH2#	UH	✓	✓	UH				UH	A	20,800,670	4,161,290	2,080,665	H	2,026.5	G	Mo	n/k	✓	✓	459,583	✓	✓	2,031,878	✓	✓	43,607	✓	56,625					
									Warrior - H	H	✓	✓	H				H	A	4,563,594	912,717	456,601	H	145.0	G	Mo	2.1	✓	✓	96,497	✓	✓	44,599	✓	✓	9,079	✓	10,741					
									Warrior - M	M	✓	✓	M				M	Mo	1,092,005	218,401	109,286		39.3			5.1	✓	✓	21,673	✓	✓	10,340	✓	✓	3,173	✓	4,935					
									Warrior - L	L	✓	✓	L				L	Mo	257,873	180,000	90,002		14.5			4.9	✓	✓	17,668	✓	✓	8,659	✓	✓	2,899	✓	3,411					
									Warrior - UL	UL	✓	✓	UL				UL	M	59,545	118,690	59,347		8.6			4.8	✓	✓	11,597	✓	✓	5,706	✓	✓	2,300	✓	2,668					
			138			✓	n/a	✓	Warrior J - UH	UH	✓	✓	UH	138	16,205	29.9	UH	A	18,928,476	3,786,846	1,893,461	H	952.2	G	Mo	6.9	✓	✓	420,501	✓	✓	179,617	✓	✓	33,917	-						
									Warrior J - H	H	✓	✓					H	A	4,628,238	925,066	462,550		163.7			1.5	✓	✓	97,586	✓	✓	44,045	✓	✓	8,530	-						
									Warrior J - M	M	✓	✓					M	Mo	1,111,324	222,426	111,217		40.4			1.0	✓	✓	21,993	✓	✓	10,575	✓	✓	2,972	-						
									Warrior J - L	L	✓	✓					L	Mo	257,873	180,000	90,018		16.3			0.8	✓	✓	17,569	✓	✓	8,575	✓	✓	2,719	-						
									Warrior J - UL	UL	✓	✓					UL	M	59,939	119,842	59,923		9.0			0.8	✓	✓	11,621	✓	✓	5,783	✓	✓	2,324	-						
38	03/11/2013		109			✓	No	✓	Warrior - m1. psz	H	✓		H	109	56,663		H	A		196,498	98,239		280.0	G	Mo	4.0	✓	✓	19,618	-	-	-	-	-	-	-						
38	Re-processed 17/02/17		109	No	No	✓	No	✓	Warrior - m1.psx	H	✓	✓	UH	109	42,990	16.9	H	A	2,854,427	570,885	285,609	H	72.4	G	Mo	3.5	✓	✓	59,493	✓	-	27,321	-	✓	6,403	-						
30R - Serenity RAW		17/11/16	145	✓	✓	n/a	✓	✓	30R - Serenity - UH	UH	✓	✓	UH	134	142,744	18.9	UH	A	Out of memory - two attempts - old GPU				1,500.0	X			X	X	X	-	-		X	X		-						
									30R - Serenity - UH*	UH			UH				UH	A	16,961,556	3,392,310	1,696,773	H	438.4	G	Mo	3.4	✓	✓	372,438	✓	-	165,084										
									30R - Serenity - H*	H	✓	✓	H				H	A	4,404,664	881,466	440,729	H	83.9			2.0	✓	✓	92,145	✓	-	42,824										
									30R - Serenity - M*	M	✓	✓	M				M	Mo	1,055,471	211,093	105,665		23.6			1.8	✓	✓	20,791	✓	-	10,279										
									30R - Serenity - L*	L	✓	✓	L				L	Mo	248,163	180,000	89,988		8.7			1.7	✓	✓	17,564													
									30R - Serenity - UL*	UL	✓	✓	UL				UL	M	55,888	117,484	58,732		5.0			1.1	✓	✓	11,345													
			145			✓	n/a	✓	Serenity - J - UH	UH	✓	✓	UH	145	103,098	19.5	UH	A	16,742,122	3,348,424	1,674,963	H	506.7	G	Mo	3.2	✓	✓	368,950													
									Serenity - J - H	H	✓	✓					H	A	4,509,068	901,210	450,604		96.5			1.5	✓	✓	94,304													
									Serenity - J - M	M	✓	✓					M	Mo	1,091,318	218,262	109,248		24.0			1.5	✓	✓	21,431													
									Serenity - J - L	L	✓	✓					L	Mo	254,730	179,776	89,878		8.0			5.5	✓	✓	17,394													
									Serenity - J - UL	UL	✓	✓					UL	M	57,202	118,712	59,350		4.0			1.1	✓	✓	11,473													
32	17/10/2013		92			✓	No	✓	Serenity - m4.psz	UH	✓		UH	145	64,693		UH	A	5,157,703	1,038,788	519,404	H		G	Mo		✓	✓	30,555													
32	Re-processed 22/02/17		141	No	No	✓	No	✓	Serenity - H.psx	H	✓	✓	UH	141	98,648	10.6	H	A	5,008,844	1,002,640	501,334	H	231.0	G	Mo	4.2	✓	✓	106,041													
31R - Dolphins RAW		17/11/16	141	✓	✓	n/a	✓	✓	31R - Dolphin - UH	UH	✓	✓	UH	141	74,892	23.3	UH	A	Out of memory - two attempts - old GPU			H	2,766.0	X			X	X	X	-	-		X	X		-						
									31R - Dolphin - UH*	UH	✓	✓	UH				UH	A	Filtering Depth Map error				1,966.8	X			X	X	X	-	-		X	X		-						
									31R - Dolphin - UH2#	UH	✓	✓	UH		75,164	24.0	UH	A	29,386,865	5,878,456	2,939,224	H	2,028.5	G	Mo	n/k	✓	✓	660,044													
									31R - Dolphin - H	H	✓	✓	H		74,892	23.3	H	A	6,678,548	1,335,709	668,179	H	510.4	G	Mo	9.0	✓	✓	141,073													
									31R - Dolphin - M	M	✓	✓	M				M	Mo	1,666,196	333,246	166,754		96.0			7.4	✓	✓	33,944													
									31R - Dolphin - L	L	✓	✓	L				L	Mo	417,918	179,999	90,008		27.0			8.1	✓	✓	17,584													
									31R - Dolphin - UL	UL	✓	✓	UH				UL	M	101,390	180,000	89,996		12.7			7.1	✓	✓	17,527													
						✓	n/a	✓	Dolphin - J - UH	UH	✓	✓	UH	141	83,167	21.0	UH	A	Out of memory - old GPU			H	1,860.0	X			X	X	X	-	-		X	X		-						
									Dolphin - J - UH*	UH	✓	✓	UH				UH	A	27,456,391	5,492,718	2,746,359	H	2,126.5	G	Mo	3.0	✓	✓	612,820													
									Dolphin - J - H	H	✓	✓	UH				H	A	6,662,748	1,332,548	666,616	H	539.6			4.3	✓	✓	140,070													
									Dolphin - J - M	M	✓	✓					M	Mo	1,659,383	331,898	166,084		91.7			1.2	✓	✓	33,523													
									Dolphin - J - L	L	✓	✓					L	Mo	415,718	180,052	90,022		25.8			1.0	✓	✓	17,492													
									Dolphin - J - UL	UL	✓	✓					UL	M	101,135	20,000	9,996	L	11.6			1.0	✓	✓	1,804													
33	17/10/2013		98			✓		No	Dolphine - v3c.psz	H	✓		UH	96	41,792		Data not available as original Data set was too distored - Not Masked										✓	X	X	-	-		X	X		-						
33	Re-processed 16/02/17		96	No	No	✓	No	✓	Dolphin - m1.psx	H	✓	✓	UH	96	101,718	9.4	H	A	5,632,775	1,126,554	563,577	H	118.4	G	Mo	0.8	✓	✓	118,204													

