UNIVERSITY OF SOUTHAMPTON

FACULTY OF HUMANITIES

ARCHAEOLOGY

The Road to Valhalla: Can the application of 3D printing technologies benefit the interpretation of museum archaeology?

by

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ABSTRACT

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Museum artefacts are usually kept behind special glass cases for protection and preservation with access confined to experts; essentially creating a barrier between visitor and priceless artefact. However, only well-funded museums have been able to circumvent these barriers through expensive reproductions, reaping benefits that offer visitors the luxury of touch and the advantages of tactile interaction. These include positive developments in attention, spatial awareness, memory, and in some cases, even healing.

To date, little attention has been given to new and inexpensive technologies such as three-dimensional printing technologies as generative tools and as vehicles for interpretation. It is possible with application of Three-dimensional printing technologies that this will benefit the conceptual/methodological growth of the museum where it is applied in the discipline of Archaeology: breaking down barriers between the visitor and the artefact in museums.

Data for this thesis is obtained through a mixed-methodology of two separate surveys on museum curators, and general visitors at two museums, and an experiment on object handling with three-dimensional replicas. Results of these areas of analyses also include discussions on copyright laws, the ethics of three-dimensional replicas of artefacts for museums, as well as research from psychology on the effects of sensory and haptic interaction in various fields of study. With the consideration of application, accessibility, and interpretation, this thesis expands upon the overlapping benefits that Three-dimensional printing can bring to artefact interaction in a museum.

The implications on both the viability and the benefit of haptic interaction for museum object interpretation and sensory reaffirmation suggest its application as a possible new standard for object handling in museums that offer focus on participatory experiences for the general visitor. This thesis, therefore, presents from a functionalist perspective, new strategies on 21st century museology for the display of artefacts through three-

dimensional replicas as complementary to the exhibits. As a multi-sensory norm in museum exhibition, this will not only encourage greater immersion and interaction by non-specialist visitors, but eliminate barriers to accessibility, while incorporating deeper appreciation for the object, and greater interaction with handle-able replicas, in tandem with developments and application of accessible and affordable technologies across multiple fields.

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DECLARATION OF AUTHORSHIP

I, PETER MAX BRUGGER

declare that this thesis and the work presented in it are my own and has been generated by me as the result of my own original research.

The road to Valhalla: Can the application of 3D printing technologies benefit museum interpretation of archaeology?

I confirm that:

1. This work was done wholly or mainly while in candidature for a research degree at this University;
2. Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;
3. Where I have consulted the published work of others, this is always clearly attributed;
4. Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;
5. I have acknowledged all main sources of help;
6. Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;
7. None of this work has been published before submission.

Signed:.................................Date: 5 January 2018

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Definitions and Abbreviations

Praxis:	1. The accepted practice or custom. (OED 1996, p.1074)
	2. The Practising of an Art or a skill. (ibid)
Appetency:	1. Longing for or desire (OED 1996, p.59)
3DM:	A name given to the replicated piece of museum archaeology that is the product of a three-dimensional printer.
Actor:	The person performing an action such as a museum visitor.
Tactile interaction:	Touch based interpretation of an artefact or 3DM. This is object-focused and provides the actor with information and interpretative data concerned with but not limited to shape, texture and identifying features.
Closeness:	Handling an object as a form of informal interaction that often results in play or the development of related effort based participatory learning activities.
The Original's Companion:	A framework for the use in exhibition of the 3DM. The 3DM is an accompanying piece to the artefact and its use is that of an additional method of interpretation.
Three-Part Exploratory Activity:	An action that requires a degree of effort. Based on the framework of the Original's Companion, the actor interacts with the 3DM, seeks out the original artefact and then returns to offer a comparison. This is often accompanied by note/photograph taking for critical comparison.
Haptic Play:	Tactile interaction with the artefact that goes beyond formal identification purposes whereby the actor's interaction develops upon a degree of spontaneity towards an enjoyable handling activity with informality and personal relevance.

Three-Dimensional Printing technology	3DPT
Three-Dimensional Printing	3DP
Three-Dimensional Model	3DM
Fused Filament Fabrication	FFF
Laminate Object Manufacture	LOM
Stereolithography	SLA
Intellectual Property	IP
Computer Aided Design	CAD
Joint Photographic Experts Group	JPEG
Object File	OBJ
Surface Tessellation Language	STL

Chapter 1: Introduction

Visitation is important to any museum; it is the treatment of the individual and their experiences within the building that will likely attract return visitation or new audiences (Doering 1999; Hood 2004; Paris 2006). However, museum attendance has, over recent years, been in decline: a collective reversal of the fortunes in visitation that saw a 5% increase in 2011 (MA 2011), whereas the period 2015-2016 has seen museum attendance dropping 6% in 2016, based on data from the UK government's Department of Digital, Culture, Media and Sport, and the Association of Leading Visitor Attractions (*DCMS* 2015; 2016; 2017; *ALVA* 2014; 2015; 2016). There are many reasons as to why people visit or do not visit a museum or a specific gallery in the first place: the individual's motive could range from something specific concerning an object, something of academic curiosity, or an interest in a topic which is more akin to browsing and the social (Hood 2004; Black 2012). However, any slight decline in museum attendance is not likely seen to have resulted from a perceived lack of relevance but instead something that is symptomatic of a combination of social and economic factors that are external to the museum (Black 2012). Whilst there is no chance that museum visitation and public perception will ever return to the view that museums are irrelevant and places 'to store dead and decaying things' (Merriman 1989, p.156), there is no reason why any museum should be hesitant in exploring the potentials of novel methods of expression as an addition to interpretation. In fact, would the application of an innovative technology or a new method of visitor-focused exhibition encourage and indeed foster greater public interest should a museum change and show innovation through the adoption of new methods to assist its exhibition of artefacts?

This thesis considers the importance of museum adoption of Three-dimensional Printing (3DP) as an innovative technology that can benefit visitor interaction and interpretation of collections. The focus on Three-Dimensional Printing Technologies (3DPT) will be for the production and exhibition of a Three-Dimensional Model (3DM) and to benefit engagement and appreciation of collections and individual artefacts. In short, the adoption of 3DPT as innovative technology to better interpret and benefit the exhibition of artefacts is viewed as important, if not crucial, and as part of the overall museum strategy to offer greater engagement, involvement and participation for museum visitors. The application of such technologies will offer new interpretive insights which can be viewed as complementary to the exhibited artefact. According to Stephanie Moser (2003, p.3), in the interpretation of artefacts, or the ‘production of knowledge’, every museum holds ‘massive, largely little-understood sway over the interpretation of artefacts and indeed the public impression of artefacts’. If as Moser asserts, museums have ‘little-understood sway’ over how the public views its artefacts, shouldn’t museums then make their artefacts as accessible as possible, so as to encourage greater appreciation of the artefacts and increase positive reception? Given this concern, there is even now a pressing need to investigate how museums can offer greater accessibility, interaction, interpretation and overall appreciation to museum visitors in observation of their exhibited artefacts.

This thesis posits that such an outcome, challenging as it seems to be, can be achieved through the focused application of an innovative technology, that of Three-Dimensional Printing (3DP). To better understand how this technology could be applied within a museum, the focus will be on museum artefacts within the field of archaeology, and through this prism, discuss and investigate the complementary benefits to be gained from the application of 3DP within museum settings. My main research question is thus: can the application of 3D Printing technologies benefit archaeology in the museum? In this I will explore the impact of 3DP upon museums, looking specifically at how the use of 3DM can assist visitor interpretation of pieces of archaeology and in general benefit museum accessibility towards collections. This can be delineated into three questions: 1) How can 3DPT help museums? 2) What types of 3DM will encourage greater visitor interaction and interpretation? 3) What are the main features of 3DM that can affect visitors’ interpretation of the artefact?

The ability of 3DP, for the purposes of museum-based application, is to exploit the technical ability to make Three-dimensional models (3DM) which are similar to the original artefact. This ultimately will result in an actor focused exhibition that will allow for the additional potential of touch. It is not desired that 3DMs will exist as stand-alone curiosities, but that they will be companionable to the exhibited archaeological artefact: as the ‘The Original’s Companion’.

As an accompanying piece to the exhibited artefact, this will introduce touch to a previously vision-heavy exhibitions paradigm. Current museum exhibition is, for reasons of necessity, vision-centric which I discuss more in the next chapter. A vision-centric exhibition requires application of effort in observation of the artefact, and abilities in comprehension of any descriptive accompanying text for the artefact. Any interaction on the part of the museum visitor is, therefore, dependent upon effort. This is because observation of the artefact or an interpretive text, either by an interested or disinterested actor, is still open to misinterpretation, as acts which are ultimately dependent on comprehension. It is the companionable potential of a 3DM that, on the actor's or museum visitor's first sight of the exhibited original artefact, they can touch the corresponding model whereby, through this engagement via tactile stimulation with the 3DM, there will be a response in touch interpretation (Spence and Gallace 2008). This tactile interpretation, unlike visual interpretation of an object or text, is not dependent on effort but has been viewed as effortless and automatic which is discussed in more detail in the next chapter.

Innovation in exhibition through the use of 3DPT and the introduction of touch stimulation via 3DMs will encourage development in the appreciation of the original artefact. The desired outcome, resulting from the companionable exhibit of the 3DM and the artefact, is the increase in the interpretative ability of the actor who now benefits from additional information that is complementary to their previous, purely visual experience. As such, I am making a case for the addition of 3DM as a crucial and needed development within the current museum exhibitions paradigm.

Stating the obvious, the experience of the traditional museum collection in exhibition is vision-centric in which a visitor views an artefact behind a glass case; this has even been viewed as 'purified', presented in a sterile environment and lacking context (Alberti 2008). To this extent, the potential of 3DMs to allow for touch could be revelatory in introducing an extension to current museum interaction for visitors. The turn of the 21stCentury has seen experimentation into tactile object recognition, categorisation and even tentative museum in-house applications. However, despite this research and perhaps influenced by the relative newness of the technology, the potential of object replication via 3DPT to benefit the interpretation of museum archaeology has yet to be fully explored.

1.1 3D Printing: Expectations and Implications

Three-Dimensional Printing technology (3DPT) is the additive ability of a Three-Dimensional Printer (3DP) to manufacture solid objects by adding layers of malleable, quickly solidifying material on top of each other, as dictated by a carefully digitised and designed computer model held in a Computer Aided

Design (CAD) software programme (Lipson and Kurman 2013, p.11). This is not a new idea and even if the technology seems only to have sprung up within the first decade of the twenty-first century, it in fact, dates from the latter half of the twentieth century with experimentation in the 1970s and later introduction as a viable technology with great potential in the 1980s (Jones 1974, p.80; Lipson and Kurman 2013, p.37). Through experimentation, came the development of various 3DPT, some which suited other disciplines more than others. However, in parallel with this technological and functional growth, legal patents on certain technologies were granted (Mendis et al 2015, p.2).

Development of 3DPT has led to increased standardisation in application concerning areas of research in academia as well as that of practical engineering in industry. To focus on the technical application of 3DP, increasing standardisation in both areas seems increasingly to focus upon technologies that are dominated by a few large companies (Lipson and Kurman 2013). However, the original experimental nature of the technology is still present, with the applicability of 3DPT flexible enough to be explored and used in medicine (Atala 2012; European Commission 2014), engineering (Chandani et al 2013), aerospace (Jase 2013), fashion (Park 2012) and architecture (Molitch-Hou 2014).

The innovation of something apparently new and radical that has many possible ingenious applications has excited hype in the media. Seen as an emergent technology (Dougherty 2012), hype surrounds 3DPT, which in turn has led to inflated expectations. After all, this is a technology that has the potential 'of a machine that can print (almost) anything' (Lipson and Kurman 2013). The wide-ranging potential of this technology for future innovation has, like many other technologies, been validated by inclusion in Gartner's 'Hype cycle for emerging technologies'.

Conceived as a one-off indicator of media hype in the late 1990s, Gartner's Hype Cycle of Emerging technologies subsequently became an annual event (Hobson 2008). Its usefulness became apparent with real-world applicability for industries keen to know predictions for trends in rapidly developing computing technologies. The Hype Cycle tracks the progress of technology that is viewed as the breakthrough technology for that year by comparing innovation, proof of concept and applications with the rise and decline of media hype surrounding the technology (Gartner 2018). As early as 2007 (Hobson 2008), the development of 3DP was already predicted by the Hype Cycle to be relatively fast, with the 'Plateau of Productivity' reached in 2 to 5 years (Hobson 2008; **Figure 1**;

Appendix D). Indeed, as of 2014, it was estimated that there were in the UK between '38 – 40 3D print manufacturers' (Barnatt 2014, p.98), an estimate that indicates the utility and versatile nature of 3DPT in the manufacturing uptake of 3DPT in the early 2000s.

There are five sections to the hype cycle: Technology Trigger, Peak of Inflated Expectations, Trough of Disillusionment, Slope of Enlightenment, and Plateau of Productivity (Hong and Fenn 2013; Gartner 2018). Soon after first being charted, 3DPT was divided into two applications: 'Enterprise 3D Printing' and 'Consumer 3D Printing', the former concerned with experimental applications in the fields of Engineering and the Sciences, and the latter concerned with application by businesses and hobbyists. It is the category of 'Consumer 3D Printing' which is of interest here because of its much lower costs and direct applicability to museums which I will mention more in the next section.

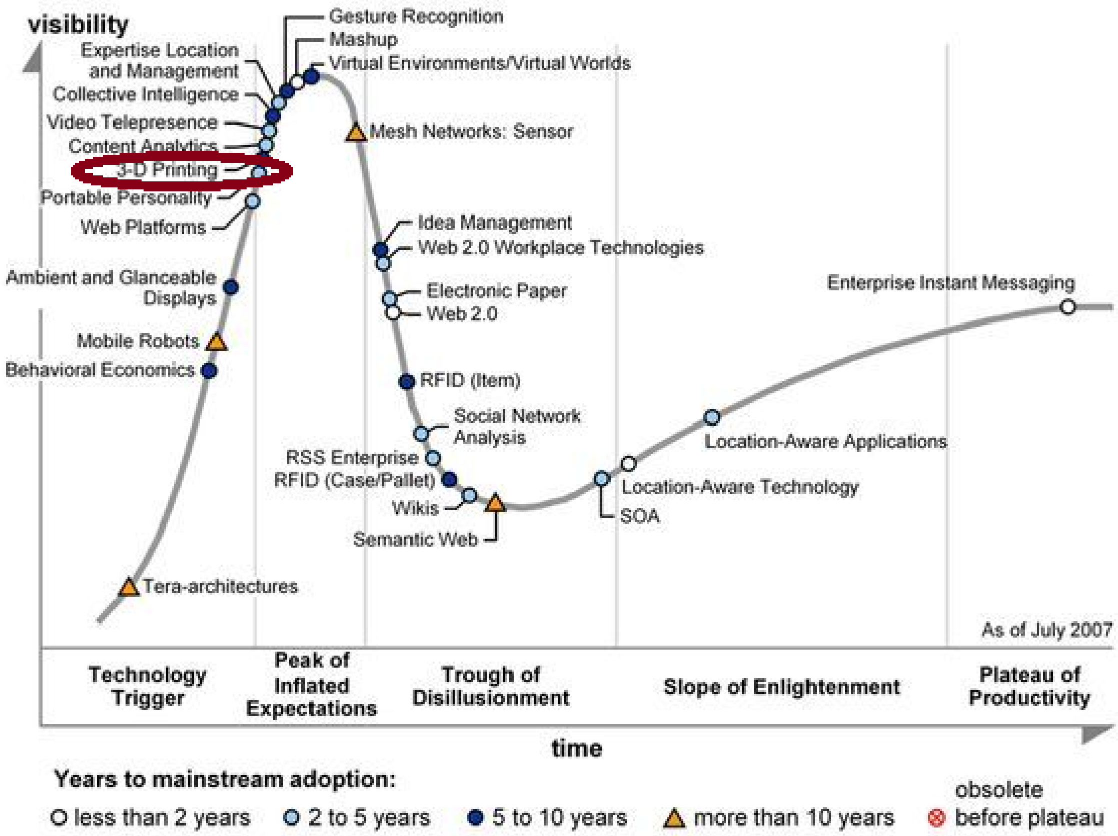

Figure 1 - Gartner's Hype Cycle of Emerging Technologies for the year 2007. Published by Hobson. Source Gartner, Inc. (Hobson 2008)

Unsurprisingly, since 2007, much has changed for 3DPT and this can be seen in a new plotting given in 2013 and 2014 **(Appendix D)** with 3DPT having passed the 'peak of inflated expectations' (Schofield 2013; Hong and Fenn 2013) and continuing through the 'Trough of Disillusionment' towards the 'Slope of

Enterprise'. The latter description being the timeframe which is predicted that the limitations of this technology will be learnt i.e. that in the immediate future, the technology cannot do everything (Gartner 2018).

Gartner's 'Hype cycle for emerging technologies' is useful as it helps to explain the reluctance of some curatorial staff to adopt 3DPT in their museum: for them, the technology has not yet proven its worth. In fact, in the field of archaeology, emerging technologies such as remote-sensing technologies have not lived up to their hype and yet, 'extravagant claims with regard to [them] are still being made', with Yannis Hamilakis (2013) being particularly critical of its archaeological application vis-à-vis its hype in his widely cited book *Archaeology and the Senses*,

> A new wave of applications and developments came with digital computing technology, and range from visualisation of spatial relationships… to 'virtual reality' applications… [however there is now] a progressive realisation that the early futuristic and overoptimistic proclamations, that such technologies allowed the study and full understanding of past sensorial experience were both premature and naïve (Hamilakis 2013, pp. 104-107).

In the case of 3DPT, there seems to be similar optimism with reports of its practical applications and possibilities for 3DPT such as to build bases on the Moon and on Mars, printed out of rubble (Molitch-Hou 2013 A); grand architectural schemes for building residential houses (Molitch-Hou 2014); or to manufacture part of or even complete jet engines (Koslow 2015). The above examples were discussed in the trade magazine *3D Printing Industry* and are, unsurprisingly, of future projects on a grand-scale reported for public interest, and replete with potential and idealism, concerning possible practical applications of the technology. In other words, such news was designed to catch public imagination. In parallel to what the future holds for 3DPT, there is a seemingly endless and still growing list of materials that can be used by 3DP machines and suggesting a sci-fi element which is now attainable: plastic, paper, gold, silver, titanium, graphene, brick, clay, wood, wax, sugar, salt and even stem cells (Barnatt 2014).

Media reports such as these lead members of the public to become over-confident in the abilities of home 3DPT such as in 3D 'desktop printers' with the average price below £1000 (Holbrook 2012). However, there is a large gulf between the high-end Enterprise 3DP reported on, and the reality of the more common lower-end 'desktop printers' for consumer use: a gulf that in the short term, if not reconciled with, can only create or provoke greater disillusionment with the current accessible technology that is marketed for the consumer and is overwhelmingly representative of one type of 3DPT, with printers such as the 'Cube' (2012), 'Replicator 2' (2013) and the 'Up' (Denford 2013). People are experimenting with their own machines, with new materials and creating open-access models for anyone to download and print, for example from free access online databases like 'Thingiverse' (MakerBot 2012). The models placed on open access platforms, like 'Thingiverse', mirror just what the majority use the 'desktop printer' for: to make toys and disposable novelty items. There are, of course, models for practical applications, but many users simply have these machines to manufacture disposable novelty items.

Despite such uses i.e. for novelty, there are viable future practical applications for this technology in museum settings and therefore, this thesis aims to separate hype from the viable, and expand upon the remit of this technology to investigate how its application can be adopted in museums. Where the museum is concerned, this will see the widening of the functions and aspirations of museums in which tactile stimulation will become a reality, allowing for immersive object interaction and greater object interpretation through the use of 3DM of original artefacts collected and owned by the respective museums for exhibition purposes.

In practice for a museum to begin to use 3DMs, this will mean a digitisation project will be necessary (Appendix E): it will include 3D scans of the original artefact, post-processing of the digital model, and then 3D prints to make a 3DM. The 3DM will, to varying degrees, be superficially like the original, but will remove any barriers to the visitor in offering handling opportunities, which can in turn, be an interpretive boon for the original artefacts exhibited. Ultimately, the museum will exhibit a 3DM that is similar to the original, but through the addition of touch, becomes complementary to interpretation by museum visitors. In other words, the replication and production of 3DM would open avenues for the development in exhibition and museum interpretative ability, adding to the potential wider scope of museum-run activities.

There are benefits for a museum in running a 3DP project manufacturing 3DM, this shall be further divided into short and long term. In the short-term it is likely to show a readiness to embrace a novel and innovative technology to challenge interpretation and thereby attract visitor interest. Long-term reception can develop further to alter the reception of the visiting public toward archaeological artefacts. In fact, through technological application, 3DP can offer museums the opportunity to experiment and innovate by producing a variety of 3DMs of different materials, weights or scales. Indeed, the addition of 3DM allows for close comparison with the original through tactile engagement. Presented with a scaled, weighted or textured 3DM may evoke an interpretation of the artefact that is beneficial to the understanding of the original artefact.

Indeed, whereas the original can only be observed and separated by glass, the 3DM on display nearby can be handled, allowing for haptic interaction and immersive closeness, thereby encouraging effortless interpretation and greater visitor-object interaction. This would augment and complement the meaning of the object and thereby adding another layer of legitimisation to the exhibited original (Shelton 1990, p.87).

Haptic engagement in the museum would mean a multi-sensory exhibition whereby the option of touch becomes a standard in exhibition, and an addition to visual interpretation. Object interpretation would not be wholly dependent upon a person's sight or reading comprehension because to touch a replica will add another layer of interpretation which requires less effort such as holding, picking-up and playing with the 3DM as opposed to scanning, reading and comprehending the accompanying text for the object on display. This thesis therefore aims to investigate the possibility of a multimodal tactile and visual stimulation paradigm that can encourage and direct the attention of the individual and thus reaffirming the museum-gained benefits of the object-led museum exhibition.

The addition of 3D Printing is not simply a method by the museum to direct attention toward the artefact. Through application of 3DPT there is potential to elaborate upon visitor reception and challenge preconceptions surrounding the artefact. The addition of 3DM to an exhibition introduces the potential for tactile engagement, where the visitor can reach-out, hold and engage in haptic play. It is with this addition in the level of engagement with 3DM that greater visitor interaction with collections will likely alter actions inside the museum. As shall be seen in the later chapter on 'Findings from "The Original's Companion"', it is the use of 3DM that adds to interpretation and motivates the individual to alter their interaction and, in certain cases locate the original, in order to know more.

In 1999 a paper was presented in Germany by Zahava Doering which interrogated the view of museums, as seen through the perspective of visitors. In the paper, 'Strangers, Guests or Clients? Visitor Experiences in Museums', Doering who was then attached to the US Smithsonian Institution, urged a perspective to treat visitors as clients, and therefore respecting their needs and interests (1999, p.14). Understandably, museums have come a long way with researchers expanding the concepts of visitor interest and motivations, where, Marsha Semmell states, 'museum visitors may see themselves as explorers, facilitators, professionals/hobbyists, experience seekers, researchers, respectful pilgrims, and/or affinity seekers, and these various identities colour and characterise their museums experiences' (Semmell 2016, p.9).

In other words, museum visitors, with their many different reasons for visiting and viewing original artefacts on display, are not passive visitors who are easily satisfied by just passing through glass exhibits with their accompanying texts. Or at least they should not be viewed as such. Therefore, it is through this desire to offer a more participatory experience for visitors, that museums can encourage more visits by offering people compelling reasons to visit in the first place, such as the opportunity of touching original artefacts by proxy i.e. 3DMs, a privilege to touch and interact, previously granted only to specialists and lucky VIPs.

1.2 An Example of a 3D Printing Technology

Given the current state of technological development as compared to future possible iterations, the technology that is open to institutions like museums in the first half of the 21st century concerning replication will seem crude and given the pace of technological development, is actively courting obsolescence. For my research, one type of 3DPT, currently an iteration of this technology has been chosen which, not coincidentally, is currently the least demanding of technical skills and the most cost-effective, and therefore, a likely candidate for application in any public museum, as all organisations have to show an awareness of cost in these financially straitened times (Bumgarner 2013; Barnatt 2014). The technology in question, popular with home users, amateurs as well as experts, is known as 'Fused Filament Fabrication' (FFF) or 'Fused Deposition Modelling' and brings with it certain features that make this attractive to the use by a museum. The technology of FFF is representative of what is described as a 'Desktop' 3D printer i.e. suitable for the home user (Bumgarner 2013).

Like all 3DPT, the FFF technology is an additive process whereby a physical model is built upwards by laying a molten material in a continuous line on top of the last and thereby constructing a solid object (Barnatt 2014). As the material needs to be part melted, it must react to heat to become malleable with the more common use of two types of plastics: Acrylonitrile Butadiene Styrene (ABS) or Polylactic Acid (PLA) plastics. A 3DM is made when the material chosen is deployed through a heated nozzle, where the process is then repeated perhaps hundreds, if not thousands of times, with each layer of material placed on top of the last. The result, as seen in the examples of **Figures 2** and **3** below[1], is a 3DM built out of the solid layers of the material forming a model (Barnatt 2014, pp.250; 254).

With the current technology, a resulting 3DM will likely consist of one solid colour made of plastic, or any other malleable material and will weigh as much as a piece of plastic. With the production of an exact copy of a piece of archaeology, the 3DM would contrast to the original object. The 3DM will not be an exact copy; similarities or differences will depend on the chosen 3DPT. Any limitations underscoring the current impossibility of total replication may be rectified in the future; in point of fact, the current technologies available in the early 21st century are indeed limited in aspects of replicating the weight, colour and material of the artefact. This is not so for all 3DPT; some may be able to replicate the colours of the artefact or the material of the original artefact. However, as of yet, none can replicate with accuracy the weight of the artefact.

The 3DM is not so much a replica, but akin to a close approximate (Lipson and Kurman 2013) as the resemblance to the original object is superficial. With the pace of technological development, there are other 3DPT such as: Stereolithography (SLA) and Laminate Object Manufacture (LOM), where indeed both have been used to make 3DM for museum-quality exhibits which I will discuss in the next chapter.

However, in the creation of handling activities requiring small models, FFF seems to be an ideal example of technology that can be readily applied to the field of museum archaeology. It is the flexibility of the technology as well as the relative ease of use, which suggest the application of this by the museum. It is for the ease of access and the flexibility that, with the exception of a few 3DMs, FFF could be used to produce any 3DM for handling purposes. Touch is the key potential benefit that FFF can exploit in the context of the museum and its handling activities. In short, FFF dissimilar from the other 3DPT as described

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[1] At the time of writing this was open access and freely available to download from Thingiverse as part of the 3D Archaeolab Project. This lion column base was used in the third round of Data Collection, this is discussed in chapters 3, 4 and 5. Subsequent to this it has been removed from the website Thingiverse.

above, is a technology that is flexible in application and that can produce hardy and inexpensive 3DMs that unlike other museum replicas do not need to be treated as artefacts that are distanced from the visiting public (Allard et al 2005; Scopigno et al 2014; **Table 3 and Appendix E).** FFF, in the production of 3DM can span the gap between the visitor and the exhibition, introducing the potential for touch-based interaction that is otherwise lacking from museums today.

Therefore, the introduction of 3DM into the museum will offer the potential for interaction with the object through touch. This closeness of interaction will feature the visitor touching, handling and haptically exploring the 3DM. It is the potential represented by 3DMs which can expand upon the interpretation of the original artefact in a visitor focused way that is of interest, in particular as it will benefit museums through appreciation of artefacts.

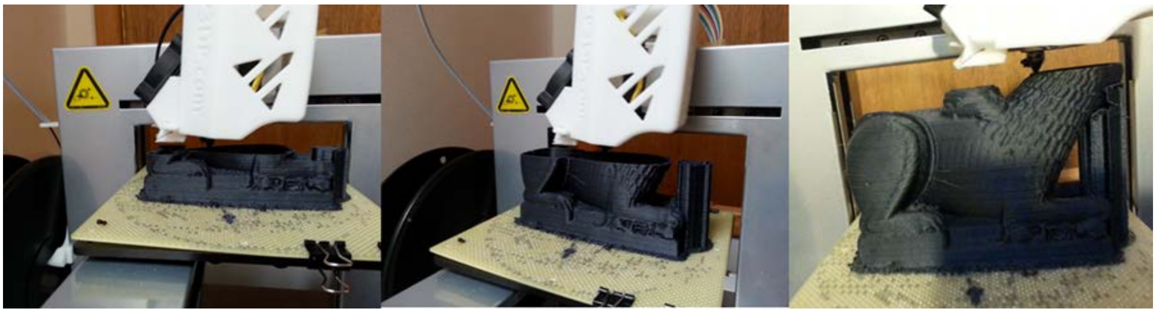

Figure 2 – Three stages of printing a 3DM of a Lion Column Base. Fused Filament Fabrication Printing using an 'UP' 3D printer.

Figure 3 - 3DM of the Lion Column Base. The 3DM is printed of Black PLA plastic and is scaled and is 10×3×8cm. The original is exhibited in Parma Museum.

1.3 Rationale

For the interpretive needs of museum collections to be met, arguably there must be a certain degree of innovation. As museum collections expand and the visitor base either widens or narrows, the exhibition of artefacts should be interpreted and reinterpreted with the purpose of maintaining and increasing interest (Black 2012, Bitgood 2013). For museum visitors viewing exhibited artefacts, whether original or 3DM, there must be a 'drawing-in' factor, something with staying power that will impact in a positive way on the visitor whilst enhancing the collection to which the artefact belongs (Bitgood 2013).

To observe an object exhibited in a museum is only to know so much. Physical and abstract barriers between the observer and the observed: be they real, imagined or knowledge-based are a limit to engagement. The visitor looks and reads, they know the name, age, origin, colour and maybe material; and all this is gained through a non-immersive effort-based activity.

If a museum is simply visited because it provides a worthwhile experience (Hood 2004), what then do visitors take away from an exhibition? Observing and reading about an object is effort-related and dependant on comprehension but the information received from touching an object has been found to be effortless and automatic (Wolf 2008; Linden 2015). The former – visual input – is open to misinterpretation by the visitor either from a lack of comprehension or disinterest but is still the most common form of museum exhibition; however, this can be rectified with the application of the 3DPT.

It is time for new developments in the provision of museum based in-house object lessons (Lawrence 1990). Away from the vision-dependant exhibition paradigm to a complementary multimodal paradigm that exploits both tactile and visual stimuli in order to create an exhibition environment where, for the museum visitor, the object is accessible and beneficial to interpretation through touching and picking up a 3DM. Touch is the sensation that is missing from museums particularly as touch between the 3DM and the visitor has the potential to be impactful and formative of a privileged personal level of access. Touching a 3DM that is the counterpart to an artefact would provide an experience that is complementary to the visitor's experience of archaeology.

Numerous experiments have tested the replicable viability of this technology to produce museum-worthy 3DM for exhibitions of which I shall mention more in the next chapter. Two such early 21st century experiments (Allard et al 2005; Tschopp and Dzemski 2012) were interested in the ability of 3DPT to reconstruct objects for a museum exhibition, ultimately both reached positive conclusions as to the exhibitions potential of 3DPT. These experiments in a similar way to others focus on the technology rather than visitor reception something that this thesis will expand upon in the chapter on Findings. The relatively recent museum application of 3DPT, experiments like these and others have been designed to achieve short-term fixed goals. There are of course exceptions, such as the Dalhousie Library Project where 3DP is used for academic research and a method of expression (Dalhousie University 2013); but for the majority, further expansion and development is needed before museums would be willing to wholeheartedly endorse and adopt 3DPT for the production of 3DM as handling activities for visitors. These experiments do show that 3D Printing is a flexible technology with many potential museum-based applications. Such an example is the 'Touching the Past' project: this was designed to test the benefits to touch interpretation of 3DM in a museum (Dima et al 2014, Pitt and Hurcomb 2017). I will discuss the 'Touching the Past' project further in the next chapter; however, it is worth noting that this did expand upon the benefits that 3DMs bring to visitor reception in object interpretation and exhibition immersion (ibid).

The application of 3DPT to produce 3DM is not limited to reconstruction of what amounts to a distance-learned sight dependant museum exhibition but serves to introduce tactile interaction as assistive to interpretation within the museum. Indeed, the ultimate use of the 3DMs will be to complement the original artefact, allowing for tactile closeness, and exhibition in parallel to the original artefact. In addition, the potential of the 3DM is also much more than just a one-off product; in the post-processing stage of the digital model **(Appendix E)**, there is the possibility to modify and print the 3DM to scale or to amplify so as to emphasise one detail to benefit interpretation. The use of this technology can collectively increase access to potentially inaccessible or very small pieces of archaeology focussing interpretation on specific aspects.

1.4 The Museum and the Use of 3DM

An example of 3DPT, Fused Filament Fabrication manufactures 3DM that today have characteristics different to those of 3DM from the late 20th century, and indeed 3DM made in the future will be different to what is possible today. No matter how advanced the technology becomes, or how accurate the 3DM, in direct comparison with the original, the model will require a certain degree of perceptive completeness and will seem more like a gestalt figure, which is incomplete and require further input (Gallace and Spence 2014). This does not contradict what museums can do with 3DM: the 3DM can offer additional input for museum visitors such as the benefits of accessibility and the opportunity to appreciate the original artefact (behind glass). Indeed as the next chapter will discuss, there is more to the 3DM than accessibility, namely benefits such as the increase in appreciation, recall of memories, and even delivery of effortless comprehensible information. Understandably, the aforementioned can be of benefit to museums once tactile interaction and involvement becomes a standard alongside their collection on display. In introducing 3DM to the museum for handling activities it is good to keep in mind that participants who have engaged in object handling feel a greater attachment and display genuine curiosity (Doonan and Boyd 2008).

To choose and handle a 3DM, it is likely that the individual would interpret this through a personal point of reference. Tactile interaction on any level has been shown to evoke memories and increase a personal awareness with any interpretation focused upon the object (Chatterjee et al 2009; Peck and Shu 2009). Indeed, with any object handling, there is a greater likelihood of an emotive situation with the object, which can prove beneficial offering immersive interpretation with the original piece of archaeology through the accompanying 3DM. It is, however, the materiality of the object that arises from the ascription of an individual's valuation, as well as benefitting interpretation and immersive 'personal' artefact valuation, which suggests a subjective though focused and specific reaction to the 3DM (Peck and Shu 2009; Linden 2015).

Certainly, the sensation of touch is powerful in its immediacy, it has a seeming omnipresence which, enables interpretation without even requiring thought and for the most part to be processed unconsciously (Linden 2015). However, because of this relative effortlessness of interpretation, the importance of touch as a sense, particularly concerning interpretation has been in the past somewhat overlooked. Literature and academic study over the past few years have sought to redress the balance, and touch, as part of accessibility, is now a consideration for museums (Zimmer et al 2008).

It certainly has not gone un-noticed that a 3D printer can print replica objects, and that pieces of archaeology have been photographed and 3D models printed by enthusiasts, irrespective of permissions or legality (MakerBot 2012). In parallel with this, the 'MicroPasts' project was begun by three institutions: The British Museum, University College London, and the Arts and Humanities Research Council. The project, unlike 'Thingiverse' and 'Shapeways' seeks to use visitor goodwill in requesting that they submit pre-existing photographs or scanned data so that 3DM can be made (2014). The 'MicroPasts' project is carried out with the idea of creating a database, and sharing the objects with other institutions, possibly at a later date to be 3D printed (2014). In fact this has resulted in collaborative cross museum research: where the 'MicroPasts' project has the British Museum working with UCL and other institutions (2014); collaboration between the Natural History Museum and the Smithsonian Institution has resulted in a project to digitise and share fossil collections for academic research and present it on an accessible database, such as: iDigBio (Marshall et al 2018; iDigBio 2018). These applications and receptivity by some of the bigger national museums also signal how less well-funded museums can benefit from this data base. The idea of museums printing out 3DMs, as part of an exhibition, where groups of people can potentially have greater immersion, while a great concept, unfortunately has not had much 'uptake' because of various practical and functional considerations.

However, for the museum visitor to see the original artefact and to handle the completed 3DM adds another dimension to the visit. Rather than passively observing and then reading the accompanying text, visitors can touch the 3DM, interact (Simon 2010) with it and learn more about the original artefact from their tactile engagement and interpretation of the 3DM.

However, this is not an argument to impose 3DP projects in a museum at the cost of textual descriptions which declare to visitors 'we know what it is but we shall not tell you, so interpret it for yourself'. Instead, tactile engagement with the 3DM should be complementary to the exhibited artefact, in addition to the accompanying text (Shelton 1990). In a museum, we may consider the accepted method of object exhibition and visitor interpretation as regulated by an established hierarchy: primary is the artefact, the text is secondary, and a library – such as the Courtney Library[3] – for further research is tertiary source (Mensch 1990). However, to then add 3DM and handling into the mix, this would add to object exhibition as assisting visitor interpretation, and therefore would deserve a place within the hierarchy – perhaps as a new secondary source of information. A

[3] The Courtney Library & Cornish Research Centre is part of the Royal Cornwall Museum in Truro

secondary source of information parallel to the descriptive text, but unlike the text the 3DM is free from the necessity of prior-knowledge that would indicate comprehension. The emphasis put on prior-knowledge can be off-putting to those people who usually do not visit a museum (Hood 2004); so to add a 3DM may be to add to the understanding of what was once described, more than a hundred years ago, as the 'democratic institution of the museum' by George Brown Goode in 1891 (Goode 1891, p.432).

In short, the key benefits of 3DM to artefact interpretation, is based upon touch. The matter of touching, holding and even playing with a model, has shown to positively affect visitor interpretation of the original artefact (Roussou 2004; Lacey and Sathian 2014). The introduction of touch into a museum is, therefore, likely to have profound effects on visitor interaction and interpretation with exhibits and 3DM. The choice of 3DPT and the application of 3DM will act as a vehicle in which the success of the introduction of touch will be dependant.

It is certain that 3DPT has a great future, and with every technological advance a myriad of opportunities for exploitation becomes apparent. There is potential for the museum, and for 3DMs to present an addition to interpretation in order to shed light on perhaps obscure or little understood pieces of archaeology. With the discussion on the potential of 3DPT and how this can benefit archaeology, there have been documented cases towards its flexibility in application. Practical and experimental potential of 3DPT indicates the flexibility in application of this technology and its viability within the context of participatory museums. As will be discussed later in the chapter, 'Findings from the Original's Companion', 3D Printing in application is not a distraction to the normal activities of the museum, but something with which museums need to engage.

1.5 Overview of Chapters

With the aim of understanding how the application of 3DM can benefit the interpretation of archaeology in the museum, this thesis has adopted an approach that is multidisciplinary in outlook. Considering the subjects of museology, archaeology, history, haptics, ethics and law, I will explore current as well as possible future understanding of the application of 3DMs in a museum. It must be acknowledged here that despite the use of 3DMs in the museum, this is still, for many, a short-term novelty instead of long-term innovative reality, and thus necessary that a historical grounding is required. I will therefore be discussing literature as well as contemporary experimentation with important implications for the use of haptic possibilities in the context of museums.

The next chapter - **Chapter 2: Scientific and Theoretical Overview** discusses the use of 3DMs and the understanding of haptics through historic and contemporary literature and experimentations as seen from the context of museums and haptic handling deployment for museum visitors.

Chapter 3: Methodological Overview: 'The Original's Companion', draws from the discussion of previous experiments and offers a methodological framework called 'The Original's Companion'. Taking a mixed-methodology approach this will collect original data derived from three groups of stakeholders – curatorial staff (from 11 museums); museum visitors (42 participants) from two museums; and academics (12 participants), both staff and postgraduate students, who underwent a series of experiments with 3DMs and original artefacts.

Following the detailed discussions of how data would be collected, and informed by extensive research, the next chapter, **Chapter 4: Findings from 'The Original's Companion'**, discusses what each of the three separate sets of data collection show, which together, offer a comprehensive picture of how museums might want to incorporate 3DMs and the use of 3DPT for their visitors. In short, this chapter offers original data, previously unavailable, which investigates reception and the application of 3DMs in the museum from the perspectives of both museum visitors and curatorial staff.

Chapter 5: Discussion - The Potential of 3DMs in Museums offers in-depth discussions to previous research mentioned in Chapter 2 vis-à-vis implications derived from data on the three groups in my methodological framework of 'The Original's Companion' which are from curatorial staff from participating museums, museum visitors from two different museums, and haptic interpretation based on a series of experiments with participants who were recruited from The University of Southampton's Winchester School of Art.

Chapter 6: Considerations Legal and Ethical discusses the current understanding and future practical applications of 3DMs through the provision of existing Intellectual Property law with the issue of who owns the copyrights, along with practical museum ethics which would be eminently useful for museums keen on utilising the full potential of 3DMs and 3DPT for greater visitor engagement and involvement.

Chapter 7: Conclusion offers not just an overview of this research with functional considerations appropriate for the participatory museum but also offers insights into future research elaborating on that conducted here on haptic interpretation, greater visitor engagement through tactile involvement, and also re-considerations of the museum exhibitions paradigm which would meet future challenges posed by changing circumstances.

In short, this thesis is aimed at providing systematic data on the application of 3D Printing technologies that can not only encourage greater immersion and interaction by non-specialist visitors but can benefit the interpretation of artefacts vital for 21st century museology.

Chapter 2: Scientific and Theoretical Overview

Many academics from different disciplines have benefited and continue to benefit from the technologies presented by 3D Printing. The technology is already used in the domains of architecture, engineering, and the health sciences, such as medicine and dentistry (Brooke 2013; Molitch-Hou 2014; Koslow 2015). It is within one of these disciplines, architecture that 3DP is now seen as established, as a method of expression in producing architectural models as well as building houses (Lipson and Kurman 2013, pp.65-68; Sher 2014). 3DPT represents fantastic potential in experimentation and application and it is the potential represented by this technology to benefit archaeological object exhibition within museums that this thesis will expand upon.

This chapter reviews literature from a variety of disciplines and sources ranging from technology, museology, archaeology and haptics to psychology, in order to investigate how 3DPT can be beneficial to museums and actor focused in-house object interpretation. Drawing from the above fields, my focus is on how the use of technology, particularly that of 3DMs within the museum, can encourage and increase visitor engagement while providing directions on how museums of the 21st century can adapt for current and future audiences through greater haptic interaction and involvement.

2.1 History and Application of 3DP

The technology of 3DP has been around since the middle of the twentieth century. Described as a 'Polymerisation Technique' by 'New Scientist' (Jones 1974, p.80), the article mentions the early polymer reaction to lasers, and the future potential of the technology which gave rise to 3D Printing. Until the mid-1980s, any work with 3DPT was experimental, but in 1986, Chuck Hull patented a 3DPT known as Stereolithography (SLA) and with this patent, the idea of consumer 3D Printing began to become popular (Barnatt 2014 p.85).

From the early 1990s into the 21stCentury, many types of 3DPT were developed; one however even now, dominates the public market which is Fused Deposition Modelling, or as it has become more commonly known, Fused Filament Fabrication (FFF). The technology of FFF, as described in the previous chapter (Bumgarner 2013), came to prominence in the late 2000s. This technology soon proved itself to be suited for the construction of small models, and successive FFF printers were advertised as 'Desktop' because they were intended for home users, as opposed to commercial use. Largely due to this focus on home application, the end of the first decade of the 21st Century has witnessed a growth in technical capability and media interest concerning 3DPT as charted by Gartner's 'Hype Cycle for Emerging Technologies' (**Figure 1** and **Appendix D**). However, irrespective of the hype, the last few years have seen museum specialists, librarians and other academic researchers understandably curious about using 3DPT specifically FFF for practical experiments to study their viability in application to their respective fields. For my research, I have deliberately adopted the most common 3DPT – Fused Filament Fabrication – so as to ensure that cost is low and that these are widely available for adoption or application.