* processed with GTX 1060 GPU | # - processed by Agisoft useing Depth Maps | Original 2013 Camera ready Jpeg | Original Camera ready Jpeg images re-processed 2017

Capture Log for PhotoScan

RAW image Processing log - PhotoScan Data processing Information

For sizes of artifacts see Appendix J - All times in minutes

Appendix N Page 2

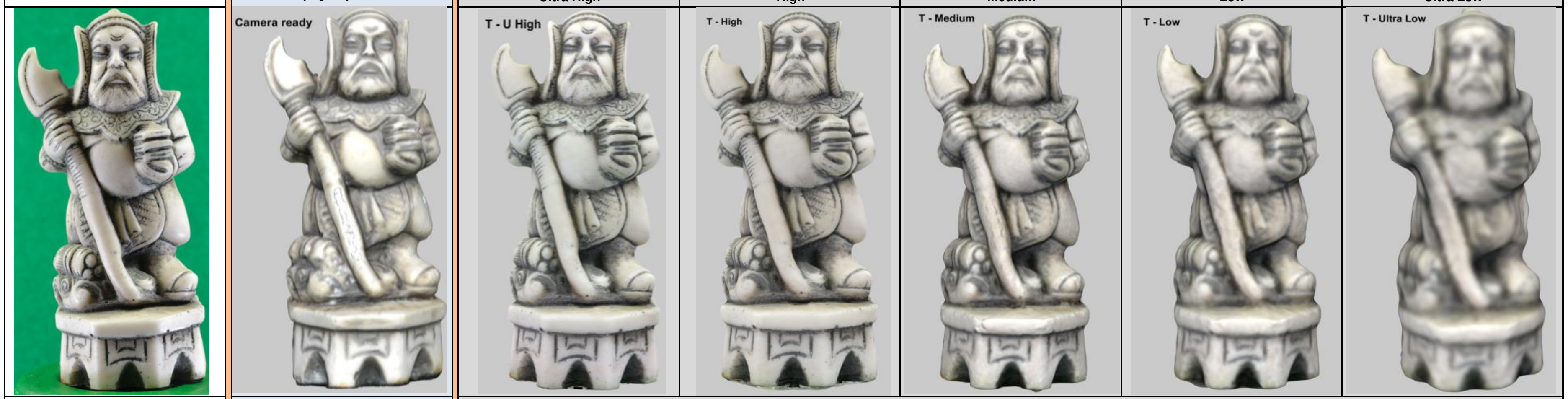
		Date processed	No. Images	Cir. Polaroid Filter	RAW Photo Data Set	Jpeg Photo Data Set	Tiff Photo Data Set	Mask	File name	Version	Project file	Processing Log	Align photo: Accuracy	Align photo: No Aligned	Align photo: Sparse Point Cloud	Align photo: Time-Align photo in seconds	Building geometry: Quality	Building geometry: Depth filter	Building geometry: Dense Cloud Count	Building geometry: faces	Building geometry: vertices	Face Count	Time - Building geometry minutes	Texture mapping: Generic	Texture mapping: Blending mode	Texture mapping: Time - Building texture	Shaded D Cloud	OBJ	Obj file Size in Kb	Solid STL	Hollow STL	Stl file Size in Kb						AM Model - FDM	AM Model - SLS	AM Model - DLP	AM Model - PolyJet
37R - China Dish RAW		04/01/17	107	✓	✓	No	✓	X	bowl	UH	✓		UH	61	896	2.4	UH	A	1,820,087	595,777	299,883	H	600.0	G	Mo	4.2	✓	✓	63,173												
									bowl2	H	✓		H	61	908	1.6	H	A	1,833,888	366,771	184,345		450.0			4	✓	✓	37,173												
									bowl3	H	✓		UL	60	816	1.7	UH	A	3,080,034	427,212	220,261		65.4			2.7	✓	X	X	Distorted image											
		05/01/17					✓	X	bowl4	H	✓		UH	61	834	1.4	H	A	800,925	263,169	132,169		6.0	G	Mo	2.6	✓	X	X	Distorted image											
								✓	bowl5 - mask & target disk	H	✓	✓	UH	71	2,835	1.0	UH	A	18,714,463	3,742,891	1,878,602		143.0	G		26	✓	✓	X	Distorted image											
			120				✓	X	bowl6	H	✓	✓	H	119	4,414	1.5	H	A	6,715,774	1,343,153	675,344		204.0	G	Mo	1.5	✓	X	X	Distorted image											
							n/a			UH								A																							
										L								A																							