The 6th international Symposium on 'Virtual Reality, Archaeology and Cultural Heritage' saw a project presentation exploring the 'Use of Hand-Held Laser Scanning and 3D Printing for Creation of a Museum Exhibit' (Allard et al 2005). In this, archaeology was not the subject, but rather anthropology with the replication of human bones for a museum display. With the aim of producing a museum-quality replica, the team from the University of Manitoba completed the entire process of 3D production: scanning, post-processing and then printing the 3DM of the human bones (Allard et al 2005). Key requirements, such as the quality of materials, the method of manufacture and the ultimate desired uses for the object, all had a crucial role in the type of 3DPT finally chosen.

The objective for the project was to provide for an exhibition on 'Funeral as a Rite of Passage', held in the Mennonite Heritage Museum in Manitoba and to be exhibited was a nearly two-hundred-year-old skeleton of a Russian Mennonite woman (Allard et al 2005, p.1). It was due, however, to the various cultural sensitivities associated with the display of bodily remains that the decision was made to display a to-scale 3DM (Allard et al 2005, p.1). Thus for the exhibition, SLA technology was used for its ability to replicate tensile strength and mimic the aesthetic structure of the bones, with larger bones such as the tibia and femur printed in parts which were later glued together (Allard et al 2005, p.3; p. 9).

The experiences of Allard et al (2005) with the Z406 3D printer were for the majority positive: after 40 hours of printing and 125 USD in expenses, they produced a high-quality replica (p.4). The relatively low cost was also due to the fact that the team discounted the cost or rental of the printer in the final consideration of the technology. Nonetheless, the process of this type of SLA production was deemed 'practical and economical', as well as 'ideal' in the production of exhibition replicas (ibid 2005, p.5). This was probably due to three practical factors: this was undertaken ‘in-house’ and therefore the team could have full control; the cost of the 3DM was low as opposed to commercial replicas traditionally used; and this could act as a template for future 3DM and exhibitions.

Reception was not recorded, and Allard et al (2005), like many researchers then, left this open as an ongoing experiment, Allard in fact concludes: ‘Ultimately, however, the success of this project is in the experience that museum visitors take with them’ (ibid, p.5). Based on this, no conclusions can be made regarding visitor experience e.g. if visitors benefitted from this 3D replication or were widely receptive. However, as reported by Allard et al, the 3DPT process undertaken was shown to be viable (Allard et al, 2005, p.4). While it is indeed good to know that the process was viable with contemporary technology, the fact that visitor reception was not recorded means that assumptions can only be made that the 3DPT process was beneficial and well-received by visitors of the exhibit. This may prove an assumption too far for many museums, with assumed benefits being outweighed by the ultimate cost in time as well as money. Clearly there is a gap in information on visitor reception of 3DMs, which my research hopes to address in this thesis.

In a similar vein, Tschopp and Dzemski, as reported in the ‘Journal of Paleontological Techniques’ (2012), chose to compare two very different 3DP techniques in a project to re-construct a Sauropod neck, a dinosaur that was widespread during the late Jurassic period. One technique used was additive, the other subtractive, but both were mechanical processes that come loosely under the umbrella of 3DPT. The two methods chosen for re-construction were: wooden sintering as carried out by a CNC-milling machine, and Stereolithography (SLA) using a Z printer 510. The CNC-milling machine, as compared to the Z printer 510, was the more established technology for model making, seen as being accurate, reliable and capable of producing objects of detail of up to 0.01 mm drilling resolution from the chosen medium: in this case wood, although capable and flexible enough to drill in the media of plastic, metal or anything synthetic (Tschopp and Dzemski 2012, p.5). The Z printer, was used as it was capable of producing very strong, chemically-bound full-colour prints. However, in order to print from either of the machines, Tschopp and Dzemski found that they needed to resize the model, a task that damaged the resolution of the milled print but was unaffected in the Stereolithographic (SLA) process with the researchers concluding that both methods were more than capable of producing museum-quality replicas for exhibitions (Tschopp and Dzemski 2012, p. 6).

Time and money, in these given examples, are the limiting factors. As can be seen regarding appropriateness – the technology is more than adequate in manufacturing the replicas ultimately used in exhibitions - but the technology may not, especially for institutions such as museums, be worth the investment. While the printing process for a Z printer takes a few hours, on a human level it takes days of intensive hours to learn. Though a short-term problem, the fact that much time and energy in learning something new has to be allocated may be a sufficient barrier to its application for understaffed museums.

In June 2003, a temporary exhibition in the Hunt Museum, was set up which aimed to engage visitors through the application of various technologies that would provoke interaction with the exhibits (Ferris et al 2004). It did not feature 3DPT: in fact, the focus was not on technologies used but on the objects (ibid). As the focus was on visitor engagement and their reception of the exhibition, it was felt that the exhibition would 'add to the understanding of the materials already in the museum, rather than focus on "gee-whiz" technology' (ibid, p.1). Engagement with the materials was found to be positive with visitors saying how 'fresh' the exhibition felt, and how it had 'brought the past to the present' (Ferris et al 2004, p.10). The people who visited this exhibition engaged with the exhibits, interacted with the technology and recorded their impressions of their visit (Ferris et al 2004); it must be noted though, that the people who visited the museum and interacted with the exhibit were already pre-disposed to be positive about the experience. The Hunt Museum exhibition called 'Re-Tracing the Past: exploring objects, stories, mysteries' was divided between two rooms: the first was the 'study space', this was designed to provoke exploration through interaction with exhibits. The second was called the 'Room of Opinion' which allowed for personal opinions to be given and formed concerning the 'nature and uses of the mysterious objects' (ibid). Touch was encouraged in the exhibition: there was the 'Touch machine' which allowed interaction with projected virtual 3D models, and in the 'Study Room', touching the exhibits was encouraged (Ferris et al 2004, pp.7-9).

The exhibition did not simply focus on encouraging interaction through one sense as it also encouraged multimodal interaction, using computers, virtual reality machines, mid-twentieth century radios and antique furniture (ibid, pp.2-3;8). The last was used as part of an immersive room designed to exploit natural curiosity where interaction, such as holding objects and exploring exhibits was encouraged. Emphasis was on the complementary nature of all sensory stimulation to benefit the museum experience and in this case, beneficial and positively received by the majority of the 1000 visitors (ibid, pp.7 and 9). Ferris et al did not explicit state what the benefits were for the visitors, merely how visitors enjoyed the exhibition, suggesting, as we can infer, that the addition of touch was the main draw and that it added to the museum visitors' positive experience.

Out of the two exhibitions discussed earlier, we are left to consider the importance of choice in exhibition, and how the addition of one technology or the allowance of a different form of interaction, could benefit the overall immersive experience for museum visitors. It is not always the case that more is better; there may be a good reason for the exhibition of something in a certain way as with Allard et al and their replication of the skeleton, because of the sensitivities involved in dealing with human remains (Allard et al 2005, p.1). Exhibition in the Hunt Museum was well managed, and the immersive 'Study Room' was seen as beneficial to the visitor experience, with complementary sensory stimulus and the creation of an immersive atmosphere (Ferris et al 2004).

However, this could easily have resulted in confusion and hampered the visitor experience to the Hunt Museum exhibition. Hypothetically, this could provide different or conflicting interpretations of the same object or stimulus in interpretation: one provided by sight, the other through tactile interaction with an unrelated model; the presentation of an ill-chosen audio-recording; even an odious smell that seems unrelated to the immersive atmosphere of the exhibition: all such sensory bombardment that may limit the ability to concentrate. It is important, therefore, to consider whether the exhibition of 3DMs alongside the original artefact and the subsequent interactive requirement of looking at the original and touching the 3DM would result in any potential confusion.

The experiments above could be both used as practical guides, one in the production of 3DM in the reconstruction (Tschopp and Dzemski 2012) and one in exhibition (Allard et al 2005), with a third, by the creation of an interactive museum exhibition designed to explore new modalities in praxis (Ferris et al 2004). These three experiments, however, are arguably much more than they seem as we begin to appreciate the viability of this technology to print detailed replicas with high-quality results that are suitable for museum exhibitions. Ferris et al's research (2004) shows us that experimentation would be welcomed in a museum exhibit, and in praxis, can become an event that demonstrates the point of academics studying museum attendance who desire innovation and greater originality.

The potential of 3DPT is not just in steadfast detailed replication, as we have seen above, but as a form of expression that can be accessed by the audience. One such example is 'The Dalhousie Library Project' where a MakerBot Replicator 2 3D printer is used for academic research by students from different academic disciplines of Dalhousie University (Groenendyk and Gallant 2013, p.40). The printer was chosen due to flexibility in its potential application with a print resolution of 100 microns and a print volume of 15.2 cm wide, 15.5 cm high and 24.6cm long (Groenendyk and Gallant 2013, p.36). Its limitation is in the size of the 3D prints made, possibly suggesting the redesign or rescaling of certain projects, or simply forcing the creation of bigger modular models. Nonetheless, Groenendyk and Gallant write (2013) that the limitation of the printer has not prevented its wide use by students within both the Sciences and Humanities. The flexibility and wide use of the 3DP, necessary in the on-going Dalhousie Library Project, stands in marked contrast to Allard et al, who saw the 3D printing purely as a method to replicate an exact object for a museum exhibition.

A recent showcase for 3DPT was the exhibition held in The Science Museum's touring exhibition: '3D Printing the Future' (2013), which introduced the current ability of 3DPT viewed from a wide range of its use from medical, educational and industrial to novelty uses. It was intended to suggest the long-term viability of this technology. Although the exhibition highlighted the usefulness of the current technology in certain industries, unfortunately when it came to 3DP as formative technology useful for an exhibition or museum, this suggested it was more of a short-term novelty than a long-term serious exhibition technology. The adoption of 3DP technology for exhibition purposes is viable, but only to an extent; no recording of footfall means that visitor numbers were not considered, while reports of the exhibition by the organisers themselves (Science Museum) apparently receiving remarkable reviews, leaves the implication that visitor reception of the exhibition was based on anecdotal impressions. The exhibition was more of a showcase, designed to portray the technology and the range of 3DP; and despite the various disciplines introduced in which the technology has been adopted, there was a hint that this had been conceived for the novelty value of the technology in general, rather than suggesting or offering instances for future museum application. Perhaps this is reasonable for an exhibition showcasing a new technology, its ranging impacts meandering through many disciplines perhaps designed to treat the audience to novel applications rather than to make a statement meant to encourage the greatest visitor interests with some applications tailored for museums. The exhibition and the research discussed only go so far as to describe the process of production and the immediate application: they do not record the execution or actual reception.

3DPT has entered the public imagination. More focused online news journals, such as ‘3D Printing Industry News’, report on developments that happen within the 3D printing industry; usually the staple fare for this is Medicine, Engineering, Architecture or Art – sometimes though, there are short reports on the production of a replica museum piece for display. The articles on the replication and the exhibition of a whale skeleton at the Smithsonian Institute (Park 2013), and on the Tokyo exhibition documenting the ‘History of 3D Printing’ (Chavez 2014), are examples that provide a narrative more akin to advertising, than an academic review. Amidst the many ‘Look what this technology can do’ articles, there is development showing the apparent readiness of 3DP technology to benefit the interpretation of archaeology.

Aside from sometimes promotional and narrative articles, reports have begun showing specific instances how museums can benefit from the use of 3DPT. These reports can either be one-off cases, such as in the replication of a piece of cuneiform (Lipson and Kurman 2013, p.17-20) reported in ‘Fabricated’ (ibid 2013); or on a larger scale, such as the aforementioned travelling exhibition, ‘3D: Printing the Future’ (Science Museum 2013). Running from October 2013 to January 2015 at its London base, the exhibition was well-attended, and the fact that it was on tour suggested there was public interest: not just in the technology or the current uses but also in its potential. The replication and printing of a piece of Cuneiform (Lipson and Kurman 2013, p.17-20) does, however, also indicate the potential ease of replication (from a fragile cuneiform) and the ability to offer or share the use of digital data, and manufacture accurate replica models for detailed study by other researchers who may not necessarily be located in the same country as the original artefact.

As can be seen in the previous studies, criticisms of 3DPT seem to surround issues on print size (Allard et al 2005, p.4; Dalhousie University 2013), but it is the reception and further use of this technology that is important in evaluating any long-term usefulness for its application in museums. Reception has, however, been recorded in the follow-up report to the Dalhousie Library Project which indicated a steep learning curve for its users: printing services were dominated by students from Engineering, Architecture and late adopters in Computer Science (Groenendyk and Gallant 2013, p.10). In fact, Groenendyk and Gallant (2013) found that the majority of users who, if they had no previous experience in using a 3DP, would not invest the time to learn as they sought help from others experienced in it; but, crucially, out of the total users, 72% returned to make use of this service suggesting an active uptake and a positive reception from those motivated to try it in the first place (ibid, p.11).

There is interest in 3DPT, the investigation into the '3D Printing the Future' exhibition suggests a positive public reception (Science Museum 2013) whilst the reception of the Dalhousie Library Project demonstrates, even from the beginning of the project, that there were people ready to use this technology (Groenendyk and Gallant 2013, p.10). The use of 3DP was, for the Dalhousie Library Project, initially limited: Engineering students were the first to use the 3DP, but as the project continued, more students from other disciplines within the Sciences and Humanities began to use it (ibid, p.11).

Concerning the adoption by museums in the replication of archaeology, there clearly is an appetite to know the limits and flexibility of this technology (Allard et al 2005; Tschopp and Dzemski 2012). Experimentation and exhibitions (Science Museum 2013) show that there is curiosity leading to public interest. Indeed, as shown in the next section below, there are larger scale experimental exhibitions attempting research into public reception surrounding the use of 3DM in the museum. However, until the benefits of using 3DM in a museum exhibition are fully explored, it is likely that 3DPT will remain as temporary exhibitions dependent on interest, belief and inclination of the curatorial staff on the role of 3DPT in museums.

2.2 The Need to Innovate

Museums are neither dusty places filled with objects of interest only appreciated by a select few, nor are they places for only static exhibition. The museums of today have come a long way from the nadir of the late 1980s, when economic decline, unambitious curation, and falling public interest inevitably led to the unfortunate perception of traditional museums as 'Monuments to the Dead' (Merriman 1989, p.156). Indeed, this declining image of the museum has been cast aside by more contemporaneous studies, from the field of museology and archaeology, as Janet Owen has suggested, a growing number of the public “Feel it is worth knowing about the past” and indeed Owen also urged for museums to offer a less traditional approach in the exhibition of archaeology (Owen 1999, p.201).

More recently, the article ‘Visitors love Museums’ from the *Museums Association* (*MA* 2011) concluded that the number of audiences have risen by 5% for local visitors and that overall visitor figures have risen over the past few years, and are predicted, with certain exceptions to continue to rise (*MA* 2011, p.3). However, while visitor numbers for museums in the early 2010s were rising, this has not been sustained. In fact, since 2015 the numbers have started to decline slightly and the museum industry has begun to realise that there is the possibility that this could turn into a downward trend. Based on figures released by the Department for Culture, Media and Sport (*DCMS*) in their annual performance indicators for 2015/2016 and 2016/2017 with a decrease of 0.8% but crucially, there was a decline of 6% for child visits, which had already experienced a decline of 14.4% on data from 2014/2015 (*DCMS* 2015; *DCMS* 2016; *DCMS* 2017). These are rather worrying visitor numbers to museums particularly on child visits.

A possible reason for this switch or change in attitude towards museum visits and hence actual visits, may be explained in Hood’s widely cited and prescient 1983 article, ‘Staying away: Why people choose not to visit museums’ which suggests that museum visitors have come to associate visiting museums as a ‘leisure experience’, and that it is necessitated by the consideration of six criteria (2004 p.151). Although the data from which Hood’s the article was based is no longer new – it was collected at least a decade ago - the findings on what museum visitors value are still relevant with his article republished in 2004,

> “Social interaction, doing something worthwhile, feeling at ease in their surroundings, having a challenge of new experiences, having the opportunity to learn, participating actively” (Hood 2004, p.151).

After interviewing 502 residents, conclusions were drawn from which three types of potential audiences emerged: frequent, occasional and nonparticipants (Hood 2004, p.152). From the data, it soon became apparent that it was indeed differing leisure priorities that affected museum visitation: socialisation was the top most for the nonparticipant, whereas having the opportunity to learn and be challenged, were the top most for the frequent participant (ibid, p.153).

Interestingly, Hood has given one reason for non-visitation: the lack of knowledge of a “museum code” in which museum nonparticipants do not know how to act or participate in the museum (ibid, p.156). The last reason is rather interesting: possibly having interactive activities with 3DM may negate this fear of a lack of knowledge for the reluctant visitor.

Despite the time-lapse of 1983 to 2004, republication of Hood’s article seems to add to the importance of his study, lending it a rather contemporary feel; especially when read alongside other studies by Black (2012), Janes (2007), and Martinon (2006). Black’s study urged museums to encourage a greater number of visitors through the use of more innovative approaches, and thereby more interesting exhibitions (2012); while Janes wrote that museums have a social responsibility to exhibit their artefacts to the public meeting and exceeding expectations in exhibition (2007); Martinon has emphasised the need for museums to change in order to keep attracting audiences (2006). The studies by the three researchers place the visitor at the centre of the museum where visitor attendance and appreciation are key for them. In the review of literature - at least sixty years - on museum attendance and non-attendance, Hood (2004), in asking the reasons why people stay away, has suggested a plausible reason that infers a trend: that of greater familiarisation with the museum which is dependent on association with leisure and therefore recreation (ibid, p.150).

The popularity of museum visitation is not solely dependent on it becoming understood as a chosen recreational activity (Hood 2004); there are other factors such as economic and social. This has been somewhat presaged by the ‘Museums Association’ reporting on a disquieting trend on museum visitation. Footfall declined between the years 2007 to 2008 in 35% of museums which responded to its survey where the decline in the number of specialist or focused activities like school visits was seen to be the main cause (*MA* 2011, p.3). As mentioned earlier, visitor numbers increased after 2008 but by 2016, the numbers have dropped and seem to be declining; a warning perhaps that complacency and over-confidence have no place in museums but that they have to continually innovate and make their visitor experience count.

It is quite possible that research carried out, similar to the one above, was the signal for academics like Owen (1999), Simon (2010) and Black (2012) to begin debating the future developmental direction of the museum – certainly this could not be put down to millennial angst. Of the three researchers mentioned, the conclusions drawn are collection-centric; these consist of ideas from greater exhibition originality (Owen 1999), interactive and immersive participation (Simon 2010), and technical innovation (Black 2012). This collection-centric conclusion is not universal, but it is interesting that these three have chosen to focus on it; and shows an emphasis that is rapidly gaining ground.

As suggested by Owen (1999), greater originality in the exhibition of artefacts and deeper thought as to the representation of each object must be shown: the received wisdom on this being that the more originality in interpretation is shown, the greater the number of audiences attracted to the museum (Owen 1999, p.201) and this has proved a popular idea. Owen uses the examples of the Jorvik Viking Centre in York, Museum of London, as well as later additions through practice, in Colchester Castle Museum, and Stoke-on-Trent City Museum to show how the exhibitions in the museums have attempted to show the dialectic, contextual, narrative, and potential relevancies of their respective exhibitions, which would not have been teased-out in the more traditional display of archaeology (ibid, pp. 205; 207; 213 and 214).

Owen's collection-centric approach is often combined with that of Janes et al (2007), who in 'Museums, social responsibility and the future we desire' repeats the entrenched and deservedly popular idea that museums are there to provide a public service. Academics like Simon in his 'The Participatory Museum' (2010), argue for a visitor first approach whilst Kavanagh (2000) in 'Dream Spaces, Museum and Memory', discusses the power of museum objects to provoke visitors and memories in order for audiences to relive experiences, and how museum in-house interaction is capable of provoking such emotions. Ultimately, there is perhaps no distinction to be made between curatorial and social bias for museums because in the twenty-first century, we are, perhaps more likely to associate a development in curation, with an exercise in greater social interaction. It is Hood's suggestion that development and attraction should come from development of a system of exhibition that is designed to benefit the social leisure time needs of the visitor (Hood 2004, p.157).

Museums certainly do not represent, as the art historian Winckelmann puts it, 'The crepuscular time when the Owl of Minerva takes its flight' (Diddier 1999, p.23), or Quatremère's post-revolutionary experiences in which he equated the museum to the impoverishment of creative societies (Schubert 2009, p.22): museums as institutions have a collective future but as a cause of their foundation and growth frequently ill-planned. As an institution, the success of an exhibition relies, almost entirely on public reception, interest and curiosity (Carr

2006). So, as an institution patronised by the public, it must change; in other words, it should attempt to cater to meet the changing needs of visitors while retaining its mission. Within the museum, there is an inherent need to collect, catalogue and learn (Radnóti 1999, pp.4 -5); but if carried to extremes, this could, to the public, appear boring and self-indulgent. There is a need to change and innovate, thereby to interpret and tease the most information out of the objects as well as offer interaction and engagement for museum visitors to ensure continual relevance (Carr 2006).

If, in fact, museums do want change; they could, as is the desire of this thesis, adopt an additional dynamic to expand upon, that of the museum collections: the object replication and museum exhibition for educational or interpretive purposes.

The last decade or so has seen the technical scope of 3D Printing develop in capability and potential (Lipson and Kurman 2013); high quality objects using any of the various technologies of 3DP can produce museum quality replicas (ibid, p.19). It seems, however, rather interesting that published academic literature concerning this technology has developed in parallel with a sort of museological soul searching where there have been experiments and even museum projects of stand-alone experiments (Allard et al 2005; Tschopp and Dzemski 2012; Groenendyk and Gallant 2013; Nicholas et al 2014; Dima et al 2014; Pitt and Hurcombe 2017). The aforementioned examples however suggest that there is a general world-wide desire to innovate in their application of 3DPT in the museum, with examples from England, Canada and the USA as represented above. We can also consider national as well as local museums **(Table 3, p. 72)** too in their specific uses of 3DPT to innovate in the exhibition and use of collections. The variety of applications in innovation for exhibition and collections use have been developed upon by certain museums. The British Museum, for example, has a digital collections policy that deals with current as well as future application (British Museum 2007), and looks to other museums in United Kingdom as well from the world-wide community to survey and research other projects (Hancock 2015) and collaborate with on their own original projects (MicroPasts 2014).

However, the example of the British Museum, and those museum projects as seen in **Table 1** and **Appendix F**, do not automatically translate to every museum. This could be due to various reasons: a lack of knowledge, expertise, or investment in the technology, or a view that the application of 3DPT is either not required as it is tangential to the objectives of the individual museum and thus these reasons could arguably result in the low adoption of 3DPT in museums.

A study from 2014 suggests that there is little reticence exhibited by museum professionals in applying innovative technologies to develop and support the visitor experience of an exhibition (Maye et al 2014 p.606). The study 'Interactive Exhibitions Design – What Can We Learn From Cultural Heritage Professionals?' (Maye et al 2014) interviewed 23 museum professionals defined as 'Cultural Heritage Professionals' (CHP) who work as museum directors, exhibitions managers and curators; in-short museum professionals who are used to applying a variety of technologies in museum exhibitions (Maye et al 2014 p.598). The individuals from the UK, Ireland, Netherlands, Italy and Germany were chosen as they represented a range of experiences on the application of digital technology for an exhibition in museums (ibid p.600). The skillset of these museum professionals or CHP ranged from those with frequent experience in the application of such technologies to never having experienced exhibition use of digital technologies.

For the majority, the Museum Professionals cited a variety of motivating factors behind their application of interactive digital technologies in exhibitions: attracting greater audience numbers, encouraging greater understanding through engagement with the exhibition, and education (Maye et al p.601). The use of digital technologies in a supporting role to the exhibition, and not as the sole or dominant interpretative measure employed was to widen the appeal of the exhibition (ibid pp.603-5). Two interviewees did mention that the benefit in application of these technologies was the potential to assist in interpretation and through this, to experience something "real" (ibid p.602). An example provided by one museum curator said that initially the application of a 'digital interactive exhibition' in her museum was exciting but, *"we quickly learnt that human engagement was lacking"* (ibid p.603) and thus did not present continued appeal to visitors. In other examples, this lack of interaction was circumvented by the use of technologies in roles that were complementary to interpretation of the exhibition: achieved in certain cases with the addition of a button to press, a knob to tweak or something of weight to hold, and through this, to experience the 'materiality' of the artefact offered (ibid pp.603-606). The study suggests there is a strong link between the interpretation and effectiveness in visitor engagement with which is attributed to the addition of an *'Analogue Element'* (ibid p.606); the latter, viewed as something tangible for visitors to (directly) interact with, as part of their engagement with the artefact. The study has two important implications for museum professionals particularly for participatory museums vis-à-vis 3DM. The first, is to consider the implementation of the 3DM where visitor use of a model in exhibition is akin to being provided an 'analogue element' which can convey the materiality of the original artefact, and therefore encourage interpretation through engagement and increase visitor engagement. The second implication is the employment of the technology as complementary in museums, and never as the primary driver in exhibitions, given that appeal for museum visitors was ultimately, based on engagement and by inference, interaction with and not distant, from the artefact.

A similar project on the uses of new technologies, part of the 'Material Encounters with digital cultural heritage' (meSch) European community project, was the project, 'Co-designing a Collaborative Platform With Cultural Heritage Professionals' (McDermot et al 2014). Working with CHPs at the museum 'Museon' in the Netherlands, the aim was the application of digital technologies to better facilitate museum visitor learning (McDermott 2014 p.4). Collaboration with the museums professionals for the curation of an exhibition employed digital technologies to support and focus exhibition learning which was found to be effective; thus showing the suitability of certain digital technologies to benefit visitor interaction in a museum (McDermott 2014).

The research, 'Impact of Digital Content of Audience Communication in Interactive exhibitions' seems to expand upon what can be understood as visitor reaction to the application to interactive exhibitions that exploit digital content (Tsau and Ko-Chiu 2016). The working hypothesis for this was that interactive technologies can alter visitor action or response (ibid p.62). The research required that the publicly accessible multisensory exhibitions which were held in Taipei (ibid, p.65) be curated by artists who have experience as digital content creators (ibid). Returned were 300 valid questionnaires from museum visitors (ibid p.66) which indicated positive responses to interactive elements of the exhibition, in which the individual's reaction to the exhibit was to explore and physically engage with artefacts (ibid pp.67-72). Factors such as narrative creation and interactivity of the selected technology were seen to have importance in forming a positive audience experience (ibid p.70). Whereas the experience depended upon the individual, the 'Design concept' of the exhibition presented an influence over the exhibition narrative (ibid). It was found that visitor interaction or, 'patterns of visits' were influenced through this design as this altered the museum environment as well as receptivity toward interactive exhibition content (ibid pp.73-74). In other words, the deployment of technology around the use of greater visitor interactivity and engagement encouraged higher levels of appreciation and possibly visitor enjoyment. Given the increasing importance of visitor engagement, interaction and visits, it is therefore crucial that museums revise their exhibitions paradigm and consider the adoption and application of 3DPT for its haptic possibilities (Dalama et al 2016).

Earlier books focussing on museums such as 'Transforming Museums in the twenty-first century' (Black 2005) and 'Museum Philosophy for the 21st Century' (Genoways 2006) do not specifically mention 3DPT, written as they were before this technology entered public consciousness. However, over the past decade, the industry has seen a growth in research with a museum-focus looking at haptic technology, and the use and relevance, if not importance of this as a device within the setting of the museum: namely the edited volume by Helen Chatterjee, 'Touch in Museums: Policy and Practice in Object Handling' (2008). In this, the articles argue for the positive restoration and encouragement of touch in the museum, and its benefits as an inclusive device in museums. Perhaps obviously, the chapters of this book then go on to develop upon the idea that understanding and museum interpretation could be further developed using digital technologies: virtual visualisation for learning (Doonan and Boyd 2008; Were 2008; Onil 2008); the importance of touch to evoke memories (Gallace and Spence 2014), and the benefits of visitors actively interacting to stimuli produced inside the museum (Zimmer et al 2008). Chatterjee (2008) clearly is not alone; many other academic works argue for similar change or development with the publication of books along the same lines such as 'The Participatory Museum' (Simon 2010), 'Transforming Museums in the Twenty First Century' (Black 2012) and 'Museum Philosophy for the Twenty first Century' (Genoways 2006).

In fact, two exhibitions have experimented with visitor reception and interpretation of 3DMs, these were two distinct exhibitions held in three museums under the same project name: 'Touching the Past'. The first exhibition was held in the National Museum Scotland and Orkney Museum (Dima et al 2014); and the second was undertaken as an exhibition in the Plymouth City Museum and Art Gallery (Pitt and Hurcombe 2017). These will be discussed further in the next chapter. However, the positive reception that this and other 3DM projects/experiments were met suggests the importance of the addition of tactile interaction with the collection as permitted through innovation in exhibition.

2.3 Touching the Past

The use of 3DPT in the production of 3DM for an exhibition can assist visitor focused artefact interpretation (Gallace and Spence 2014). The 'Touching the Past' project sought to develop upon ideas concerned with the beneficial nature of 3DM to provide a tactile dynamic and thereby assist museum visitor interpretation. Selection and replication of a museum artefact producing a 3DM was seen as important; selection was believed to increase the likelihood of interaction and thereby result in data concerned with interpretation and re-interpretation of the 3DM as well as the artefact. The first exhibition was held in the 'The National Museum of Scotland' as well as the 'Orkney Museum', and the artefact selected was an Isle of Lewis Chess Piece. The Chess piece was chosen for familiarity as it was thought that this would exploit the instinct to touch (Dima et al 2014, p.4). The second exhibition was held at the 'Plymouth Museum and Art Gallery', in this the artefact selected was a recent archaeological find, a Lidded Basket from the Bronze Age. The Basket was selected as this was seen as an 'incredible artefact' and ideal for reinterpretation (Pitt and Hurcombe 2017, p.110).

The Isle of Lewis Chess piece was exhibited for a period of only two days at two different locations, the National Museum of Scotland and the Orkney Museum (Dima et al 2014, p.4). The exhibition featured two touch experiments but only one featured the 3DM. This experiment featured the original in its glass case facing the 3DM, which was painted black and covered from the side, by a case that was only accessible on both sides by touch. It was desired that when the 3DM was handled, that the black backing to the 3DM would create a reflection of the actor's hand in the glass case of the original, making it look as though the actor were touching the original (ibid, p.6). The second installation featured a digital device in which a tracking pen provided haptic feedback to the actor as this allowed visitors to trace the surface detail of the Chess piece (Dima et al 2004, p.8).

Crucially, the exhibition elicited feedback from its visitors: in total 60 questionnaire responses were returned, with visitors offering thoughts about the importance of object artefact feeling, connection, engagement and the museum experience (ibid, p.10). One interesting finding was that the preferred interaction was with the 3DM, handling the model and looking at the superimposed reflection on the glass, one person wrote 'I felt that I was touching the one in the reflection and not the replica' (Dima et al 2004, p.10). This method of interaction was limited as the people conducting the experiment found that the method of exhibition did not allow for detailed examination (ibid). Finally, the conclusion suggests that interaction with the 3DM gave 'rich sensory information' and that the potential of 3DM in the museum is manifold (ibid, p.13).

The second exhibition, held over three months in 2014, by the Plymouth City Museum and Art Gallery, was a temporary exhibition called the 'Whitehorse Hill: A Prehistoric Dartmoor Discovery'. The exhibition featured finds from the dig which included: a wrist or arm band, four wooden studs, a fir pelt garment or girdle and a lidded basket (Pitt and Hurcombe 2017, p.110). The exhibition consisted of two projects: the first, was the production of a computer game, the second was the exhibition of a 3DM of a lidded basket. This study made no mention what 3DPT was used, merely the fact that the 3DM took 130 hours to make (ibid, p.111), a disclosure of time hinting at Stereolithography (SLA) being used. If this is true, it is a good choice for the level of detail required producing a detailed and tough print but perhaps not the most cost-effective or indeed quickest to print.

The exhibition included interaction with the 3DM basket; the activity was puzzle-like with the 3DM divided into tiles to be matched together and the texture to be examined (ibid, pp.120–121). This 3DM, like the chess piece, was exhibited next to the original, but unlike the chess piece experiment, it was not limited to haptic-only interaction, and could be seen as an interactive exhibit itself. Feedback from visitors were also sought; out of a total of 123 responses, 68 were positive, 44 neutral with only 7 as negative, indicating that its visitors were receptive to the 3DM and responded accordingly to the expansive potential of the 3DM used in the museum (ibid, p. 122).[7]

One negative response given to the 'Whitehorse Hill' exhibition: 'Waste of money, the real thing is not plastic' (Pitt and Hurcombe 2017, p. 122). This sums up a current limitation of 3DPT, technologies that can make 3DM cannot replicate the exact materials and therefore can only print the current range of materials. Each 3DPT has its own range of materials that it can use in printing, and for this exhibition a printer that produced 3DM from a photo-reactive plastic resin was used. The list of printable materials for 3DPT is expanding, in the future exact

[7] Pitt and Hurcombe did not mention what happened to the remaining four survey questionnaires: presumably they were returned incomplete or discarded for a reason.

replication of materials may be possible, however the current list of printable materials shall be discussed later.

It must be mentioned that the two exhibitions were both conducted in the short-term, that is 6 months or less. Nonetheless, for a temporary exhibition in a museum, three months is considered a rather impressive length of time displaying the practical realities of haptic interaction, or some forms of it, to assist visitor interpretation and accessibility. Considering the positive reception towards the 3DM in these exhibitions it begs the question: could 3DM be used as a major interpretative device in a museum exhibition?

'Touching the Past' shows us that the use of 3DM for the running of visitor exhibitions is viable. However, the positive reception of the exhibitions cannot be said to have exclusively relied upon the use of 3DPT. Artefact selection in these exhibitions played a role in interpretation and re-interpretation resulting from tactile engagement. The use of a familiar artefact, a 3DM of a Lewis Chess piece, provoked reinterpretation by participants who showed familiarity with the artefact (Dima et al 2014). This is in contrast to interpretation through interaction with a 3DM which was achieved through the selection and replication of an unfamiliar rare lidded basket (Pitt and Hurcombe 2017). Selection of the artefact was important in provoking the engagement with the artefact and the 3DM, where the use of the 3DM developed upon interest showed and the knowledge surrounding the artefact (Dima et al 2014; Pitt and Hurcombe 2017).

Participants enjoy handling activities; there seems to be no doubt about it based on visitor surveys and experiments (Gallace and Spence 2014). Indeed, through literature as well as experimentation, any enjoyment of touch and positive reception to be gained from such stimuli seems to be mirrored in fiction as well, both historical and contemporary.

2.4 Historic Reception of Touch

The link between the individual and the object that has been touched has an impact: with the act communicating an image, reaffirming agency, realism, and even reviving old memories (Chatterjee et al 2009); to touch something will affect us. According to Linden (2015) in his research investigating the influence and benefits of touch, individuals were born to touch, and it is the sense that dominates actions. The sensory stimulus that is interpreted as touch is frequently multimodal, often seen as complementary to smell, sight or sound. Touch guides conclusions, and in a deceptively complex way, without knowing, touch also dominates our lived experiences. It is therefore, not surprising, that the sense of touch, especially its ability to dominate, and thereby communicate a range of feelings have resulted in conclusions being drawn that have even entered popular consciousness.

The importance of haptics has been recorded in historic understanding, ranging from classical to popular fiction: demonstrating the understanding that touch has the ability to influence individual reactions and interpretation of events. The following three examples demonstrate this intuitive understanding of a causal link between touch and interpretation. The first is from the science fiction television programme *Doctor Who*, the second from *Something Fresh*, a book by P.G. Wodehouse and the third, is from an old Indian folklore, popularised in an 18th century poem.

There are four episodes of 'The Space Museum' which was later published in a book; incidentally, it is also the only *Doctor Who* story that is set entirely in a museum which is also a planet. The story raises many issues which may be relevant to failed museums such as decay, memory, the lack of purpose, decline and change. What the story highlights is the crucial role played by touch in a museum.

Set within the Morok Empire, the Doctor's TARDIS lands on the abandoned planet museum Xeros, which naturally, the Doctor with his companions, have to explore. Just like in museums, some visitors follow behaviour protocols, but others do not. The Doctor, typical of museum authority, tells his companion Vicki, "I thought that I told you not to touch anything!" However, touch plays a vital role: Vicki in touching the exhibits and seeing how her hand goes through the exhibits, leads to the discovery by the Doctor that they had become invisible because of a 'time track' not being synchronised. Seemingly inconsequential, the revelation of the plot then begins, with touch playing an important role as it also helps them to escape the planet, but not before the Doctor and his companions continue to explore tactile differences in objects displayed in the museum (ibid, p.28).

The next story is the first in the 'Blandings' series by P.G Wodehouse, and revolves around the relation of an artefact, an Egyptian Scarab, to identification as well as memory, and tactile interpretation. The artefact, owned by Mr Peters gets misplaced when Lord Emsworth, an absentminded peer, puts the object in his pocket after being allowed to inspect it which sets the plot in motion. However, this extract shows what touch sometimes can inspire: Lord Emsworth became

> "aware of some curious little object in his hand; he accorded it a momentary inspection. It had no message for him. It was probably something, but he could not remember what. He put it in his pocket and turned to his meditations." (Wodehouse 1915/1999, p.46)

After this contemplation, the peer wanders off with the scarab in his pocket only later to discover it inside and revise his initial conclusion. Lord Emsworth is forgetful, but even his attention is caught by the object that he has discovered in his hand: he may not know or indeed care about the object but it is there, and it has left an impression as an object of value and importance which is evidenced by the fact that he puts it back in his pocket seemingly to review it later. Thus, touch, as depicted in the book, shows how it can catch one's attention, and inspire cogitation, although in this case, there was no successful retrieval of memory. Nonetheless, the object has not been discarded but has been kept, suggesting value.

The third story 'The Blind Men and the Elephant' has many iterations of the same parable which are both religious and secular, but always with one moral to the tale: in restricting our exposure to something how can we ever conclude with the correct interpretation? The potential problem occurs when each of the six blind individuals touches only one part of the elephant. The version below has been re-written by John Geoffrey Saxe (Saxe 19thC/2016) and begins thus:

> "It was six men of Indostan, to learning much inclined, who went to see the Elephant, though all of them were blind, that each by observation might satisfy his mind."

This continues with each individual touching only part of the elephant and concluding that an elephant is what he expects in relation to what he has touched. The first man touches the flank, and concludes that it is hard, and so the elephant is like a wall. The second feels the tusk and says that the elephant is akin to a spear. The third the trunk, and concludes it is like a snake. The fourth, the knee and believes the elephant to be like a tree while the fifth touches the ear and says that the elephant is like a fan. Finally, the sixth touches the tail and says that it is like a rope. The penultimate stanza in this poem has it that:

> "And so these men of Indostan, disputed loud and long, each in his own opinion exceeding stiff and strong, though each was partly in the right, and all were in the wrong!" (Saxe 19thC/2016).

Particularly of interest are the parallels that we can draw between the unfamiliarity with the elephant and the possible public unfamiliarity with the archaeology. The museum artefact, much like the elephant may be unknown to the actors - the museum visitors - with only certain details bearing relation to the specifically unknown object. The actor approaches an unknown piece of museum archaeology with a vision-centric approach, interpretation is often distance-based and effort dependent with features like previous artefacts offering general points of reference. Generalities that in interpretation stand the possibility of offering specifics in object related information but are – like with the elephant – often misleading as generalities offer neither object, nor topic-specific detail as necessary for detailed interpretation within the discipline.

As introduced by the above, touch encourages exploration and it is the driver in these characters' understanding of the situation. In 'The Space Museum' and 'Something Fresh' touch is a novel and expansive experience; a stimulus that despite being far from a received mode of interaction (Jones 1987) is found to be crucial to understanding. For 'The Blind Men and the Elephant' touch is a received mode of interaction, but it is their self-imposed restriction to feel only one part and not the whole, that leads to misinterpretations. Experimentation even in fiction, suggests that touch is very important. Like Lord Emsworth, it is when we touch something, that we enter a temporary immersive relationship (Linden 2015).

2.5 The Benefits of Tactile Stimulation

In the curation of the large majority of museum exhibitions, those in charge seem to overlook the benefits of in-house tactile stimulation. The simple matter of touch can be illuminating; without effort, this provides the individual who is performing the action with information that they are privy to: information that sight and reading cannot easily provide (Wolf 2008). To touch an object is to unconsciously receive certain information on temperature, shape, weight and texture (Locke 1689/1997). These four types of information – temperature, shape, weight and texture – as noted by Locke, suggest that when an individual touches something, information about the object, related to how cold or warm, how spherical, or angular and so on, is immediately received and that these types of information become obvious from touch alone. As such, considerations on haptic interaction for the museum should take these types of information into account. Another consideration beyond those that convey information about objects clearly must be on the practical or functional for museums; and sometimes, these latter considerations may have been prioritised over haptic handling activities by museum visitors. In fact, Childe (1997) identifies five important considerations which are viewed from practical or functional perspectives against the handling of museum objects on exhibitions: they are concerned with issues of fragility, decomposition, monetary value, irreplaceability, and being hazardous to the public.

Therefore, it is unsurprising that most, if not practically, all displays are kept out of reach of the museum visitor, often behind glass cases. Thus for the museum visitor, the sense that is used most in navigating and interpreting an exhibition in the museum, is by default, sight. Other sensorial stimuli can be used for exhibition purposes: such as sounds being played e.g. the smiting of hammers; or music to encourage immersion; and odours being released for smells to evoke memories (Simon 2010). However, when presented with an artefact in a glass cabinet, the visitor can only rely on sight alone. Visual input is needed in order to view the object on display: to remotely inspect it at various angles, looking out for little details that may tell of its origin or maltreatment, all in a bid to learn about its history (Taborsky 1990). Therefore, sight, in observing the object can inform us no more than what can be seen, and so a text, designed to complement the object, is often provided for visitors to read more about the context of the object on display (Malton-Howarth 1990).

This dependence on sight seems ideal, and even convenient and safe. However, this is uni-sensory distance learning: sight or visual stimulus is the primary method of obtaining information about the object, and there is a barrier between the visitor and object in the form of the glass cabinet. The provision of stimulus that can be interpreted in the way that the museum curator wants the visitor to understand, is rather idealistic. To view an artefact and interpret it through sight alone requires interest, cognition and a certain degree of prior-knowledge (Wolf 2008), all of which takes effort, something that is not associated as a leisure activity which Hood's study (2004) has revealed to be how museum visitors view their trips to the museum: as a form of leisure. I will be returning to this point about this association between leisure and museum visits because this type of link or association makes it imperative for museum curatorial staff to re-consider how their displays of important artefacts can not only inform and inspire but can be seen as something suitable to be carried out as a form of leisure. Therefore, the addition of tactile stimulation in an exhibition could prove a new additive paradigm to the exhibition of objects which encourages more leisurely visits. Instead of just seeing an artefact behind glass, museum visitors would pick it up and enjoy orientating it. Passive tactile interaction does not require effort: it is effortless, and in certain cases, can even assist the retrieval of memories (Chatterjee et al 2009) as well as the development of spatial awareness (Newell et al 2000), qualities which can only offer benefits (increase in cognitive abilities, navigation, digital dexterity, etc.) in our daily life, besides naturally, the addition of enjoyment as a leisurely activity located in the museum.

Touch-based stimulation is expansive and in every-day life, complements other senses, adding to information from visual, auditory, and olfactory stimuli. We would find it very difficult to survive without touch, but if we had to, Linden (2015) even asserts that the lack of touch-based stimulation would then reduce us to becoming socially and educationally stunted. In another study, Keltner (2010) demonstrates that tactile stimulation provides the receiver with data about the external world to appreciate a variety of properties that is automatically, subconsciously, and effortlessly interpreted and understood by the recipient. In other words, tactile engagement or involvement is an important sensory stimulus; and increasingly, a few more museums are making allowances for such engagement with their visitors, although in most cases, this seems confined to their outreach or educational programmes for younger museum visitors.