Appendix P

Pre-processed RAW images v Camera ready Jpeg images

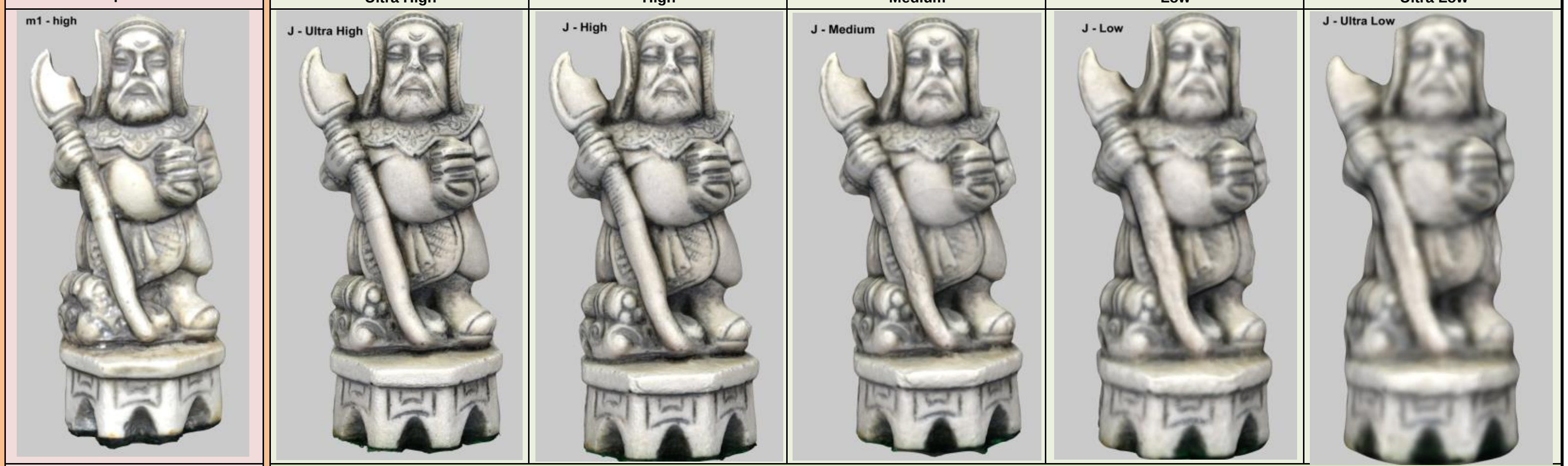
Warrior

Warrior		IS.1 : Pre-processed RAW images v Camera ready Jpeg images				Appendix P
Original Image	Original processed Camera ready Jpeg - *.psz file	Pre processed Tiff image format				
		Ultra High	High	Medium	Low	Ultra Low



	Original processed Camera ready Jpeg - *.psz file	Ultra High	High	Medium	Low	Ultra Low
Sparse Cloud	56,663	67,063				
Dense Cloud		20,800,670	4,563,594	1,092,005	257,873.0000	59,545
Faces	196,498	4,161,290	913,206	218,401	180,000.0000	118,690
Vertices	98,239	2,080,665	456,601	109,286	90,002.0000	59,347

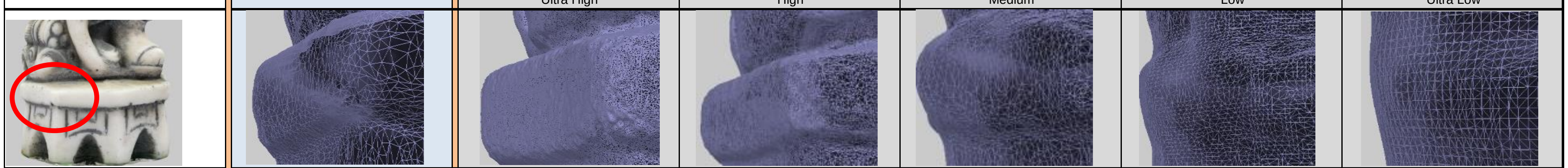
	Re-processed Camera ready Jpeg - *.psx file	Pre-processed Jpeg image formate				
		Ultra High	High	Medium	Low	Ultra Low