To touch anything, a 3DM of a museum artefact for example, is to set off a series of complex biological processes that we have come to take for granted. The somatosensory sensation telling us of touch, pleasure, pain, pressure, or heat is, in the end, a reactive process. This process begins with the excitement of nerve bundles beneath the dermis of the skin that include: Merkel's discs, Meissner's corpuscle, Ruffini's endings and Pacinian corpuscles (Spence and Gallace 2014, pp.21-23); all nerve endings, and all with different jobs, but all providing information that will be built upon to form a haptic picture of the object or thing providing the stimuli. To begin with, stimulation of the skin results in the reaction of a nerve, which sends a series of chemical impulses to the synapse, where it is converted into an electric signal that is sent along the vagus nerve along the spinal column to the brainstem, and to the cortex where it is processed (Linden 2015). The interpretations of these stimuli are varied: proprioception, the process by which we remember joint movement, the orientation of our body and the positioning of limbs that are out of sight; fine tactile discrimination; and temperature and pain, all of this happening at 150 – 250 miles per hour (Linden 2015, p.78). In reaction, for example, if we are holding an item or purposely prolonging the haptic experience, then the pituitary gland stimulated by these various impulses will begin production of oxytocin, the amounts of which will vary per the duration and place of stimulation (Keltner 2010). In other words, the interpretation of tactile stimulation is not dependent on a person's effort or on knowledge: it is natural for a person to react and understand from this sensory stimulus. This natural response is important to the museum because of its effortlessness (automatic reaction) for the museum visitor, which makes the latter's haptic engagement and interaction with the 3DM leisurely, or at least more so than consciously processing the text accompanying the object on display.

Besides this effortless action/reaction, touch also brings with it medical benefits such as assisting rehabilitation, recovery and mental health benefits (Chatterjee et al 2009; Ander et al, 2013; Solway et al 2015; Camic et al 2017). It is the multimodal stimulation of the mind that is important to the museum: to provoke memories of either reminiscences, or offer new experiential ones (Lacey and Sathian 2014) and/or the affordance provided by tactile inclusion of a real space to dream (Kavanagh 2000). Hence, in museums, the inclusion of touch or tactile interaction for visitors should be encouraged and further explored, given its many benefits as mentioned, and how effortless the whole process is, which makes no extra demands on the visitor's prior knowledge nor relies on comprehensive abilities in reading the accompanying text for the artefact on display.

People do learn with tactile engagement, simply performing an action begins the process of forming 'muscle memory' (Linden 2015) whereby people can learn to modify their future actions and build upon a process or sequence of processes better until their reaction becomes automatic (Gallace and Spence 2014). Museums should exploit this stimulus by boosting visitor confidence in the handling of 3DMs, as well as benefitting visitors' ability to interpret and appreciate the original artefact from which the 3DM has been made. Given that haptic interaction can be so effortlessly interpreted, museums can and ought to incorporate it for their visitors. After all, as indicated in previous exhibitions, the cost of printing the 3DM for exhibition is relatively low, especially when compared to other replication technologies (**Table 3**, p.72), and therefore need not impose such a great financial burden on the museum.

2.6 Haptic Engagement in Museums

Museums do hold activities that encourage haptic engagement; often, however, these are held in a limited fashion. Of an educational bent, these in-house activities are designed to support what can be gained from sight requiring reading or following an actor (Simon 2012). Given the medium, handling activities are limited in scope and duration and are increasingly formal with set agendas; the outcomes of such learning activities are artificially limited with the traditional reception seeing them as events analogous to a slideshow, where one picture appears and then is replaced by another, to be soon forgotten. It is understandable that object-handling activities are limited in content and are supervised in execution as this is of importance when the objects in the collection are very fragile, irreplaceable or potentially hazardous.

The inclusion of a real touch, assistive, multi-sensory museum exhibition, could perhaps find accommodation in various forms of innovative technologies; particularly the reception of tactile stimulation brought by the handling of 3DM as exhibiting long-term potential for general visitors and not necessarily confined to adults only. Children or younger museum visitors can similarly engage with haptic activities, thereby encouraging more families to visit the museum.

Haptic stimulation plays an incredible role in the individual's interpretation. To concern ourselves with a historic grounding of the importance of touch, we can consider Locke in his extended work, ‘An Essay Concerning Human Understanding’ (Locke 1689/1997). His thesis on ‘Simple Ideas’, suggests that the concepts derived from touch in the moment of receipt are unconscious, and therefore, require no effort in interpretation (ibid, p.124-128). He further stated that the individual, in receipt of the sensory information, must make sense of and synthesise the data for it to become useful information; an action that requires only a momentary reflection, but one which in this instance is affected by the individual’s own ‘judgement’ (Locke, 1689/1997, p.143).

When we consider this as part of a historic grounding we can consider how the application of haptics into a 3DM may be interpreted. To consider the role of the individual’s ‘judgement’ (ibid, p.143) would be fair to suggest that their past is going to alter interpretation. For the individual to touch a 3DM, it is likely that their perception will be private and subjective.

The University of Berkeley’s Greater Good Science Centre (GGSC) has conducted extensive research into the biological and social benefits gained through touch. These include: stimulation of mental activity in the brain, resulting in the release of various hormones (Linden 2015) and the subsequent positive reaction such as the increase in trust, and the decrease in stress (Keltner 2010). Linden and Keltner, researchers associated with Berkeley’s GGSC, who have published the benefits of touch, clearly view haptic involvement as important activities for individuals given the positive results from their experiments.

To look at this through the prism of museum objects, we can see that potential for artefact handling is already present but under-researched. Clearly more can be done in this area if museums are to accept the undeniable benefits from the increased haptic involvement for visitors in museums. One useful research which can point museums into this direction is the experimentation of tactile stimulation with museum objects by Chatterjee et al (2009) in the article, ‘Museopathy: Exploring the healing potential of handling museum objects’. The study sought to ‘access whether the handling of museum objects has a positive impact on patient wellbeing’, and after a series of sessions with a group of 19 patients, there was a measurable increase in the health and life satisfaction of the patients (ibid, p.164). Through handling, the patients’ responses indicated two reactions: one, the desire for impersonal, objective information regarding the object, and therefore, educational; and second, the recall of memories or reminiscence by the handler (ibid). With exposure over a period of time, it was also found that both the impersonal/educational information sought, and the personal reminiscences provoked memories that were associated with powerful emotional responses (Chatterjee et al 2009). Similar results were found in another piece of research, this time looking at the responses to handling-activities on dementia patients (Camic et al 2017). Conducted in community centres in the South-East of the UK (ibid, p.4), this found that handling activities regardless of age, sex or stage of dementia increased their overall medical well-being, promoting the recall and retention of memories (Camic et al 2017, pp.9-10).

Citing research by historian Constance Classen, Chatterjee et al write that the idea of 'museum objects [being] medicinal is not particularly strange' and that 'some objects made their way into late 17th and early 18th century museums precisely because of their medicinal use' (ibid, p.164). In Classen's research, she gives examples which early museum collections, more than two hundred years ago procured such as 'pharmacopoeia' items which 'included not just specimens of plants and animals, however, but also such things as mummy flesh and even fossils and stone axes – which would be taken in powdered form. The rare and wondrous qualities that made an object a likely museum piece, might also make it strong medicine' (Classen 2007, p. 905). As such, the collections in the past already had medicinal value and worth, and to investigate the therapeutic element in modern museums is not too much of a leap with haptic engagement, involvement and interaction.

To touch was therefore to show a relationship or desire to understand or be informed about the object touched and/or to recall a memory exclusive to the participant. Although the research of Chatterjee and others was on patients, their work points to the therapeutic benefits from touch based on museum artefacts. Stating the obvious, museums objects are different from ordinary objects. I am referring, of course, to museum collections of artefacts which clearly have important significance and relevance: why else would museums have kept these objects as part of their collection in the first place? Returning to Chatterjee et al's research, their work is important because it offers contemporary data on the causal or direct links to therapeutic benefits from touching museum artefacts.

This fascinating experiment raises many questions regarding the ability of object handling to be in some way, beneficial to the handler or museum visitor in provoking memories, emotions and to stimulate learning through greater sensory perception which is the role of a museum or should be the role of good museums. In other words, tactile engagement is very important for the individual's valuation and judgement.

In the article: 'Can Museums Heal? Can Museums Hoard?', Gent (2012) conducted research on tactile stimulation and haptic interaction by making the direct comparison between visitor experiences in two types of heritage situation: one outside with the events in-situ, and the other, inside various museums in Northumbria with both looking at visitor haptic interaction and perception of Neolithic Rock Art. The case studies concerning the in-situ rock art, as compared with the museum exhibited material indicated a variety of actions: visitors removing backpacks, walking barefoot on the rock and engaging with the tactile surfaces at a slow pace (Gent 2012, p.14). This was found to be encouraged by the open space and the perceived ability to explore by visitors.

The data gathered inside the museums though, showed a stark contrast in visitor behaviour: visitors inside the museum were guided through exhibitions, and despite being encouraged to touch and interact with similar rock art, they often would not slow down to take the time to engage with objects that were perceived as out-of-context, i.e. being removed from natural landscape outdoors (ibid, p.19). In comparison, the in-situ exploration of the Rock Art was judged to be more worthwhile and memorable in contrast to the haptic engagement inside the museum which fell short – visitors did not interact much nor pause to touch - and more likely, had less positive reactions for the not so museum-friendly medium of Rock Art as compared to something more accessible and handle-able.[8]

'Attention to touch weakens audio-visual speech integration' is an experiment that explores touch as a multisensory stimulus that might not always be complementary. Alsuis et al (2007) propose that within the individual, there may be present a type of attention constraint that hampers multisensory integration (ibid, p.399). Based in part to investigate the general principle of 'Attention Resource', that is known as the 'McGurk effect'; it is an effect more associated with speech as a phenomenon to describe the interaction between speech recognition concerning the synthesis of audio and visual sensory data. The experiment required the 32 participants to successfully identify a series of words with haptic stimulation (through electrodes on two fingertips) which was designed to test the limitation on certain attention recognition resources. Results from the experiment showed that the drop in recognition occurred with the visual-only and audio-visual groups, as opposed to the audio-only group (ibid p.403). The audio-

[8] At this point, I would like to mention that to have similar reactions and behaviour from both types of exhibitions (one indoors, the other outdoors) would have been rather strange: taking off shoes (and presumably exposing smelly socks indoors) is not standard museum protocol.

only group was perhaps not affected because of the easy recognition of the words; however, if the audio had been conducted in a language foreign to the participants, then the results may have been different. The drop off in audio-visual and visual-only recognition however, seems to suggest that tactile stimulation may have conflicted with vision, and taxed the resources required for linguistic cognition as a diagnostic in the McGurk effect (ibid).

The results gained from the above experiment suggest that tactile stimulation can conflict with audio-visual processing affected by a limited 'Attention resource'. Further processing and interpretation as required by the two sources of sensory excitement may be complementary, but the addition of a third and conflicting sense is somewhat limiting to interpretation. To exhibit 3DM in a museum and to allow people to touch and handle the replica objects, the visitors would be subject to two complementary stimuli: tactile touch sense as well as visual details either provided by the original or the replica (Lacey and Sathian 2014).

However, another haptic experiment which was conducted by Helbig and Ernst (2007), offered a refinement in results which, instead of showing how stimuli can conflict, this experiment indicated the elements which aided haptic recognition. The research looked at how optimal integration of shape can provide information from vision and touch and was conducted in order to expand upon the work previously conducted into the integration of sensory data concerning the size and weight of the object (Helbig and Ernst 2007, pp. 595-606). In other words, the experiment tested visual and haptic interpretation concerning the shape of the object, which is of interest to museums to help them provide objects for their handling activities that can offer ease in object recognition.

In the experiment by Helbig and Ernst, the haptic and visual stimulation for both was provided by a set of 3D printed elliptical shapes – these shapes were handled by the participants - providing haptic stimulation and viewed as a reflection, allowing the experimenters to create conflict between visual and haptic sense datum (Helbig and Ernst 2007, pp.595 - 606). Working from previous experiments based on the complementary nature of touch and vision, this experiment had sought to develop from these findings, such as in previous experiments where it had been found that this complementary nature, whereby participants' ability to judge shape and/or size of the object was found to begin to deteriorate over distance, and was particularly aggravated when the visual stimuli was provided by a recorded image on a screen. Therefore, it was preferable that real objects were to be handled as well as viewed (ibid). The objects used for the experiment were 3D printed using a 3D printer from the company Stratasys. This produced planar elliptical objects, made distinctive with an ellipsis on the front, and elliptical ridges on the back (ibid, p.597).

Results from this experiment showed what happens when there is not a good integration of vision and haptics, such as when visual stimuli become limited (such as the blurring of an image). When visual stimuli was limited, it was found that there was more reliance on the haptic sense for participants. However, this only happened when blurring of the visual stimuli was pronounced. Thus, when in conflict and given two different elliptical objects, one to feel, the other to see, with all participants believing them to be the same; visual stimuli was still the dominant source of information even with slight blurring of the visual image. This of course changed when the blurring was pronounced, indicating that when visual sensory data decreased markedly in reliability, more sensory weight was applied to haptic information (Helbig and Ernst 2007). This experiment by Helbig and Ernst is useful, because under dim lighting for certain museum exhibitions, having 3DMs alongside the displayed artefact behind glass, would serve a crucial role in conveying key information on the artefact, analogous to the blurred visual stimuli which could no longer and reliably convey accurate information to observers.

2.7 Haptic Potential of 3DM

It would seem as though 3DM used in exhibitions have been positively received by visitors (Dima et al 2004 and Pitt and Hurcombe 2017) and by implication, encouraged visitor engagement. However, there is still the need to gauge the impact that touch plays on individual interpretation, and therefore the following section looks at experiments which investigated haptics and the factors which influence haptic interpretation.

Tactile interaction with original artefacts is generally not possible except to specialist visitors. Public tactile interaction with archaeology can, however, be recreated with 3DM (Spence and Gallace 2008). The possibility of tactile interaction offers two benefits. Firstly, it will provide an addition to object interpretation for the visitor and secondly, for the museum, it represents an innovative approach to their existing or new exhibitions. In exhibition, the 3DM can either serve to focus attention upon one object or benefit the entire collection as an interpretive model. However, both, through the tactile interaction with the 3DM will benefit the museum visitor. Encouraging greater interest in the original.

Tactile object studies of a comparative nature (Heller et al 2005) have explored this perception in a series of experiments measuring the accuracy and time of recognition, using subjects from four groups who are sighted, have very low vision, late onset blindness or are congenitally blind (ibid, p.163; Heller 2002). This required the tactile recognition and picture matching of raised line pictures (Heller 2002). Irrespective of the level of sightedness, picture recognition in the experiment was found to be impacted by two factors, the size of the sample, and novelty of the picture (Heller 2002, p.66-67). Identification benefited by the guidance to a selection of alternatives, but the novelty of the pictures and task was found to detract from picture perception (ibid, pp. 66- 67). In other words, the perception of newness and additional sensory information reduced interpretation.

In another research by Norman et al (2004) on 'The visual and haptic perception of natural object shape', they experimented with the recognition of 3D printed models of 12 bell peppers where each was replicated twice. Fifty participants in both experiments were tasked with finding the match (ibid, p. 344). The first was a set of unimodal experiments, touch or sight and the second was bimodal, combining touch and sight. Presented with one model to compare to 12 others, it was found that the unimodal interaction had the greater accuracy (ibid, p.348). In discussion, it was believed that the confusion from both touch and sight could have resulted either from the 3DP as some sort of its shortcoming in the technology, or in the processing of touch and vision sensory stimulation (ibid, p.349). Interaction in both experiments was limited to increments of time of 3, 5, 7, 9, 13 seconds (Norman et al 2004), something that will not be relevant to the actor in the museum (although useful for future experiments in haptic interpretation which I will mention more in the next chapter). Time-based sensory input on haptic engagement will not be relevant in a museum because visitors who are engaged with the 3DMs and the artefact in a multisensory way, decide on how their time is spent. So while object recognition is important; in the museum, this will be untimed as visitors can take as long or as short as they wish.

Another experiment, this time by Newell et al (2000) in 'Viewpoint dependence in visual and haptic object recognition' involved participants who were asked to identify and compare the shape of differently orientated original compositions of Lego block models. Newell et al found a complementary and positive correlation between object orientation by participants when holding an object in the hand, and participant's 'viewpoint dependence' in both assisting identification (ibid, pp.2;7-8). This was a three-part experiment: the first on visual, then haptic, and visual-haptic identification of three sets of four stationary objects; the second test was similar but required the identification of rotated objects on the X and Z axis; and the third, had a restrained haptic identification without the use of thumbs (ibid, pp.3; 5; 6). The findings, consistent in all experiments, emphasised the view-point and specific nature of object recognition, and the direct complementary link between visual and haptic object identification (ibid, p.7). Curiously, for haptic identification, the research concluded that it was the 'back of the objects' which was requisite for an optimal haptic view (ibid, p.8). In other words, museums should ideally deploy the whole object with their use of 3DMs and not part of it, for their haptic activities to be enjoyed and appreciated by their visitors. Such a haptic 'view' as noted by Newell et al (2000) can elaborate upon certain other sensory data. Therefore, to grab something and look at it and orientate the object in a certain way that is perceptually revealing to the actor offers interpretive potential and/or information (ibid, p.8).

In a similar vein, 3D haptic shape perception was examined by Plaisier et al in 2009. With a group of 10 university students this required the tactile-only identification of either a sphere amongst cubes, or a cube amongst spheres. The models were made of brass and dangled by a wire above the participant's hand, they were then instructed to cradle the objects in their palm and say whether the object was present (Plaisier et al 2009). There were two experiments: the first only featured cubes and spheres but the second featured distractors such as ellipsoids or tetrahedrons (ibid, p.425). The results from these experiments were consistent and suggested that 'edges and vertices' of 3DM were easier to identify than the spherical as the former was perceived as more noticeable (ibid, pp.429-430). This has important implications for the museum because the research of Plaisier et al offers some direction into the types and shapes of objects which, by implication have been viewed as more pleasing or 'pleasurable' to touch because these objects offer easier and possibly quicker object identification and hence achievement of the task at hand; considerations which I have explored in my data collection which I report in the next two chapters.

To further consider the importance of the addition of haptics to the museum, the role of mental visualisation and processing concerning tactile perception of shape and texture must involve interpretation and its biological processes. As informed by studies from the biological sciences, sensory information from touch and vision are processed in similar regions within the brain (Stilla and Sathian 2014, p. 6). The 'Lateral Occipital Complex' (LOC) plays a role in object recognition, and scans from the new and the less intrusive use of functional Magnetic Resonance Imaging (fMRIs), scanning participants holding 3D objects, have been found to excite the 'Posterior intraparietal Sulcus' (pIPS) (Stilla and Sathian 2008, p.1313).

Stilla and Sathian (2008) go on to show in their article, 'Selective Visio-Haptic Processing of Shape and Texture', that shape rather than texture had an overlap with vision (ibid, p.1129) as shapes are also processed in the LOC (ibid. p.1131; James et al 2002). Thus, the processing tactile information on 'Shape' and 'Texture' is divergent although the latter shares an overlap with the processing for vision (Stilla and Sathian 2008, p.1136). Therefore, in the processing of touch, whether in shape or texture there are boundaries between the two with the processing of information on shape having the larger overlap with vision. Another research, by Spence and Gallace (2014), show that this overlap is in part down to the need for a fast object recognition; for this reason, touch processing is considered to have a hierarchy where one information process is prioritised over the other. Later research has also shown that it is the 'Cortex' which has been found to be responsible for the processing of visual as well as tactile data from 2D as well as 3D pictures and objects (Linden 2015). It must be noted that any overlap in processing can be a symptom of evolution offering the individual to perceive a total view of what they are holding although how individuals (or museum visitors) then interpret the stimulation for their own understanding is still up to them (Newell et al 2000, p.8; Gregory and Whitcomb 2007, p.263). These studies looking into the biological processing of information from haptic interactions are important because they indicate how haptic interpretation would take place, and therefore how best to allocate, select and 3D print objects for ease and encouragement in object handling activities in the museum.

2.8 Categorisation by Touch

As can be seen, touch, whether from a passive tactile stimulus or engaged haptic involvement, is expansive in areas such as temperature, texture, weight and build material as mentioned earlier in the study by Spence and Gallace (2008). However, the studies mentioned earlier such as those by Helbig and Ernst (2007) and Norman (2004) do not deal with haptic engagement with multiple objects which have more relevance for the museum intent on expanding its tactile engagement activities for their visitors.

Touch is rarely unimodal, blending and operating as a multimodal sensory perception that is almost indistinguishable from other sensorial data (Lacey and Sathian 2014). Research experiments concerned with categorisation and the recognition of objects have been conducted under restrictive circumstances of sensory deprivation. These experiments required the recognition and grouping of a range of objects from simple to perceptively complex and those of two and three dimensions.

In the article, ‘Categorizing natural objects: a comparison of the visual and haptic modalities’, Gaissert and Wallraven (2012) experimented with visual and haptic recognition of mollusc shells. The selection of 24 sea shells of two groups classified as gastropods and bivalves (Gaissert and Wallraven 2012, p.125) was to test the ability of haptic classification. In total there were 22 participants who were divided equally into two groups where the first group was tested on visual-only similarity tests, and the second group on haptic-similarity tests (ibid).

Using a Likert scale with a score of 1 for ‘Not Similar’ and 7 for ‘Very Similar’, each participant, for the haptic exploration was presented with one shell at a time. Concealed behind a curtain, this would be raised to enable haptic exploration and only lowered after 15 seconds later where each participant would vocalise the similarities and differences based on their tactile involvement with the shell (ibid p.126). The results for the haptic-only experiment were seen to be positive with a success rate of 83% in identification and classification. It did seem, as suggested by Gaissert and Wallraven, that haptic-only identification was open to greater errors, made more apparent when directly compared to visual-only identification which had a success rate of 96% (ibid). Haptic-only identification required the participants to place shells into two classifications, this perhaps increased the likelihood of correct classification as having a 50/50 chance of success. However, it is interesting that in both the haptic-only and visual-only examination, the participants mentioned that shape, more than other elements such as colour (for the vision-only participants), texture, weight or material, was the more important deciding factor for their answer (Gaissert and Wallraven 2012, p.128).

It is interesting that shape, rather than any other feature, was rated the highest as the participants’ deciding criteria for their answer or interpretation for classifying or grouping the shell into gastropods or bivalves. This was made more significant as two weeks later, the same participants were called back to perform categorisation tasks on 24 shells from the same two classifications. The experiment was repeated, with the two original groups with the addition of identifying the shells into their corresponding six super families (Gaissert and Wallraven 2012, p.128). Like the first experiment, it was found that haptic recognition was prone to errors, but that identification seemed to have a spatial preference, in which shape remained dominant as the deciding criteria for the participants (Gaissert and Wallraven 2012, p.131).

Shape dominance in classification, however, was not particularly encouraged by the choice of the experimental object, a sea shell, in which shape is more telling than size. In the study by James et al (2007) in 'The Neural Basis of Haptic and Object processing', it reported that the processing of tactile information is done sequentially, where processing takes on a distinct hierarchy that arises from two neuronal pathways, one for geometric and the other for material information p.219). This system of spatial classification, when compared to visual interpretation, is considered more time-consuming because shape is considered first, and then object configuration (James et al 2007, p.220).

In research by Overvilet et al (2012), on shape detection and categorisation in the observation paper, 'Perceptual grouping in Haptic Search: The influence of Proximity, Similarity, and Good Condition', they tested people's accuracy in identification, and showed that accuracy was dependent on tactile handling or its more technical term, somatotopic proximity; and spatial proximity (Overvilet et al 2012, p.817). Twelve participants took part in two experiments whereby the stimuli were raised vertical and horizontal lines, on a two-dimensional plane surrounded by distractor pairs (Overvilet 2012, p.819). On finding a matching pair of lines, the blindfolded participants would then signal this by pressing a foot pedal with the first experiment testing the accuracy of proximity identification, and the second experiment on somatotopic proximity; with the use of two fingers of two hands and also, in two fingers of one hand. However, while it was found that two fingers from two hands could process separate items faster than two fingers of one hand, the difference diminished when a single (grouped) object was touched in both configurations (Overvilet et al 2012, p.819). The results of the experiment confirmed the hypothesis that the decline in accuracy concerning tactile or somatotopic proximity, became increasingly aggravated in relation to the increase in distance of the lines (ibid, p.820).

The relationship and consideration, of effort and time, in tactile interpretation, are suggested in the results of the above categorisation experiments by Gaissert and Wallraven (2012) and by Overvilet et al (2012). However, as mentioned earlier, this could be due to the hierarchical nature of data processing from touch and therefore the dependence on those factors is not surprising (James et al 2007, p. 219). Touch as a sense, is rarely unaccompanied, and in sensorial interpretation, is often multimodal. In fact, other haptic studies by researchers such as Lacey and Sathian (2014) and Heller et al (2002), in a similar way, indicate the importance of view-dependence, and the consideration of types of object recognition, which can be applied in museum environments, and crucially, has been studied in a controlled test environment offering results that could be transferred in museum settings. This research was conducted by Di Giuseppantonio Di Franco et al (2015) which sought to investigate the introduction and immersive value of a 'non-traditional object observation policy' with haptic manipulation of 3D printed replicas of museum artefacts.

In a series of three experiments, the study attempted to expand upon how the traditional museum experience can limit the experience with past material cultures with 60 participants. The first experiment tested participants' comparison of object perception and interaction where each of the three tests used a different interpretive paradigm: visual; three-dimensional immersive visualisation, and thirdly, three-dimensional printed replica interaction (ibid, p.6). The second experiment only had thirty participants who were presented with three modalities: traditional visual examination, 3D immersive visualisation, and 3D printed replica interaction in order to investigate the altered differences in participants' gestures when describing the objects in front of them (ibid, p14). The third experiment was the organisation of a one-day exhibition called 'What are you looking at? Experiencing ancient artefacts' in which 60 participants were each given a questionnaire and asked to rate their reactions to differing virtual and material interaction in viewing and exploring an immersive exhibition.

Throughout all three parts of this experiment, a certain theme was observed which showed that participants would use certain paralinguistic gestures whilst describing the artefacts regardless of the type of questioning: face-to-face or through video recordings, suggestive of an immersive potential encouraged by object interaction. An interesting finding from the study was also the fact that participants were also influenced by variations in certain physical characteristics of the 3D printed replica artefacts such as colour, material and weight (ibid, p.22) which affected the participant's interpretation of the object. However, it was also observed that when such variations occurred, this was often mitigated by the participants' behaviour in closely examining the exhibition of the original artefact, am action which the study aims to investigate in the future (ibid, p.24). This is crucial, because data like this is important for museums and as stated by Giuseppantonio Di Franco et al, the potential from this finding is significant and that it can be the:

> 'starting point for the creation and a protocol or methodology that envisages the integration of different technologies in the museum' (ibid, p.23)

With regards to the use of 3DPT and 3DM inside the museum, Giuseppantonio Di Franco et al's research is important because it suggests a close relationship between the physical and emotional understanding of touch. The correlation between participant's emotional reaction towards the similarity in physical characteristics between the original artefact and the 3DM is significant and suggests that greater physical likeness in aspects such as colour or weight will add to an increase in the possible emotive presence for participants when handling the object, viewing the original artefact, and comparing both.

It is important here to mention that in handling a replica piece of archaeology, any increasing likeness, in particular even with the possession of physical aspects leading to perfect facsimile, this will never produce the same emotive interpretive reaction as handling the original, which Giuseppantonio Di Franco et al acknowledge in their research (2015, p.23). This acknowledgement is important and while I would agree that actors or handlers might not have the same emotional 'connection' from touching a 3DM as they would a thousand-year-old artefact - there is no denying the value of history and being able to hold part of it – I do not see this as a clear distinction between the 3DM and the original artefact in absolutely all aspects. In fact, I would like to make a slight distinction here: that 3DMs may possibly possess some of the emotive qualities and features attributed by people to the original artefact, and it is this distinction which I aim to investigate as part of my thesis on how museums can benefit from the addition of touch using 3DMs. To be clear, I am not advocating the wholesale replication through 3DMs and affording them the equivalence of value and worth as the original artefacts; far from it. Instead, what I aim to show in my research is that 3DMs of a certain type – size, shape, texture, among others - offer the best and closest opportunity for the general museum visitor to 'handle', 'touch' and ultimately appreciate the original artefact.

As previously mentioned for the museum visitor, the historical object or artefact, is not what is already at hand, but is behind a glass case. A 'successful' interpretation will require a certain amount of cognitive dissonance: this comes in play with the reception, due to the belief that the replica presented is complementary to the original behind the glass. This, however, will only be possible with a certain degree of accuracy, already provided through the physical albeit, superficial resemblance in the replication of shape, therefore consideration of other physical qualities brought on by the visual stimuli of the original must be considered. In short, visitor interpretation will be dependent on both their willingness and acceptance of the replica as a gestalt of the original and hence, this is why I am pursuing this line of inquiry.

Given time, museum 3DMs will likely develop greater physical similarities, in line with the original artefacts and some researchers have already begun to speculate that the status of the replica will become viewed in an increasingly positive light as even complementary to the process of artefact interpretation (Radnóti 1999; Lipson and Kurman 2013).

When considering the above articles in relation to the synthesis of 3DP technologies with that of the museum, it is clear that in holding interactive activities in exhibitions (Tschopp and Dzemski 2012; Lipson 2007) areas such as visualisation (Newell et al 2000), categorisation (Gaissert and Wallraven 2012; Overvilet et al 2012), documentation (Allard et al 2005), interpretation (Di Giuseppantonio Di Franco et al 2015) and research (Dalhousie 2013); (Groenendyk and Gallant 2013) can point us to a clearer path on how and what to select as suitable and appropriate activities to suit and tempt the museum visitor bent on leisure and being entertained, besides learning something from the past.

2.9 Historic Approach to Replicas

Three-dimensional rapid prototyping, as the now rather archaic version of its name suggests, was developed and first applied to engineering to produce prototypes or models that could be replaced by conventional industrial production (Lipson and Kurman 2013). This ability is easily transferable to fit the replication of museum pieces, an idea that is not new but one that, as discussed in 2.10, is part of a tradition of replication by a museum.

The concept of artistic forgery, as explored in 'Fake, forgery and its place in Art' (Radnóti 1999), offers an interesting conundrum: if we were to transfer this over to archaeology, superficially it would seem as though we may be no better in producing and exhibiting 3DM than Michelangelo in replacing and presenting his masters with a fraudulent copy whilst keeping their original (Radnóti 1999 pp.1-8). The latter example was an attempt to deceive, whilst confirming his own skill and demonstrating to him, and later historians, the ignorance of the deceived owners and collectors (Radnóti 1999). The concept of forgery as something wholly negative is in fact relatively recent (ibid). If we were to go back even further in time, we would come to appreciate that the concept of the fake or forgery in the Middle Ages was not seen as something negative, but simply a way to replicate and renew originals or re-establish authority (Hiatt 2004).

Replication was not designed to supersede or re-write the history of something that had vanished but instead was designed to evoke and renew in the same or similar tradition reaffirming continuity and assurance that nothing has been lost (Hiatt 2004; Anderson 2006, p.187). Concerning an act of copying to replicate a document, this was seen as a tool necessary for apprentices and those in education. To consider one famous and most lauded replica - the statue of Michelangelo's David - it is a statue with many copies with its origin as a copy that was an interpretation from a source which in turn had its origins in antiquity. The original Michelangelo's David initially stood outside the Palazzo della Signoria in Florence, from 1504 but was removed in 1878, where now there is a copy in place of the original (Burckhardt 1855/1990, p.56; 355), with the latter safely exhibited inside the Uffizi Gallery Museum.[9] Not necessarily exclusive to the Italian Renaissance or to art, but in nearly every other professional occupation, copying and replication were considered part of an educational tradition that was designed to maintain certain skills and competencies, as well as the encouragement and development of skill-sets in design and innovation in craftsmanship (Radnóti 1999).

The aim of copying has never been slavish replication, neither during the Renaissance nor at any other time. To think of the Renaissance from a European perspective, is to think of southern central Europe, specifically the Italian states of the 15th to early 17th centuries; but this, in fact, was not the first nor the last

[9] The date of 1878 for the removal of Michelangelo's David was added as an endnote by the translator SGC Middlemore for the 1990 Penguin re-publication of Burckhardt's book (p. 389).

Renaissance: the word was coined during the period dividing itself from the period before, and emphasising rebirth, rejuvenation and revival (Burckhardt 1990, p.11) but is only a description of the spirit of a time. The initial inspiration for the Italian Renaissance was the emulation of antiquity and therefore in that emulation grew the concept of copying even when it came to the re-codifying of laws, this was seen as positive. The idea of replication, since the last period of Renaissance, in Britain in the 18th century, this had come to be looked upon as derisory in academic worth and indicative of a stagnation in progress.

It is quite clear that if any museum were to produce a replica and then present that as the original, then this would be seen as deception (Edson 1997), an action that would be un-ethical with an intent to mislead. A museum may exhibit fakes, many do, highlighting the point that they are not the originals. An exhibiting authority could in the exhibition describe a replica as ‘an original replica’; potentially this could necessitate the rebranding of many Classical, Medieval and Renaissance collections (Hiatt 2004). As suggested in research, historical replicas and the originals gain academic credibility when accompanied by three factors: exclusivity, production method and time (Radnóti 1999). It seems that the amount of time distancing an object from its origin of replication and therefore production and later academic scrutiny, may be the great redeemer giving rise to people who, unfortunately, hold the current view that the study of replicas as a waste of time. In fact a negative opinion is what was expressed by the *Guardian* newspaper art critic Jonathan Jones who, rather grandiosely, asserts that ‘Celebrating fakes is moronic ... it’s real art that matters’ (*Guardian* 14 January, 2015).

This is particularly ill-conceived when we consider that the majority of pieces of art studied are replications and forgeries. This argument as exemplified by art critic Jonathan Jones, is in favour of the original as authentic, to the detriment of what is lesser, and as Radnóti has shown, this often rests on the age of the artefact and, that argument, simply put, is untenable (1999, p.6). Indeed, Jones offers a definition of fakes in part being objects that lack age and therefore are not worthy of study because they are not authentic (*Guardian* 2015). In this he ignores the tradition of model making and the use of replicas in museum exhibitions (Simon 2000). It simply cannot be said that a fake is something that lacks age. Many of the most keenly studied statues and pieces of art may be hundreds of years old but they still are forgeries; they have literally been forged as copies of copies (Radnóti 1999) but they possess an age and are seen and studied as authentic.

In order for a replica of an artefact to be considered as authentic it may be more than age that carries the authority of authenticity. In an article 'Authenticity in the age of digital companions', Turkle considers how technology can recreate certain stimulus as to represent, or portray, authenticity through digital media developing upon a nascent relationship between the technology and the user. In this article computer games, gaming consoles and various digital technologies all designed to replicate certain emotions are used as examples of digital technologies that have the potential to provide an authentic experience (Turkle 2007). Authenticity is suggested as to be provided through representation adding to experience through what is named as relational objects (ibid pp.504-507). This idea of authenticity is however dependent upon a relationship; and is defined as pre-programmed digital devices that mimic certain human emotions and animal behaviours in order to form a relationship between itself and the user, which is, in part based upon the authenticity of what is portrayed (Turkle 2007).

In the consideration of what is an authentic artefact, it may be the age of the object, as well as the attributed experience of the receiver that describes something as authentic (Radnóti 1999; Turkle 2007 p.501). A piece of archaeology in a museum is unlikely to have its age contested and neither is the experience that the visitor takes from the encounter. Analogous to this: what can be said of the 3DM? The 3DM would never replace the original, and it ought never be represented as such but it would be an addition to the interpretation of the artefact and thereby, it is as an extra experience with the introduction of tactile engagement that the 3DM will prove its worth.

2.10 The Tradition of Copies within Museums

For exhibition purposes, there is a long tradition of making replicas of artefacts and exhibiting them within museums (Radnóti 1999 and Neilson 2010). Indeed, the consideration of the use of replicas in a museum will always be seen as emotive (Spence and Gallace 2008b; Beath 2008). Contemporary use of replicas by museums may be to fill a gap in representation, to exhibit a distinct function or pattern or to appear in the place of an artefact that is too fragile to be exhibited. However, in the recent past the use of and study of replicas has gained a negative association as inauthentic and somewhat lacking in any intrinsic or extrinsic quality (Radnóti 1999; *Guardian* 2015). However, to take a negative view on the use of replicas in the museum is to ignore the long tradition of making copies within the museum for the benefit of the public.

For a museum to commission a replica of an artefact, three techniques seem to be preferred: electrotyping, casting, and practical reconstruction techniques (Jones 1990; Radnóti 1999; Short 2015). **Table 1** on the next page provides a comparison of these three techniques along with 3DPT in describing the suitability, method, and materials that can be used by these means. Each of the technologies represented in **Table 1**- electrotyping, casting, practical methods, and 3DPT – have their own suitability and range of materials that can be used.

In point of fact, casting, moulding, electroplating and practical reconstruction techniques are on exhibition in the 'Model Walkway' of the Science Museum (Science Museum 2013). These historical models, containing artefacts from the last 300 years to the present day, are copies, but also scaled, with discrepancies in weight, material, and colour, but these were forged and manufactured as an expression of originality to fulfil a specific purpose. The purpose of these models was at the time of making to enlighten, instruct and to provide an explanatory guide as a teaching or visualisation aid. A written introduction to the gallery says: "Model-making lies at the heart of Scientific and Technical Development" (ibid), the models exhibited in the Gallery were originally manufactured as tools for education through demonstration but now displayed as artefacts, and seemingly given to be works of art. The models are replicas: they are greatly changed replicas but also represent an amount of artisanal skill, and in forgery of and originality of expression, they represent something novel (Radnóti 1999, p. 35). With reference to the model's intended use, the object is afforded a new status within the gallery as an artefact (Conn 2010). The original utilitarian nature of these models in science and industry meant that these models were handled, played with and, with models with moving parts, manipulated; they were not treated as artefacts but as tools for reference and education. Thus, the technique of manufacture of each model would vary as to the intended use, the material required and the representational purpose of the model.

Name	Method	Replication Materials	Negative/s of using the method
Electrotyping	A mould is made of the artefact; coated with a conductive layer, this attracts the desired metallic substance to the body of the object. The mould is then discarded.	Conductive Metals	The initial mould requires contact with the original artefact.
Casting	A hollow mould is made of the artefact. The desired material/s are poured into the mould and solidify within the cast. When cooled the cast model is ready and the mould is discarded.	Materials that can be heated, moulded and set, this includes: metals, glass, and plastics.	The initial mould requires contact with the original artefact.
Practical Reconstruction	Through academic rigour, the original tools/methods of construction is researched and replicated. The resulting replica is manufactured in an approximate way as to the original.	The material that the original artefact is made	Access to original or approximate resources or manufacturing techniques are required. Time-dependant if undertaken in-house
3DPT	3D Data is held as a digital file on a computer and is expressed as a physical model by a 3D printing machine.	Materials that can be heated, moulded and set. Included also are woods that can be ground and mixed with a polymer base. Paper can be used	Requires excellent data capture. The construction of the 3DM using 3DPT will be dependent upon the quality of the digital data captured as well as the ability of the individual using the 3DPT.

Table 1 - Types of replication

In consideration of the type of replication required in museum model-making, different techniques produce different results. Electrotyping is limited to the use of conducting metals (McLeod et al 2010) but is ideal if a replica of a large ornate goblet is required. Similarly, the ability to produce a cast may allow the museum to use a wider variety of materials (Coutinho et al 2009) and therefore be useful for the replication of statues. 3DPT however presents the possibility of using a range of materials that can be made malleable (Barnatt 2014), which in application presents a replication potential that includes materials and models traditionally associated with casting and electroplating.

The level of contact with the original that is necessary in order to make the replica is a concern. As shown in **Table 1,** both electrotyping and casting rely on moulds to be made of the original, and this in part requires direct contact with the fragile artefact. However, for practical reconstruction methods and 3DPT, direct contact with the original is optional and for the most-part non-existent. Approximation for replication in both can be made remotely, whereas practical methods use approximate tools and methods that are thought to have been used at the time, and 3D scanning for printing allows the capture of digital data from images or scans of the artefact whereby a digital model can be completed remotely (Barnatt 2014).

In planning to use 3DPT to print 3DMs as museum pieces, it is important to remember that the technology cannot print everything (Barnatt 2014). Therefore, for the museum to choose to use this technology to print 3DMs they need to consider the current technological limitations weighed up against the suitability of the other methods of replication. The quality of a 3DM will depend upon the quality of digital capture, provided through scanning technology or photogrammetry, as discussed in **Table 5** (p. 99). As listed in **Table 2** (next page) and later in **Table 4** (p. 96), there are different types of 3DPT, each with its benefits and limitations. Some of these limitations have previously been discussed, such as the limited print size as well as the range of materials. However, to consider the pace of technological development surrounding 3DPT there will not be such limitations in the future.

The issue of cost in the price of copying has bearing over how the object will be treated by the museum. As we shall see later in the findings chapter, a cast of a Bronze Age Dagger that is made out of bronze from a clay mould costs £250, and therefore it is likely that the object is going to be exhibited behind glass. Whereas in the application of 3DPT to benefit the museum with the aim of using 3DM to benefit visitor interaction with collections, considerations of cost in using 3DM for handling purposes may influence the museum. **Table 2** shows a comparison of approximate price ranges from these techniques.

The Cost of replicating a Roman Samian Ware Bowl: 9cm height, 9cm deep, 8 cm wide[10].	
	Electrotyping: £80-300
	Casting: £50-250
	Practical Reconstruction: £50-100
	3DM: £20-30[11]

Table 2 - Comparison of prices to replicate a Roman Samian Ware Bowl.

This high price often means that the replica is treated as a museum piece, placed behind glass and an artefact for privileged academic study (Simon 2010; Jones and Alberti 2006; Spence and Gallace 2008). One such example of this is the artefact mentioned in the 2010 book “The Heritage of ‘Maître Alpais”. This was a 2009 collaborative project undertaken by the British Museum, with the aim of re-assessing the Medieval Collection (McLeod et al 2010). In this project, it was found that a 13th century *champlevé* enamelled Ciborium (communion goblet) (McLeod and Röhrs 2010) exhibited by the British Museum had two replica Electrotyped Ciboria made in the mid-19thCentury (McLeod and Röhrs 2010). According to the British Museum publication “The Heritage of ‘Maître Alpais”, the original goblet dates from 1200AD and is exhibited in the British Museum, whilst the two copies were sold for exhibition purposes (Röhrs et al 2010) to the Victoria and Albert Museum in London and the Museum of London (McLeod and Röhrs 2010). The electroplated copies have therefore come under scrutiny: looking superficially like the artefact there are key differences, such as the slightly raised surface details, subtle differences in the figures on the bowl and the use of a pin to attach the bowl to the foot (Röhrs et al 2010). The artefacts are of historical

[10] Price-ranges are provided and they are based upon approximations.
[11] The much lower price of the 3DM Samian Ware, as seen in **Appendix E**, only takes into consideration the cost of the material Olive Green PLA the and estimation of the hours of individual work in scanning, processing and printing the 3DM.

importance to the museum and to research, because of this any tactile interaction is limited to the privileged few academics. Ironically as McLeod writes, these objects were originally made as they were part of a 19th-century tradition to exhibit to as wide an audience as possible (2010). Thus, as a copy, the Electrotype of the Ciborium of Maître Alpais – registered number REPRO 1888-450 (McLeod et al 2010) – is not for handling purposes; the electroplating method used in replication has subsequently meant that there is the current need for conservation.

It is not a coincidence there is a sense of history repeating with the current importance of reaching a wider audience similar to the 19th century sentiment (McLeod et al 2010) to encourage greater appreciation of archaeology: albeit with the application of a different technology through the use of 3DM. The introduction of the 3DM is an extension of this tradition of replicas in museums because through access to 3DPT making 3DM, it is the addition of tactile interaction not just for academics, but potentially for every museum visitor.

2.11 Museum Uses of 3D Printing

The question of how the application of 3DPT can benefit visitor interpretation of archaeology in the museum has of yet few examples; the 'Touching the past' project, as described previously received generally positive reception by visitors keen to interact with the 3DM (Dima et al 2014, Pitt and Hurcombe 2017). In further exhibitions, 3D Printing had been used primarily as a method of representation with the idea of introducing or elaborating upon received perception. A growing number of exhibitions have undertaken projects designed to test the viability of 3DPT in the recreation of certain 3DM for public exhibition. As exhibited in **Table 3** (p. 72), there is an increasing number of museums in Britain that use 3DM for visual and tactile exhibition purposes. The implications from exhibitions of 3DM are for the museum greater visitor interaction with 3DM and interest in archaeological artefacts. The use of 3DPT for exhibition purposes is not limited to Britain however, and it is below that a selection of museums from around the world that use 3DPT and 3DM for exhibition purposes is discussed.

In the case of the previously mentioned Allard et al (2005), 3DPT was chosen in the exhibition of this sensitive artefact. The technology allowed for replication of the complete human skeleton whilst also allowing the repatriation of the Skeleton to the ethnic Mennonite grouping (ibid, p.4). The 3DM then was exhibited as part of the exhibition 'Funeral as a Rite of Passage' in the Mennonite Heritage Village in Manitoba, Canada (Allard et al 2005, p.1). The use of this technology demonstrating twofold: the ability of the technology to print artefacts for museum exhibition, and the suitability of the 3DM to act as a proxy for artefact, allowing exhibition of the 3DM when for ethical reasons the original cannot go on display.

Reconstruction for exhibition purposes, similar to the above, can also be seen in the two following examples: the reconstruction of a Sauropod neck (Tschopp and Dzemski 2012), and the scanning and 3D printing of a Whale Fossil from Chile (Park 2013). The former, the reconstruction of the Sauropod neck was primarily concerned with the ability of 3D scanning and printing technologies to reconstruct individual vertebrae, and only in passing does it mention the potential of 3DPT to assist museums in handling activities (Tschopp and Dzemski 2012, p.6). The latter however, a Whale Fossil from Chile was undertaken by the Smithsonian Institution specifically with the aim that this should produce a 3DM that is accessible to all museum visitors (Short 2015) and exhibited in the 'Smithsonian Institution National Museum of Natural History'.

An exhibition of the Ancient Egyptian Mummy called 'Neswaiu' (RI.SE 2014) was housed in the Museum of Near Eastern and Medieval Antiquities known as the 'Medelhavsmuseet' in Stockholm, this was in partnership with 'The interactive institute Swedish ICT' (Medelhavsmuseet 2017). Using a combination of 3D scanning and printing technologies which showed similarities with the British Museum's exhibition of Sobek in 'Scanning Sobek: mummy of the crocodile god' (British Museum 2017c), the above exhibition of 'Neswaiu' used this combination of technologies in order to portray a specifically focused narrative (Medelhavsmuseet 2017). The use of technology was therefore aimed at challenging perceptions, encouraging interaction with 3D virtual scans as well as tactile engagement with a 3DM such as with a gold necklace (ibid). With visitors encouraged by being granted a level of access that previously was limited to only a few professionals, it was hoped that close tactile engagement with the reconstructed 3DM and virtual 3D scans would encourage a revaluation of the 'Neswaiu' and the society of Ancient Egypt (Medelhavsmuseet 2017).

The application of 3DPT by these museums has been used to produce reconstructions of exhibitions focused around one specific artefact. The use of these 3DM for museum exhibitions in Canada, America, and Sweden allow for close tactile access affording a visitor reinterpretation of their understanding of the object. In this way, the level of engagement with the 3DM is not limited to a privileged few, but as tactile engagement, is available to everybody.

The ‘Royal Ontario Museum’ has expanded in their use of 3DPT as an interpretative tool for 3DM of archaeology. The reconstruction and reinterpretation of a 3DM scaled city from Mesopotamia (ROM 2013); this is intended to challenge perceptions and received wisdom surrounding historical sites (MAKE LAB 2013). As a 3DM this demonstrates the ability of the technology to exhibit interpretations that are fully accessible. This 3DM represents a development of the use of the technology for interpretative purposes, as this presents the chance of a top-down view of a city: by its very presence it is to be appreciated in a new light (ROM 2013).

The ‘Royal Ontario Museum’ may challenge preconceptions toward a period of history, but the exhibition in the ‘DX’ Design Exchange Museum in Toronto called ‘3D XL’ challenges visitor perception of 3DPT to produce ornate architecture (Chin 2015). The ‘3D XL’ exhibit is important because it invites visitors to question the perception that 3DPT can only produce small plastic and novelty 3DMs (ibid). Therefore, to see, touch and handle some of the ornate wood, brick, or metal 3DMs is to allow public interrogation of common misconceptions of 3DPT particularly in a museum setting (Canadian Architect 2015).

Continuing to challenge preconceptions of what 3DPT can achieve in a museum is the travelling exhibition ‘Sight Unseen: International Photography by Blind Artists’, this exhibition will be hosted in 16 museums in four different countries (Curatorial Assistance 2018). This exhibition features 121 photographs taken by blind photographers and explores ‘ideas about the nature of seeing’ as many photographs have been augmented with 3DMs and tactile interaction is encouraged (Puxley 2016; CMHR 2018). In a way similar to the above mentioned ‘Neswaiu’ (Medelhavsmuseet 2017) and ‘Sobek’ exhibitions (British Museum 2017c), this features a combination of technologies that are intended to complement each other and thereby challenge visitors to think about alternative methods of engagement.

As the above exhibits indicate, the use of 3DMs to show different perspectives of an ancient city (ROM 2013), modern architecture (Chin 2015), and augmented photographs (Curatorial Assistance 2018), is just the tip of the iceberg of what 3DPT can offer to museums. Its adaptability and variety of uses in this case, can produce 3DMs that offer new ways of interrogation and interpretation of artefacts, i.e by encouraging alternative engagement through viewing and handling 3DMs. 3DPT within the museum represents the potential of a new medium of expression and it is that method of expression that should be welcomed by any museum wishing to offer a fresh reinterpretation of their current collections.

However, in order to produce a 3DM, scanning or digitisation of the artefact must first take place, and it is on occasion that certain museums opt to exhibit virtual renderings of artefacts in order to immerse the individual in a reconstructed environment. The University of Manchester Museum is one example of a British museum using 3D augmented reality to recreate an interactive haptic experience. This is done with the addition of a 'Haptic Station' which replicates a tactile textured experience, as the visitor can handle the simulation (Beath 2018). With the application of Haptic Modelling Software as provided by 'Touch & Discover Systems Ltd' (2018) tactile interaction with the models are realised through the use of a 'Probos Sensory Console' in which the actor handles the virtual model and sees the reconstructed digital image as displayed on a screen (Beath 2018). Providing tactile feedback, this is an immersive method of engagement that adds to the perception of how the archaeological artefacts are displayed and how they should be engaged with (Zero Project 2017).

As an early adopter of the 'Probos Sensory Console' (Touch & Discover Systems Ltd 2018) the Manchester Museum has been able to refine and focus their use of this virtual representation in order to provide visitors with an immersive experience (Beath 2018). Whereas Manchester University is not a stand-alone case in the implementation of technology to provide immersive experiences to aid interpretation, it is interesting that the museum has chosen to use a technology that represents a fully restored virtual tactile model. This virtual model however while accessible is distanced, particularly as the visitor is interacting with a representation of an artefact that is behind glass. However, as we shall later discuss, in feedback received on the use of virtual representation technologies to represent archaeology in museums as compared with 3DM handling activities, it is the distance placed between the individual and the representation, usually by the use of a technology to provide an interface that has been recorded as limiting immersion and detracting from the experience (Di Giuseppantonio Di Franco 2015; Pitt and Hurcomb 2017).

The application of 3DMs and virtual digital technologies in order to express or reinterpret artefacts is appealing to museums who realise that these innovations may offer an expression that whilst appealing to audiences can also challenge received wisdom. It is innovation through the application of these technologies that presents a multisensory focus that is intended to enrich visitor experience (Black 2005, p178). Reinterpretation through museum engagement with 3DPT or 3D scanning technologies serves to engage visitors through providing an immersive environment. These technologies allow for the museum to innovate through a new method of expression to reach-out and attract those, who perhaps, would not otherwise have engaged with collections (Roberts 2004).

Indeed, there are an increasing number of museums internationally as well as in Britain that have adopted 3D technologies in scanning and in printing to create exhibitions, conserve artefacts and benefit the immersive visitor experience. In **Table 1** (p. 61) there are at least 18 National, University, or Local Authority museums in Britain that between the years 2011 – 2018 have adopted 3DPT in order to apply 3DM either for exhibition, academic research, or income generation purposes. Some initiatives to introduce 3DPT to the museum have not remained stand-alone: research projects undertaken, for example by the Grant Museum of the University College London in the restoration of a Quagga Skeleton (UCL 2015) have become part of the exhibition in 'Bone Idols' (UCL 2018); and the University of Oxford working with the Bate Collection has undertaken restoration and the creation of replica 3DMs from their collection of musical instruments (University of Oxford 2018).

In most cases, museum exhibitions employ 3DM for exhibition purposes. Within these exhibitions they represent the impact that 3DPT have whilst experimenting with the types of 3DM that encourage greater interaction in a museum setting. Three of the museums, as recorded in **Table 1**, and the importance of their exhibited 3DM are discussed below.

The Lothian birth cohort is a current exhibition at the National Museums Scotland, this consists of 3D brain scans and a 3DM brain (NMS 2018b). The origin of the Lothian birth cohort is from between the years 1932-1947 and consisted of 70,805 schoolchildren who took this survey on their mental health (ibid). Reviewed in 2016 on the 1936 cohort, and identifying participants willing to undertake a series of MRI scans as well as other health examinations, this resulted in 3D visualisation and printing of the subjects' brains. Primarily undertaken as a source of research to study neurological development, such as in 'Cortical Thickness' (Hewer 2016), this research has, since 2016, resulted in the exhibition of a brain from one participant: John Scott. On display is the 3DM, a laser etched crystal map of the neural connections, and the MRI scans that helped make the 3DM (NMS 2018b). As a novel expression of scientific data, the document 'Collecting contemporary science, technology and medicine' (Alberti et al 2018) displays the importance of this project and exhibition. The importance of this in not limited to the field of scientific research that it typifies, but as part of a wider trend of museums using technology to assist the exhibition of current scientific research; this shows what can be achieved with the focused application of such technologies (Alberti et al 2018). The importance of this exhibition of the 3DM is not just given to its visual representation but its tactile potential. Through the application of 3DPT visitors can become engaged in the innovative exhibition and actually handle a brain (NMS 2018b).

The Garstang Museum exhibition 'Meroë: Africa's Forgotten Empire' was an exhibition of artefacts from the 1910 excavation (University of Liverpool 2018). Inclusive of 3DM as well as the original artefacts, this exhibition aimed to better represent the history of an often forgotten or overlooked empire (ibid; Tetisheri 2016). Indeed, 3DM in this exhibition was used in a way to encourage revisualisation of an African Empire, confronting the stereotypical image of North Africa at that time as being dominated by Ancient Egypt. However, the Garstang Museum is only one of a collection of museums, including Rochdale's Touchstone Museums, Maidstone Museum, and the British Museum, that have looked at similar periods of time and applied 3D technologies for public orientated exhibitions. 3D printing has been used in the Touchstone Museums, in the printing of Canopic Jars, and in the Maidstone Museum for the Reconstruction of the Mummy 'Ta Kush' (Touchstone Museums 2018; Maidstone Museum 2017); both museums challenging reception by applying 3DPT to provide a novel reconstruction. The British Museum's exhibition 'The Asahi Shimbun Displays: Scanning Sobek: mummy of the crocodile god', discussed later in **Chapter 6**, used visualisation through CT scans to challenge public perception on Ancient Egyptian culture, gods and society (British Museum 2017c).

Reinterpreted, re-visualised and re-exhibition of museum collections of Egyptology and Sudanese, Ethiopian (Nubian) Kingdoms are often seen as necessary (Black 2018). Backed up by a long history of academic study (Stevenson 2013) this also has resulted on occasion in misrepresentation or focus developing on one aspect of history (Jenkins 2011). Indeed, as the curator of the Egypt Centre Museum in Swansea has said about this period of history in exhibition: 'It's not all pyramids and mummies' (Black 2018, p.31). Museum visitors are attracted to exhibition of this period of history, the reason in part is as Neal Spencer, Keeper of the Department of Ancient Egypt and Sudan at the British Museum says, 'It was such a visual culture, so it has continued to capture the imagination' (Black 2018, p.27). Museum exhibitions often challenge this image of pyramids and mummies (ibid, p.31; Jenkins 2011). Indeed, like the Garstang, British, Maidstone and Touchstone museums, the application of innovative 3D technologies has allowed their exhibition to represent the subject matter in a way that is publicly accessible whilst challenging received wisdom surrounding the historical period. As indicated in the examples mentioned, 3DPT can help the museum in exhibition, challenging reception through the application of innovative technologies and expand and inform public perception about archaeology.

The Sikh Museum Initiative in Leicester exhibits 3DMs alongside original artefacts representative of the Sikh Faith (Sikh Museum Initiative 2018c). This is to encourage tactile interaction whereby the visitor can feel a personal connection with the source of their heritage (Sikh Museum Initiative 2018a). In this exhibition it is the ability to form a personal connection through the emotive in haptic interaction with the model that is encouraged (ibid). The topic of this exhibition is the Sikh faith as taught in part through the history of the artefacts exhibited, it is in this exhibition that visitors from Sikh as well as other communities are encouraged to get in touch, or indeed, to reconnect with their faith (Sikh Museum Initiative 2018c). It is for the aim of personal connection or reconnection that 3DMs are used as a vehicle to further the appreciation and connection with a shared faith.

The application of 3DPT and 3DM is not limited to the use by these museums, as seen above and in **Table 3** (p. 72), however these do provide examples of the range in application of the technology. The selection of museums included in **Table 3**, are 19 museums that between the years 2011-2018 have run 23 different exhibitions, projects, income generation and special activities collection, all of which apply 3DM to benefit their exhibition. It must be emphasised that any museum can adopt 3DPT: the selection of museums mentioned – both in the UK and globally – indicate the range and types of exhibitions and purposes to which 3DPT can be utilised. That is why museums, whether big or small; well-funded or with limited funds, should consider adopting and introducing the relatively low-cost 3DPT as part of their remit, given how 3DPT can challenge perception, encourage positive reception and expand and inform public knowledge about archaeology.

Status [12]	Museum	Name of Exhibition	Dates Running	Exhibition/Project
National	The British Museum	Tomb of the Unknown Craftsman & Ancient lives, New discoveries	6th October 2011 – 19th February 2012 & 22nd May 2014 – 12th July 2015	Exhibition & Exhibition
	Victoria And Albert Museum	Rapid Response collecting & Jewellery Visions: Digital Processes and 3D Printing	2014 & 2nd March 2018 – 3rd March 2018	Exhibition & Exhibition
	Science Museum	3D Printing the Future	October 2013 – February 2014	Exhibition
	National Museums Scotland	The Lothian Birth Cohort & Making it	2016 – Ongoing & Permanent	Exhibition & Exhibition
	National Maritime Museum Cornwall	Tattoo: British Art revealed	17th March 2017 – 7th January 2018	Exhibition
	Royal Albert Memorial Museum	Cloning Collections	Permanent	Exhibition
University	Oriental Museum, Durham University	Walking with the Buddha: Discovering the Natal Landscape of the Buddha	12th May 2018 – 30th September 2018	Exhibition
	Grant Museum, UCL	Bone Idols & Skullputure	2015 – Ongoing & 26th May 2016 – 6th August 2016	Project/Exhibition & Exhibition
	Oxford University, Bate Collection	3D printing of an 18th Century French Church Serpent	Ongoing	Project
	Garstang Museum of Archaeology	Meroë: Africa's Forgotten Empire	16th May - 14th September 2016	Exhibition
Trust	Yorkshire Museum	Star Carr Handling Box	2016 - Ongoing	Special Collection
Local Authority	Bristol Museum & Art Gallery	Pliosaurus! Face to face with a Jurassic beast	17th June 2017 – 18th February 2018	Exhibition
	Sikh Museum	Sikh Museum Initiative	12th May 2018 – 31st July 2018	Exhibition
	Touchstone Museums, Rochdale	Ancient Egypt, 3D printing Canopic Jars	Ongoing	Exhibition
	Maidstone Museum and Bentlif Art Gallery	Reconstruction of the Mummy 'Ta Kush'	Ongoing	Exhibition
	The Design Museum	Designer Maker User	Ongoing	Exhibition
	Wiltshire Museum	Spoil Heap	8th July 2017 – 3rd September 2017	Exhibition
	Inverness Museum and Art Gallery	Space Craft	5th April 2016 – 15th April 2016	Exhibition
	New Walk Museum and Art Gallery, Leicester	Museum Metamorphosis	26th September 2013 – 10th February 2014	Exhibition

Table 3 - British Museums that use 3DM for public exhibition, academic projects, or sales purposes[13]

[12] The information on the status of the museum from the Museums Association
[13] This is not an exhaustive list of museums using 3DM for exhibition purposes.

2.12 The Curious Case of the Statue of Queen Nefertiti's Head

News of 3DMs have a way of reaching the media, and there is one case of replication and printing of a museum artefact which excited the media in 2016: The case of Nefertiti's Head. This was reported as treading the murky waters of a legal and ethical grey area with some reports suggesting that the replication of this 3DM was highly dubious and duplicitous in practice. I am referring to the news in late February 2016, where it was reported that 'a precise model' of the statue of Nefertiti's head had been made (*The Times*, 25th Feb, 2015, p.3). It was reported that the two artists visiting the Neues Museum in Berlin, where it was on display, used a horizontally placed Kinect 360 camera (made for Microsoft for gamers and thereby easily available) that was secreted under their clothes – a jumper and a scarf - to intermittently take scans of the artefact (ibid). The model was then pieced together using a computer software in a technique called photogrammetry, which then found its way online where data for the statue could then be downloaded for free and printed by others (Molitch-Hou 2016; Nelles and Al-Badri 2016). There were many problems with this case, the most apparent was the limitations of the technology used to scan the artefact. The scanner used was a 'Kinect 360': this was originally made as a real-time motion capture for a games console and therefore only equipped to scan anything the size of a human. This has been used to scan people and large human-sized objects before to produce digital images, but because of the intended use the resulting digital models are of low resolution. Therefore, the news two artists used a 'Kinect 360' camera placed horizontally under a jumper and scarf and at undetermined intervals was capable of capturing still photographs, of the 48cm tall artefact resulting in a model that could be 3D printed, seemed impossible given the limited technology of the camera (Molitch-Hou 2016). To consider the popularity of the exhibit combined with the slow nature of any scanning the still photos taken with the 'Kinect 360' – which currently is not possible – the gallery would have had to be empty. However, with the state of the technology used and the digital model that was later uploaded to the internet, as can be seen on the website Thingiverse then disbelief could only continue (Mar 2016). This was finally revealed, to no surprise to technology insiders, to be a hoax, and that the photos, which were real, had been taken instead from a replica statue which was created in 1912 (Molitch-Hou 2016).

With the news of the apparent replication of Nefertiti's Head exhibited in the Neues Museum – before this had been exposed as fraudulent – there was initial anger from certain quarters; but why should there have been the anger? Museums have indeed embraced digital scanning technologies and developed digital policies through which the scanning and uploading of artefacts to online databases is encouraged **(Appendix F).** In fact, the British Museum does encourage the scanning and uploading of artefacts as part of specific projects, such as the MicroPasts Project (British Museum et al 2014). However, with the scanning of Nefertiti's Head the implications must be considered. Issues of Intellectual Property, such as ownership and copyright; as well as issues surrounding ethical behaviour in a museum are all raised; though if we consider the digital policies of certain museums that were pre-2015, as discussed below and in **Appendix F**, then the replication of the bust of Nefertiti should not have been a cause for such annoyance. This action was unsanctioned and resulted in the digitisation of a piece of archaeology which could have resulted in the printing of multiple 3DMs. Indeed, if this venture were true and a digital scan had been taken of the original in the Neues Museum and not the 1912 replica, then the world-wide aggregation of such a piece of archaeology may not have sat well with Egypt's Supreme Council of Antiquities who as recently as 2011 called for the repatriation of the artefact (Rohan 2011). It was therefore a relief that this 3DM was taken from scans of a previously made replica (Molitch-Hou 2016). The success in replication and aggregation of the original would likely result in the view that the artefact is not secure and thereby result in new calls for repatriation (Rohan 2011).

At this point a mention must be given to the 'Europeana' project (Europeana 2018). This is a Europe-wide project that has the aim of bringing the cultural heritage and research sectors together, linking 3,500 European museums (ibid). Released as early as 2008 this has the objective of digitally archiving materials of historic cultural importance. Initially launching as a web-based archive offering access to 4.5 million pieces of art, history and archaeology, this is now an aggregation archive that offers access to 50 million digitally scanned documents, models and statues (ibid). Photogrammetry as well as laser scanning are the technologies that have been used to digitally capture materials assisting in the archiving of these artefacts (ibid). Currently the scanning, archiving and aggregation of all culturally important artefacts, as undertaken by the 'Europeana' project, is open to all on a searchable database and is under a 'Public Domain Mark 1.0' licence (cc 2018a). This licence is under the 'Creative Commons' and as

'Mark 1' this means that there are no copyright restrictions and the individual can download, distribute modify and use the resulting 3DM form 'commercial purposes' (cc 2018d). The 'Europeana' Project is important to the aggregation and the printing of 3DM: with access to the digital artefacts through a searchable database, this allows the printing, and even potential for third party income generation through the application of a standard legal framework (Europeana 2018). Indeed, the legal advice regulating the aggregation of digital materials has many global differences and the Creative Commons (cc 2018a) serves as a baseline to many other regulatory principles and these differences will be discussed further in **Chapter 6**. The 'Europeana' Project is sanctioned and regulated whereas the potential actions that happened in the Neues Museum resulted in furore as this was unsanctioned and seen as something unregulated and open to abuse.

There are museum projects that endorse visitor digitisation of artefacts. 'The MicroPasts project' has been warmly received by museum visitors and 3DP enthusiasts. Understandably, there is a stark difference, the MicroPasts project had the ringing endorsement from the British Museum whereas the replication in the Neues Museum did not. The purpose of 'The MicroPasts Project' (2014) is to expand the online library of digital objects and to connect people to history. Participation was in the form of visitors sending in their digital photographs of artefacts taken in the museum in which project staff would then, if possible, produce a 3D digital model. Unsurprisingly, enthusiasts have embraced the idea although it must be noted that it has become quite common to find a museum piece that has been posted as a 3D digital model online by enthusiasts (MakerBot 2012). In the case above with 'The MicroPasts Project' (2014), permission has been granted to the public to take photographs, with the understanding that they will be submitted to a database controlled by the museum and its partners. However, crucially, nothing has been mentioned about making available to the public the options of 3D printing the museum artefacts. The ethical and legal points here are: acting without permission to reproduce a piece of publicly owned heritage for personal use, immediately positions one further into the 'grey area' of intellectual property that is, the ownership of copyright (Poltorak and Lerner 2002; Mendis et al 2015; Schlesinger et al 2016).

Another grey area besides considerations of intellectual property and the ownership of copyright is the concept of 3D Printing Ancient Egyptian Mummies and how this is carried out. As discussed in the previous chapter this project was undertaken in 2013 with the exhibition called 'The re-visualisation of an ancient Egyptian Mummy' by Stockholm's 'Medelhavsmuseet' (2017). Collaborating with their partners in 'The Interactive Institute Swedish ICT' every aspect of the Mummy was scanned and visually realised with 3DM produced. The scanning technologies used included 'hand held scanners', the use of 'Photogrammetric Technologies' and the 'CT scanner' from the Linköping University Hospital (Medelhavsmueets 2017). 3D scanning therefore, was intended to be as high a quality as possible, because the resulting 3DM mummy was to go on permanent exhibition and be made accessible to the public (BBC 2013). The project also featured 3D Printing and a 3DP model of a golden amulet found with the mummy called 'Neswaiu' (RI.SE 2014) which, as an addition to the exhibition allowed visitors to explore 'with their own hands' (ibid).

The fact that this project offers the potential for tactile interaction with the 3DM of an amulet is of interest (RI.SE 2014), this challenges preconceptions and encourages greater interaction. Visitor-focussed accessibility, as a permanent addition to the exhibition, offers interaction that is two-fold: visual and haptic (ibid). This close interaction offered visitors the chance or opportunity to examine not just the mummy but also as a form of context to their everyday life (Medelhavsmueets 2017). Unsurprisingly, the BBC found the exhibit of the mummy and its use of the 3DM amulet interesting enough to give a glowing report of it in 2013. All these examples, along with the previously discussed museum exhibits and 3DM replicas of a 'sauropod bone' (Tschopp and Dzemski 2012), a 'Mennonite woman's skeleton' (Allard et al 2005) may have lacked the focus on accessibility and data on reception but as indicated, they have caught public imagination and collectively, show the incredible potential that this technology represents in application for museums. Crucially, they also highlight the potential minefield for museums about how such displays can be received by the public if sensitivities and emerging concerns are not taken into consideration; in the case of the mummy, only the amulet was used as haptic interaction.

2.13 In Summary

Touch as an act has been found to be beneficial and 3DM, whether reconstructive, interpretive, or experimental has been shown that with the correct application, can offer great potential to museums. Research derived from experiments into sensory stimulation, the processing, and interpretation of touch as well as considerations of case studies for exhibitions all point to a positive role for haptic engagement and involvement in museums with its practicalities and introduction such as in the expanding Dalhousie University use suggest a wider academic application, particularly as a complementary aid that expands upon experimental and interpretive research.

However, as noted, the research discussed here have only focussed on reconstruction, or the creation of a specific exhibition with only a few reporting on the process of construction and layout of the exhibits. Additionally, there are few studies on its reception based on a systematic study of the public, particularly on museum visitors. As such, this thesis seeks to investigate reception towards 3DPT and 3DMs by stakeholders – curatorial staff and museum visitors – and to obtain and collect data on types of 3DM for the adoption by museums for more haptic involvement, engagement and interpretation by visitors.

Chapter 3: Methodological Overview: 'The Original's Companion'

The methodology of 'The Original's Companion' was designed in part to accommodate the need for original data concerned with the reception of groups of actors toward the application of 3DM within a museum. Delineation would therefore shed light on different aspects of the beneficial nature of a museum's use of 3DPT. This division identifies three specific demographic groupings of museum stakeholders. These three groupings of stakeholders would be: curatorial staff, museum visitors, and University academics of which the final grouping will include University staff as well as postgraduate students. Identification of these groups was made to represent experts, non-experts and academics; and therefore, in data collection, present differing viewpoints surrounding museum uses of 3DPT and 3DM. These viewpoints would therefore provide information surrounding application, reception and interaction with 3DM. The aim of 'The Originals Companion' will be to ultimately exhibit 3DM that accompany and complement the understanding of the original artefact exhibited in the museum.

In the collection of this data, three questions were asked: i) How can 3DPT help museums? ii) What types of 3DM will encourage greater interaction in a museum setting? iii) What are the main features that can affect visitors' interpretation of 3DM? The scale of the impact to the museum in the application of 3DPT and 3DM within the museum could alter nearly everything, from exhibitions, activities, research and income generation to name a few.

As discussed earlier, clarification needs to be provided surrounding certain attitudes expressed regarding 3DPT and 3DM. Museums that adopted the use of 3DMs for exhibition purposes recognised the beneficial nature of 3DPT and put this technology to work in their museum. The data collection, in the following chapter, shall expand upon this, gauging the attitudes surrounding the museum applications and visitor reception toward these technologies.

This thesis however is not looking at the use of 3DM within the museum for one-off exhibition purposes but instead the focus is on the long-term viability of 3DM inside a museum. Thus, identification of three types of museum stakeholders would provide insight into the potential scale of application and offer data, previously unavailable, for museums interested in increasing visitor appreciation of exhibited artefacts, and ultimately in visitor numbers. For analytical purposes, the three groups will be termed as Group A for curatorial staff, Group B for museum visitors, and Group C for University academics. Data was collected using questionnaires (Appendices A, B and C), in order to look at practical museum application and reception of 3DM.

The methodological framework 'The Original's Companion' was based in part on research by Anderson on 'Imagined communities' (Anderson 2006) which suggests that curators play a crucial role in museums with regards to decisions on exhibitions. For my research, I have borrowed Anderson's term 'imagined communities' and coined the phrase 'imagined audience' to narrow my focus on the museum itself i.e. staff and visitors, rather than on the wider community as theorised by Anderson. Shape Identification (Heller 2002, Heller et al 2002, and Heller et al 2006), classification of objects as well as viewpoint dependence (Newell et al 2000) research point to the importance of investigating further into tactile reception although both studies relied on university students. The other research by Chatterjee et al (2009 p.175) points to the strong link between an individual's response to object interaction, in which haptic interaction or handling of the object led to the 'provocation of memory' and the increase in personal interpretation. This suggests the emotional or emotive aspect of interpretation in Chatterjee's research on actual handling of objects from museums. Although her studies focussed on museum object handling and interpretation within hospital premises by patients, nonetheless her research strongly suggests the therapeutic benefits of object handling, albeit on actual museum artefacts (Chatterjee et al 2009).

Given these studies, my framework 'The Original's Companion' was designed with the aim of investigating how any museum can employ and thereby encourage touch in their exhibitions so as to encourage greater appreciation and interpretation as part of a 3DM project. In other words, the framework has been designed to emphasise and to complement visitor-focused interpretation of the original artefact. In short, the 3DM, to be companionable to the artefact, will add something to the visitor's experience of that artefact. The addition will be tactile stimulation through the addition of touch and holding of the 3DM (Linden 2015, Heller 2002). After all, many studies have shown that upon seeing an object, the natural reaction of anybody is to pick it up (McGlore 2008, Chatterjee 2009 and Linden 2015). Thus the conscious visual appreciation of the artefact combined with the tactile appreciation of the 3DM will work together to assist in the interpretation and appreciation of the artefact, if not even offer therapeutic benefits (Chatterjee et al 2009; Camic et al 2017; Thompson et al 2017).

I designed the 'The Original's Companion' with the intention that 3DM would be exhibited next to or in the same building as the original artefact and any other interpretative media, like text. Thereby, any interpretation of the original would be informed and therefore complemented by the 3DM acting as this elaborative source. The relative closeness of the objects in exhibition would then allow for easy comparison, and the possible encouragement of activity by the visitors in their interaction with handling the artefact. However, the consideration of distance may be a factor to consider, although this may be negated with publicly accessible online platforms such as 'Thingiverse' (MakerBot industries 2012) and Shapeways (Shapeways, Inc. 2013). For the purpose of this thesis, my design of 'The Original's Companion' has been narrowed to investigate how 3DM can work together with the exhibited artefact in the museum i.e. in the same building. This is also due to my intention to include immersion or an immersive experience for museum visitors. Therefore, my methodology has included feedback and actual responses from visitors in museums at the point of their visit when they handled 3DMs inside the museum.

As such, the possible impact that printing a 3DM of a museum artefact has on the appreciation of the original is worth investigation. Certain museums, such as the British Museum, the Metropolitan Museum of Art and the Archaeological Museum of Parma have a presence on these online platforms and have publicly stated that downloading and printing 3DM may increase visitor interest (MakerBot industries 2012). Although it would be valuable information to know how the influence and access to 3DM would have on subsequent visits by the public, this is out of the scope of this thesis. Instead this thesis was developed to study the in-house addition in the interpretation and reception of 3DMs alongside the original artefacts. To reiterate, 'The Original's Companion' was designed with three different stake-holder groups in mind – A – museum curatorial staff; B – non-specialist museum visitors and C – academics – to represent the range of people and the depth in both specialist and non-specialist knowledge and interest in 3DP and 3DMs.

3.1 Exemplary Exhibition: Brief Overview

The design and running of a museum exhibition is dependent on three variables; and according to Swain (2007), it is a tripartite structure of equal dependence which are the museum building, the curatorial department and the expectations of the visiting audience. In fact, the term 'imagined audience', an adaptation from Anderson's 'imagined community' (Anderson 2006), views the museum as part of a community of staff and visitors who are responsive to developments and changes in day to day events. It is worth noting that this 'imagined audience' with the two main groups of staff and visitors play different roles. As such, this also implies curatorial staff holding notional expectations of visitors for their exhibitions. The 'imagined audience' will include museum stake-holders, specialists and non-specialists, all of whom will approach and interact with the 3DM in an altered way providing a variety of interpretation. Hence, the importance of eliciting feedback from three distinct groups, curatorial staff (Group A) and museum visitors (Group B) regarding exhibits and their experience particularly on both 3DP and 3DMs.

Operating within the community the success of any exhibition and museum is first dependent upon two variables: firstly, the museum itself, the space, and the visitors; and then secondly, communication by the museum to their visitors (Mensch 1990, Silverman 1999, Packer and Ballantyne 2016). The latter includes object exhibitions, accompanying text, and additional immersive stimuli such as the recording of audio materials or the inclusion of some types of realistic scent or smell which, unsurprisingly, is more commonly used in the retail sector (Hertz 2011). All these stimuli – of text, object exhibitions, accompanying text, smell - have the benefit of evoking memories, benefitting the exhibition or increasing immersion for the museum visitors (Kavanagh 2000).

The interpretative potential exhibited by a piece of museum archaeology will be down to certain factors: the relation to the location, public interest in the object, and the ability for further interpretation within the museum gallery (Mares 2006). Opportunities for interpretation are key in the establishment and running of an exhibition; without them attendance will wane. Much of this is left up to the curatorial department to decide on the interpretive measures intended best to bring out the narrative behind any museum piece (Kavanagh 1999, Owen 1999). It is worth noting that any interest exhibited by visitors may be diffused into interest in both the object and the greater story, and therefore, the strategies of interpretation of the artefact can become limited. This may be due to the process and time taken to understand and comprehend the narrative angle sought by the curatorial department for the exhibition.

According to Alberti (2008), in some museums, artefacts have been exhibited like a piece taken out of its archaeological context, without any interpretation, as if to strip it bare and say to visitors: make of it what you will and form your own conclusion. This lack of context, Alberti (2008) feels, is inadequate for a museum exhibition. This method of exhibition which is isolated from its archaeological context, is probably applicable in two ways: first, as a form of formal display and secondly, as part of an experiment. However, in such exhibitions, this lack of context makes it hard for visitors to interpret, and even appreciate the exhibited object. There are many reasons for this difficulty. Firstly, given the subject matter of archaeology, the visitor would need to have some context and idea for the implied age of the object, or have some knowledge of the originating culture of the artefact, and secondly, this implies the need to process information regarding the number of differences or the lack of similarities when viewing the artefact. Thus, points of reference as delineated above are needed for interpretation and appreciation of the object; this can be learned from distanced text or with the addition of 3DM through the close tactile interaction and personal interpretation. In other words, with regards to the artefact, conclusions would either be drawn from deductions as mentioned above, or the object would already be known; either way, visitor interpretation of the object demands a great deal of effort as such interpretation is reliant on prior knowledge gained through education and experience (Pearce 1990).

A piece of archaeology has a story to tell (Pearce 1990, Taborsky 1990, Owen 1999) and it is for the museum to tell that story (Mares 2006). A piece of archaeology can be so devolved from the way people live now, that every aspect of the creation, manufacture and function of the object can be seen as alien from 21st century audiences' expectations (Anderson 2006). Therefore, interpretation is seen as a necessity. The artefact, which is on exhibition is out of its own time, separated from the people who manufactured and made use of it, and the culture from which the artefact originated. In other words, Alberti (2008) asserts, museum exhibition removes context.

In the article 'Constructing nature behind glass', Alberti (2008) describes the act of putting an artefact on exhibition as being 'purified in its construction behind glass' (p.83); in this instance, he describes the method of diorama construction in natural history displays of taxidermy and compares it to art. However, taxidermy displays in a natural history collection do not need interpretation: upon viewing the exhibit, it is easy to recognise a fox, perhaps a little bit more difficult to recognise an ibex or scarab beetle. Since these objects exist in the real world, visitors are likely to recognise them for what they are because they have a context in 21st century society, and therefore, they already have points of reference. An object that is one thousand years old is not going to have this reference point; the latter, which Wachterhauser (1986, p.9) stresses, plays a key role in people's understanding of any historical object. It therefore will require interpretation for artefacts, in order to make understanding accessible to as many people as possible (Preziosi 2006). In short, any artefact removed from present-day context, will require additional interpretation to explain and show relevance, in varying degrees, to the various audiences of museum visitors (Watson 2007).

Another reason for the focus on interpretation by visitors is, that it will help to increase learning besides inculcating appreciation of the object within the museum; the success of this, in fact, will be determined by the focus of interpretative measures (Hooper-Greenhill 2006). These can be done through several ways such as linking exhibits with the greater context, the use of smell or even evoking memory. Whether a stand-alone exhibit or as part of an exhibition, the focus of interpretation is to add context to the object which can then aim for the greatest accessibility possible i.e. for as many people to approach and interpret the museum object in the exhibition. Measures to increase accessibility may include recreating various surroundings, or provoking various memories or reminiscences, both either focused on the topic or more general in character. All these would encourage a participatory environment in a museum (Simon 2010; Bossen et al 2016). Common methods include the addition of a factual text explaining the origins and genesis of the object (Simon 2010; Bitgood 2013). A recorded sound or audio file closely related to the construction or the society of the object may be of benefit to immersive interpretation by adding historical context to the object. A development since the latter half of the twentieth century has been the inclusion of certain scents, such as those manufactured by the company Dale Air which specialises in fragrances used in a variety of industries that are evocative of the period and designed to provoke a more general and immersive atmosphere that provokes reminiscences. The use of scents within museums plays upon the sense of smell; in exhibitions, this is a highly evocative method, playing on the most primitive i.e. linked to the most instinctual part of the cortex (Hertz 2011), and able to instantly transport (Kavanagh 2000) anyone to a specific time or place to allow for a conclusion to be drawn: for example, the smell of baking in an exhibition on culinary science, leading us to draw conclusions to remember the captivating café in Como. In other words, as Hooper-Greenhill (2006) would agree and possibly approve, learning can happen alongside the interpretation of the exhibited objects.

Not surprisingly, multisensory inclusion of interpretive devices is often required with one device used to complement the other in creating an immersive exhibition accessible to the widest range of people (Lawrence 1990, Paris 2006). To state the obvious: touch, sight, smell and sound are senses that have an innate evolutionary purpose and any stimulus that plays directly upon these uses the least effort (Linden 2015, Hertz 2011). However, in object interpretation, if prior knowledge, abilities of comprehension or the need for digital literacies are required, then the effort made by the individual to interpret and appreciate the artefact is open to limitations, diversions and inaccuracies surrounding the artefact unless positive measures such as those discussed above have been taken.

An example of positive measures in use can be found in the interpretation on a Roman Samian Ware Pot in the ‘Gateway’ Gallery of the Sea City Museum in Southampton which opened in 2012. Using the suggestions and framework by Simon (2010) who discussed how immersive measures can be utilised by museums and how they can provoke a response from visitors, the exhibits for the Roman Samian Ware pot seemed to follow his rubric successfully. Samian pots in the gallery were exhibited with similar artefacts in an accessible way. Interpretation for this exhibition is provided through visual and audio stimulation and each were immersive and thereby could provoke a response from the visitor as defined and explained by Simon (2010). Visual stimulation in the exhibit was provided by text explaining where, when and why this was made; and audio provided through a video, described the archaeological record, the find and the manufacture; in a similar way, this could then be extended to provide an analysis from the curator as suggested in Simon’s framework. This immersive measure and interpretation such as this does not rely on prior knowledge while audio and visual stimulation in this manner is complementary for analysis by the museum visitor. However, immersive narrative could be given to this exhibition by the inclusion of olfactory stimulation, such as the scent of drying clay to produce an odour suggestive of a workshop. This type of multisensory inclusion would not only encourage reminiscences but also help to create an intimate atmosphere granting the provision of an immersive experience as if the clay was being fired (Hood 2004).

For the purposes of a museum exhibition, the stimulation of the senses has transformative potential for the visitor (Kavanagh 2000). Visual (Wolf 2008), olfactory (Hertz 2011) and auditory stimulation can tap into visitors' subconscious, and within a fraction of a second, either locate a memory or construct an imaginative scenario. In particular, the sense of vision can be exploited in two ways: firstly, in the exhibition of the artefact, where the visitor can scrutinise and evaluate it; and secondly, the museum text, where the visitor is required to read a short narrative describing the artefact. In fact, it is often through the writing of a text accompanying the artefact, that the first interpretive method is used by the visitor towards the exhibited object. This implies interest but also effort.

This is because as opposed to viewing an object, reading a text requires effort in interpretation in which comprehension is dependent on the text as well as the abilities of the reader (Wolf 2008). Obfuscation may occur in many ways: namely with the specialisation and topic-specific nature of the text, the readers' lack of attention, possession of a specific learning disability (ibid, p.168-169) and/or visual impairment. Reading text requires the effort of sustained attention, and unless maintained, misinterpretation is possible. In other words, the museum text is reliant on the goodwill and interest of the reader.

With visual learning, less so the case with audio and olfactory stimulation, the data source, in this case a text, has a distance, thereby requiring effort in learning. This learning may be distance-related, but unlike stimuli that are directed at the person, this seems impersonal and general. A text requires the compatibility of the readers' comprehensive abilities to something described and interpreted by somebody else, so this is less about the interpretative ability of the museum visitor and more about their ability to understand the description of the object through the 'world view' (Anderson 2006) of the organisers or in this case, the curatorial staff (Roberts 2004). Understanding text is, therefore, for the museum visitor without a learning difficulty like dyslexia or dyspraxia (Wolf 2008), reliant on comprehension and prior knowledge. This is also dependent on the interest, motivation, comprehension (Gadamer 1986), imagination and effort of the visitor, if not the goodwill of the visitor. If any of these are not present, misinterpretation will likely occur (Gadamer 1986; Wright 1986; Roberts 1997, 2004; Hooper-Greenhill 2006; Wolf 2008; Jones and Alberti 2016).

It is visual interpretation that is often the museum's first interpretive choice as an accompaniment to the piece of archaeology (Pearce 1990; Lacey and Sathian 2014) where the inclusion of texts and videos are seen as accessible despite these stimuli being heavily reliant on the visitor i.e. visitor involvement and interest. Therefore, it is much more common to see objects exhibited for visual impact rather than with artefacts accompanied by immersive auditory, olfactory or tactile stimulus (Bitgood 2013), in spite of the many advantages just mentioned.

Therefore, concerned with the engagement and subsequent object-focused interpretation of the museum visitor, the addition of the 3DM is not to supplant the artefact or any current museum interpretation; the 3DM is there to become an addition to interpretation with the introduction of a tactile dynamic. **Figure 4** (next page), 'The Original's Companion' is presented as an illustration of the potential relationship between the individual, the artefact, interpretative materials, and the 3DM. A framework for this relationship, 'The Original's Companion' allows for visual-only and visual-tactile engagement. Interpretation resulting from visual-only engagement with the artefact and any provided museum interpretation, such as a 'text', is contingent upon educative comprehension and the effort-based scrutiny of the individual (Jones and Alberti 2016). However, visual-tactile interaction with the 3DM, in which the individual can pick-up and handle the model is an addition to interpretation. The handler required to perform a natural action, to handle the 3DM is in automatic and effortless receipt of information surrounding shape and texture (Norman et al 2008; Gaissert and Wallraven 2012; Linden 2015).

The potential for close haptic engagement with the 3DM can – expanded upon in the findings chapter – suggest the potential for elaboration as provided by the addition of touch: therefore, the 3DM is complementary to the artefact. 'The Original's Companion' is open to further experimentation, the 3DM is complementary to the original, indeed the distance placed between Visitor, Artefact, Text and 3DM - such as that explored in **Chapter 4.4.4** - can be experimented upon and in practicality will vary considerably. Ultimately with operation under the 'The Originals Companion', provision of an additional source, the 3DM, as offering companionable information will be irrespective of distance.