	Re-processed Camera ready Jpeg - *.psx file	Ultra High	High	Medium	Low	Ultra Low
Sparse Cloud	56,653	16,205				
Dense Cloud	2,854,427	18,928,476	4,628,238	1,111,324	261,351	59,939
Faces	571,210	3,786,846	925,066	222,426	180,032	119,842
Vertices	285,609	1,893,461	462,550	111,217	90,018	59,923

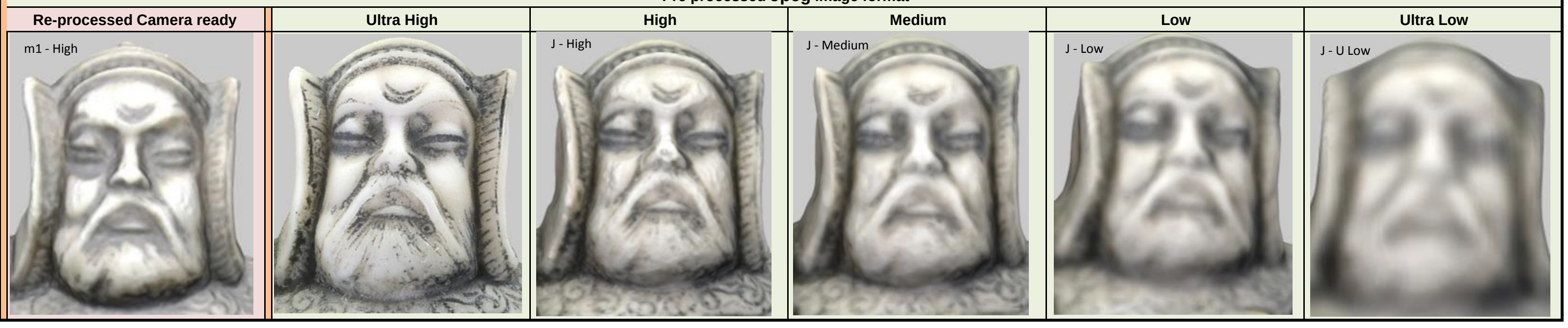
Warrior enlargements

Section of enlargement	Original processed Camera ready	Tiff image format mesh				
		Ultra High	High	Medium	Low	Ultra Low

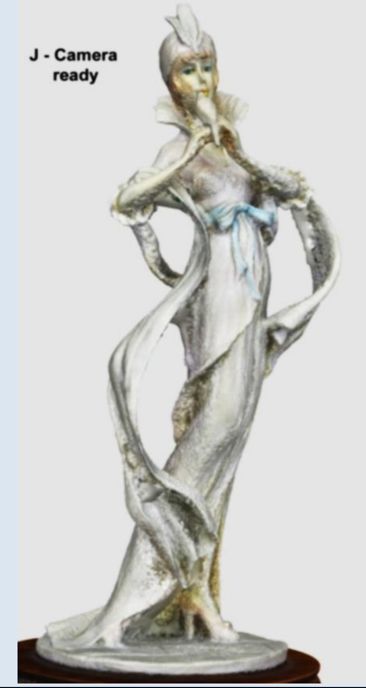


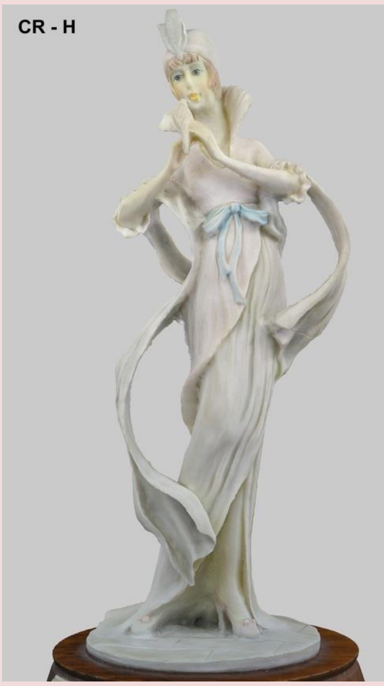
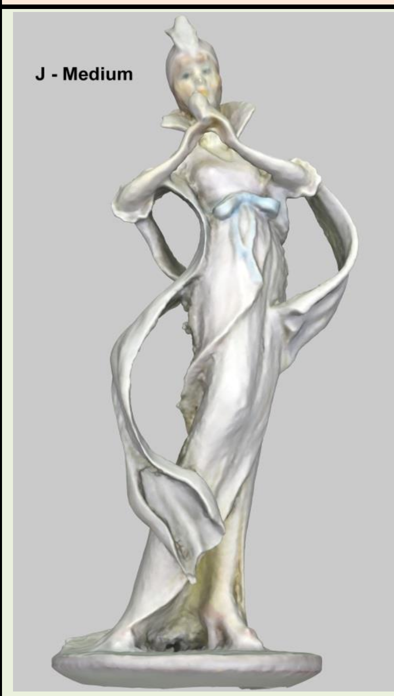
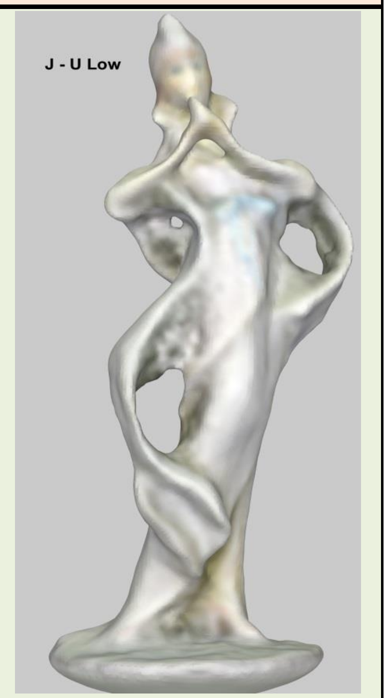
	Original processed Camera ready Jpeg	Pre processed Tiff image format				
		Ultra High	High	Medium	Low	Ultra Low