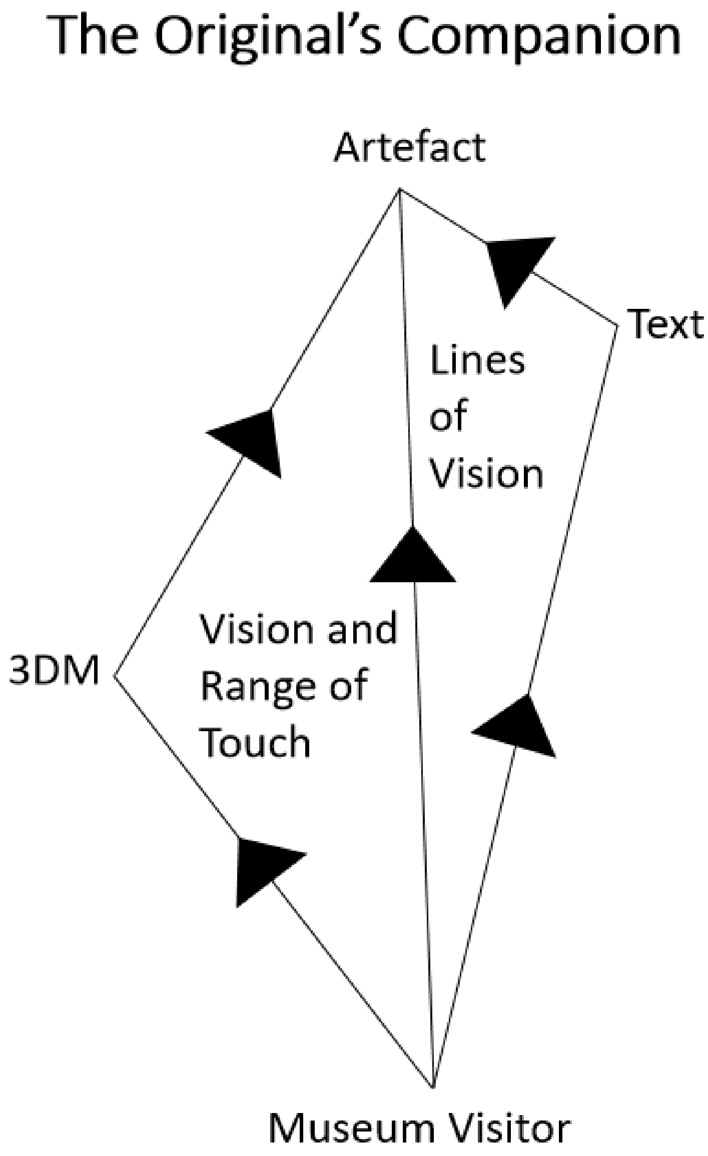

Figure 4 - 'The Original's Companion' a singular perspective[17].

[17] The distances between the visitor, 3DM, textual interpretation and the artefact can vary within the museum. The distance observed between the individual and the 3DM is limited only by accessibility.

3.2 The Original's Companion: Theory

A 3DM that the museum decides to print from the artefact, can contribute to visitors' interpretation of the original artefact. Concerning visitor interpretation, it is important to note that having the 3DM alone will give an incomplete interpretation: it will only be with haptic engagement and possible direct comparison that artefact interpretation will benefit. It is likely though, that the addition of the 3DM, irrespective of museum interpretation, will influence visitor engagement (Rowland and Rojas 2006; Tsau and Ko-Chiu 2016). The 3DM is to introduce tactile engagement allowing the visitor to touch, grab and hold the model. It is useful to note that the museum which exhibits the artefact will decide how the 3DM is to be placed for visitor interaction. The 3DM is to assist the visitor in their interpretation, it is through their engagement with the model that can develop their interpretation of the artefact (Maye et al 2014). Interaction with the 3DM should be unrestricted: previous research has shown that close interaction should be encouraged as this enables greater object orientation in viewpoint for visitors (Newell et al 2000) and also in visitor categorisation of objects (Gaissert and Wallraven 2012).

In short, it is because of the museum's focus on visitors, and the emphasis on visitor accessibility towards the artefact, that the addition of 3DM should be unrestricted so as to increase any interpretative experience. If properly exploited, this interpretive experience can then assist the museum to further develop (Lindauer 2008; Simon 2010) or extend its pedagogic role and contribution to the community at large (Hooper-Greenhill 2006).

For the actor who is encouraged to interact with the 3DM, their reception could either be positive, negative or neutral. A neutral reaction could be that the actor believes the addition of the 3DM does nothing and neither benefits nor detracts from their interpretation of the object and therefore, does not impact upon how they view the host museum. A reaction similar to the one expressed above seems unlikely, as similar exhibitions that use 3DM indicated in their reception of 3DM that most respondents were positive (Dima et al 2014, Pitt and Hurcombe 2017). Positive as well as negative reactions towards reception and interaction with the 3DM will also be dependent on communication (Taborsky 1990; Tsau and Ko-Chiu 2016). It is understandable that there will be a variety of reactions by visitors, as mentioned earlier. However, if the museums are able to communicate and indicate the relevance, purpose, and desired experience whereby the audience know that the 3DM is there for a reason or outcome, the reactions are likely to be mostly positive.

It must be noted that the 3DM is not simply to introduce the opportunities only for touch. 3DM, used as a companion piece to the original, represents the interpretive potential of handling: to stroke, hold or pick up the object and thereby to learn more about the original artefact (Lacey and Sathian 2014). It is the extent or degree of exposure which matters: vision-centric without touch, or tactile without sight; such interactions suggest a direction for interpretation that is both limited and biased through actor accessibility or in this case, actor inaccessibility. The story of 'The Blind men and the Elephant' (Saxe 19thC/2016), is a reminder of the importance of accessibility in the formation of an actor-driven interpretation of the artefact; it was, after all, not blindness but their limited tactile interaction, touching only one part of the elephant, which distorted each of their interpretations. To avoid this, in the exhibition of artefacts accompanied by the companionable 3DM, we must therefore think about accessibility in allowing for the widest possible extent of interaction and exposure towards the exhibition, in this case, to handle the whole object (Newell et al 2000, Heller et al 2002, 2006) and to assist perception and interpretation of the original artefact (Onil 2008).

3.2.1 The Imagined Audience

Within the methodological framework of 'The Original's Companion' consideration is given to an imagined audience; museum professionals, curators, and non-expert, museum visitors: these are people who will react to the museum addition of 3DM. The individuals in the audience will be those who visit and re-visit a museum exhibition and may engage with a novel addition of a 3DM in a variety of ways. Indeed, museum visitors will typically consist of audiences with a mix of interests and motivations (Hood 2004; Anderson 2006). Age will also likely be a factor to consider, as visitor data suggests a trend which indicates that museum visitors are predominantly younger adults and children (MA 2012, p.2).

The acceptance of the idea of 3DM in the museum is crucial. In other words, for the public, this acceptance and openness (Moser 2010), will be an underwriting factor that determines the potential of 3DM that benefits interpretation. However, general acceptance towards 3DM can be enhanced if properly communicated to museum visitors by curatorial staff. Such communication should also take into account the range of professions and educational backgrounds that visitors bring with their varying degrees of comprehensive abilities.

As suggested, the educational and professional background of the visitor that attends the museum will be wide. The motivations of visitors to the exhibition will be informed by their background: some may be interested in the artefacts and others in just seeing what 3DPT can produce. Whatever the motive, tactile interaction with the 3DM and visual comparison with the artefact, can benefit visitors' interpretation of the artefact.

3.2.2 3DM in Application

The different questionnaires for 'A', 'B' and the script for group 'C' **(Appendices A, B and C)** were designed for a potential or imagined audience in museums as suggested by Anderson (2006). The reasoning behind the three-part data collection of 'The Original's Companion' was to investigate present and future viability of the use of 3DM in the museum. With this in mind, each round of data collection has a specific focus: 'A' explored the openness towards application of 3DM within the context of museums; 'B' examined the accessibility and receptiveness of museum visitors towards 3DMs, and 'C' looked at the Interpretation of 3DMs within the scope of haptic interaction by non-specialists.

Therefore, 'A' was a questionnaire sent to museum curators **(Appendix A)** in England and Scotland. In total, 41 questionnaires were sent in order to elicit the views of museum curatorial staff towards 3DPT and 3DM vis-à-vis their collections of archaeology. Data from 'B' **(Appendix B)** was from two locations, the Dorset County Museum and the Winchester City Museum which investigated the interpretive benefits of 3DM by museum visitors. Finally, data from 'C' considered the interpretive potential of haptic engagement in a set of tests **(Appendix C)** which was collected from participating academics – staff and postgraduate students based at the University of Southampton's Winchester School of Arts - who volunteered in advance as each experiment for the participant took between 40 to 45 minutes which needed close coordination between the school and myself.

The questionnaires of data collection group 'A' and 'B' as well as the experiment of group 'C' sought to investigate different aspects of reception towards the use of 3DM in a museum. Whilst each of the activities were designed to combine both theory and practicalities of adopting 3D Printing and the introduction of 3DMs into the museum setting all three would approach their stake-holder demographic groupings with a nuanced focus. i) Group ‘A’ would focus upon the assistive curatorial qualities of 3DM within the museum; ii) ‘B’ sought to understand the greater interpretive qualities of 3DM whilst focussing on the models encouragement of greater visitor interaction; iii)‘C’ researched into certain details of 3DM in tactile-only and tactile-visual interpretation of 3DM to encourage interpretation through engagement in a formal environment.

Though, before data collection could begin a method of initial data capture for the 3D replication of museum artefacts needed to be decided upon. The method of this initial digital replication was seen as important given the variety of technologies available. At the time of digitisation 2012-2013 the selected museums that were to assist data collection, in the provision of facilities, had no 3D digital models of their artefacts. 3D replication, selecting the 3D technology and the museum artefact – a process described in **Appendix E** – was required. Indeed, as shall be discussed in ‘Data Capture’, each digitisation technology presents a series of benefits and also limitations.

3.3 3D Data Capture

Data collection for object handling by groups ‘B’ and ‘C’ first necessitated work in digitisation and post-processing. As mentioned earlier in chapter 2 and later in **Appendix E** a structure for digitisation was necessary and this would feature 3D scanning, post-processing and 3D Printing. To consider 3DM as part of the tradition of model making in the museum, thought should be given to the method of data capture. It is the accuracy of the initial data capture, 3D scans or from photogrammetry, that will have sway over the accuracy of the final 3DM.

In preparation to digitally scan artefacts, consideration should be given to an alternative project: the ARCO project (White et al 2004). The ARCO project describes a method of future digitisation and post-processing so that the museum can exhibit virtual models to visitors (White et al 2004). ARCO’s aim was to define a collections digitisation route for the museum that would end in the virtual exhibition of the artefact within a constructed environment (ibid, p2-3). Employing technologies like photogrammetry, whereby 3D virtual models are constructed from digital photographs (White et al 2014), the eventual goal of the project was to demonstrate the potential of digitisation and exhibition of a 3D virtual environment in order to attract audiences and elaborate upon the histories represented by the original artefacts (ibid, pp.2-3). With similarities to ARCO as well as other 3D Printing projects, this thesis uses a variety of open-access technologies available to museums. However, unlike projects that aim to exhibit virtual models in a constructed digital environment, this study investigates the viability and application of 3DPT by museums to produce 3DM that can be handled as a tangible object.

As can be seen in **Table 4** (p. 96), photogrammetry is only one digitisation technology with each technology presenting its own capabilities. Indeed, some may be better suited to certain materials, object sizes or present difficulties in logistics, such as accessibility. Therefore, the selection of the artefact is crucial in determining the technology that would provide the best results when digitising a range of models. None of the artefacts were substantially large or unwieldy and indeed it had been requested that none of the pieces of archaeology be greater than 5 by 5 inches so that the resulting 3DM can be printed either to scale as a single model, or if required for later data collection then printed as scaled up iterations of the original 3DM. Indeed, in order to best capture images of the artefacts provided it was decided that a 'Next Engine 3D' Scanner should be used. The 'Next Engine 3D' scanner is a laser scanner, and it was thought this would be best suited for the necessary task of scanning a range of artefacts that were of comparatively small in sizes and that were each made of different materials. This would ensure accurate scanning maintaining the detailed quality of the reconstructed model. The scanner was paired with a slowly rotating platform and the artefact was placed upon this, whilst on the platform multiple scans were taken and a virtual 3D model was the result. The scanner was on loan from the University of Southampton, and the scanning of artefacts would be repeated 13 times on location within the 3 museums.

After the scanning of the piece of archaeology it is necessary to prepare the model for 3D Printing by sending the model too post-processing using 3D modelling software[18]. However, in preparing the digital model for printing the software can on occasion attempt to "smooth over" or ignore cracks and details that for the needs of archaeological representation should be kept. As any 3DM

[18] In my case I have been using a combination of the open-access software: Netfabb Studio and MeshLab. I have found that the use of both open-access software programmes to be crucial in post-processing. After post-processing I export the model to the chosen 'UP' printer an example of this can be seen in **Appendix E**.

aims to preserve as much of the detail shown by the original, the choice of technology in software as well as in scanning hardware is of great importance. In post-processing a model can be readied for Printing while maintaining details, though as seen in **Figure 6** this is not always the case.

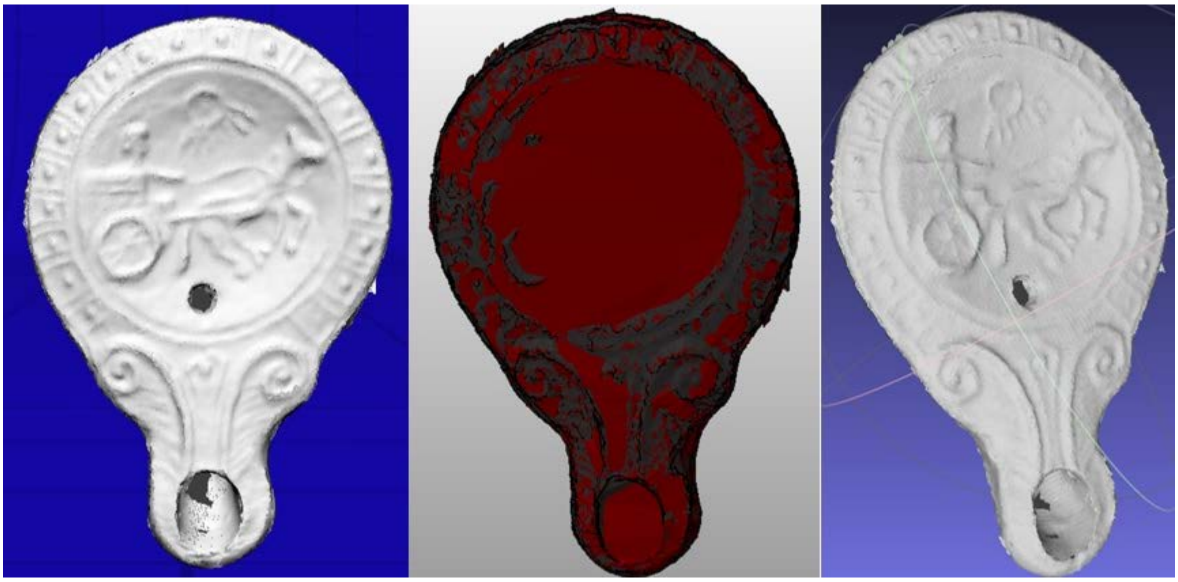

Figure 5 - The same 3D model of an Oil Lamp. Left to Right, 'Scan Studio' software as used by the 'Next Engine 3D' scanner. Middle, the over-processed results from the 'Automatic repair' option on Netfabb Studio. Right, 'MeshLab' software, the digital model is repaired and simplified.

As we can see, in **Figure 6** the software used for visualisation and processing of the digital model will, on occasion – in attempting to ready the model for printing – result in the loss of detail unless closely observed to prevent this from occurring, by either stopping the process and re-adjusting it or checking periodically to ensure accuracy. The Oil Lamp, that is exhibited above was done using the 'Next Engine' 3D Laser Scanner. In post-processing I found that on this occasion a restart was required as opting for a default or in this case 'Automatic Repair'.[19] resulted in the erosion of details on the Oil Lamp that other post-processing would preserve. However, in opting for 'Automatic repair' on occasion the exact opposite can occur, the difference is in the level of detail exhibited by the model.

[19] A default function of most post-processing software that applies a pre-defined simplification to the intended model. In the software Netfabb this default is called 'Automatic Repair'. This default function, as seen in **Appendix E**, works well on certain details, like the figures on a Samian Ware Pot, but not with the mix of textures and details presented by the Oil Lamp.

Irrespective of how good the post-processing is, the digital model will still be dependent upon the original digital data from the scanner. The Oil Lamp from **Figure 6** was initially made of fusing 3 different scans **Figure 7.**

Figure 6 - The 3 scans of the Oil Lamp. Taken using a 'Next Engine' 3D Scanner and shown on the 'Scan Studio' Software[20].

It is important that the method of digitising the artefact be first decided upon as there is a wide range of choices available to the museum. Listed in **Table 4** (p. 96) are the technologies most often used in 3D Scanning projects for 3DM. Every 3D technology whether it be a scanner, photogrammetric device, or a CT scanner can capture 3D data and express it as a model. As each technology is different and has its own specifications, there are projects that use a variety of technologies. It is also worth mentioning that there are projects that combine multiple 3D scanning technologies. A recent programme on the BBC, “Attenborough and the Sea Dragon” (2018), featured the CT Scanning of an Ichthyosaur fossil for 3D digital replication of every bone and scale to re-create a virtual model of the entire marine reptile. Conducted in partnership with the University of Southampton (University of Southampton 2018), this CT scanning allowed for an accurate reconstruction of the entire Ichthyosaur as a digitally reconstructed virtual model.

Ambitions surrounding scanning projects have increased along with the achievable potential of the technologies. Some National, Council, and University museums do indeed employ a variety of 3D scanning and printing technologies: the MicroPasts project as well as the exhibition ‘Scanning Sobek’ at the British

[20] The colour of the model is preserved in post-processing if exporting using an obj file format instead of an stl or ply format. Exporting as an obj would only be of use to us to preserve the colour for printing a 3DM. This was attempted on two occasions printing using LOM technology, a Bone Comb **(Figure 22)** and the Samian Pot **(Table 13)** however through a problem in the host software the colour was lost. However, the ‘UP’ 3D printer can only open stl files and can only print in the colour of the material filament.

Museum (MicroPasts 2014; the British Museum 2017c), and the Manchester museum (Zero Project 2017) which have used a variety of innovative 3D technologies for immersive visitor activities. Such examples indicate the viability of 3DPT and the use of 3DM as part of a new museum praxis.

Name	Capabilities	Names of Notable 3D scanning Projects/Exhibitions[21]
Photogrammetry	Inexpensive Hardware	ARCO
	Expensive Software	MicroPasts
	Requires any Digital Camera	The Digital Hammurabi Project
	Specialist Software Required	Europeana
	Computer Processing Dependency is High	
	Reliant on Photography	
	Portable Technology	
Stationary Laser Scanning	Inexpensive Hardware	Dalhousie Library Project
	Expensive Software	Stanford Digital: Forma Urbis Romae Project
	Measurements of Artefacts provided through Scanning	The Virtual Lives of Things
	Open to Non-Specialist Use	The Digital Hammurabi Project
	Light Refraction can Disrupt the Accuracy of the Scan	Europeana
	Ability to Scan Small Artefacts	
Hand-Held Laser Scanning	Expensive Hardware	Funeral as a Rite of Passage
	Inexpensive Software	Stanford Digital: Forma Urbis Romae Project
	Training Required	A Case Study with Diplodocid Sauropod Neck
	Light Refraction has the potential to Disrupt Scanning Process	The Virtual Lives of Things
	Mobile Scanning of Large Immovable Objects	Europeana
	Mobile Scanning means all Surfaces can be Scanned	
Computerised Tomography (CT) Scan	Expensive Hardware	A Case Study with Diplodocid Sauropod Neck
	Expensive Software	Attenborough and the Sea Dragon
	Operated only by a Trained Radiographer	The Asahi Shimbun Displays: Scanning Sobek, Mummy of the Crocodile God
	Not mobile. The artefact or individual object is required to be tied down on a bed and scanned in situe inside the machine	Manchester University Museum: Gift from the God's
	Scans Hard and Soft Organic Tissues	Europeana
	Medical Application	
	Scans reveal Imbedded Artefacts or Obscured Details	

Table 4 - 3D Scanning Technologies and Associated Projects

[21] Listed are the names of 12 different 3D scanning projects; 6 of the scanning projects have used multiple technologies. Therefore, when applicable the project/exhibition names are repeated beside the technology. This is a selection and not an exhaustive list.

3.4 Data Collection

Qualitative data was collected from three demographic groupings, known as groups A, B and C: curators, visitors and academics **(Appendices A, B and C).** For the first two groups, data collection was primarily through questionnaire format, but the method of distribution was different. Group A was sent by two means: the post and email. Data collection for group B was administered in person following a brief presentation as a way of introduction to 3DPT. While 'C' was formalised through an experiment in which I as the facilitator, asked a series of questions while getting each respondent to handle both museum artefacts and 3DM.

Questionnaires 'A' and 'B', for the most part, looked at the reception of their varying demographics to 3DM. The focus on reception considered the positive roles that 3DM could play in the museum. 'A' focussed largely on the first-hand practical knowledge of the curators. 'B' looked at the visitor's knowledge as informed through experience with application of that same knowledge towards their interpretation of 3DMs. 'C' looked at the interpretive potentials of 3DM, appreciative of past tactile-only experiments (Newell et al 2000, Heller 2002, Heller et al 2002 and 2006; Gaissert and Wallraven 2012), as the range of interpretation through touch-only and visual-haptic interaction with 3DMs would provide useful data for our understanding of companionable 3DMs in complementing original artefacts in museums.

Therefore, groups 'B' and 'C' necessitated the use of 3DM for practical handling activities; these were to be replica models of archaeological artefacts owned by the chosen museums. At the time of beginning this research in 2012 the necessary data needed to be collected from museum artefacts, and the 3DM were printed using a combination of three 3DPT. In printing the majority of 3DMs an 'UP' 3D printer was used, a representative of Fused Filament Fabrication (FFF). However, for certain 3DMs where multiple copies were utilised, two other technologies SLA and LOM were used to manufacture 3DMs for specific handling activities **(Table 5)**.

In 2013, I undertook this process of digitisation with the aim of 3D printing the 3DMs. Identification of artefacts and technologies, such as museum artefacts, 3D scanning technologies **(Table 4)**, post-processing software and identification of the suitable technology to print 3DM **(Table 5)** was needed to progress with this research **(Appendix E).** Initially presenting logistical difficulties, I identified three museums that were willing to participate in my research. The three museums were the Dorset County Museum, Winchester City Museum, and Poole Museum: initially the curators of the museums gave me permission to scan artefacts from their museum collections; this resulted in 13 3DMs and a return trip for data collection purposes to the Dorset County Museum and the Winchester City Museum.

However, where data collection called for multiple 3DMs, such as Samian Ware Pot and a Mammoth Tusk Fragment to be printed using other 3DPT **(Table 13, p. 149)** the number of 3DMs rose to 25. Therefore, stating the obvious, with the digitisation and multiple 3D printing of the 3DMs undertaken by the researcher, it meant that the companionable potential of the individual 3DM to the artefact could be used and built upon in data collection.

With the selection of the artefacts to be digitally scanned using the 'Next Engine 3D' Laser Scanner – as discussed previously in 'Data Capture' – the choice was taken of an accessible 3DPT: 'Fused Filament Fabrication'. Each 3DPT would present benefits and limitations in the printing of multiple 3DMs, **(Table 5, next page).** 'FFF' was the preferred technology to print 3DM; however, when it was required in experimentation, other 3DPT were used to print 3DMs of varying texture, weight and colour.

3DPT	Materials	Required Competence	Average (A) and Price-Range (R)	Price (P) and Time (T) to print a 6×6×5" 3DM[22]
Fused Filament Fabrication (FFF), also known as Fused Deposition Modelling (FDM)	All that can be Heated, Moulded, Ground and Set[23]	User-friendly Operation of Software and Printer.	A: £700 R: £300-£1,200	T: 1.45 hours P: £4.50
Stereolithography (SLA)	Photoreactive Polymer Resin	Technical Understanding of the Machine. Caution around the Liquid Polymer Resin	A: £1,800 R: £700-15000	T: 9 hours P: £12.00
Laminate Object Manufacturing (LOM)	Paper	Use by a Technician in a Controlled Environment. However still Open to Misinterpretation of Data	A: £14.500 R: £8000-25000	T: 5 hours P: £10.00

Table 5 – Three 3D Printing Technologies: FFF, SLA and LOM

[22] The estimates come from the printing of a 3DM Samian Ware Pot as shown in **Table 2**
[23] This can potentially include any material that can either be heated until it becomes malleable or can be ground-down and mixed with the malleable PLA plastic base. This includes plastics, metals and even wood.

3.4.1 Group A: Curatorial Staff

The questionnaire for ‘A’ was based on my month-long preliminary work at the National Maritime Museum Cornwall and over three months in 2011 at Poole Museum as a volunteer in both museums, prior to starting my research. During my time as a full-time volunteer, I was able to observe the curatorial staff at work where their roles were focussed mainly on collections, exhibitions and in-house education, although due to manpower concerns, their roles overlapped in both museums. In addition, conversations with staff of both museums revealed the impact of curatorial concerns on the practical application of technologies within museums. All these observations in both museums helped me to design questions for curatorial staff which were further informed by research conducted by Merriman (1989) which looked at visitor intention, and indirectly, the role played by curatorial staff; and Gallace and Spence (2014) which looked at how museums and therefore curatorial staff introduced technology in exhibitions for their visitors.

The research for group ‘A’ has a focus on obtaining information about 3DM and 3DP used in the museum by curatorial staff. It was important that information on reception as well as receptivity towards 3DPT and 3DM be obtained in order to establish the possible application of 3DM within museums as well as any policies that would influence future applications **(Appendix F)**. Therefore, obtaining information about prior-knowledge about the technology held by the curatorial staff is fundamental. As previously mentioned **(Chapter 2)** research has sought the views of Conservation Heritage Professional surrounding the application of Interactive exhibitions (Maye et al 2014), which indicated their interest and positive attitude in adopting technology in exhibitions. So data collection for group A will seek to further develop our understanding about curatorial attitudes and concerns vis-à-vis visitor reception to the use of 3DPT and 3DM. It can be hypothesised that when museums and curators have knowledge of 3DPT, this may affect receptivity to the benefits that 3DM can bring to their museums resulting in the application and introduction of 3DM in the museum. Exhibitions of 3DM **(Table 1)** suggest a pre-existing awareness of 3DPT and its applications; it is on matters such as this as well as others that further clarification through data collection is needed. It is thought that prior-knowledge from experiencing the technology first hand, or even having read about the potential of 3DPT, may affect the reception of the curatorial staff towards the application of 3DM in the museum. In other words, the application of 3DM in the museum is the vehicle that would allow the exhibition of replicas and the possibility of handling 3DM for visitors. Therefore, any discussion surrounding the application of 3DM should be left until after background information had been gathered. Thus, the questionnaire for group A had three parts:

Part one sought to establish the background and prior-knowledge of curatorial staff as this might reveal a possible a link between knowledge of 3DPT and staff receptivity towards its application within the museum. There were five questions in this section; of which four were open-ended. This was designed to obtain more elaborate information than would have been possible if I had given set options in the questions.

Part two of the questionnaire checked if 3DM were already used in the museum or if there was the possibility for the use of 3DM in the future. There were three main questions in this section; with six sub-sections which asked about specific objects which the museum could provide regarding replicas, location of the original, material of the replica, date of manufacture of replica and its cost. There was also a question regarding how the museum used its replicas i.e. public display, loans, storage or solely for school groups (educational purposes).

Part three looked at the possible practical application of 3DM in the museum. In other words, this section looked at the projection of the use of 3DM in the museum. There were six questions; of which three were open-ended which sought to discover the mission statement of the museum; the use of 3DM in a hypothetical situation and if such application could increase footfall. The hypothetical question was meant to obtain ideas on practical application by curatorial staff. Examples of practical application inside the questionnaire included options on exhibitions, supervised and unsupervised handling activities, specialist educational activities and even gift shop sales.

Data from ‘A’ was designed to obtain information on the receptivity of museum curators towards the application of 3DM in their museums. This in turn will suggest the viability of 3DM to be applied to the museum, and the potential ways in which the visitors represented in group, ‘B’ may receive the models. In all, the questionnaire for A had 13 questions and eight sub-sections.

Given the total number of museums that I could have contacted[24], a guiding criteria was developed in order that my first stage of data collection gain focus. I took the decision that the data collection for 'A' should be subject to three criteria: i) a potentially large visitor base, ii) a collection of archaeology, iii) direct contact with the curatorial department by email and post should be offered. A final decision was taken to purposefully move away from asking National Museums and instead focus the research on those with a greater local representation, these included, Council, Trust, University and with the exception of one a National museum. This final decision was taken at an early stage in my research, as I wanted to see the attitudes of curators towards the application of 3DPT within these museums, as any application of 3DPT and 3DM would result in the impactful reinterpretation and practice concerning the exhibition of collections of local representation. Indeed, one museum questioned was a national museum[25] but at the time of research, there was little known literature surrounding the museums' attitudes toward the use of 3DPT in exhibition. This final decision was not to discount the current literature or movements towards 3D printing projects **(Table 1),** but instead was to consider how these may influence my research in 'A' regarding the view of any potential benefits that 3DPT can bring to archaeology. Indeed, to consider the museums' uses of 3DPT in **Table 1**, we can see that the research presented in 'A' allows for elaboration and clarification of certain attitudes surrounding the implementation and application of 3DPT and 3DM in the museum.

3.4.2 Group B: Museum Visitors

The second part of my research design was undertaken with the intention of eliciting specific information from museum visitors upon their visit to a museum. This questionnaire was based, in part, on answers given by respondents from Group A who had sent back their replies, which indicated the type of 3DM more likely to be presented or used in museums. Thus, backed with data from Group A, the questionnaire for Group B was designed to target museum visitors within the museum, particularly non-specialist visitors, with me administering the

[24] As of 2018 the Museums Association has estimated that there are about 2,500 Museums in the UK (MA 2018c).
[25] The Royal Albert Memorial Museum (RAMM 2013) has more of a local affiliation as compared with certain other national museums.

questionnaire directly. This was done so as to obtain crucial information and data on actual visitors who would form the target of any museum exhibitions. Therefore, in order to replicate real-world situations, my questionnaire looked at three issues surrounding visitor interpretation of 3DM.

The data collection was held in two museums over two full weekdays in the Half Term of February 2014 at the Dorset County Museum and the Winchester City Museum. It was decided by each curator who gave me access that data collection would be held on a single day in each venue and would only commence after a short presentation was given **(Appendix B - Presentation Slides).** In addition, I transported a 3D Printer, called an ‘UP’, purchased from Denford Ltd, a British company specialising in the Rapid Prototyping 3D Technologies. The transportation of this printer did not present many logistical difficulties as the ‘UP’ 3D Printer weighs 11 LB and is 30 by 30 by 30cm, this fitted into my suitcase and was easy to transport by train. The purpose of having a 3D printer at hand was to show visitors how the technology works and indirectly to show the ease in printing. This demonstration was done as part of my presentation on 3DP. In Dorset County Museum, I was allocated a room called ‘The Great Hall’ which showcased local history and art which allowed for around 20 people to be comfortably seated in front of a screen and projector. In Winchester City Museum, there was no such room instead I was allocated a space within the ground floor, vying for attention with exhibits on Victorian Social History. Unlike the museum facilities in Dorset, there was no projector only the use of my laptop and several chairs placed around it.

This request for a short talk, such as an overview of the use of 3DPT in various industries, by both museums also suggests that they were receptive to my research on the use of 3DM in museums. Therefore a 20-minute presentation on the current state of 3DPT was given: where I also showed to interested audiences how the spool of ABS plastic extruded from the nozzle and printed 3DM. However, to limit the potential or possibility for bias in answering my questionnaire which was administered after my talk, due care was taken in my presentation so as to avoid topics that may be considered priming the audience. This took the form of not mentioning the use of 3DM within museums; instead my talk touched on the uses of 3DM in healthcare and engineering.

The questionnaire for Group B was divided into three sections and due to the fact that respondents may not have the benefit of time after my talk, the questions were kept as short as possible; in total there were only fourteen questions including sub-sections. The first section looked at the background and motives for visiting. This consisted of four closed questions and one open question that were structured to quickly establish the reason for visiting the museum. The second section had two open and one closed questions which looked at the attitude of museum visitors towards 3DPT. The third section consisted of six questions: four of which were closed and two of which were open, and all were designed to gauge tactile object interpretation.

All of the questions, with particular emphasis on the third interpretative section, were dependant on accessibility toward 3DM. The last section, in fact, had a direct relevance to accessibility towards 3DM as visitors were then handed four 3DMs to touch while they were answering my questionnaire. Hence I was able to obtain more information on interaction which combined both vision and haptics with the identification and examination of the 3DM. Specifically, the third section 'Hands on' in my questionnaire presented the museum visitors with 3DMs and asked them to give a name to the model. The following question asking their own interpretation as to the origin and time period of the artefact from which the 3DM had been made.

The 3DMs handed to the audience were a 'Samian Ware Pot', a 'Shabti Doll' and a 'Capitoline Wolf'. The question 'Do you recognise these items?' required a 'Yes' or 'No' answer, or a name to be written out. The next set of questions were on the 3DM 'Tauros Trigeranus' and required the visitor to interpret the model leading to their own interpretation on the provenance of the original. The importance of the question on the 'Tauros Trigeranus' 3DM was because it encouraged museum visitors to engage and display their interpretive abilities regardless of whether the model was a 3DM or the original artefact. Answers to this question would indicate a companionable overlap in interpretation i.e. the fact that museum visitors could transfer their knowledge of the original artefact onto the 3DM. This shift in interpretation, I would suggest, indicates an addition to the interpretation of both the 3DM and the original artefact.

In summary, questionnaires for group B sought to first obtain the prior knowledge of museum visitors regarding 3DPT, and secondly, to elicit information on visitor interpretation of 3DM which would offer useful data on interaction with exhibitions exhibiting 3DM. All these would help to suggest or formulate practical and viable exhibitions that seek to use 3DMs on a scale that can offer multiple objects as 3DMs in future exhibitions that can engage visitor interaction.

3.4.3 Group C: Academics of Staff and Postgraduate Students

The third and final section of my data collection ‘C’, was a formal experiment divided into four sections which looked at ‘Texture’, ‘Detail’, ‘Type’ and ‘Scale’. Held in one location over three days, this took place at the University of Southampton’s Winchester School of Art and featured a series of predominantly touch-only experiments with two visual-haptic experiments that were administered by me as the facilitator. This required individual participants to interpret a combination of objects, which consisted of both 3DMs and originals: most using only touch (their eyes were closed) while two allowed for visitors to both view and touch. This was done in March 2015.

Design for this experiment was informed and inspired by previous haptic-only experiments using 3D printed elliptic objects (Plaisier et al 2009); different tactile manipulation (Klatzky and Lederman 1992, 1993); handle-able blocks (Newell et al 2000) and selected textures on ‘meaningless objects’ (Stilla and Sathian 2008, p. 1124) and even the amount of time to hold the object (Norman et al, 2004). In addition, experiments which looked at stimulus, the interpretation is found to be hierarchical (ibid, Keltner 2010) demonstrating a shape bias over texture (Stilla and Sathian 2008, p.1313). Thus all these were considered in my design, including my selection of objects (3DMs and original artefacts) for my series of experiments for ‘C’. It is also useful to note that none of the above research just mentioned studied museum artefacts or used 3DMs based on museum artefacts. Thus data from ‘C’ would provide useful information, previously unavailable, for museums. As such, I did not adopt solely one method but instead combined different approaches which suited my purpose to obtain useful information regarding the interpretation of 3DM based on museum artefacts.

As data collection for group C took the form of an experiment, this meant consistency in how the experiment was conducted **(Appendix C)**. In other words, I as the facilitator had a set number of questions to ask in a precise order in which I asked and conducted the experiment on object interaction. Tactile interpretation with respondents’ eyes closed also meant giving each respondent a range of options on selected questions as they interacted with a combination of original and 3DM artefacts. This is useful because data gained from the visio-haptic object interpretation in ‘B’ would be complemented by the mini experiments on haptic-only interpretation in ‘C’. In other words, data collection for ‘C’ emphasised predominantly haptic interpretation, with two mini experiments including both visual and haptic engagement. The range of interpretation from the series of experiments would demonstrate the potential worth and variety of in-house uses of 3DMs by providing complementary information through touch.

Divided into four sections, each section explored four different facets of object interpretation: 'Texture', 'Detail', 'Type' and 'Scale'. The experiment was designed to take no more than 45minutes for each respondent. Each part therefore, took around ten minutes. The reasoning behind this precise timing was so as not to tire the participants, who for large parts of the duration, were requested to keep their eyes closed when answering questions focussing solely on haptic feedback.

Parts one 'Texture' and three 'Type' required the focus on the texture of the object: the questions were on how the object felt to the respondent, or if there was a particular feature to the touch that added context to the object. With the requirement of greater haptic feedback and specific focus on surface texture it was thought that a novel texture feedback scale tracking this interpretation should be developed. The scale therefore would contain nine criteria, eight that would overlap and one that would be left open to participant input: 'Spiky, Bumpy, Grainy, Hard, lined, Rough, Soft, Smooth, Silky, Other'. Each criterion was chosen as this was based on a reduced one-word reaction that was not based on approximation to an object, such as an apple or potato[26], and as an adjective did not require comparison for comprehension. Nine one-word descriptors were chosen: these texture descriptors did not require extensive time-delayed comprehension; instead research has found the recognition of such vocabulary to develop in adolescence between the ages of 4-7 years of age (Lacey et al 2012; Mahler and Chenery 2018) and hence would be readily understood and applied by respondents to describe their haptic experience. This was designed to minimise dependence on prior-knowledge while allowing for input gained from real life experience with objects, in the final and tenth option of 'other' (Klatzky and Lederman 1993). In the development of this scale, it was hoped that any reaction would mimic the likely early haptic interpretation with a 3DM when comparing the latter to the original artefact. As in practice, any haptic feedback or criticisms that the actor has to the 3DM will not be limited to one criterion, therefore, it was

[26] This sort of approximation can be seen in the 'Six Blind Men and the Elephant': features of the animal are compared to either a host of animals or inanimate objects. The interpretation of every one of the six is a very specific projection from their own subjective interpretation. It is also worth speculation that if, without knowing each was describing part of an elephant, would we be able to understand through their own interpretation just what the composite animal was?

thought that multiple feedback by the inclusion of ‘other’ comments on texture must be allowed to mimic likely public reactions.

The shape of the object was considered in parts two and four ‘Detail’ and ‘Scale’. ‘Scale’ was the experiment which offered objects of different sizes – original size (1x) to six times the size (6x) - to benefit the recognition of patterns or designs such as those found on a Pot and a Shabti Doll. The part focussing on ‘Detail’ was left open in order to elicit greater input from the respondents. This was done so as to allow greater handling of the object as mentioned in Newell et al’s (2000) experiment which showed the value of orientating the object for haptic interpretation and how the shape as well the base of the object could provide points of reference. Where possible, I have noted these types of information in my next chapter on ‘Findings’. Due to both considerations of professionalism and the desire not to skew results in my experiments, I took great care not to have any skin contact when I placed any of the 3DMs or artefacts on the palm(s) of the participants, given the long literature on touch and its effects as subtle non-verbal gestures in different settings which can confer different messages: persuasion, condescension, superior status, etc. (McGlore 2008; Zimmer et al 2008).

It is useful to note that in my data collection for both groups B and C, respondents were ‘tested’ in one form or other in their ability to interpret the 3DM which focussed on visual-haptic and predominantly haptic-only interaction, respectively. This would be crucial data as information would serve to highlight the potential ability of 3DMs to add to audience interpretation of museum exhibitions. Therefore, application of this data would show the potential of introducing 3DMs inside the museum and the likely behaviour from visitors.

Any data collection such as that carried out for groups ‘A’,’B’ and/or ‘C’ would therefore consider the application of 3DP and the introduction of 3DMs within the museum. It is therefore important to consider the transferable nature of the data collected towards any in-house application of 3DMs particularly with other recent exhibitions in mind (Dima et al 2014, Pitt and Hurcombe 2017). As with any design for data collection, there is always the potential for bias. Below is the discussion on possible bias in my design of ‘The Original’s Companion’, and the steps taken to minimise it.

3.5 Possible Biases

In research design, ‘The Original’s Companion’, there were three different groups and in each group, data collection was different. Group A and group B used a questionnaire which was sent to individual curatorial members of museum staff and was administered directly to museum visitors, respectively, with ‘C’ an experiment informed by the previous data collection. In my design, attempts to minimise bias were made. For clarity, the definition of bias used here is defined as ‘any tendency which prevents unprejudiced consideration of a question’ (Pannucci and Wilkins 2010, p. 619). Two possible types of bias were identified early on and they are language and the possibility of priming.

Regarding language in my design of ‘The Original’s Companion’, the type of language used was kept neutral and the questions direct and as unambiguous as possible as suggested by Choi and Pak (2005). For example, in Questionnaire A, Number 2.2, the question, ‘Currently, does the museum house or exhibit replica objects within the collection?’ was deemed more neutral and was used instead of ‘Have you ever housed or exhibited fakes within your collection?’ As can be seen in the latter, emotive words such as ‘fakes’ and the use of second-person pronoun ‘you’ and ‘your’ are considered words which seem personal in tone, and may appear accusatory and discourage response or worse, might place the respondent on the defensive. Similarly, in Questionnaire B, Number 4 in the section ‘Hands on’, the question ‘Do you recognise these items?’ was used as it was direct, non-ambiguous and clear, with relatively little room for misunderstanding or causing offence.

It is also useful to note that with regards to format and typography in questionnaires, having a uniform distance in the ‘Yes’ or ‘No’ box would minimise confusion and therefore it was decided that the answer be labelled at a uniform distance to it (Moser and Kalton 2017). In addition, prior to sending out or using both questionnaires, they were also distributed to fellow researchers for feedback and comments which offered further guidance on the language and format adopted in both final versions of the questionnaires.

Besides the use of neutral language and style in wording the questions, the possibility of the occurrence of priming must also be considered in group B and group C. It must be noted that in group B, both curators from ‘Dorset County Museum’ and the ‘Winchester City Museum’, requested a short talk or presentation on the current uses of 3DPT, before the questionnaire was administered. The possibility that the high number of positive responses received in my data collection for group B will be discussed more fully in **Chapter 4** on 3DM findings. Nonetheless, during my talk, (seven and ten presentations of 20 minutes each in Dorset County Museum and Winchester City Museum, respectively) which was accompanied by both a power point presentation and the continuous printing from the 'UP' 3D printer, I was careful not to mention any of the following terms which I used in the questionnaire such as 3DM, replicas, etc., nor on the use of museum artefacts and 3DMs in museums. The reason for deliberately not linking my talk with what I would ask in Questionnaire B was done so as to avoid opportunities in which respondents may be led to answer in ways which are similar to my talk, and hence possibly 'ventriloquising' words or terms from my presentation.

With group C, a factor which could have been a form of priming could be how people were recruited for my experiments. In the latter, my introductory email to the Winchester School of Art Graduate Office was brief and to the point. However, as I needed to make it appealing in order to have a high response rate of volunteers, I also needed to elicit curiosity. Thus I used phrases such as the possibility of handing 'a mammoth tusk fragment' which might have ensured that the participants were primed to expect handling activities and thus be receptive towards the different activities involving touch. More details of the process in my experiment will be discussed further in the next chapter.

Secondly, the set-up of the room, as it was an experiment, could have primed the respondents as it was meant, as far as possible to replicate a likely museum setting. This could also be a biasing factor, as the experiment was laid out to mimic a museum-like atmosphere. The purpose of doing this was to imitate how museums would display both the original artefact and the 3DM of it. However, as this was held in University premises, the location may have primed my respondents to provide fuller answers than they otherwise would have in different settings. In addition, having the location in a University setting might have also added pressure for my respondents who are students to meet up to expectations of being a postgraduate in a highly-ranked University. Therefore, to minimise the possibility and the fear of not meeting notional expectations, answers on 'texture' which would normally be lengthy were avoided as the questions directed respondents to a set criteria of one-word answers. This design for one-word options for the section on 'texture' in my experiment was made so as to provide unambiguous terms of references for respondents and therefore reduce the possibility of respondents having to think or make up answers on the spot which would have skewed my data collection.

Finally, the way the objects were handed during mini experiments on visual-haptic interaction might have primed them: there were two occasions when their eyes were opened to observe the 3DMs or artefacts. The first was during the end of the experiment on ‘texture’ when participants opened their eyes to see if their responses would change from their preference based on their previous haptic-only interaction with all four Pots and three Tusks. All were placed on top of the bubble wrap for protection. The bubble wrap, it must be admitted, was chosen both for convenience i.e. it protected the artefacts, and because it signalled value on the objects (needing care in handling). Also, by virtue of the bubble wrap being commonly used, it may confer associations of day-to-day activities and hence suggest casualness, although that was also what I hoped for in the experiment setting: for the participants to feel relaxed, as they would presumably have been in a relaxed state in a museum. However, the use of the bubble wrap, instead of the use of lush velvet as a protective layer, admittedly might also have primed them about the notion of value or relative value.

3.6 In Summary

My methodological framework, called ‘The Original’s Companion’ was designed to ultimately show the benefits of 3DMs to object interpretation in museum settings. The action of touch adds to our experience of the object, in which tactile engagement adds to our understanding of the shape, texture and overall appreciation of both the museum artefact and the 3DM. Therefore, data collection was designed to include input from important museum stakeholders i.e. curatorial staff and museum visitors as feedback from them would provide important insights and valuable data. As an extension to such important data from museum visitors and curatorial staff, I also conducted a series of experiments focussing on the texture, detail, type and scale of 3DMs along with some interaction with original artefacts, so as to ascertain in greater detail what museum participants might possibly expect or desire in their haptic interaction with 3DMs in museums.

The purpose for having haptic interaction is because the interpretation of touch stimulus is almost instantaneous and instinctual. Therefore, in the museum, the addition of 3DM as a source of tactile stimulus will enable visitor observation and engagement which is neither dependent on literary comprehension, nor on distanced observation. In fact, the application of 3D printing technologies can benefit the interpretation of museum archaeology as indicated in further detail in the following chapters.

Chapter 4: Findings from 'The Original's Companion'

4.1 Introduction

The previous chapter on my methodological framework 'The Original's Companion' discussed the purpose, intention and the way data was to be collected based on three different groups of A, B and C. All three groups were composed of curatorial staff, museum visitors and academics, respectively. In my data collection, findings suggested great potential as presented by the use of 3DPT in the manufacture of 3DM artefacts within a museum. The introduction of 3DM in a museum means that having companion-piece handling models using 3DPT would encourage greater interaction through accessibility for visitors which can be of benefit to the museum.

Data collection was undertaken between 2014 and 2016. Prior to starting my research, two separate applications were made and subsequently approved by the university's Ethics Approval ERGO Board: data collection for A and B shared the same application and approval, Number 8895, while application and approval for Group C was number 19787. Data findings for A, B and C are presented in their chronological order where I present the overall process, and then detailed key findings from each group separately. As mentioned earlier, the main reason for having three different groups of participants was to obtain the range and depth of interest held by stakeholders in the museum specifically the curatorial staff and actual museum visitors. Therefore findings from each group were important because collectively, the information offered a comprehensive overview of how 3DPT could be introduced and what types of 3DM would encourage a more participatory museum environment.

4.2 Participants of the Study

As previously discussed, the three groups of participants in my research framework 'The Original's Companion' offered different aspects and insights into the application and reception of 3DM in a museum. Thus it was important to identify and differentiate these three groups. For Group A (Appendix A), participants came from curatorial staff of four different types of museums. The four types were National, Council, Trust and University Museums. As suggested by type, each had a different structure, governance and even style in the way they presented their exhibits based on their separate individual mission and governance. The eleven Museums which took part are represented in **Table 6**:

Types of Museum	National	Council	Trust	Volunteer	University
Royal Cornwall Museum, Truro		1			
New Walk Museum, Leicester		1			
Craven Museum and Art Gallery, Skipton		1			
The Museum of Classical Archaeology, Cambridge					1
Rotunda Museum, Scarborough			1		
Penlee Art Gallery and Museum, Penzance		1			
The Garstang Museum, Liverpool					1
Manchester Museum					1
Inverness Museum and Art Gallery		1			
The Museum of Lincolnshire life, Lincoln		1			
Royal Albert Memorial Museum, Exeter	1				
Total	**1**	**6**	**1**	**0**	**3**

Table 6 - Museums that took part

The eleven museums which took part were those who sent back their responses. It must be noted however that one museum while completing the majority of the questionnaire, did not submit information for Part 2. However, the 11 questionnaires were returned from the member of curatorial staff either in the self-addressed stamped envelope enclosed, or via email as questionnaire A was sent through two methods – post and email – to each of the 42 museums.

The 42 museums had been chosen as subject to criteria, as discussed in the previous chapter **3.5.1**, of which 11 were returned, resulting in the return rate of 26%. At this point, it is useful to mention about the response rate for non-profit organisations: Hager et al's (2003) research show that surveys of organisations 'typically receive substantially lower return rates than surveys of individuals, with 15% return rates sometimes reaching a level of acceptability for organisational surveys' (Hager et al 2003 p.255). Earlier research by Greer et al (2000) indicated a response rate of 25% sent to organisations (Greer et al 2000 p.103); while research by Moncrief et al (1999) show that mailed questionnaires with around 15% response rates have also been considered 'as an acceptable level' (Moncrief et al 1999 p.2). Literature published in the 'Nonprofit & voluntary Sector Quarterly', 1996-2001, cited by Hager et al, show that return rates of 16% and 10% were also reported for two non-profit organisations with the latter in the educational sector (Hager et al 2003 p.256).

Although the hoped-for return rate for Group A could ideally have been higher – in spite of strategies I have adopted such as enclosing a self-addressed stamped envelope and the option to return questionnaires via e-mails cited by Porter (2004) as being successful strategies for increasing response rates – this does not mean that data from this group is not valid. In fact, research by Lambert and Miller (2014) indicate that lower response rates do not necessarily mean 'lower response representativeness', with respect to quantitative studies using a series of chi-squared analysis, with researchers noting also that rates on a variety of surveys have been falling over time (Lambert and Miller 2014 p.39). Porter (2004) also mentioned that refusals to respond to questionnaires are also on the rise[27], hence the suggestion to make returns as easy as possible through multiple channels, which, it must be emphasised have all been adopted. The response rate notwithstanding, my data collection of Group A is not meant to be representative of all museums in the UK; the primary aim, as stated in the previous chapter, is to extend my qualitative study on attitudes toward 3DPT and to evaluate the use or non-use of 3DMs in local museums. Thus, this return of the questionnaires would allow for the clarification of the uses of 3DPT **(Table 1)** from the contacted curators regarding attitudes of implementation, reception and future use of this technology within the museum. This in turn would allow for further discussion in the following discussions chapter, but for data collection the findings as well as adding clarity to certain matters this will go on to inform data collections for Groups B and C.

Data collection for Group B **(Appendix B)**, took place at two participating museums: Dorset County Museum and Winchester City Museum. This data collection, as discussed in the previous chapter, introduced 3DPT and later tested members of the public on their interpretation of four 3DMs in the museum. In total, there were 42 participants, with 29 from the Dorset County Museum and 13 from the Winchester City Museum. All these took place in February 2014, at least seven months after data collection for A had started. The timing was deliberate, as mentioned in the previous chapter, because design for Group B data collection was based in part on information provided by Group A.

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[27] In fact, after presenting a paper on my findings at a conference in 2018, in which I mentioned about the difficulty encountered in getting museums to return my questionnaires and indirectly my disappointment, two curators came up to me after my paper to apologise for their inaction.

As discussed earlier, data collection for Group C (Appendix C), was designed to be systematic so as to follow a specific order because this experiment was formalised as a set of four smaller experiments investigating texture, detail, type and scale of 3DM on each respondent. This was undertaken at one location, the Winchester School of Art which is part of the University of Southampton. Out of the twelve volunteers, seven were postgraduate students and five academic staff from the university, of which one was the university librarian while the rest were lecturers or tutors at the Winchester School of Art. No one was offered any honorarium. Instead participants were offered the possibility of handling a mammoth tusk fragment, as mentioned in the previous chapter. It must be noted that Linden (2015) asserts that people are generally attracted to object handling activities: the possible reason why there were five members of staff who volunteered for the 45-minute session, instead of only students.

In short, the respondents for my theoretical framework, 'The Original's Companion' were from three different groups of museum stakeholders with Group A made up of curatorial staff, in order to elicit information on reception and potential practical application in a museum; Group B were museum visitors from Dorset County Museum and Winchester City Museum who answered my Questionnaire B immediately after my brief presentation on the uses of 3DPT in healthcare and engineering; and finally, Group C whereby these participants were engaged in a variety of tactile experiments. Collectively, these three groups of participants and respondents offered different insights into how 3DPT and 3DM would be received if they were introduced and applied by museums interested in offering a participatory environment.

4.3 Group A – Curatorial Staff

Questionnaire A (Appendix A) consisted of three parts of which Part 1 focussed on the curator's prior knowledge of 3DP; Part 2 looked at the current situation of the museum with regards to the curator's existing use of replicas (not necessarily 3DM) and Part 3 looked at the application of 3DM in the museum, using hypothetical scenarios based on the curator's likely experience and reception towards 3DPT. Taking inspiration, in part, from previous examples of museums' use of 3DP for exhibitions purposes - as discussed in chapter 2 – this questionnaire looked toward the practical as well as developmental role in which 3DPT can benefit the museum.

To reiterate, the method of distribution for questionnaire A was twofold, conducted through a combination of direct email and first-class mail. The posted mail consisted of both Questionnaire A and a self-addressed stamped envelope to avoid individual or corporate expense in returning the paper-based questionnaire. The email, to avoid change in the set format of the questionnaire by the receiving browser, was designed as a comment-enabled PDF. There was a 26% return rate in the questionnaires of which 10 were fully completed while 1 chose not to include any information in part 2. Of the 11 questionnaires returned out of the 41 sent out through post and email, six were posted back using the self-addressed stamped envelope enclosed, and five were via email. It must be noted that in the email, it was sent and addressed to the individual curator of the museum except for ten museums which only had a general department email on the staff list of their website. The questionnaires which were returned reflected the sentiments of the contemporary literature (Chapter 2) that was emerging from research conducted in national as well as international museums concerning the application of innovative technologies to develop collections use, and benefit visitor access and interpretation of archaeology **(Table 1 & 2)**.

Question 1:	Have you heard about 3-dimensional rapid prototyping?
Question 1.1:	If you have answered 'Yes', where did you first see/ hear about this technology?
Question 1.2:	Are you aware of any time when this technology has been used to further people's understanding of archaeology?
Question 1.3:	Have you ever used a 3- dimensional rapid prototyping machine?

Table 7 – Data collection A: Establishing previous knowledge and experience of 3DPT

4.3.1 Part 1 - Curatorial knowledge of 3D Printing

Questions in Part 1 were asked in order to establish first, the prior knowledge of curatorial staff and secondly, to gauge the possible interest held by them regarding 3DPT. Hence, what the respondents replied may have a direct bearing on how they would respond in Part 3. This is because information in Part 1 could reveal receptivity and knowledge of 3DPT held by curatorial staff. This would also suggest the presence of an active and developing interest in 3DPT that can be applied in the future by the museum. Although I am not stating a direct causal relationship here between prior knowledge and receptivity to 3DPT application in the museum, what I am suggesting is that prior knowledge may lead some curatorial staff to explore and invest in time and effort to see how such technology could be applied in the museum. It must also be stated here that as Questionnaire A focussed on 3DPT and 3DM, returned answers were mostly positive towards 3DPT with only one which questioned the viability and use of 3DPT in the museum. In other words, the respondent indicated scepticism towards having 3DM in their museum.

Out of the eleven curators who replied to the questionnaire, all said that they had heard about 3D Printing. This was not unexpected. In my trial run before sending out the final version of questionnaire A, answers which indicated a lack of knowledge and even interest in 3DPT would mean that half of the Questionnaire would be left empty. After some consideration, it was decided that there would be no further questions for curators without prior knowledge of 3DPT in Questionnaire A. This was done because additional questions catering to this group of curatorial staff would have led to a lengthier questionnaire, and possibly added more barriers towards curatorial staff responding in the first place. As such, non-respondents are worth considering because of the information this may indicate. This time, the group of curatorial staff who did not respond came not only from the four types of museums – National, Council, Trust and University Museums, they also included volunteer-run museums **(Table 5)**. I will not speculate why only 11 museums responded while 30 museums did not reply either via email nor post: there could be a variety of reasons. Unsurprisingly there is a growing body of research looking at non-response in surveys (Rogelberg et al 2000; Groves 2006; Rogelberg and Stanton 2007). One reason which has emerged from these studies is the phenomenon of ‘over-surveying’, referred by Weiner and Dalessio (2006) as a growing situation in which employees are continually inundated by requests to answer questionnaires. Therefore, Baruch and Holtam (2008) state, this has led to circumstances where ‘a large number of target individuals or firms [become] fatigued and therefore refuse to respond to non-essential questionnaires’ (Baruch and Holtam 2008 p. 1142). Admittedly, I did not pursue this further with the 30 museums which did not respond beyond the strategies suggested by Porter (2004) mentioned earlier, because I needed the goodwill of these museums for my Group B which needed to take place in a museum on actual visitors.

Figure 7 below presents responses from the 11 museums regarding their source of information on 3DP. The sources mentioned by the curatorial staff were from university courses, professional training, television programmes, newspaper articles and projects undertaken by them which could be collaborative with other parties or by the museum alone.

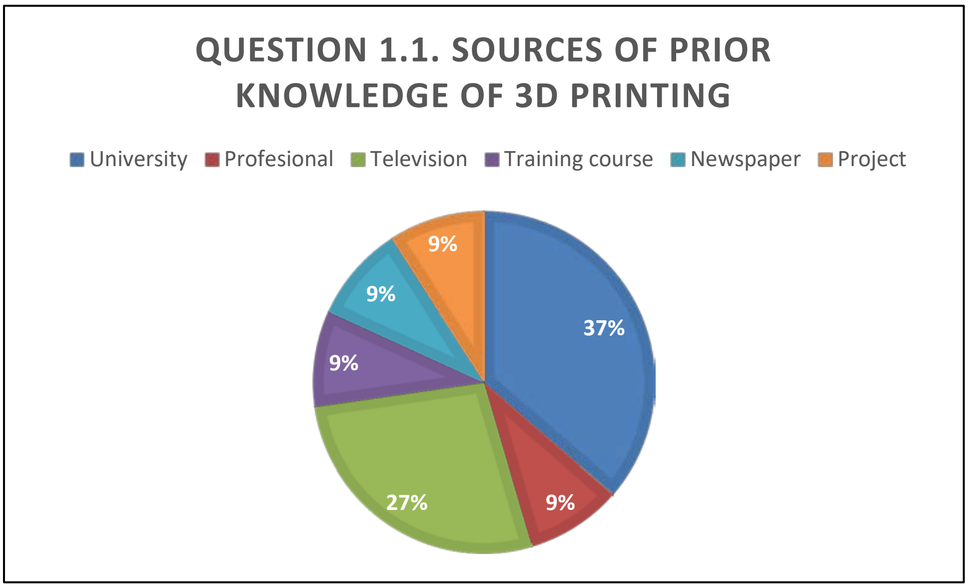

Figure 7 - Sources of 3DPT Knowledge shown by curatorial staff

The information given by the 11 curatorial staff shown in the table above is rather interesting because one would expect their responses to be more specific if not specialised in nature such as from trade journals such as 'Museum Journal', 'Curator', etc. Instead these responses indicated greater variation which included sources from popular culture which seemed in direct contrast to research reported by Melton and Montgomery (2011) which showed that the more specific the profession i.e. curatorial staff, the greater the possibility of having specific responses stemming from trade journals and specialist sources. The questions in Part 1 then graduated in specifics which asked for curatorial awareness, knowledge of and prior use of 3DPT in the museum. This was important given the admittedly relative newness of the technology and the predominant use of 3DP in the health sciences, construction and engineering. The responses from the 11 curatorial staff are shown below in **Figure 8** which linked their answers from **Figure 7** to specific knowledge on the uses of 3DPT in archaeology and the practical use of a 3D printer. **Figure 8** thus indicated that from the positive reply of all 11 respondents' knowledge about 3DP, only 5 (45%) knew about specific examples when 3DP was used in their field of archaeology. Then from the five curatorial staff who knew or have heard of specific examples and application of 3DP in museums, only one mentioned the use or application of 3DP. As Questionnaire A was deliberately phrased so as not to point or highlight any lack of knowledge on the part of curatorial staff on 3DM and 3DPT, the last question 'Have you ever used a 3D rapid prototyping machine?' was kept open and non-specific and made no mention of their use in a museum. Thus, the use could be derived from a training course. In fact one museum, the 10%, as detailed bellow did say that they had used this for a particular project.[28]

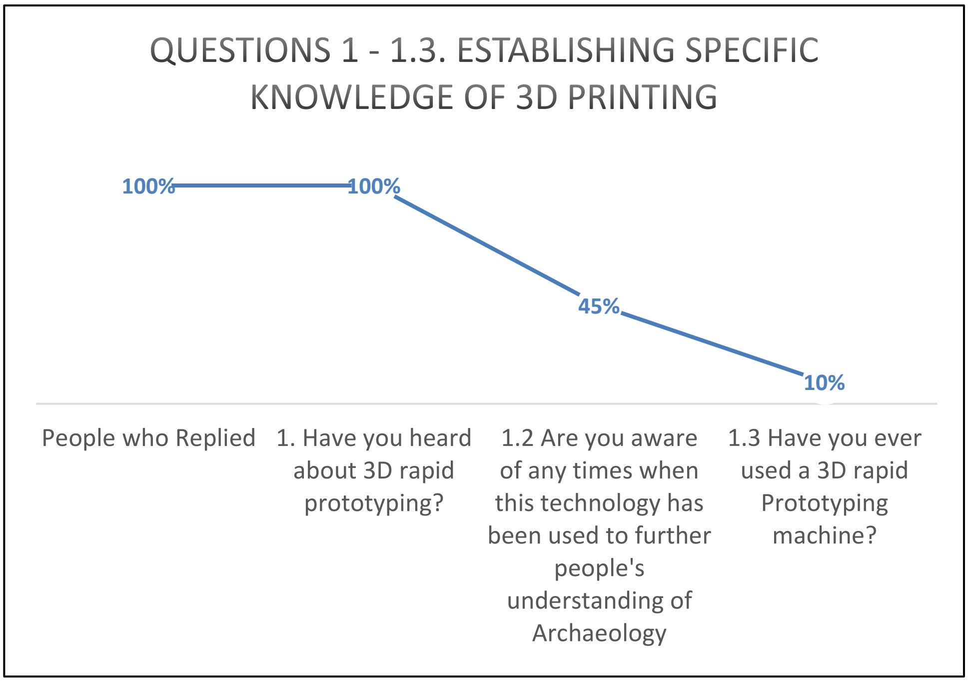

Figure 8 - Specific knowledge of 3DPT by Curatorial Staff

The fact that only 1 member of curatorial staff (10%) out of the eleven respondents showed more specific knowledge about 3DPT and their use and application of it, this can be an indication that knowledge of 3DPT, let alone museum use of 3DM, was then, in 2013, regarded as specialist, and therefore could have been out of the scope of their museum. This may have important implications which will be discussed in the next chapter.

[28] This project was undertaken by the Royal Cornwall Museum in Truro and was for the 2012 project "Unwrapping the Past" for the reconstruction of the head of a statue which was later exhibited in 'The New Gallery' of the museum.

4.3.2 Part 2 - Room for 3D replicas

Question 2:	Does the museum collection contain any objects that are too fragile to exhibit to the public?
Question 2.2:	Currently does the museum house or exhibit replica objects within the collection?
Question 2.2.1:	The method to which one or more of the replicas were produced?
Question 2.2.1:	ii) Is the replica on: public display, loan, storage, reserve for educational purposes?

Table 8 – Data Collection A: The museum use of collections and replicas

The questions in Part 2 were about generic museum replicas and how each museum used their collection of artefacts vis-à-vis replicas in different ways. These questions in Part 2 of Questionnaire A were aimed at obtaining specific information on the individual museum's collection of replicas, and the purposes that these replicas offered for the museum. There were three main questions and six sub-sections which the curatorial staff answered, presenting useful and specific information on their generic use and range of museum replicas. It must be noted that one museum chose to leave the section in Part 2 blank. Hence information presented below is only for 10 museums.

For ease in comprehending the information given by the 10 curatorial staff who answered this section, **Figure 9**, p. 122, shows the answers by the ten museums regarding how they have utilised replicas within their collection. Of the 10 museums which replied, some offered detailed information such as Royal Albert Memorial Museum in Exeter. Information provided by the curatorial staff had been categorised into three sections which were firstly, object; secondly, the uses or more specifically how the museums used the replicas; and finally, production of the replica or how the replica(s) was/were produced.

With regards to generic replicas owned by the museum, only one museum – The Royal Albert Memorial Museum in Exeter - mentioned having in their collection two replicas while the remaining nine cited one each. This answer was not surprising because most, if not all museums, would at least own an artefact that was a replica. It was perhaps unsurprising that a question concerning the price of a replica went unanswered by most museums, although there was information on price regarding the "Hameldon Bronze Age Dagger", of which two replicas, were made in 1983, ‘cast in resin from a silicon mould’ and in 2010, it was ‘cast in bronze using a clay mould’ with the latter costing £250. The original was destroyed in WWII and, according to the curatorial staff from the museum, the ‘bronze replica is on display, the other is in store (and is unlikely to be used for display or handling)’. The same museum curatorial staff also added the comment that, ‘Archaeological iron is particularly difficult to keep stable under display conditions. I think there would be strong interest in seeing this type of objects’; and therefore, the inference that such 3DMs would be used for display. I will discuss this more in my next chapter together with reception of 3DPT from other various museum stakeholders.

For the category of ‘uses’, seven of the museums reported their replicas were part of their permanent exhibition while the other three offered the information that their replicas were either on loan, reserved for educational purposes, or in storage. The fact that the majority of the museums used their replicas as exhibits also suggested that they were displayed like artefacts or were presented as part of an exhibition to their visitors. As the seven museums which cited using their replicas as exhibits had been identified as institutional members of the ‘Museums Association’, which has its own specific guidelines on display of replicas, we can therefore make the assumption that these seven have labelled and identified the replicas on display as such.

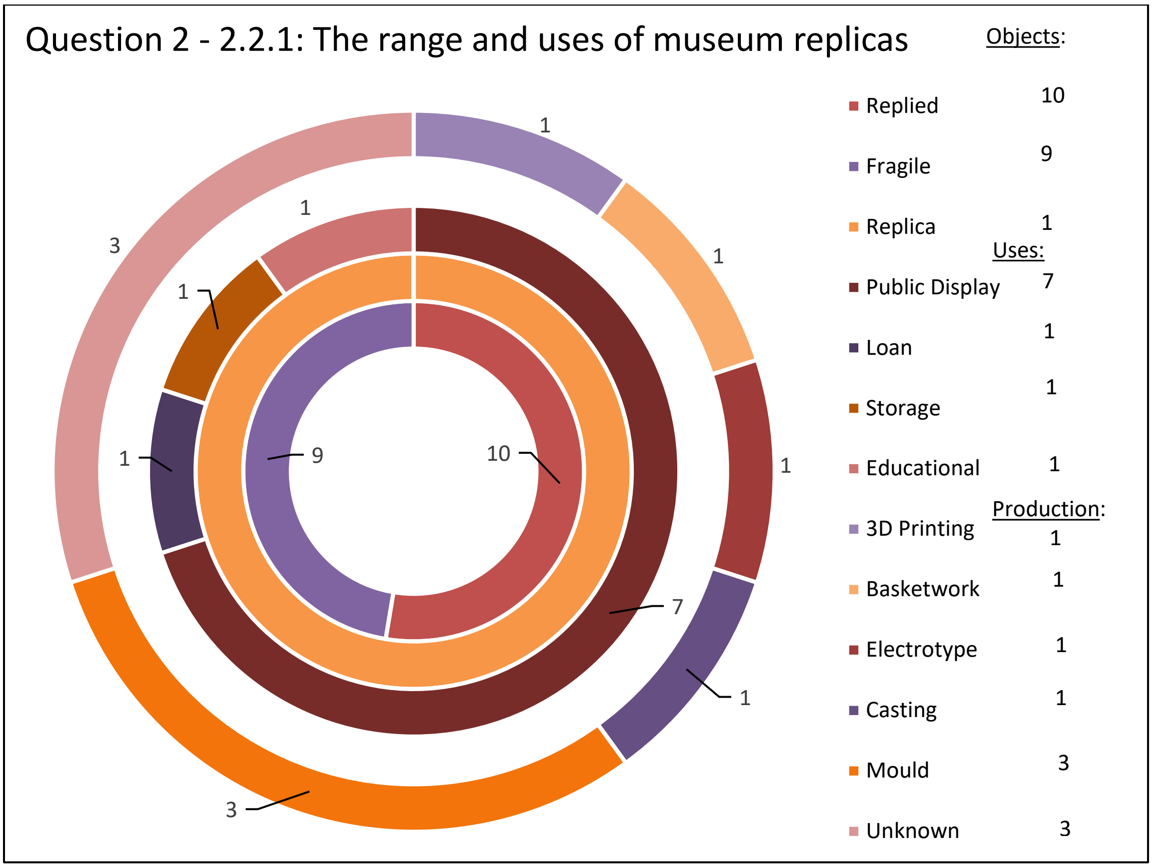

Figure 9 - The current range and uses of museum replicas

Finally, for the category of 'production', the ten museums wrote down specific information on the replica(s) that they owned, with the majority citing casting a mould as the way their replicas were produced. The other answers written down were 3D Printing, basketwork, electrotype and for three museums, the method of production was unknown. Presumably there was no data kept by them, or it could be due to the fact that they opted for 'unknown' because to check and verify the production by looking up their records would have taken too much time.

The variety of information provided by the ten museums also suggested there was no standard method of production. This is understandable because production would be artefact or object-dependent i.e. if the historical artefact were to be made of basket, then its replica would similarly use basketwork as a method of production.

In sum, answers for Part Two indicated that current replicas are used by museums for a variety of reasons, either as part of an exhibition or as an item reserved for specialist activity. However, with the production and use of these replicas, information from Part Two also point to the fact that if 3DM were to be used for future application, it should ideally print a variety of objects and have multiple uses in which one should be for handling purposes or haptic interaction. Also, the answers on the use of replicas seem to imply that their use by the museum as part of the public exhibition is distanced from the visitor and therefore, there is a barrier in the form of some restriction to access for museum visitors.

4.3.3 Part 3 - Museum interest and use in 3D Printing Technology

Question 3: Certain museums in England already use 3D rapid prototyping... […] do you think that it would be in your museum's interest to invest in this technology?
Question 3.1: If the museum could produce 3 dimensional rapidly prototyped objects do you think that this would encourage the museum to: …?
Question 3.2: If the museum has one, what is its mission statement?
Question 3.2.1: If the museum began to produce its own collection through 3-dimensional rapid prototyping technologies, do you think that this would complement: the museum's mission statement; the work that the museum is already doing; the preservation of fragile objects; the way that the museum is seen in the community?
Question 3.3: In displaying original objects side by side with replicas, do you think that the museum is running the chance of misleading the public?

Table 9 – Data Collection A: The current and predicted use of 3DPT

The four questions and two sub-questions, questions 3 to 3.3, asked for specific projections and predictions concerning the role that 3D printed replicas could play within their museum. These were, in part, based upon the daily operation of the museum, and by varying degrees, required the participation in hypotheticals or projections based on the 3DM potential in the museum. Answers for Part 3 are interesting as they could provide insight on the possible receptivity or openness towards 3DPT and by inference investment in the technology (provided funds are available, of course).

The answers for the question, 'Do you think that it would be in your museum's interest to invest in this technology?' were almost equally divided with six museums answering 'no' and five with 'yes'. Three of the six museum curatorial staff respondents cited budgetary concerns as the reason for not investing in 3DPT. However, three, did not rule out the possibility that the technology would be used in the future; just not in the immediate future. One respondent even wrote that the answer was currently ‘no’ but in the future “I think museums would ‘buy in’ the service”. One museum from Exeter was more nuanced in the answer:

> ‘I think there is great potential for 3D scanning, the ability to resize objects, see inside them, reveal micro-architecture are all of huge benefit. The production of 3D printed objects is perhaps of less use’.

But the answer to the question, ‘If the museum began to produce replicas of its own collection… [..] Would you like to add anything?’, the same museum responded with the following, ‘I also think there is potential for 3D scanning and rapid prototyping, the museum is active in projects to try and realise this potential.’ It would seem that for this museum in Exeter, the current priorities with the use of 3DPT were conservation and documentation purposes, just not as handling activities, supervised or unsupervised. Besides the positive responses, the willingness to change views (‘museums will buy in [the technology in the future]’) or sometimes to sit on the fence regarding certain concerns, all these are rather positive vis-à-vis the future of 3DM in museums. As shown above, even the museum in Exeter which was not keen on both supervised and unsupervised activities, was already using 3DPT in ‘conservation’ of its ‘archaeological objects’.

The five museums which gave positive answers cited reasons such as, “Possible as they had used them before” and “yes … we are here to engage communities with our collections and this includes in research and interpreting them” (Manchester Museum). It must be reiterated that these positive responses towards the future use of 3DM by museum curatorial staff who have direct bearing on exhibitions, is of some significance as they are indicative of positive reception on future technological developments of 3DPT by stakeholders. I would make this assertion as curatorial staff have direct impact on technological applications in museums.

Question 3.1 was designed to explore the potential application of 3DM in the museum by curatorial staff. More specifically, the questions were directly related to museum practice such as unsupervised and supervised handling activities; specialist educational activities and even the use of novelty replicas as gift shop sales. The four-parts are shown in **Figure 10** below. As can be seen, the answers did not require radical projections but instead extensions of their current individual museum practice.

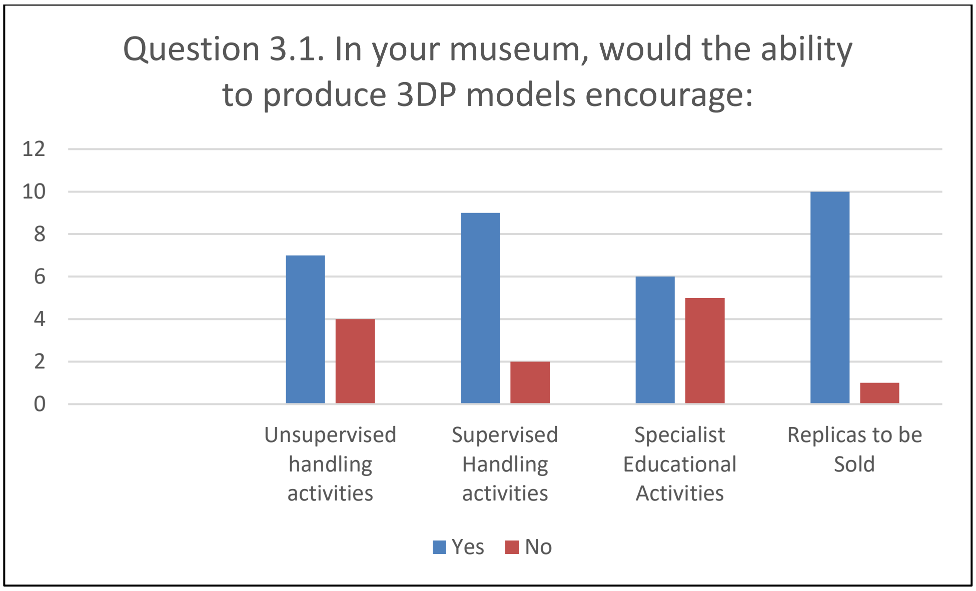

Figure 10 - 3DM production and possible museum activities

Based on the data given in the table above, the highest number of positive answers by curatorial staff was regarding the use of replicas (3DM of artefacts) for sale in their respective gift shops with one suggesting, half-humorously the 'potential to produce novelty replicas for sale. Chocolate handaxe anyone?'. It must be stressed that although the two museums which said 'no' to both supervised and unsupervised activities, both answered 'yes' to producing 'replica objects for sale', indicating a nuanced answer regarding how these two museums would apply 3DPT in their museum. The fact that income-generation was seen as a motivating factor in the answer provided suggests also the importance of sales to the museums as well as their concerns regarding funding for their museum. This has a strong implication because the fact that these curatorial staff were so receptive to the idea of replicas being sold for income, that they do not view as an issue the current state of intellectual property (IP) and ownership rights which will be fully discussed in Chapter 6. At this point, it is useful to note that the ten curators who agreed, saw the financial viability and use for 3DM for their museum collections. This is also not surprising because, as mentioned, funding for museums have decreased over the years and museums now have the added imperative to cut cost so as not to rely too much on external funding.

The next highest number among the 11 museums was the information that nine cited supervised handling activities while seven museums mentioned having the use of unsupervised activities if they had replicas of artefacts made into 3DM. In other words, some museums did not find it contradictory to have both supervised and unsupervised handling activities (7 in all), while two found that if they had supervised activities, then unsupervised activities with regards to 3DM were not part of their museum's day-to-day practice in the foreseeable future. This may have some repercussions because by answering 'yes' to both supervised and unsupervised handling activities, this implies that the seven curatorial staff have activities in mind for the future which require supervision that can take the form of explanation, guidance and/or active interaction with museum visitors.

The other part of the question which looked at 'specialist educational activities' had a more even divide with six museums viewing specialist educational activities as possible future practice with 3DM while five did not seem to view this as viable in the immediate future. This suggests that the use of the term 'specialist' linked with the term 'education activities' may imply expert help and guidance which can incur additional costs. It is worth noting that the term 'specialist' has a wide interpretation and when used in the context of school outreach and visits, this often implies expert guidance from someone not necessarily from the curatorial staff in the museum. Therefore in this light, the addition of 'specialist educational activities' on 3DM in the museum would not be viewed that positively by curatorial staff.

The follow-up question, 3.2 asked about the museum's mission statement, and in response, five themes seemed to emerge with regards to the museum's own collections, conservation and possibly even on being viewed positively by their community ('We challenge ourselves in order to provide visitors with a range of different experiences' – Exeter museum). This can also be seen in the largely positive way the museums viewed having the addition of 3DM in their future exhibitions, and with a large majority receptive to the addition of supervised and unsupervised handling activities. This is shown in **Figure 11** as one section asked on how 3DM would directly benefit the museum's existing collection/ exhibition. For that, the answer was unanimous with all 11 writing that they could foresee how the production of 3DM would complement their current work. In other words, the

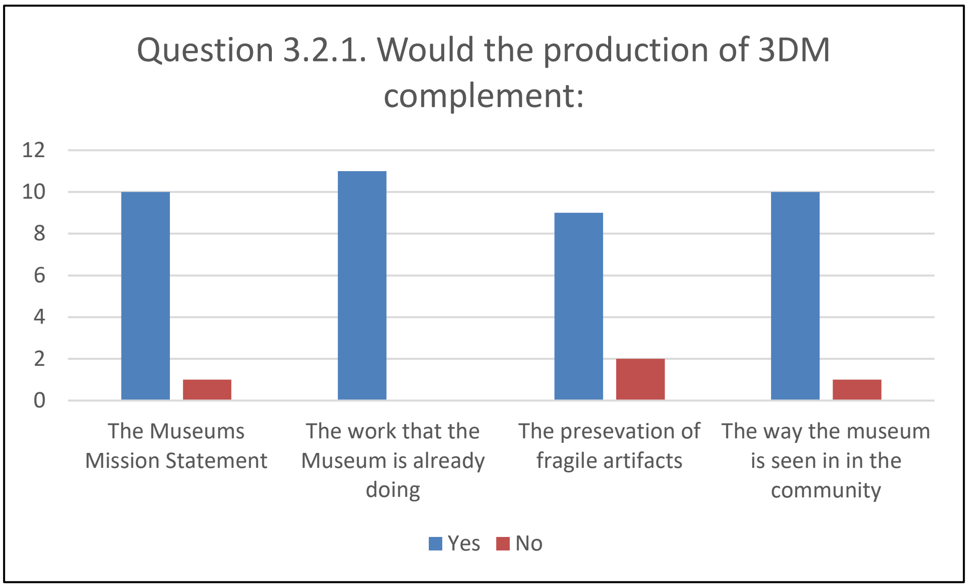

Figure 11 - The ways 3DM complement museum activities

application of 3DM and the use of 3DPT were seen as having a complementary effect in each museum, should the technology be applied in the near future.

The last question was concerned with ethics, and looked at how curatorial staff viewed the use of 3DM in their exhibition, with a simple choice of either 'yes' or 'no' as I wanted a clear answer for my data. This was important because I could then link the answers to the earlier question about the viability of having 3DMs as gift shop sales. As can be seen from the data in **Figure 12**, four (36%) said yes to the display of 3DM alongside the artefacts as misleading while seven (64%) replied that this would not lead to any misunderstanding on the part of their visitors. To reiterate, the earlier question on gift shop sales of 3DMs indicated that ten museums found it a good and viable idea to one museum's refusal to do so. There may not be any direct comparisons between the two on misleading visitors versus the sales of the replicas because these might have been viewed as separate issues with one on educating and informing the public and therefore a higher standard is applied while the latter is on merchandising, and possibly seen as unlikely to mislead the public that the 3DM was a genuine artefact with a price tag of £3.

However, given the fact that four museums felt that the display may be misleading, this would require the object to be "labelled clearly to show it is a replica" (Exeter Museum) should the museums use them in the future. The purpose of this question was to provoke further thought on authoritative representation by curatorial staff which would be discussed further in Chapter 6.

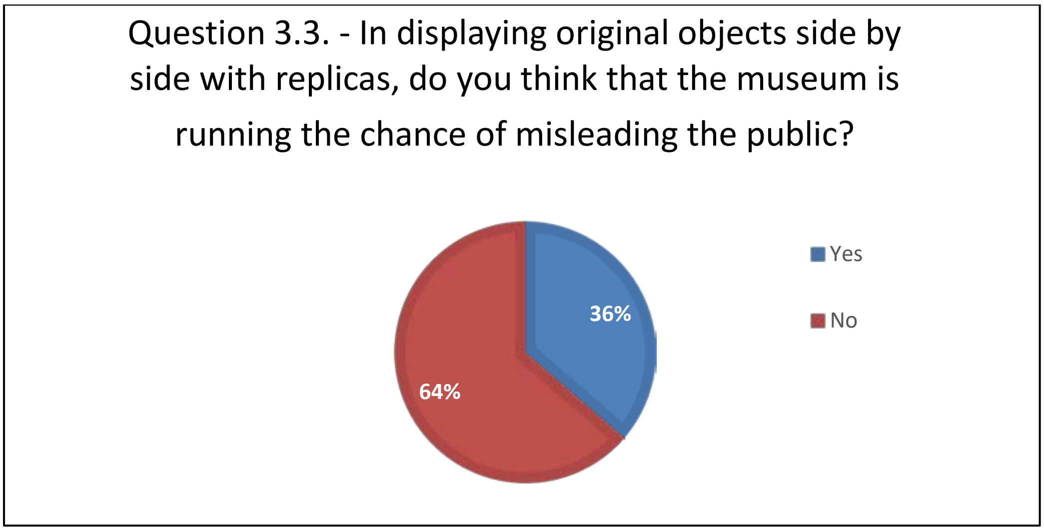

Figure 12 - The possibility of misleading the public

In sum, answers from Group A which was made up by 11 curatorial staff from four different types of museums showed positive signs of future application of 3DPT. This was particularly evident with regards to handling activities with 3DM in the foreseeable future, both supervised and unsupervised, as well as with how museums are currently using their own replicas (which are not produced with 3DPT). As mentioned earlier, data from Group A which took place in 2013 was used to guide and design my questionnaire for Group B which was undertaken in February 2014 at two museums. The findings are reported in the next section which investigated actual responses from 41 museum visitors then inside the two museums.

4.4 Group B - Museum Visitors

For my data collection, there were 29 respondents from Dorset County Museum and 13 respondents from Winchester City Museum. Altogether, there were 42 museum visitors who returned my Questionnaire B (Appendix B). This had four main questions which were then divided into several sub-sections. In all, Questionnaire B was kept short and was printed on three single-sided sheets of paper: one for their consent with a brief description of my research, student details and contact; and two single pages for my four main questions. My original intention of administering the questionnaire was by positioning myself inside the museum and approaching visitors based on the order that they entered the building.

The four museums chosen were conveniently located and had easy access to rail and bus services which would encourage greater footfall. Out of the four which I first emailed, one did not respond while three responded positively. However, due to timing, only two museums worked with me for my data collection. As mentioned earlier, they were Dorset County Museum and Winchester City Museum. With both museums, I was given permission to 3D scan and then print any artefact which suited my research; the third museum which initially responded positively – Poole Museum[29] – also allowed me to 3D scan and print albeit pre-chosen selection of museum artefacts. What I found particularly interesting and significant was the fact that both curatorial staff requested for a presentation prior to me administering my questionnaire (see Appendix B – Presentation Slides).

For Dorset County Museum, the person whom I worked with (who requested anonymity) mentioned that having a presentation would offer 'background [information] to the current uses of 3DPT and [would] be of interest' to their visitors. For Winchester City Museum, it was the same reason: that 'it would be interesting' for their visitors. As such, I modified my research design to incorporate a short (20-minute) presentation which would briefly introduce the uses of 3DPT in general, before any questionnaire would be administered. It is also worth noting that because there was activity embedded into my research design here, I was also closely observing the behaviour of my audience particularly in Dorset County Museum as mine was the only activity in the room allocated to me which enabled

[29] I was not able to do any data collection at Poole Museum because my contact, who was supportive of my project, was no longer with the museum. By that time, I was already preparing to visit Dorset County Museum and Winchester City Museum.

me to observe and note the actions of my participants unlike at the other museum. I used four 3DMs which I handed out, when administering my questionnaire and I also displayed two different 3DMs which were placed on the table next to my laptop at both museums. After each session, all 3DMs were collected back: no one walked away with my 3DMs.

Did you visit the museum to see this demonstration?
Is this a return visit to the Museum?
How often do you visit museums?
How old are you?
Before this presentation, had you heard about 3D Printing?
Where did you first hear about this technology?

Table 10 – Data Collection B: Background and Purpose for visit

4.4.1 Background and Purpose for visit

The first three sets of questions asked about the museum visitor's background: first was on the reason(s) for their visit; frequency of their visits to the museum; their age range (as used by the Museum Association); and finally, their prior knowledge of 3DP.

For museum visitors in Dorset County Museum (Dorset CM), 29 mentioned that they had made a visit for that day because of my presentation which had been publicised by the museum itself: I included the volunteer as well because she was on duty at that point in time. This was not surprising: as mentioned previously, Dorset County Museum had allocated a room called 'The Great Hall' which allowed for around 20 people to be comfortably seated in front of a screen and projector. Unsurprisingly, given the effort made for prior arrangements and publicity by the curatorial staff, there were also more respondents for my data collection from Dorset County Museum. There were 30 visitors who took my questionnaires although only 29 were returned; presumably, the missing one was taken home by mistake. At Dorset County Museum, I did seven presentations in all for the one day I was allocated, with intervals of sometimes only 10 minutes with the first presentation at 10:30 am. The last one ended at 4 pm; this was because there was a constant stream of footfall and I did not want to lose my audience.

The 29 respondents I had in Dorset County Museum was in contrast to the 13 respondents who volunteered to answer my questionnaire in Winchester City Museum (WCM). The number of respondents and attendance for my presentation in these two museums also underlined the importance of the curatorial staff, and the vital role they play in promoting activities, and possibly the influence that they have on visitors which will be discussed later in the next chapter, Chapter 5.