	Pre processed Jpeg image format					
	Re-processed Camera ready	Ultra High	High	Medium	Low	Ultra Low



Serenity | **IS. 2: Serenity - Pre-processed RAW images v Camera ready Jpeg images** | **Appendix P**

Original Image	Original processed Camera ready - U.High	Pre processed Tiff image format				
		Ultra-High	High	Medium	Low	Ultra-Low
						
Sparse Cloud	64,407	142,744				
Dense Cloud	18,814,479	16,961,556	4,404,664	1,055,471	248,163	55,888
Faces	3,774,572	3,392,310	881,466	211,093	180,000	117,484
Vertices	1,887,438	1,696,773	440,729	105,665	89,988	58,732

	Re- processed Camera ready - High	Pre-processed Jpeg images				
		Ultra-High	High	Medium	Low	Ultra-Low
						
Sparse Cloud	98,648	103,098				
Dense Cloud	5,008,844	16,742,122	4,506,969	1,091,318	254,730	57,202
Faces	1,002,640	3,348,788	901,210	218,512	179,776	118,712
Vertices	501,334	1,674,458	450,604	109,248	89,878	59,350

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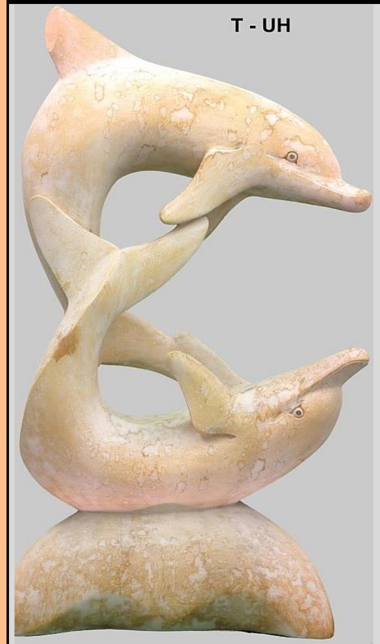
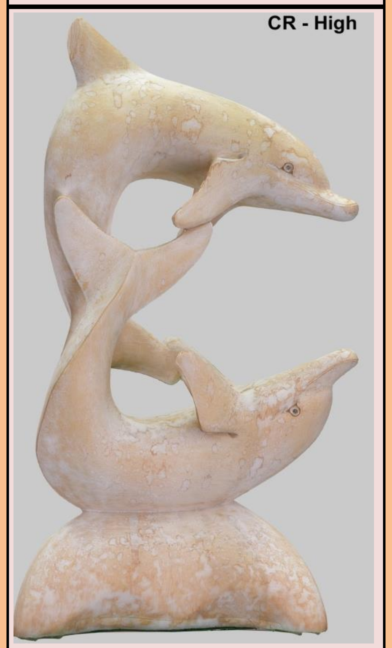
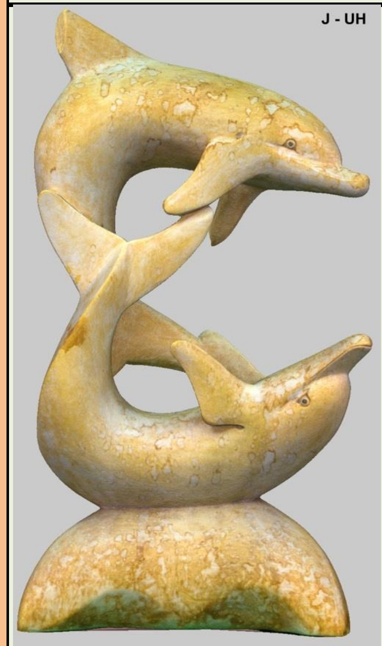
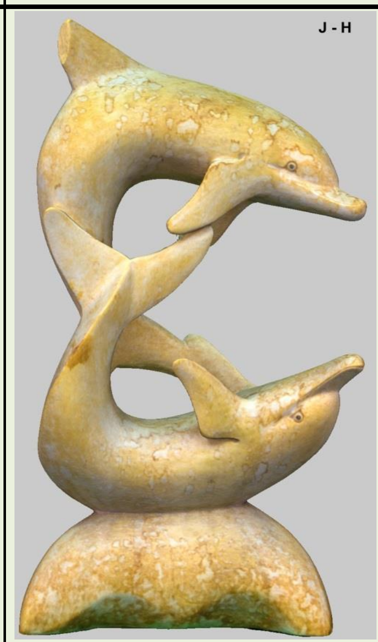
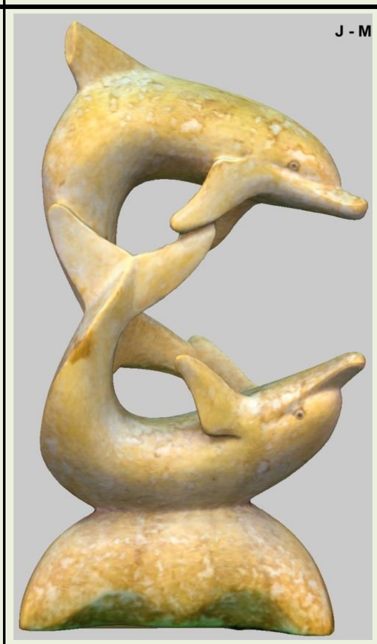
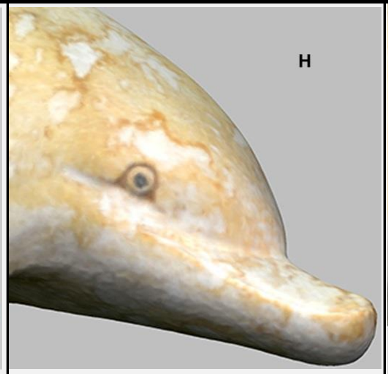
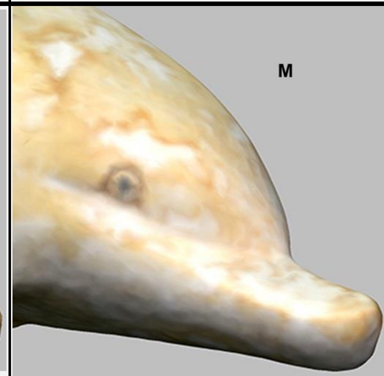
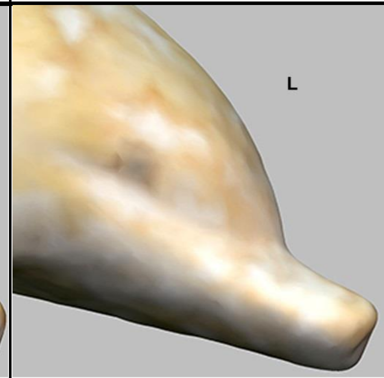
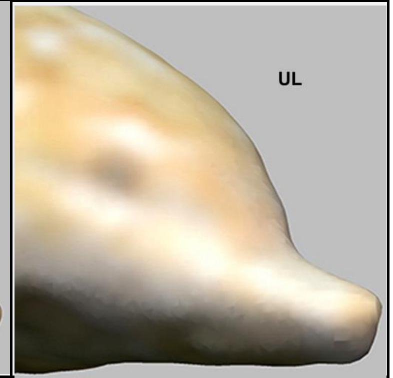
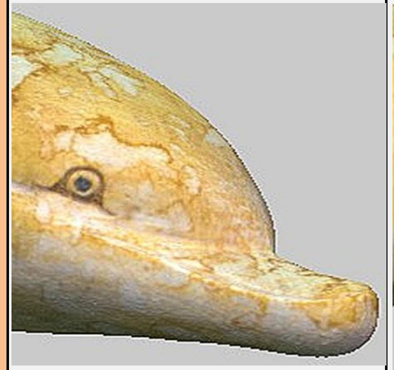
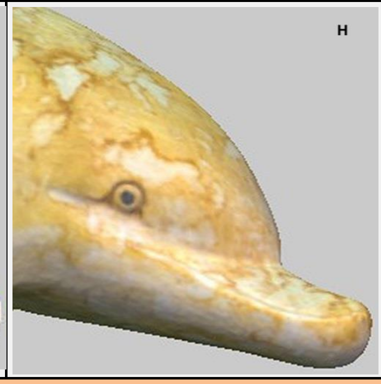
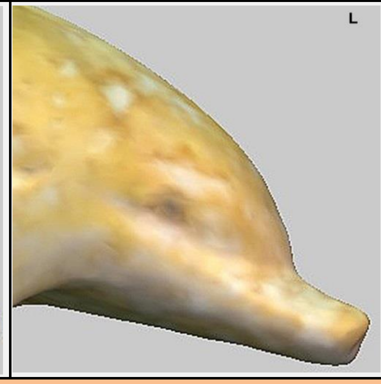
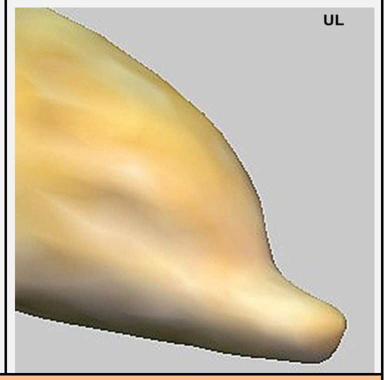
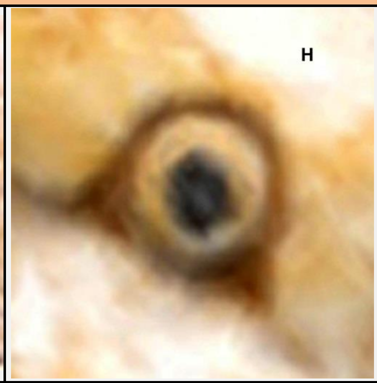
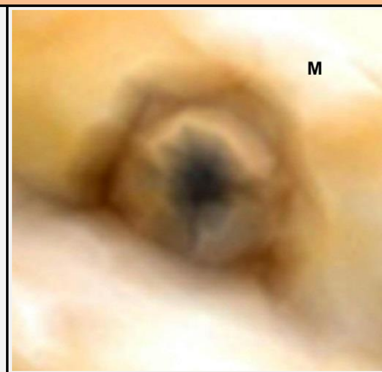
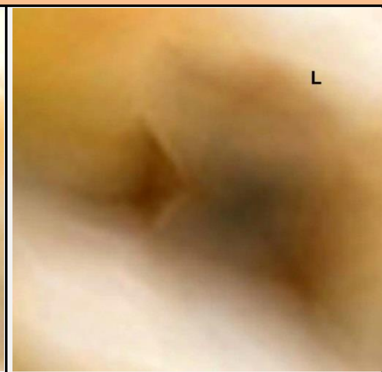