Figure 13 below showed the reasons for the museum visit by both visitors to the two museums as well as motives for participation in my questionnaire. As can be seen, the number of people who answered that it was not their return visit was quite small: eight from WCM out of the 13; while only three out of 26 from Dorset CM said that it was not a return visit. In other words, most visitors in fact, were regular visitors for Dorset CM. This was different in WCM because many were in the museum because they were either visiting as tourists (two) or they were there for the activity organised by the museum, namely the Roman re-enactors (four). Several offered the information that their visit was due to the fact that it was the half-term holiday and that they were there with young children.

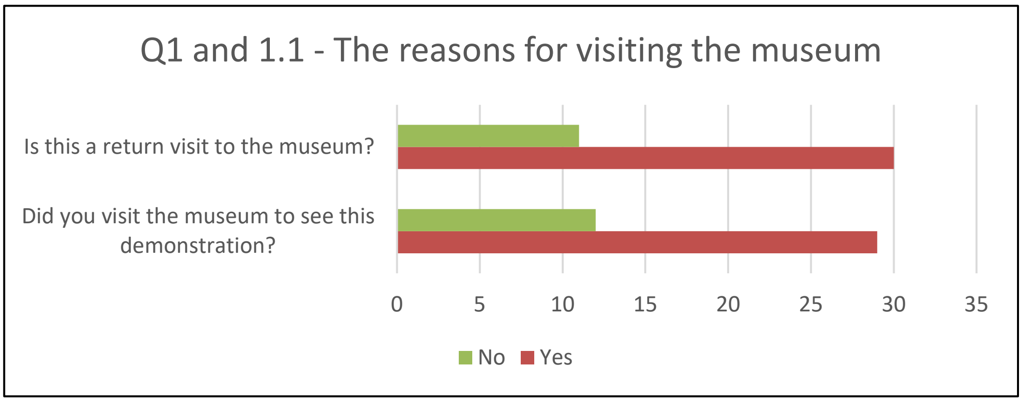

Figure 13 - The reasons for visiting the museum

Figure 14 below showed that the majority of museum visitors were in the age range of 66 to 76, with the next highest at the age range of 34 to 44 for both museums. Specifically, for Dorset CM 22 out of the 29 belonged to the age range of 54 and over, which included those in the age range of 66 to 76 and 77 or over. This was in contrast to those in WCM of which six of the respondents belonged to the age range of 34 to 44 out of 13. This was not unexpected because they were mothers (no fathers attended my talk) who were with their child (normally a child, rather than several children in tow).

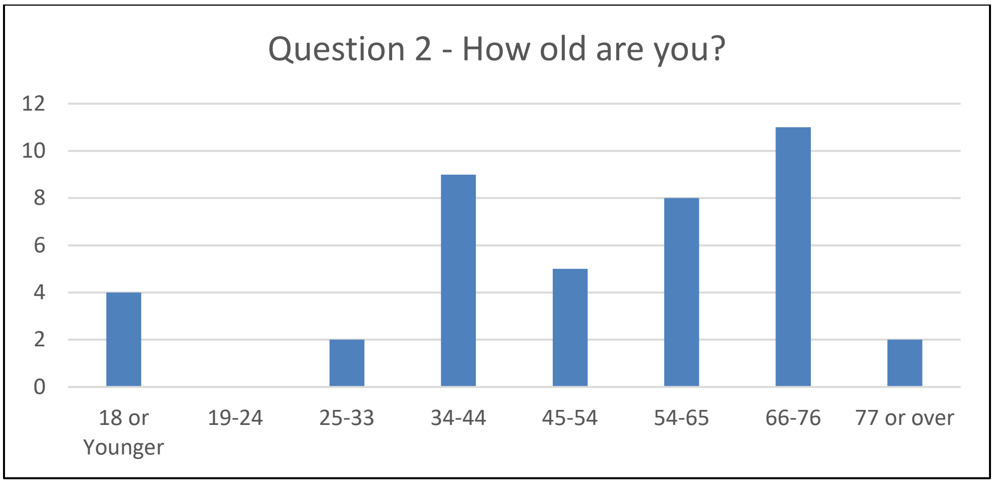

Figure 14 - Age Range of museum visitors

The range in age, particularly if the range showed younger visitors in museums, is important. This is because youth has been linked to positive reception or greater receptivity to new technology in general, and in this case to the uses of 3DP in the museum. In fact, in answering question 3, ‘Before the presentation, have you heard about 3D Printing?’ one person admitted that they had never heard of this technology. This was not surprising: the respondent wrote his age range as 77 or over. In fact, in a later question, another who was in the age range of 66 to 76, was rather negative about the use of 3DM, which will be discussed more later as he/she wrote in detail about how 3DM should not be in museums.

In **Figure 15,** the pie chart showed that the sources of information were quite diverse with one respondent offering detailed and highly relevant information, specifically the Rep Rap Group. Upon inquiry, she revealed that this information was due to the fact that her spouse worked with the RepRap Group, which originated in Bath University focussing on 3DP. There were other specific answers given such as: the Internet Science Forum.

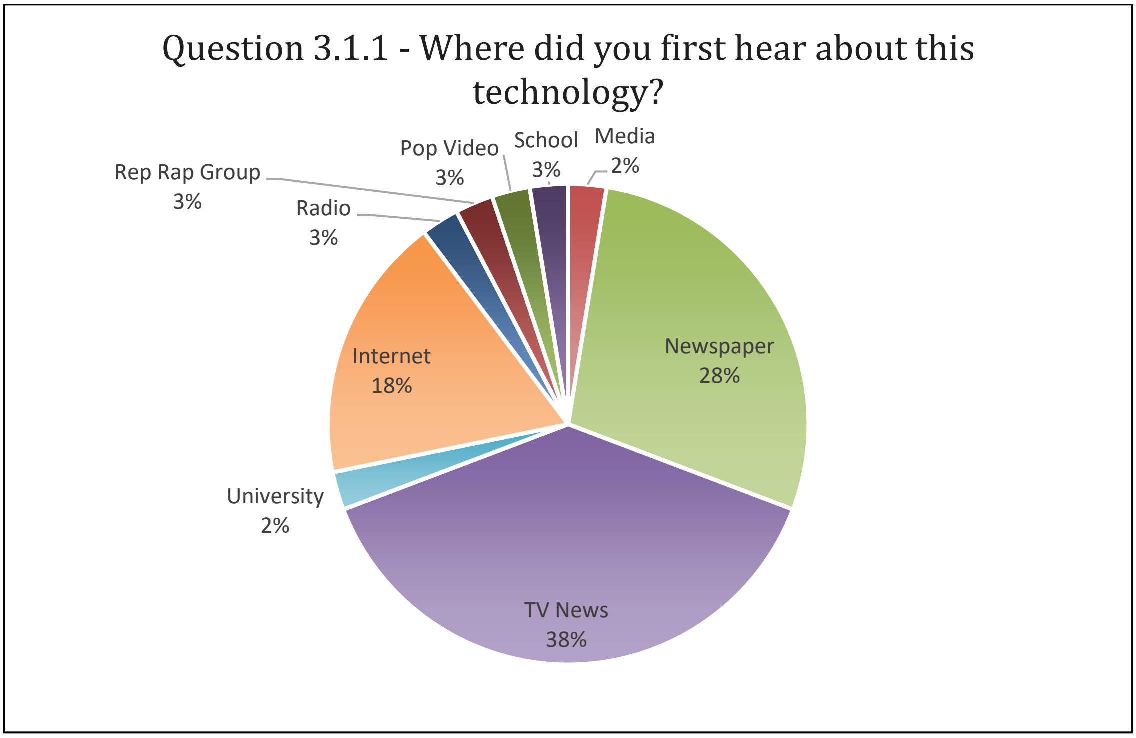

Figure 15 - Where did you first hear about this technology?

In fact, two respondents from Dorset CM recalled hearing about 3DPT: 'About 5 years ago? Newspaper – New Scientist' (D15)[30]; another (D23) wrote '2006 Portsmouth University'. Their answers are rather interesting if they could recall something which occurred at least five to seven years ago, leading to the inference that the information gained then must have been memorable. In fact, the more detailed the answer, the greater the likelihood of the respondents being equally detailed in their subsequent answers which proved highly illuminating. One respondent (D5) went as far as urging for information to be made more accessible at the museum:

> Presentation on a set of display boards so information could be taken in at own pace and then a chance to see the objects and printer working. Plus ask the gentleman could have been more efficient. Why struggle?

This suggests that for some museum visitors, even a presentation with PowerPoint slides was too fast-paced (my talk took twenty minutes) and not something which they could experience or view at their own time. Hence, the suggestion made for more visual stimuli albeit static ones.

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[30] The respondents from Dorset County Museum (Dorset CM) had their questionnaires labelled from D1 to D29 for the 29 respondents. Similarly, the 13 respondents from Winchester City Museum (WCM) were labelled from W1 to W13 for all 13 questionnaires handed in.

Question 4 Do you recognise these items?
Question 4.1 When you see this replica, what do you think?
Question 4.1.1 What is the replica of?
Question 4.1.2 Where does the original come from?
Question 4.1.3 What is the date of the Original?

Table 11 – Data Collection B: Prior Knowledge about 3DM and Handling activities

4.4.2 Prior Knowledge about 3DM and Handling Activities

Coming under the title of 'Hands On', questions 4 to 4.2 consisted of a series of haptic-orientated questions (Appendix B). These questions graduated in difficulty and were open to deductive interpretation. Question 4 'Do you recognise these items' consisted of three identification tests: in this test, each participant was presented with a 3DM and was asked to identify what it was a replica of. Presented sequentially with three 3DMs, it was expected that the participants would, for each model, spend more time and effort in identification. The objects were: a Samian ware pot, a Shabti doll, and a statue of the Capitoline Wolf.

Greater interaction with the Shabti Doll and the Wolf was required by the respondents in both museums, and it soon became clear that, unlike the 3DM of the Samian ware pot, having only a visual identification was not adequate for the Shabti doll and the Capitoline Wolf. This was not unexpected because of the lack of familiarity with what the latter two models represented. Hence, the participants could only reach a satisfactory conclusion for themselves after their own haptic examination.[31]

Despite this graduation in difficulty, the answers given to question 4 did not foreshadow a positive correlation of greater inaccuracy in identification. As can be seen in **Figure 16** below, fewer people attempted the last identification of the Capitoline Wolf. The results regarding the correct identification of the three objects were not surprising: many respondents spent time inspecting and feeling the

[31] Answers from two questionnaires had to be discarded because one respondent's answers were incomprehensible (D20) and the other wrote that he/she did not get the opportunity to handle the 3DM (D12).

grooves of the 3DMs, and rubbing their fingers to feel any bumps, or lines etched or raised on the 3DMs.

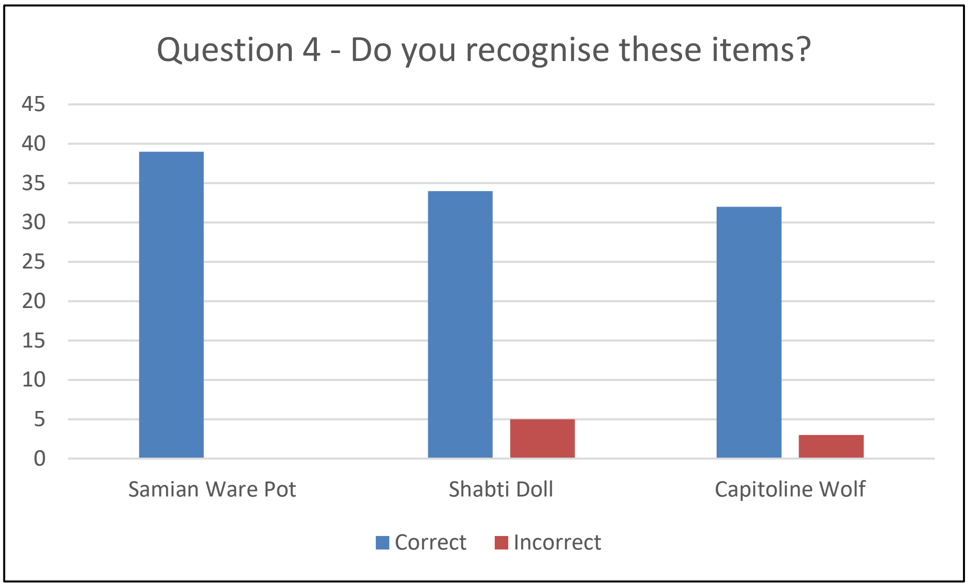


Figure 16 - 3DM identification and recognition by museum visitors

After Question 4, which was a multi-modal handling exercise intended to test object identification and accuracy, the next question, 4.1, specifically looked at the replica of Tauros Trigeranus. In turn, the participants, when presented with the 3DM of Tauros Trigeranus, they could examine it through visual and tactile interaction, just like the previous question albeit using three 3DMs to examine.

This time, in question 4.1 with the use of one 3DM – that of the Tauros Trigeranus - participants were asked: 'What is this replica?'; 'Where does the original come from?' and 'What date would you give the original?' It is understandable that answers would be highly subjective, corresponding to subjectivity in participants' interpretation from experience, but it is also informed from their education as well as current tactile investigation which led to greater accuracy in reaching conclusions about the original artefact; in this case the 3DM Tauros Trigeranus. The object in question, the Tauros Trigeranus, is of Romano-Celtic origin from the 1st century AD, found in the grounds of Maiden Castle.

Given the choice of such a specific object, Tauros Trigeranus, it was expected that none of the respondents would give the object a name, but instead, would describe what they felt the value was through multi-modal examination of the 3DM. In other words, interpretative valuation was related to the experience of handling the 3DM.

It must be noted that the original of the Tauros Trigeranus was itself displayed at the Dorset County Museum; this caused a lot of excitement among the respondents in the museum because someone (presumably the museum volunteer – D19 - who took part in my study) had mentioned this fact to them. In fact, they went on to initiate their own activity. Immediately after returning the questionnaire, some people then left to look at the original artefact of Tauros Trigeranus, and then returned to offer more detailed feedback, albeit verbally to me such as evaluative comments on the material, weight, colour and details between the original artefact and the 3DM.[32] Regarding the issue of weight, as the original artefact was behind glass, and therefore out of reach and touch, these motivated respondents drew their own conclusions that the 3DM of the Tauros Trigeranus was too light since the original was made out of solid iron, a fact which was clearly displayed in text for the artefact.

There were all together eight respondents who did this throughout my seven presentations: a mixed group of males and females, whom I counted and who sought out the original artefact. I only knew about this when they returned, after having handed in their questionnaire, asking to handle again the 3DM of the Tauros Trigeranus. Often, these highly interested museum visitors were only too happy to share their comments with me about the differences between the original they had just seen, and the 3DM; sometimes, they would then initiate conversations with others who were still with me in the room. Thus, I also overheard some happily sharing with others their impressions and comments regarding both the original and the 3DM. The eight participants clearly enjoyed their ability to compare the original with the 3DM and seemed to take pride in their ability to add their own analytical comments as part of their interpretation of both original artefact and 3DM.

As observed in the eight participants, some took down notes about the original artefact and when they returned, used their handwritten notes for comparison with the original of the 3DM. Others opted for digital photographs of the original (luckily, the museum allowed photography) to compare with the 3DM, or for others more detailed-minded, a combination of both photograph as well as written notes

[32] The original artefact of Taurus Trigeranus was not displayed in the next room to my presentation. In fact, it was in the Archaeology Gallery which was located one floor above my room. To get there, visitors have to walk across the Great Hall – a distance of around 30 metres – and then up the stairs and then walk to the end of the passageway before entering the Archaeology Gallery. In other words, the eight participants felt the activity and experience of having both haptic and visual stimuli was worth the effort and time taken.

were used for comparison. It must be noted that these eight were the only ones whom I observed using notes or their mobile phones as aids to compare the 3DM and the original artefact. Also, these participants were clearly interested and actively seeking information and details for comparison and for their own deeper interpretation and analysis of the 3DM and original artefact. I will discuss more of this three-part activity initiated by these eight museum visitors in the next chapter.

Returning to the questions, respondents were also asked three questions which were designed to encourage interpretation and greater analysis on the part of the respondents. The participants were required to think of three issues when interacting with the 3DM of the Tauros Trigeranus: ‘what the 3DM was a replica of’, ‘where they thought the original came from’ and ‘how they would date the original artefact’. Their answers showed a range, but crucially, almost all indicated a good knowledge of: artefacts typically displayed in museums (e.g. boar, emperor, vase, goat, cow, zodiac animal, etc.); ancient civilisations (e.g. Persia, Ancient Egypt,

Figure 17 - The Original (R) and the 3DM (L) of the Tauros Trigeranus

Ancient Rome, Middle East, Classical Civilisation, etc.) and dates in antiquity (10,000 BC to 1100 AD). Given the fact that until that moment the participants were unlikely to know the history of the Tauros Trigeranus and therefore unlikely to conclude that the 3DM was a replica of that artefact, it was thought that the close interaction with the 3DM would test their interpretative abilities. The object-specific focus of their interpretation demonstrated the potential of the 3DM to add

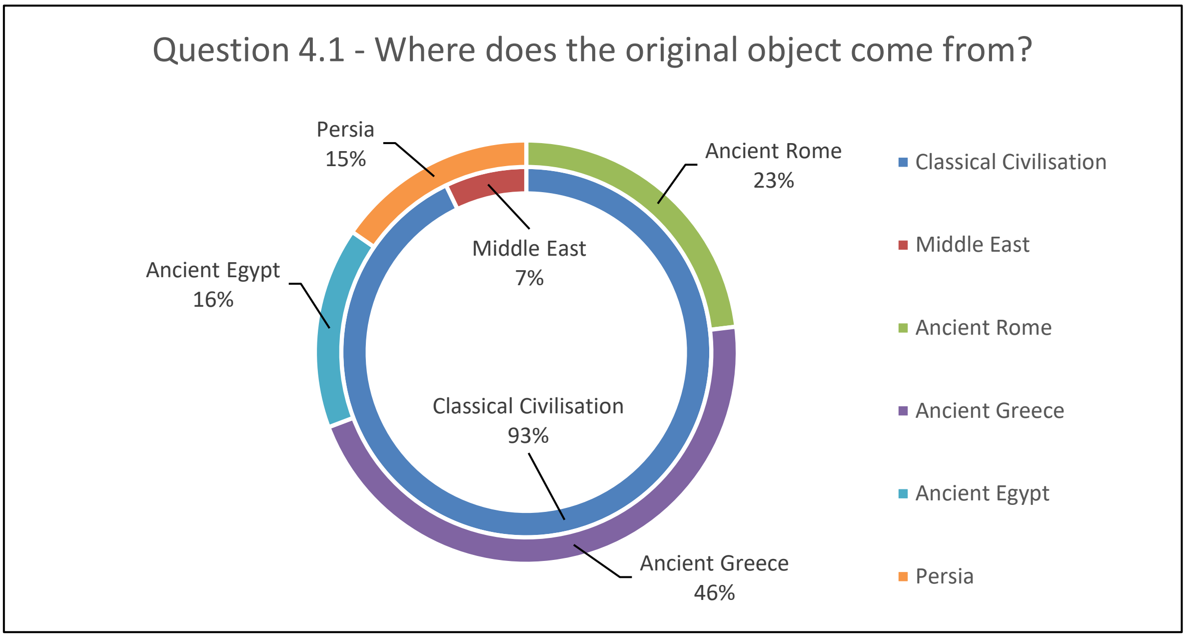


Figure 18 - Origin of the artefact as interpreted by visitors

to the appreciative value of the original. For example, the question which asked, 'Where does the original come from?', as shown in the **Figure 18**, indicated the range of knowledge of six ancient civilisations, or location of ancient civilisations.

To reiterate, the purpose of these questions was to encourage greater interpretive analysis and to see the accuracy of the museum visitors in reaching their own informed interpretations of the 3DM. As **Figure 18** showed, the museum visitors were able to provide answers which, for the majority - 93% of the answers – were restricted to a specific era and culture, indicating possible influence from education, historical appreciation informed by museum visitation, or a form of good guess work. In other words, the questions were intended for people to see beyond the stylistic limitations of 3DM and get respondents to think about historical parallels. In the same way as the first two parts of Question 4.1: to narrow down estimation of original artefact and complete their perceptive imagining of this gestalt figure of the 3DM.

Question 4.2 When you touch a replica is there on word that comes to mind?
Question 4.2.2 Do you think that being able to touch these replicas would be a useful aid to understanding the object?
Question 5 If this technology were used to exhibit replica models would you be even more likely to return to the museum?
Question 6 Would handling a replica of an archaeological artefact increase […]?
Question 6.4 Would you return to visit the museum again?

Table 12 - Data Collection B: Receptivity towards 3DPT

4.4.3 Receptivity towards 3DPT

The last few questions dealt with visitors' reception towards 3DPT and the use of 3DM in the museum context. Question 4.2 which asked 'When you touch a replica object – is there one word which comes to mind?' The answers were rather interesting with several using the word 'wow', 'amazing', 'awesome' and 'wonder' to indicate their highly positive reception towards handling the replica while some provided more nuanced one-word answers such as 'stratified', 'detailed' and even 'distant'. Many chose the more obvious point, commenting on the weight or rather, the lack of weight, offered by the 3DM of the Tauros Trigeranus which was made out of hollow ABS plastic.[33] The one-word descriptors, in other words showed a wide range in tone from highly approving and positive (e.g. wow) to neutral and analytical (light weight; stratified) to criticism of the 3DM (insubstantial). The results of the answers are shown in **Figure 19** with a variety of one-word answers counted as 14 different types.

[33] The 3DM was rather stark white. Given the respondents' interaction and handling of the 3DM, it was rather curious that no one mentioned colour at all as if to suggest that tactile interaction and feedback were the overriding sensation. Of course, this could have been influenced by the whole tactile exercise in the first place.

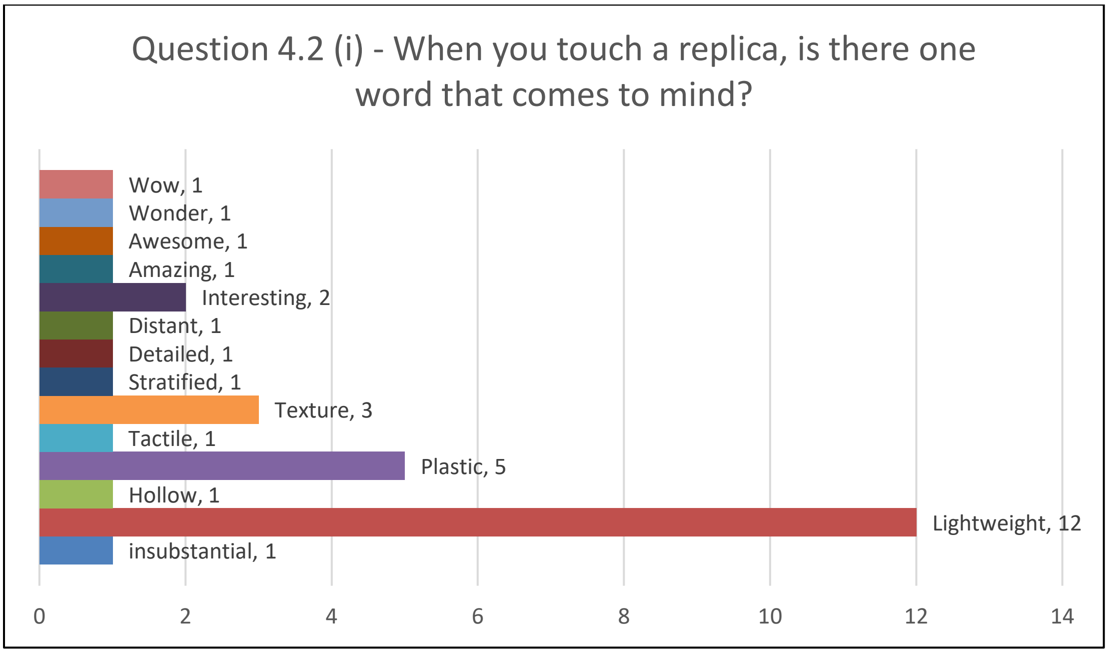


Figure 19 - One-Word descriptors provided by visitors on the 3DM handled

Despite the one-word reactions concerned with the technology, reactions in the majority listed weight and textural difference as either neutral or negative. This however, did not affect visitor willingness to interpret the object for themselves. The museum visitors willingly made the reflective leap to ponder on the origin, probable date and culture of origin from which the 3DM was made, from the earlier object handling activity in Question 4.1 with the three sub-sections asking about identification, origin and date of the original artefact. From the deductive questions, this was followed up with the inductive question of, 'Do you think that being able to touch these replicas would be a useful aid to understanding the object?' Answers to that inductive question is shown in **Figure 19** which indicated a large majority (77%) ticking the box of 'Yes', rather than 'No' (3%) or 'Maybe' (20%), for the question which asked about the usefulness of touch in aiding their understanding of the original artefact.

The positive answer – towards the use of touch in one's understanding – is very encouraging because this suggests visitors would most likely be interested in the technology of 3DP, and the novelty of viewing the technology at work, and handling the 3DM. Admittedly, the highly positive responses may be due to the fact that the museum visitors were themselves witnessing my 'Up' 3D printer in action: it was printing out using white PLA plastic the same 3DM of the Taurus Trigeranus.

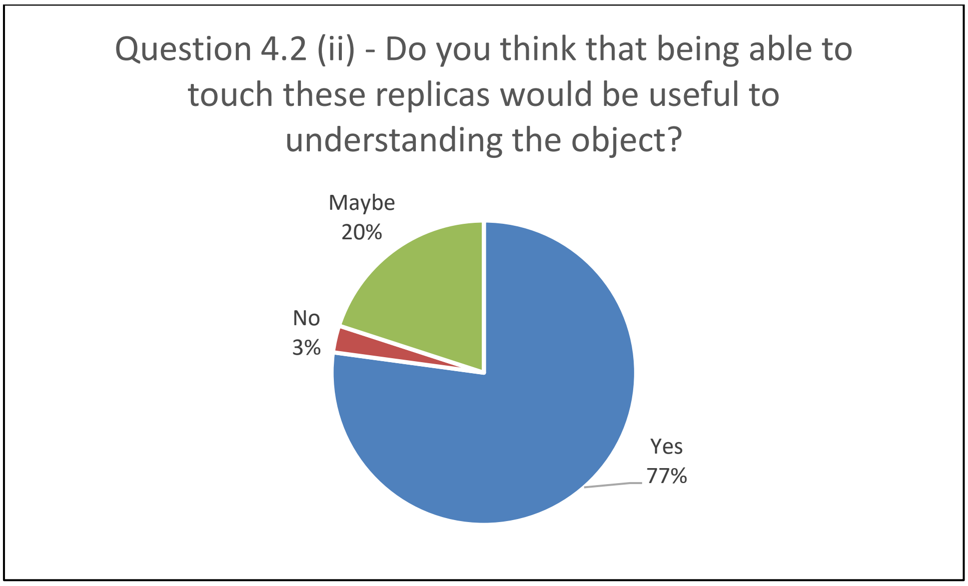


Figure 20 - 3DM as a useful aid to understanding the original artefact

Following the highly positive answers given by the respondents where 77% said being able to touch replica models aid in their understanding of the original artefact, it was not surprising that many were equally keen on future visits to museums in order to view more 3DMs. For question 5, which asked 'If the 3DM technology was used to exhibit replica models, would you be even more likely to return to the museum?', 97% of the respondents indicated they would definitely return or possibly return, while 3% indicated indifference. This enthusiastic response is highly encouraging and shows keen interest by museum visitors on the use of 3DMs as handle-able objects and even as displays. As one respondent (D16) mentioned towards how 3DPT and 3DM could be of benefit for the museum, 'It's also to display objects that can't be borrowed [from other museums]'. Another (D22) offered the suggestion that although

> (t)he technology is in its infancy. Future improvements e.g. level of fine detail, accurate colouring would make replicas more useful (e.g. museums could have copies of artefacts, the original being at another museum).

For both respondents – D16 and D22 – they were future-orientated and could foresee the future application and benefits of 3DM in the museum. Their views seemed to be echoed by another respondent from WCM who wrote that 'Good for engaging blind people in museums as technology penetration grows, sending the museum into peoples homes (sic.) W2'. I find the comment by the respondent (W2) insightful because this is what certain projects such as 'Print the Museum' is trying to do: breaking down barriers of distance between artefacts and visitors who often have to visit a museum to view the exhibition.[34]

One respondent offered a more cautionary comment which touched on the newness of 3DPT. He (D15) said that 'But the technology is in its infancy [.] If there are valuable commercial applications no doubt development will be rapid'. For a few others, they could immediately see the benefits of having 3DM and handling activities in the museum. In fact, one (D10) mentioned that his/her 'grandchildren would be more interested in museums if they can touch + hold items (sic.)'; while for another (D17), she wrote down as 'Very useful for school visits to museums'. Six respondents suggested that the technology would be practical and immediately of great use for children and the visually impaired e.g. 'probably useful for children + visually disabled visitors' (D8); '3D replicas would be particularly helpful for people with impaired vision to understand/ explore an object (D9); 'FOR THE VISUALLY IMPAIRED MUSEUM VISITORS (sic.) D3'; 'This could be very useful for people with poor english (sic.) and blind people to aid accessibility (D13).

All these details suggest that the museum visitors from WCM and Dorset CM were not passive museum visitors but had clearly thought about the use of 3DM and were willing to share their opinions on how this could benefit their museum and other museum visitors. These positive responses can be seen in **Table 15** which showed the benefits of handling a 3DM and how they visitors felt this activity would benefit them in four ways. These answers were derived from question 6 which asked 'would handling a replica of an archaeological artefact increase the following [...]? Four options were given, and they were: to increase their return visits to the museum, their interest in the original artefact as well as the people who made the original artefact, and the time they would spend with the artefact. The results in **Table 15** showed that 38 respondents would return to visit the museum; 32 would like to find out more about the peoples who designed the artefact; 28 would be interested in the original artefact while 32 said that they would spend more time with the artefact, presumably touching and handling the 3DM. One (D28) even added the comment that while having 3DM is useful as an aid to understand the original artefact, this could be made better if the 3DM 'were heavier and coloured' and also the request – 'Is there possibility of making the

[34] Although my focus is on the tactile interpretation of 3DM in a museum, the fact that the museum can be brought inside the house and was mentioned by the respondent is important. However, to investigate this further would require too much time and effort, which I acknowledge here.

objects heavier? That would make them more pleasant to handle' – which hinged on making the 3DM pleasurable as a quality for touch.

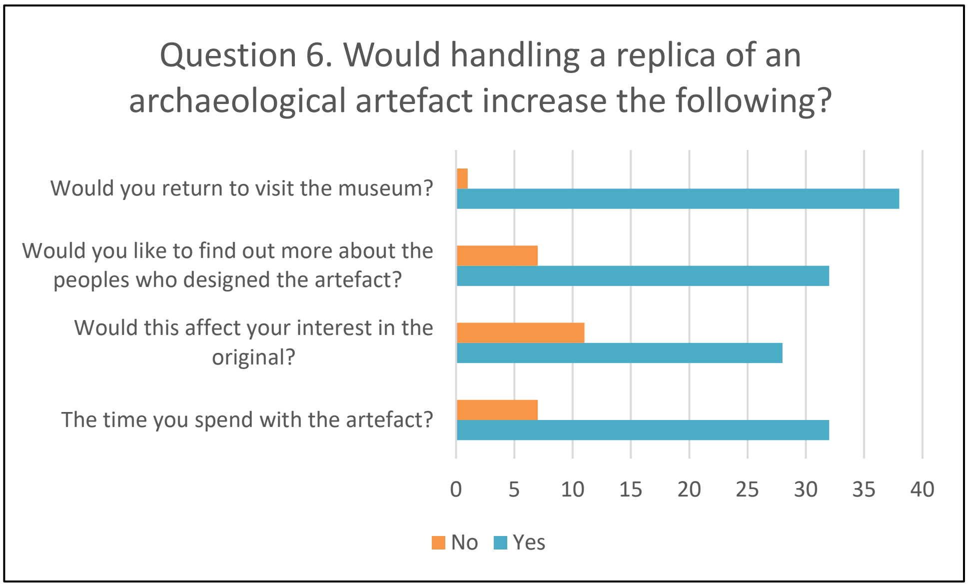


Figure 21 - Benefits of handling a 3DM and what this would increase

It is worth pointing out that even with all the positive comments regarding the uses of 3DM and the positive reception of 3DPT in the museum, there were a few museum visitors who were not so easily convinced. In fact, one respondent (D2), mentioned earlier, who was in the age range of 66 to 76, found the object 'tacky' as his/her one-word answer for 'Is there one word that comes to mind?' and chose to also add the additional comment to 'tacky': that of 'MADE BY A YOUNG CHILD – THROW AWAY OBJECT (sic.)'. Clearly, respondent D2 felt that the 3DM had little worth and was of no value in a museum. In fact, this respondent went on to write for the next question, 'Is there anything you wish to add?', that 3DM 'SHOULD NOT BE ALLOWED IN MUSEUMS, BUT KEPT TO A CHILD'S TOY CHEST (sic.)' and in another question that he/she would not return to the museum 'BECAUSE IT WOULD NO LONGER BE A MUSEUSM (sic.)'.

While respondent D2 was the only one who gave stark negative views, and understandably the rest of his/her questionnaire indicated disapproval and negative reception towards having 3DM and 3DPT in the museum, others who offered negative comments were not so extreme. One from WCM offered the comment:

> 'Only down side at moment – plain white plastic isn't that inspiring. Good to be able to handle the object but loose (sic.) "touch + feel" of original object (as not made of plastic!) sic.' (W13).

The 3DM with contemporary technology is, for the most, of one colour, hollow, and plastic, with the variety of comments mentioned by respondents mirroring both awe and inflated expectations regarding 3DPT as depicted in Gartner's hype Cycle of Emerging Technologies **(Figure 1, p. 5).** This is, however, not too great an issue, notwithstanding some of the negative comments received as for the most part, this acted as a gestalt designed for perceptive completion by the majority of the museum visitors who took part in my questionnaires. 3DM, both current and future, stand to be used in the museum as a complementary figure to the original, seen as a gestalt figure in which the properties of the original can find, through tactile stimulation, greater expression in interpretation as an addition to the mere presence of the artefact.

All these benefits as mentioned above refer to tactile stimulation and interaction with 3DM as being of benefit to museum respondents, in either provoking a return visit that possibly may be out of curiosity or formative of an interest that may develop from tactile interaction. The next section below is about one significant observation from my time in Dorset CM which, curiously, involved people not from my group of participants for my questionnaires.

4.4.4 Non-participants' Haptic engagement with the 3DM Bone Comb

As mentioned previously, data collection involved administering questionnaires to audiences in two museums who first listened to my general presentation on the uses of 3DPT in some industries. As such, my design for data collection on museum visitors may have been geared towards adults: definitely people who attended talks and then were willing to answer questionnaires. I have already written about my time spent at both museums where I displayed my 3DMs along with my 3D printer and laptop computer.

It was during the time when everything had finished at almost 5 pm in Dorset CM, when I was in conversation with one of my respondents (D18), that I noticed two young girls with a female adult who was busy reading text for a display at the Great Hall. By then, the girls had run over to my table, and immediately picked up the 3DM Bone Comb **(Figure 22)** which I used as part of my presentation though, not for handling activities in Questionnaire B. My set-up included two tables with a 3DM of the bone comb at one end, my laptop and the 'UP' printer in the middle and the 3DM of the Tauros Trigeranus at the other end. Visitors had begun to leave my data collection in the 'Great Hall' but with the activity surrounding the 3DM of the Tauros Trigeranus, a group of people had gathered around it by the table.

Thus at one end of the table there were the adults clustered by the table leaving space at the table around the 3DM Bone Comb which was at the other end of the table: the adults presumably had ignored it because it was not used in my questionnaire and was only an example I used to show what the LOM technology could or was unable to do. These two young girls, zoomed in onto the 3DM Bone Comb, then started taking turns combing each other's hair with it, giggling all the while repeating the process with each other. Both, who had long hair, spent a few minutes playing with the comb by using it, still standing by the table, and laughing at what they were doing. After that, they happily ran off to join the adult who was at the other side of the room. This spontaneous activity by the two young girls, who seemed (in my non-expert eyes) to be of around seven years old, revealed something which I found to be 'Amazing', to borrow the one-word descriptor by D6. In this case, these young girls saw the 3DM, and could immediately interpret that it was a comb or more precisely, a replica of a Bone Comb. I had used the 3DM as an example of the limitations of 3DPT to produce colour using the LOM technology, which was then considered expensive – the 3DM cost £20 to produce, even at the reduced price given to me as a student and as a potential buyer of the LOM printer. As can be seen in **Figure 22** below, the bone comb - the 3DM and the original artefact - had some 'teeth' although there are some 'teeth' missing, and do not quite follow the typical design or shape commonly associated with modern combs.

However, there were still sufficient points of reference - long, with teeth, easy to pick up with one hand - for the two young girls to recognise and immediately identify for what it represented: a comb. At this point, it is useful to note that just having the 3DM on the table was enough encouragement for the young children to pick it up, touch it, play with it and clearly, offer their own interpretation on its use but more importantly, have fun with the 3DM.

Figure 22 - The original (Top, on display at Dorset CM) and the 3DM of the Bone Comb (Bottom) representative of LOM

4.5 Group C - University Academics (Staff and Postgraduate Students)

As mentioned in the previous chapter 'The Original's Companion', data collection for Group C, was a formal experiment divided into four sections which looked at 'Texture', 'Detail', 'Type' and 'Scale'. It was held over three days at the University of Southampton's Winchester School of Art and featured a series of haptic-only and visual-haptic experiments in March 2015. The participants were recruited through mass emails sent by my contact at the Winchester School of Art. Each experiment needed around 45 minutes for every participant, and as there was a need to maximise my time at the school plus I did not want anyone to have to wait for their turn, places had to be booked. Therefore, the 12 participants confirmed their attendance three days in advance with no one dropping out.

This attendance rate of 100% was probably due to the fact that the students were told that participation might help them in designing their own research in their masters programme: this was later revealed to me by one student participant who was perhaps responding to this as an incentive. Of the 12 participants, four were male: three were postgraduate students while the other was a lecturer. For the females, three were lecturers, one was a university librarian and the rest were students.

The findings from this group of 12 volunteer participants (identified as Participants A to L) have been categorised based on their responses towards texture, details, type and scale of the six 3DM and three original artefacts used: in total, nine different objects were used. The four lecturers and the librarian were also the only ones to try to offer answers outside my 'Touch' criteria of one-word options'. Where suitable, I have identified who said what in the four experiments for all 12 participants. Overwhelmingly, there was positive reception for handling activities with 3DMs as participants offered details which indicated their curiosity and enjoyment throughout the experiment. No one was told that original museum artefacts would be used but was only given the information at the start of the experiments, that they should be careful during the handling activities as there might potentially be museum artefacts among the various 3DMs of museum artefacts. All results of the experiments were immediately noted by hand, on the set script **(Appendix C)**, and later collated for ease in analysing the data which is reported in the following four sections.

4.5.1 Location and Placement of Objects in the Experiment

To carry out the experiment, I was allocated a room at the Winchester School of Art for all three days that I held my experiment. Thus, I was given the freedom to re-arrange the furniture to suit my purpose. In the room, I opted to have two tables joined together, with an open suitcase, two flat boxes and a small set of drawers. **Figure 23** below shows the room where the experiment took place. Also laid on the table, in front of where the participant would sit, was a sheet of bubble wrap. The bubble wrap was placed to protect the objects, the 3DM and the artefacts and the other items were there for storage. The drawers, for example, came from a stationery shop and were made of faux leather, thus simulating the semblance of storage for important items. It was there to store, out of sight, the smaller artefacts, although hearing the drawer open and close, could have served to prime the individual (Dobbins et al 2004) to start thinking about artefacts of a certain size. However, when comparing this to the answers given regarding the small objects, any priming effect was offset by the range of answers given.

Figure 23 - The prepared room for group C

4.5.2 Part 1- The Texture of a Pot (4 types) and Tusk Fragment (3 types)

The four iterations from two different Samian ware pots represented three different technologies: Fused Filament Fabrication (FFF), Stereolithography (SLA), and Laminate Object Manufacturing (LOM). Replica pots ‘A’ and ‘C’, replicated using FFF technology, were of PLA and ABS plastics; pot ‘B’ using SLA technology was a photo-reactive resin from the company known as Formlabs; and pot ‘D’ was

Object	List and Details of Objects used in Experiment on Texture	
Pot A		**PLA replica pot;** using Fused Filament Fabrication (FFF), 3DM of a Samian Pot at the Dorset County Museum
Pot B		**SLA replica Pot;** using Stereolithography, 3DM of a Samian Pot at the Poole Museum
Pot C		**ABS replica Pot;** using Fused Filament Fabrication (FFF), 3DM of a Samian Pot at the Dorset County Museum
Pot D		**Paper replica Pot;** using Laminate Object Manufacturing (LOM), 3DM of a Samian Pot at the Dorset County Museum NB: Pot D was the only 3DM pot used in the experiment which was not hollow
Tusk A		**PLA Tusk fragment;** using Fused Filament Fabrication (FFF), 3DM of a Tusk Fragment from The University of Southampton
Tusk B		**Original Tusk fragment;** borrowed from The University of Southampton
Tusk D		**Paper Tusk fragment;** using Laminate Object Manufacturing (LOM), 3DM of a Tusk Fragment from The University of Southampton

Table 13 – Data Collection C: Experiment on Texture

made from LOM technology in which the model was built out of layers of paper. The objects used are shown in **Table 13** which lists the four types of 3DMs from two Samian Ware pots, and the two 3DMs of tusk fragments with the original mammoth tusk fragment used in the experiment on texture.

To reiterate, the experiment on texture was a touch-only experiment except at the end, when they were invited to offer their preference for the iteration of the pot or tusk they liked when viewed. This meant that in the early part of the experiment, all participants were asked to close their eyes: no one saw the object before, nor during the experiment. In other words, the experiment was one which focussed on interpretation of the object where participants, with eyes closed, handled four 3D printed models and commented on the texture of each object. I also asked them to choose from my criteria of nine one-word descriptors where an additional one – tenth - was ‘other’. In short, participant texture interpretation was elicited during the handling process whereby I asked for reactions on a pre-determined, overlapping scale. This pre-determined scale, mentioned earlier, helped to focus reactions into a standardised format, whilst allowing for one or more answers on texture (under ‘other’) to allow subjectivity as well as alluding to the possibility of overlapping descriptions for each object or what I refer to as ‘touch blends’.

The scale, mentioned earlier was adapted and developed to present nine touch reactions: Spiky, Bumpy, Grainy, Hard, Lined, rough, Soft, Smooth, Silky. Many of these options had significant overlaps to encourage the choice of two: the tenth option of ‘other’ was designed to encourage and elicit an optional answer, a possible addition to the specified responses from the nine one-word descriptors.

Figure 24 presented in the next page shows the two different expressions from the same data based on handling Pot A which was made using FFF technology on PLA plastic which had a particularly smooth texture. First to be expressed is the ‘primary response’ and this considers only the first or initial response given by the participant to the texture of the model that they were handling. The second, however is the ‘Secondary response’ and this includes the second and sometimes third one-word descriptor given by the respondent. This was considered necessary during the experiment as each participant was also given 10 seconds after their primary response, to then offer their second response. Often, as shown in **Figure 24**, respondents offered a third response hence the table showing a higher number for secondary responses e.g. the answers of ‘lined’, ‘grainy’, ‘bumpy’ and even ‘spiky’. This time-delayed reflection was built in so as to allow for different responses which all my respondents had no difficulty in giving me, suggesting the almost effortless relationship between haptic interpretation and responses.