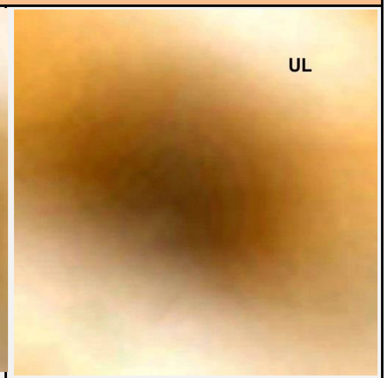
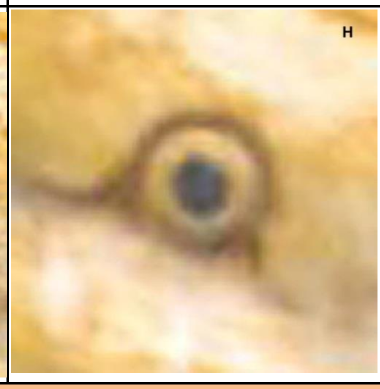
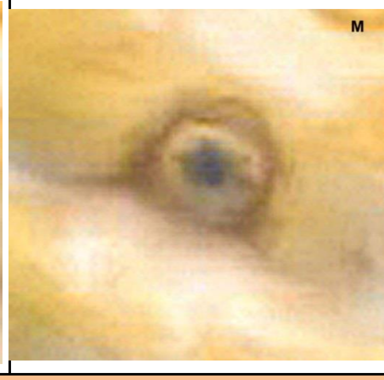
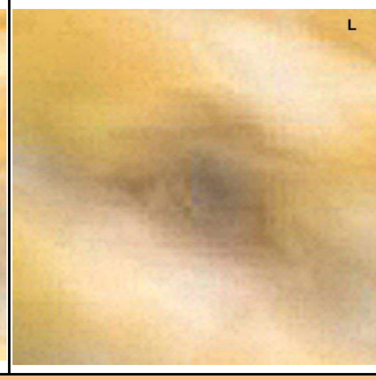
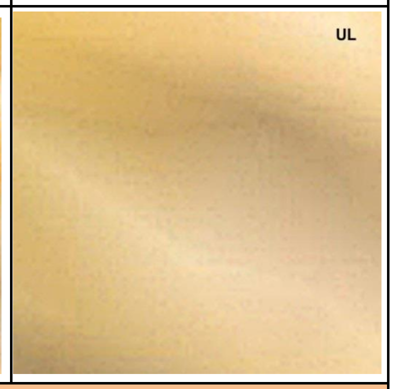
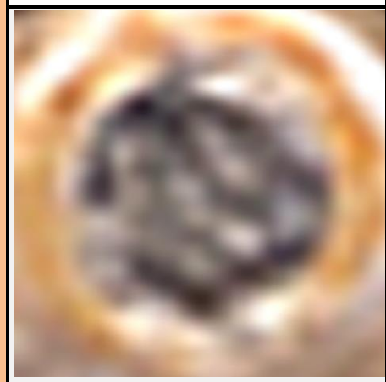
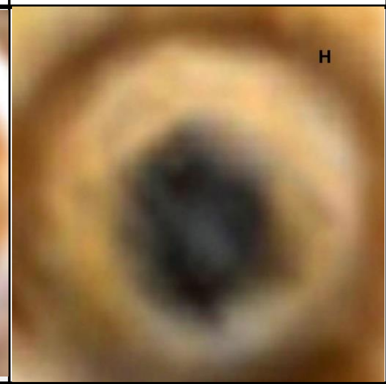
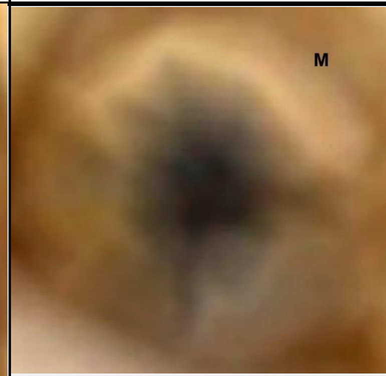
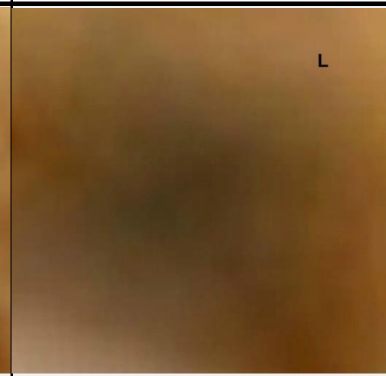
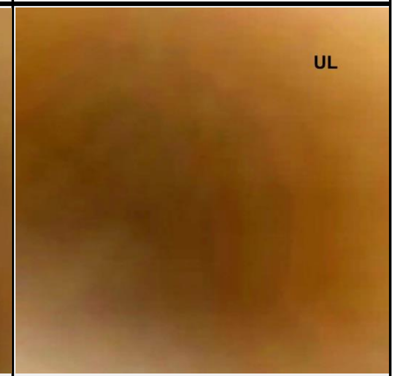
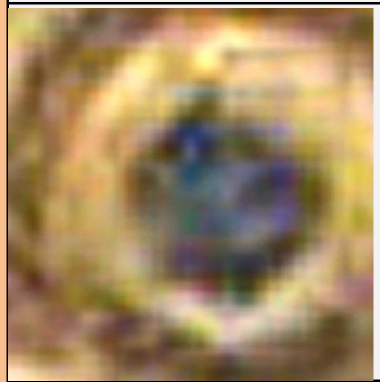
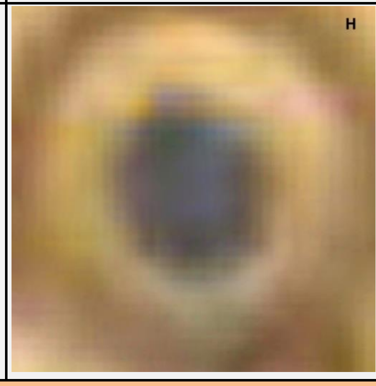
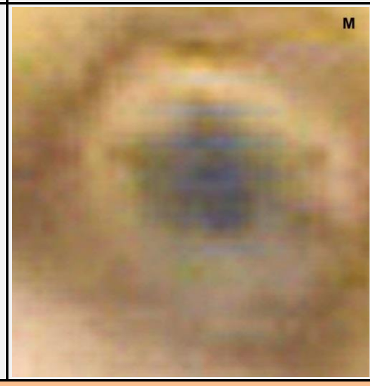
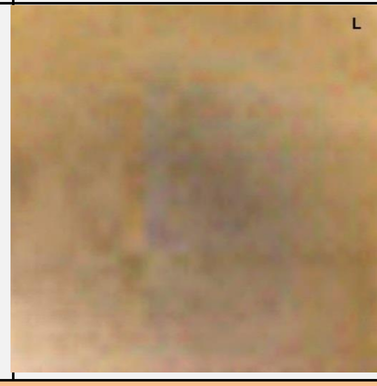
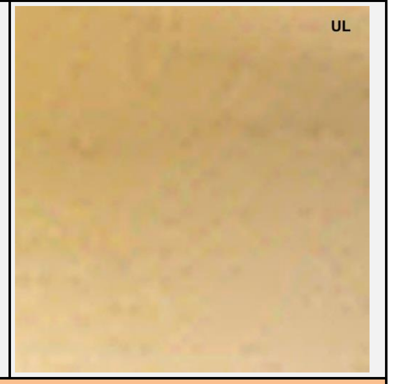
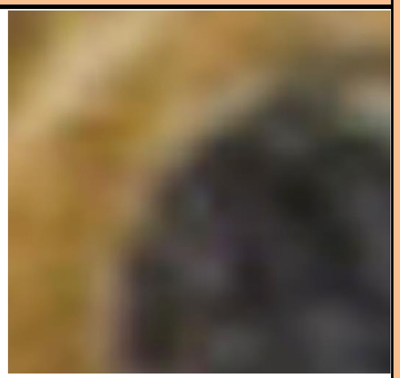
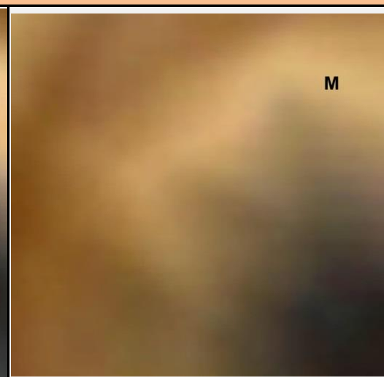
			Pre processed Tiff image format				
	Original Image	Original processed Camera ready	Ultra High	High	Medium	Low	Ultra Low
							
Sparse Cloud		Original Data set processed by PhotoScan was too distorted - above image from Catch 123	75,164	74,882			
Dense Cloud			29,386,865	6,678,545	1,666,188	417,918	101,390
Faces			5,878,456	1,336,366	333,516	179,778	180,000
Vertices			2,939,224	668,179	166,754	89,885	89,996
		Re-processed Camera ready Jpeg Screen Shot	**Pre-processed Jpeg image formate**				
			Ultra High	High	Medium	Low	Ultra Low
							
Sparse Cloud		101,718	83,167				
Dense Cloud		5,632,775	27,456,391	6,662,748	1,659,383	415,718	101,135
Faces		1,126,554	5,492,718	1,333,236	332,176	180,052	20,000
Vertices		563,577	2,746,359	666,616	166,084	90,022	9,996

Dolphines	Pre-processed RAW images v Camera ready Jpeg images - Appendix P					Page 2
Section of Original Image		Tiff and Jpeg image format - Head and Eye resolution comparisons				
		Ultra High	High	Medium	Low	Ultra Low
Head - Tiff						
Head - Jpeg						
Eye - Tiff						
Eye - Jpeg						

Section of Original Image - Pre-processed Jpeg		Tiff and Jpeg image format - Pupil and Iris resolution comparisons				
		Ultra High	High	Medium	Low	Ultra Low
Pupil - Tiff						
Pupil - Jpeg						
Section of Iris - Tiff						
Section of Iris - Jpeg