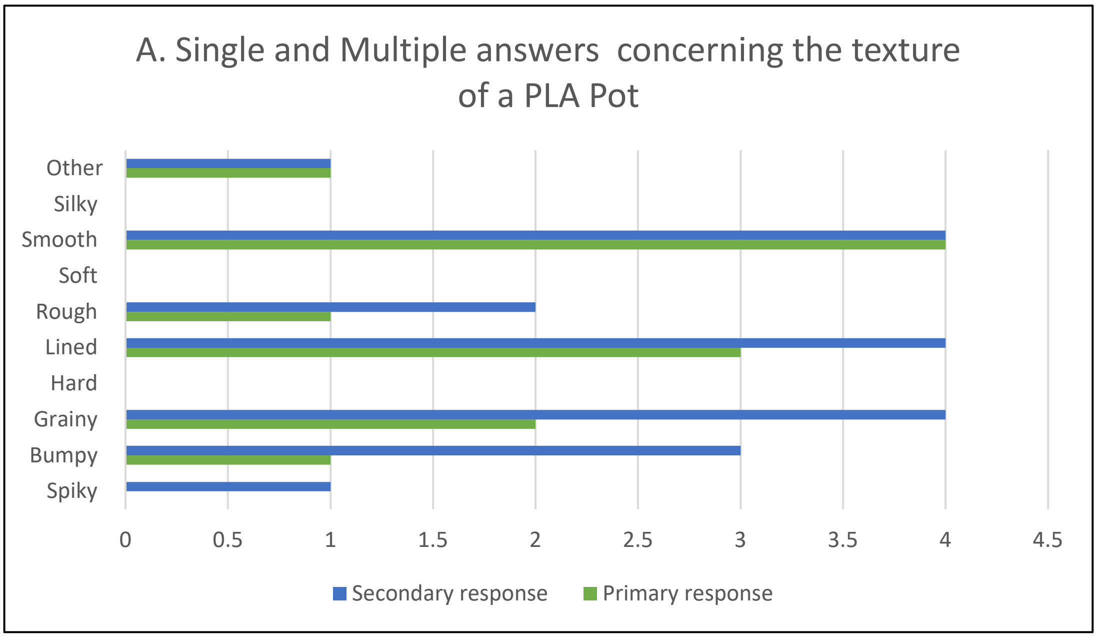


Figure 24 - Textural touch interpretation on Pot A (PLA 3DM)

The comparison of the two sets of data is rather curious, as presented with a predetermined scale in which criteria overlap; there are consistencies that seem to be upheld and in fact suggested that the first reaction of many was then reinforced by the reflective secondary reaction. For example, the primary reaction was often backed up by the secondary response – the second and third answers – which had similar overlaps such as ‘smooth’ with ‘silky’ and/or ‘soft’; or ‘grainy’ with ‘bumpy’ and/ or ‘rough’.

Considering the two types of answer, three textural criteria benefited in this way e.g. ‘Smooth’, ‘Lined’ and ‘Grainy’. Within the three, there was an interesting difference in sources, as the one-word descriptor ‘Smooth’ had equal numbers of primary and secondary responses. The one-word descriptor ‘Grainy’ had more secondary responses and this was surprising given the uniform texture of the PLA pot for Pot A. I find the variety of answers in this experiment interesting because this suggests that respondents were offering additional one-word descriptors or ascribing qualities to the 3DM which normally would not have been attributed. This may be due to the fact that respondents tried to be helpful and offered as many one-word descriptors as possible and also, this was their very first experiment that was carried out on them. However, the other experiments also showed similar increases in secondary responses, which I will mention more in my next chapter on 'Discussion'.

Participant reaction for Pot B, however, was slightly different as shown in **Figure 25.** This may be due to the fact that photo-reactive resin as used in the Stereolithographic 3DPT (SLA), like the PLA, forms a unified and smooth surface, to touch, and perhaps was not lined like the PLA pot. Instead, Pot B has an unbroken sheet-like surface. This is due to the manufacturing technology of SLA, where there is a rising platform under which a photo-reactive resin (liquid) is poured or built up by microscopic increments. Thus, this produces a smooth lining on the surface of the 3DM. In this case, Pot B (SLA) feels smoother to touch in comparison to Pot A (PLA replica). In addition, Pot B is also semi-translucent. Hence, my insistence on carrying out the experiment with all participants not looking at the 3DM as this visual feature in 3DMs such as Pot B (SLA) may influence participant's response and therefore, interpretation.

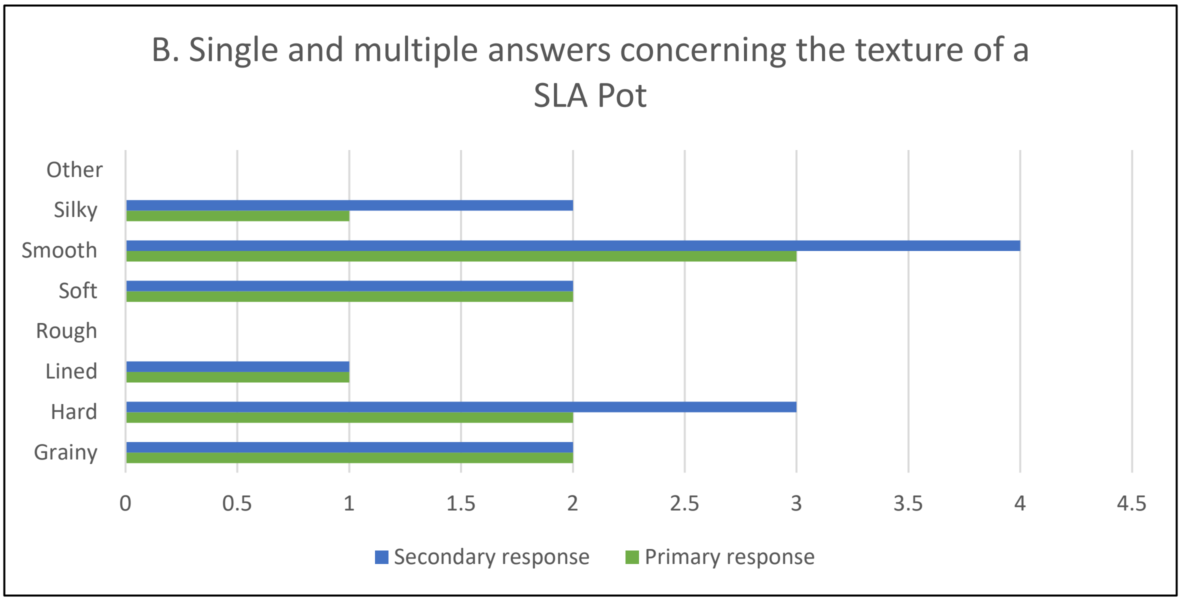


Figure 25 - Textural touch interpretation on Pot B (SLA 3DM)

It was curious, and perhaps suggestive concerning the amount of interpretive effort that one person did in order to respond to the lined texture. The majority however gave the primary reaction to this model as 'smooth' with the second reaction being 'hard'. The answers given of 'hard' were interesting as it alluded to the lack of 'give' and flexibility in the material in contrast to the earlier experiment on Pot A (PLA) which did not have anyone saying 'hard' as their one-word descriptor. This has some significance because the SLA technology used for Pot B clearly had substance which felt thicker than the one for Pot A using PLA. Thus for museums interested in producing 3DMs of original artefacts which have a solidity to them, this suggests then that SLA would be the better option for their 3DMs as compared to PLA.

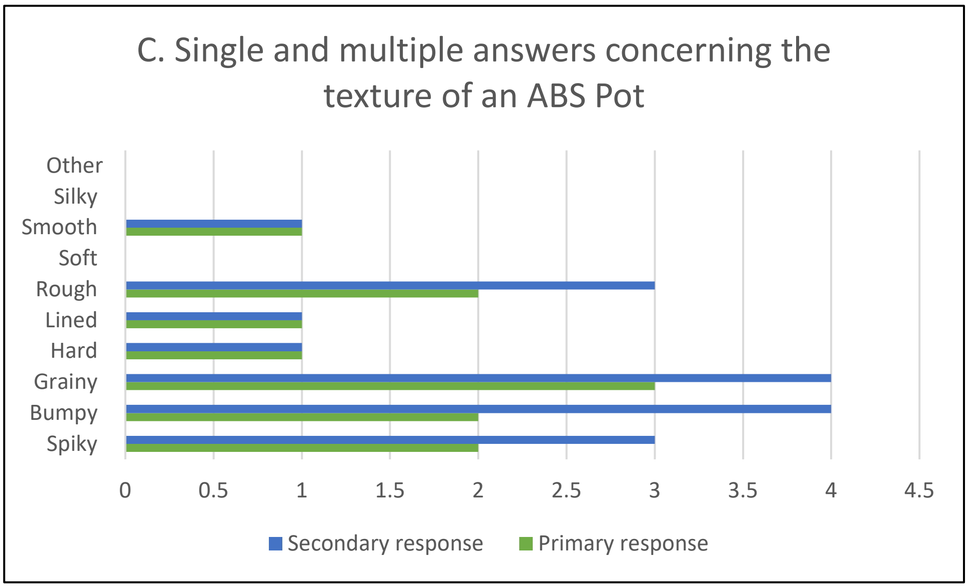


Figure 26 - Textural interpretation of Pot C (ABS 3DM)

Haptic interpretation of Pot C, made using ABS through FFF was, as we can see in **Figure 26**, much more diverse, even taking into account primary reactions. A consensus lay however towards the one-word descriptors of 'Grainy' and 'Bumpy', at the end of the scale, rather than anything 'Soft' or 'Silky'. One participant (Participant L), however, mentioned that Pots B and C seemed 'shiny'. This answer seemed rather curious given that no one could see the pots as participants still had their eyes closed; the likely answer was that, Pot B's smooth texture and Pot C's relative lack of bumps was leading him to conclude that both had to have been 'shiny' in appearance or smooth in texture. The majority consensus, however, remained rather constant, with the 'Grainy' and 'Bumpy' elements benefitting from reflection: this was perhaps indicative of the uneven feature of the ABS plastic. Although as noted, Participant L seemed to disagree with the slight uneven texture in Pot C with the verdict of 'shiny'.

To consider how the method of production may affect this, the technology of FFF, that of depositing a line of solidifying material on a platform that moves on an axis could be expected to produce a 'Grainy' or even 'Lined' textured feel. The fact that unlike the one-word descriptors for Pot A (PLA replica), 'Lined' was not chosen by the majority. Instead the predominant criterion was 'Grainy' for Pot C (ABS replica). This suggest that although ABS plastic shared a few similarities with Pot A (PLA replica) such as being both 'grainy' and 'lined', it also differed with respect to Pot C (ABS replica) as the latter was perceived as more 'spiky' and 'hard'.

The perception of Pot C (ABS replica) being more 'Lined' and 'Grainy' may have overlapping connotations. However, my criteria of nine one-word descriptors plus the tenth on 'other', offered a graduation by degrees, in the likelihood of participants to give a reaction towards more obvious features of touch such as 'hard', 'grainy' and 'spiky'. In other words, my touch criteria may have helped participants to anticipate and offer more haptic feedback on textures. At this point, the experiments on the first three 3DMs of Pots A, B and C have already shown many different features as evidenced by the different reactions given by my participants. This is highly encouraging because this shows the viability and choices in the 3DPT which museums have with regards to replicating their prized original artefacts for haptic interaction and engagement. In short, depending on the type, museums now have more options to select from the three types of technology used in my 3DMs alone.

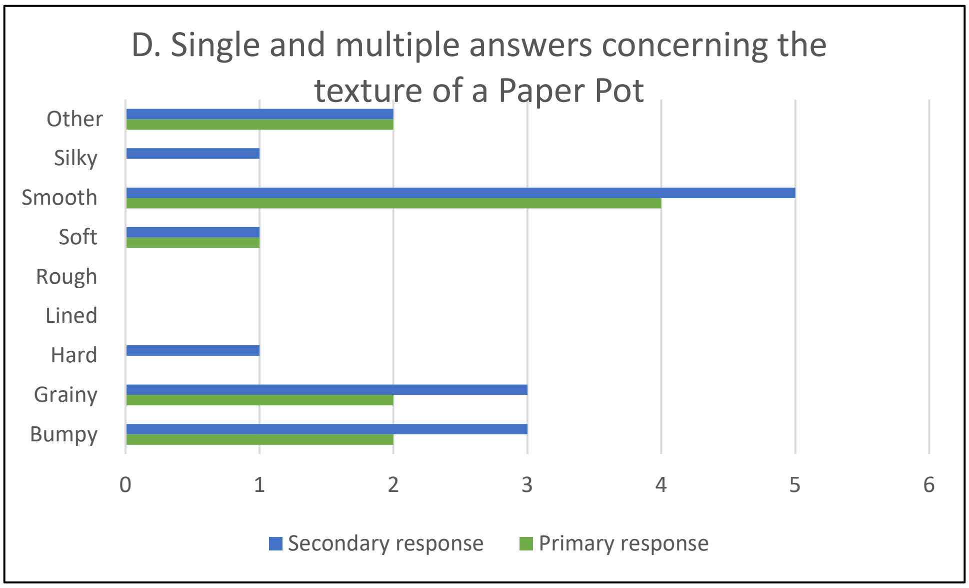


Figure 27 - Textural interpretation of Pot D (Paper 3DM)

The final experiment on 3DMs of pots was Pot D, which was made of paper. Data from the experiment is shown in **Figure 27**. Answers as shown in the table were much more diverse than the one-word descriptors in my touch criteria for Pots A, B and C. In fact, respondents chose two ends of my touch criteria – opting for the spectrum of either 'Silky' to 'Soft', or 'Hard' to 'Bumpy'. No one gave the one-word descriptors of 'Lined' or 'Rough', but instead gave a mixture of one-word descriptors of 'Smooth', 'Bumpy' and 'Grainy'. This suggested that haptic interpretation was mixed. This could be due to the type of manufacture of Pot D, which was made of paper. The technology used, as mentioned earlier was the LOM which resulted in a matt finish. This then allowed for greater discernment in the texture and lines that broke up Pot D's otherwise uniform flat exterior.

However, it is worth noting that reactions to the paper model did result in two 'Other' answers that were both given before the respondents followed my touch criteria or scale, unlike responses for Pots A, B and C. The first 'Other' reaction was 'dry' (Participant D) and the second, was 'furry' (Participant A). The respondent who first reacted with the one-word descriptor of 'dry' was, however, responding to the tactile comparison to Pots A and C, in which Pot A was previously said to be 'tacky' and 'wet', while Pot C was perceived as 'dry'. Nonetheless this instant response into a word outside my one-word descriptors also suggested that Pot D, with its different tactile feel, inspired or triggered stronger reactions.

The 'Furry' conclusion, offered as the first reaction, was interesting: it was the only reaction that the participant gave to handling the object. It is possible that my respondent was referring to the very slowly deteriorating texture of the paper material in Pot D. The paper model (Pot D) was not varnished: a feature that would require the application of glue, and hence would have changed the surface texture to something akin to plastic. As such, the handling of Pot D, with its absorbent material had begun to show wear, and to degrade in certain areas and revealed a very thin fibrous coating, similar to cotton wool; a conclusion that was drawn by my final and twelfth participant on the third day.

Therefore, replication using LOM would seem to suggest that any 3DM made from paper should be sealed using a solution similar to glue which, when hardened, produces a glossy and smooth texture. This solution can be bought from MCOR, a company based in Ireland which manufactures and retails 3DM products based on the LOM technology.

Returning to the responses by my participants, the method of 3DM and its subsequent material conditions would be key to visitor interpretation and might even influence it. Thus, the 3DPT might assume a condition materially different from the original artefact which will be discussed more in the next chapter.

Before switching to experiments using 3DMs of the mammoth tusk fragment, I also asked each of my participants which pot they preferred based on touch or their tactile engagement with each of the four Pots A, B, C and D. The words I used were: 'Which one did you like the feel of most and why?'. At this stage, no participant had seen any of the pots. This was then followed by inviting them to open their eyes where I then repeated my question, albeit in a simpler form, 'Which pot do you prefer and why?'

For the first question with eyes closed - 'Which one did you like the feel of most and why?'- eight out of the twelve respondents said that Pot D (Paper replica) was their favourite. Two common comments surrounding Pot D were that it had 'weight' which made the pot feel more 'real' (the reason why Pot D was chosen), and that it seemed to feel more 'natural' (Participant I). For the other four respondents: one chose Pot A (felt flexible), another chose Pot C (seemed 'antique') and two chose Pot B (felt substantial).

This may be due to the fact that objects A, B, C and D were iterations of pots, which every participant, though haptic interaction and interpretation soon became aware of, indicating the presence of points of reference. Hence, for some of them, 3DMs of pots should have some weight rather than the relative weightlessness of the other three 3DMs. However, when participants were asked a slight variation of the question with their eyes opened - 'Which pot do you prefer and why?' – six participants, out of the eight, who had indicated Pot D as their preferred choice, changed their minds.

Reasons were that upon viewing Pot D (Paper replica), it did not live up to expectations. Clearly, the participants had imagined a pot which was different from what they perceived in Pot D with Participant F informing me that while Pot D's weight was 'good and solid [to touch], it miss[ed] pot-like qualities'. This time, the switch in answers came from those who had initially chosen pot D when their eyes were close: now with eyes opened, there were now seven who chose Pot A (PLA replica) as their 3DM of choice, leaving still two participants who stuck with their initial choice of Pot D when their eyes were closed. For those who had initially chosen either Pots A, B or C, there was no change in their answers when they could see the pots. In all, the final answer given with eyes opened was that seven respondents chose Pot A (the earlier two stuck to their choice of Pot D) and the other two kept to Pot B and leaving one still decidedly with Pot C. In fact, the participant who chose Pot C both times, described Pot D as being 'more aesthetically pleasing' when she opened her eyes, implying that Pot D was not appealing to the touch when handled.

The next three mini experiments, still on texture, used two 3DMs of a mammoth tusk fragment. Like the earlier experiment on iterations of pots, respondents were again requested to close their eyes. First they were given Tusk Fragment A (PLA replica), followed by Tusk Fragment B (original mammoth tusk fragment) and finally Tusk Fragment D (Paper replica). Given the expectations and the relative familiarity of participants of whatever background with a pot, it was decided that the second experiment of part one should seek to distance itself from prior contextual knowledge. The object chosen therefore was a fragment of a tusk from a Mammoth. With only three iterations of this Tusk Fragments A, B and D, it was hoped that the lack of context, unlike the pot, would remove the possibility of identification and therefore any prior expectations that could lead to potential bias.

It was expected that the lack of participant familiarity with handling anything like a tusk would result in a wider range of textural interpretation. The lack of familiarity producing this greater range would therefore inhibit the ability of the participant to imagine a version, especially an idealised version of the object and thus provide me with texture-related feedback that would not try to fit in with their expectations.

The one-word descriptors given by the 12 respondents for Tusk Fragment A (PLA replica) is shown in **Figure 28**.

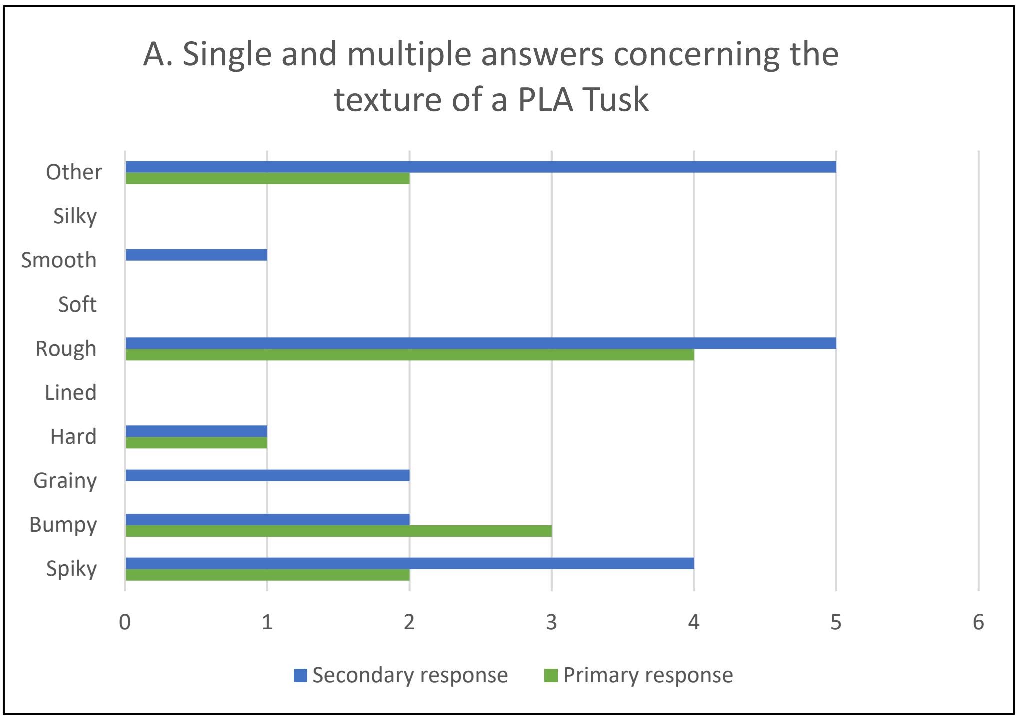


Figure 28 - Texture interpretation of a tusk Fragment (PLA 3DM)

The difference in the expression of the first and the multiple touch interpretations as exhibited in the table above display curious differences. Given the choice to provide a second reaction, the majority gave answers of ‘Rough’, ‘Spiky’, and ‘Other’. For the latter, the respondents’ own one-word descriptors include two for 'plastic', one (Participant B) for a 'mixture of wood and plastic', one for a 'sharp' object, and one who told me that the object was 'definitely not smooth'. As the 3DM was of a tusk fragment and hence thin and flat, such secondary responses

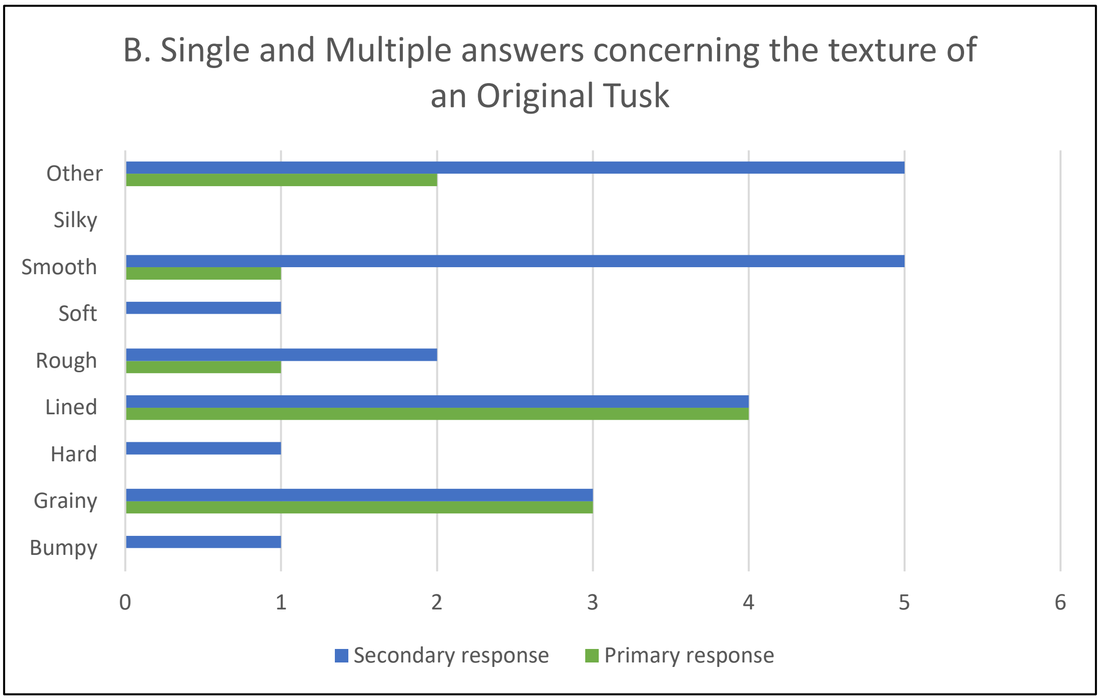


Figure 29 - Texture interpretation of a Tusk Fragment (Original)

were not unexpected, which may have encouraged respondents to think of the material e.g. 'mixture of wood and plastic'.

Definitely, given the lack of familiarity with similar objects to tusk fragments, and the combination of textures exhibited by the original tusk, it was perhaps not surprising that haptic interpretation of Tusk Fragment A (PLA replica) would result in a range of reactions. However, in contrast to Tusk Fragment B (Original mammoth tusk), no one felt that Tusk Fragment A (PLA) was lined at all. This may have been due to the fact that the manufacture of Tusk Fragment A (PLA) did not feature fine details which could be detected through haptic interaction and engagement by four respondents. In other words, eight respondents detected that Tusk Fragment B (original) had the texture of being 'lined' with four choosing 'lined' as their primary response and another four as their secondary response. For museums dealing with 3DMs, if they require fine details then the use of PLA might not be that suitable as details such as the feel of being 'lined' seemed to be undetectable by all my 12 respondents. **Figure 29** shows all the one-word descriptors given for both primary and secondary responses for Tusk Fragment B (Original). As can be seen, the descriptor of 'lined' was chosen by all together eight respondents.

Given the variety of texture exhibited by this original artefact, it is interesting that in consideration of only the first response to texture, there was only five one-word descriptors given in contrast to the secondary responses which then expanded to eight descriptors. In fact, the conclusions drawn by haptic-only manipulation presented a range of eight out of the nine criteria, 'Silky' being the only texture not exhibited by the original tusk fragment. The option 'Other' presented five extra responses: 'woody', 'bark', 'sharp', 'more appropriate to the shape of a sword', but most interestingly, 'not nice to touch' (Participant J).

This negative reaction was unexpected. In the potential of the texture conforming to one of the other nine criteria, the participant expressed some confusion: the object was 'rough and smooth with a slight mixture of everything else'. This could perhaps be the result of their unfamiliarity with the object i.e. an actual mammoth tusk fragment.

The first two responses on the actual mammoth tusk fragment were playing upon the interpretive notion that they were perhaps holding something organic such as a piece of wood from a tree; both respondents at first answered that the object was layered or lined. The previous example was perhaps, only an interpretation of a part of the texture, focussing on the lines on the surface as potential 'rings' thereby indicating an organic growth. Equally and plausibly, the suggestion related to 'wood' may, in fact, indicate a type of combined blend whereby the subject referred to qualities that offer a combination of other textures.

Curiously, for Tusk Fragment D (Paper Replica), the range of textural interpretation was, at first glance, similar to the original object. This is shown in **Figure 30** below. Differences between Tusk Fragment B (original) and Tusk Fragment D (Paper replica) include the primary and secondary reactions of the object not being 'Smooth' but instead in primary responses, as 'Rough' and 'Grainy' and secondary responses as 'Soft'. In this vein, the range bore one similarity to Pot D (paper replica) namely, that there was a breath of range but little in common, explainable by the lack of reference to anything resembling a tusk that, unlike a pot, may have previously been handled and therefore been familiar in texture. The familiar features of Tusk Fragments B (Original) and D (Paper replica) may be explained by fact that they were both organic. Both had a texture that was deemed either 'Lined' or 'Grainy' by the respondents: it was perhaps understandable, given the organic origins of both tusk fragments, that conclusions under 'Other' should, for both, mention 'Wood' as one-word descriptors for the texture and the material.

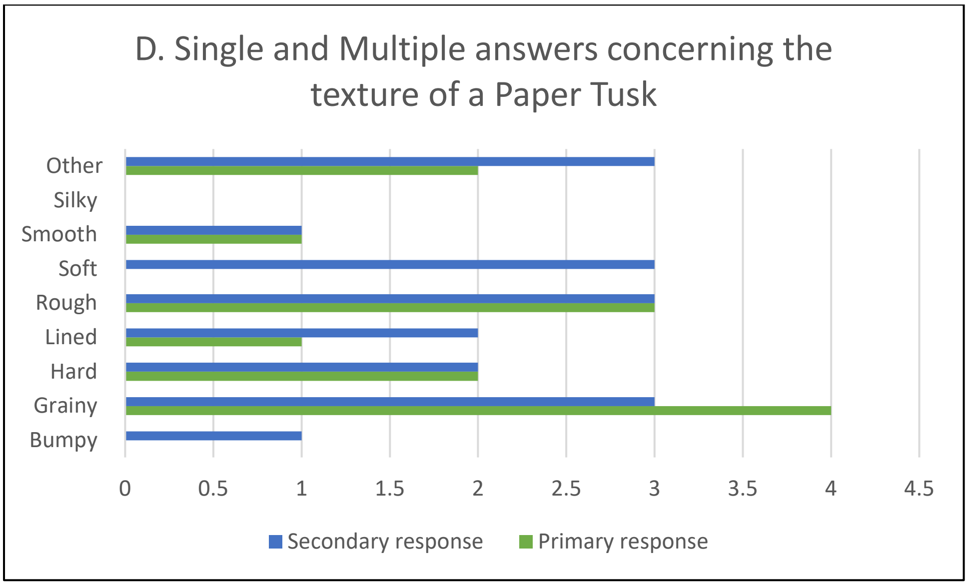


Figure 30 - Texture interpretation of Tusk fragment (Paper 3DM)

The participants, by this point, still had not been told what the object was. Like the previous experiment, they were asked to only haptically review the objects with their eyes closed. They were then asked the question, 'Which one did they like the feel the most and why?'. The majority, seven out of the twelve participants, mentioned Tusk Fragment B because it was haptically appealing as it felt 'authentic' and 'natural'. The other five chose Tusk Fragment D; for Participant J, this was because it felt 'Powdery' which appealed to him. Participant I even ascribed value to Tusk Fragment D, saying that it felt 'safe and hardy' suggesting that, for him, there was some form of emotional engagement with the 3DM via tactile interaction. Participant I was not alone in his affect: another, Participant D, one of the two female lecturers, said there was a 'pleasurable texture' to Tusk Fragment D which, to her was also 'flinty like shale [from a] beach'. Yet another, Participant A likened Tusk Fragment D to being 'furry' in the positive association. As can be seen, through this exercise or experiment in tactile engagement, these participants were having positive associations when touching the 3DM, suggesting that memory, particularly pleasant ones, were recalled. These positive evocations from memory may have been helped by the fact that participants had their eyes closed and were drawing on other sensations which could have encouraged reminiscence.

However, when all the participants opened their eyes, and were asked the question, 'Which Tusk Fragment do you prefer?' all opted for the original mammoth tusk – Tusk Fragment B - which was not unexpected. It would be a rare person not to choose the original artefact.

This mini experiment with the three different tusk fragments of PLA, Paper 3DMs and the original artefact, highlight the importance of both visual and haptic stimuli working together. In the case of both experiments, with iterations of the pots and iterations of the tusk fragments, participants in both cases changed their minds on their preferred object when given visual-haptic stimuli. Therefore, when given only haptic feedback, participants chose the 3DM which met their own expectations of what the object should feel like. However, their decision or preference, when refined by additional analysis i.e. the addition of visual stimuli, would then be reassessed and often, participants changed their minds on what they preferred; this time incorporating the additional information given through visual stimuli. In doing so, these participants indicated which haptic stimuli they preferred i.e. more textural details or types of textural details. In the case of the tusk fragments, greater details were preferred. However, for the pots, weight was the overriding preference when based on haptic-only stimuli (Pot D) but when visual stimuli was added, the preference immediately shifted to Pot A because it had a more pleasing colour as compared to Pot D which, although it had weight, was stark white and seemed to suggest its appearance was alien to the 12 respondents. This switch in preference is important and would be helpful for museums interested in greater engagement by their visitors if and when they invest in having 3DMs as companionable to their main exhibitions.

4.5.3 Part 2 - The Detail in Objects

This part of the experiment on 'detail', which is the experiment following the previous one on texture, came in four small experiments where each introduced an object accompanied by the same two questions which were, first, 'Can you describe the object please?' and secondly, 'Are there any features or patterns that stand out on this object?'. Similar to the experiment on texture which focussed on haptic-only engagement, this section on details also required participants to close their eyes. The objects and the details are shown in **Table 14** below.

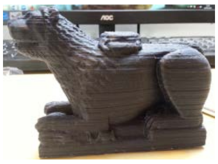
Object	Additional information of Objects used in Experiment on Detail	
Clay Oil Lamp		**18th Century fake of Grecian lamp;** borrowed from the University of Southampton (original size)
Lion Column Base		**ABS Lion Column Base**; a 10x scaled down 3DM as provided by Parma Museum as and accessible through 'Thingiverse'[35]
Shabti Doll		**ABS Shabti Doll**; using Fused Filament Fabrication, 3DM of a Shabti Doll at Winchester City Museum (original size)
Tauros Trigeranus		**PLA/Bronze mix of Tauros Trigeranus;** using Fused Filament Fabrication, 3DM of the Tauros Trigeranus at the Dorset County Museum (original size)

Table 14 – Data Collection C: Experiment of Detail

For this experiment on detail, the participants were no longer limited to my touch criteria used earlier of one-word descriptors with the tenth as 'other'. This was because I wanted my participants to freely offer descriptions which come to mind as they were no longer limited to a pot or tusk fragment but would be introduced to four very different objects and artefacts. They were an actual clay oil lamp, albeit an 18th century fake of a Grecian oil lamp made to look like an object of

[35] Scanned and uploaded by the Museum of Archaeology in Parma, I downloaded to print this as a 3DM in 2013. Subsequent to this the Museum has deleted the digital model from 'Thingiverse'

antiquity; a 3DM of a lion column base which naturally had been scaled down to 10x; and a 3DM of a Shabti doll reproduced at its original size using ABS technology. The fourth item was the 3DM of the Tauros Trigeranus which was made using a PLA/Bronze mix. The last three 3DMs were made using FFF technology although using different filaments.

This time, participants were given up to 20 seconds to offer their responses. Without a pre-determined scale or some set criteria, the variety of answers was understandably greater in context. This was specially designed to allow participants to offer multiple details on what they thought about the object rather than directing their haptic focus on textures alone. Hence, the decision made to not limit participants to the earlier touch criteria of nine one-word descriptors and one description of ‘other’.

Asked together, the two questions in the experiment on detail were designed to encourage descriptions pertaining to information regarding the surface of the object; in this case incorporating the shape of the object. The participants were presented with the object placed in their hands: they were not told about the object nor were they restricted in their own interpretive criteria, as mentioned. In total, 12 participants, all of whom proceeded to orientate the object when it was placed on their hands, gave 42 verbal reactions which corresponded to 19 reactions which is shown in **Figure 31** below. At this point, it is important to note the details on how my participants orientated the objects. Sometimes they used only one hand as a support and the other to touch. In addition, they also used both hands to support with the two hands close together, but still with their fingers feeling the object. They would also move the object, turning it around with one hand and, sometimes placing or balancing the object on a flat surface (the table) or on their other palm. Needless to say, all of my participants engaged in these forms of tactile actions sometimes repeating one action more than others.

As orientation was possible, seven people vocalised identification of a base and three participants mentioned ‘a handle’, making a combination through the addition of certain other points to guess the final object: five were able to correctly guess that it was an oil lamp. This unimodal (touch only) interpretation of this was limited to an extent, given the seemingly effortless interpretation provided by identifiable points of reference such as the handle, the flat surfaces, spherical shape and base of the oil lamp. One curious reaction was also the fact that two respondents mentioned the feeling of ‘cold’ as a detail worthy of note for them regarding the clay oil lamp. This might have been due to the fact that the room was cold and the clay had taken on the ambient temperature. Upon prompting, the two said that it just felt cold to touch. I would speculate that if this reaction was triggered by how clay felt to some of my respondents, then the use of clay in 3DMs might also trigger similar reactions in museum visitors and may be something for museums to note in the future.

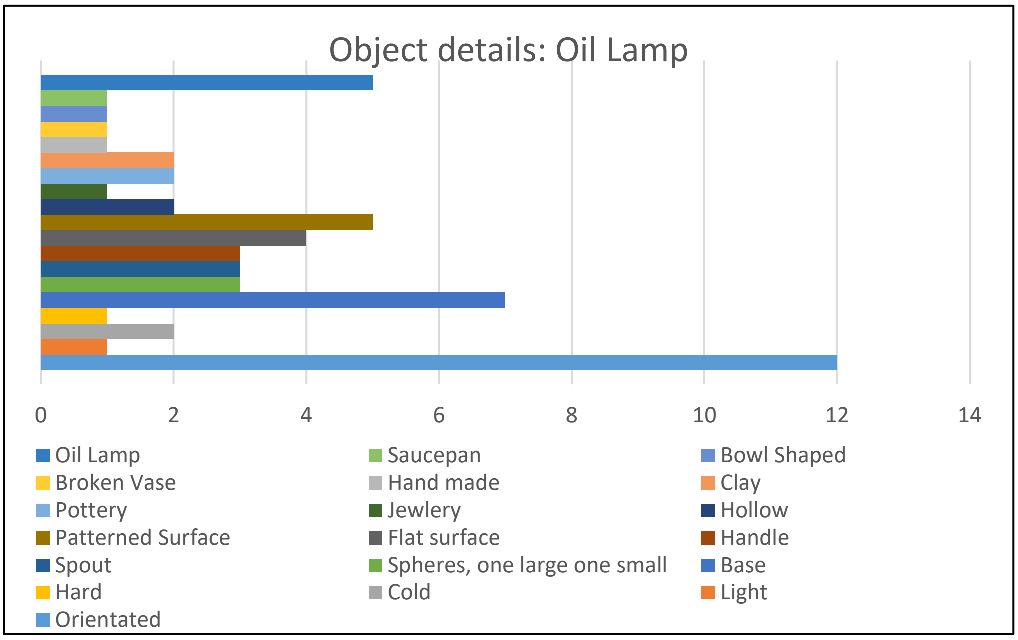


Figure 31 - Object Details of an Oil Lamp (Original)

The next experiment was with the lion column base made from ABS plastic and was about the size of an adult human hand. This object was specifically chosen because it was a scaled down model of a lion column base from the Parma Museum in Italy. As it had the shape of an animal, it was expected that this would produce a greater interpretation with any conclusions drawn being more speculative. The range of answers given by the participants is shown in **Figure 32.**

The answers included 17 different descriptions from the 40 verbal reactions given by the participants. However, due to the participants' lack of familiarity with the object, a smaller interpretive range was not unexpected. Not surprisingly, six animals were mentioned by the participants. They were giraffe, sheep, tiger, horse, bear or just the generic term 'animal', with two of the descriptions having more details such as 'horse with saddle' and 'toy of sheep'. It is worth noting that all twelve of the participants were pleasantly surprised when their touch revealed the object to be in the shape of an animal with exclamations of 'oh' and in the case of two, chuckles. This ready recognition and enjoyment in identifying an animal shape by my 12 adult participants suggest the importance of having objects which are representations of animals. Possibly their enjoyment and even delight could be because of the relatedness of the object to them in their daily life. This association of animal shapes being more relatable could be useful for museums in helping to identify objects from their collections to produce 3DMs.

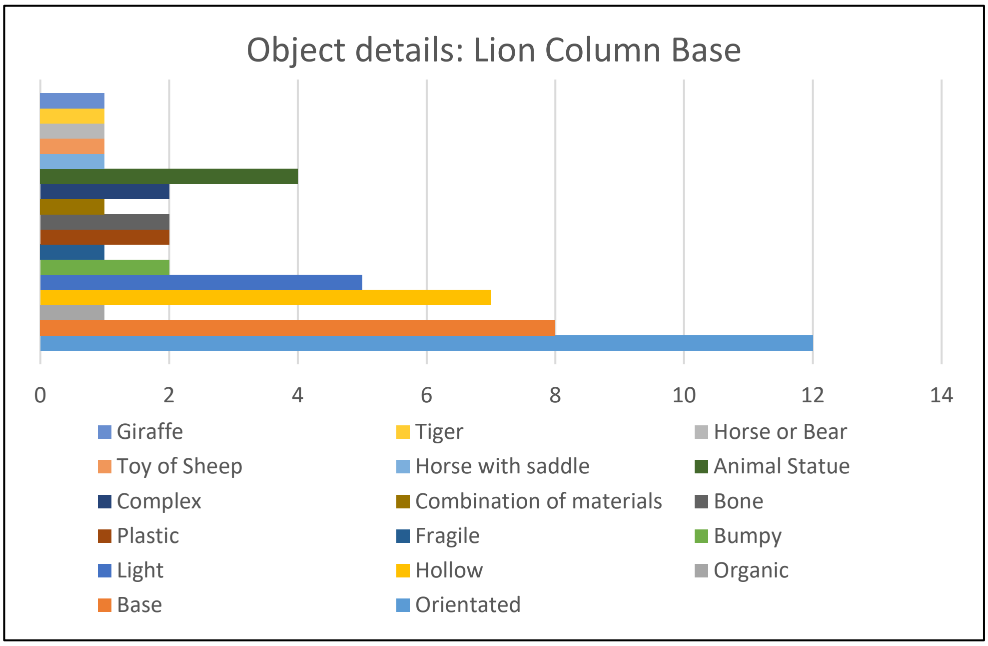


Figure 32 - Object Details of a Lion Column Base (ABS 3DM)

The third mini experiment on detail was on the ABS-produced 3DM Shabti doll, made using FFF technology. In total, the 12 participants mentioned 31 different descriptions corresponding to 14 types. The detail given of an Egyptian sarcophagus was made by one of the lecturers who took great delight in identifying the object for me. Four respondents actually identified the actual object naming it as Shabti, statue and even Egyptian people. Eight mentioned a 'face' which was also correct. Participant D, a lecturer, was most definite: that the 3DM of the Shabti Doll was a 'votive sculpture'. The range of answers for this experiment on detail is shown in **Figure 33**.

It is also worth noting that participants did not restrict themselves nor limited their comments to singular aspects such as shape, material, weight, or roughness. Instead, as seen with the Lion Column Base and the Clay Oil Lamp, participants who identified and recognised certain points of reference, would build up an imaginary picture of this incomplete gestalt. Therefore, nine interpretative images were suggested which corresponded to four descriptions which were suggestive of the ability to form an interpretation based on the addition of some points of reference.

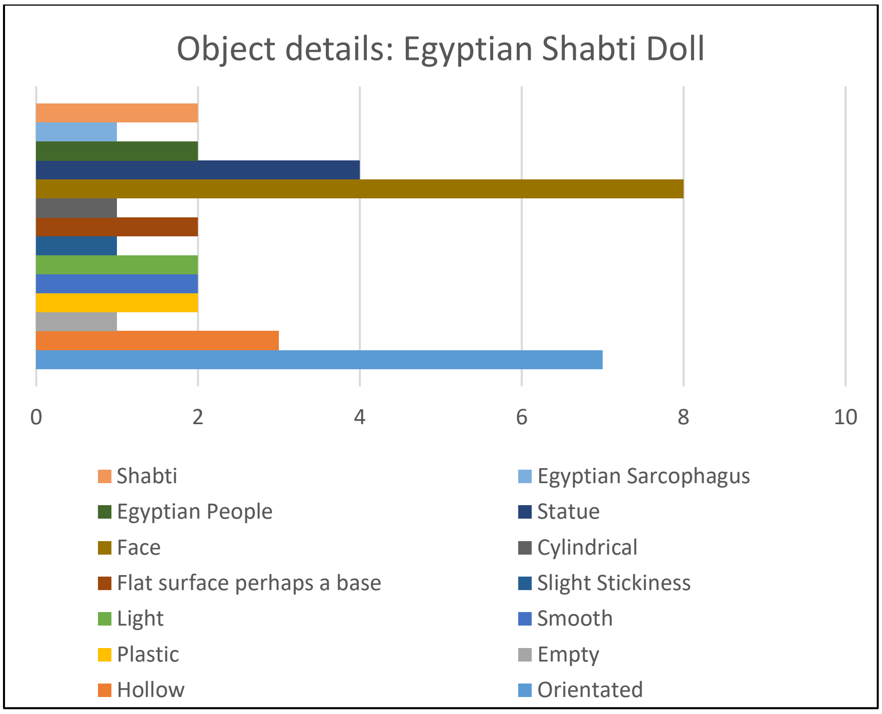


Figure 33 - Object details of a Shabti Doll (PLA 3DM)

Unlike the first three objects - Clay Oil Lamp, Lion Column Base and Shabti Doll – the fourth and final object for the participants was the Tauros Trigeranus. It was believed that none of the participants would be familiar with this object. Therefore, tactile feedback was assisted in the choice to use a rougher bronze and PLA blend material in the 3DM of the Tauros Trigeranus. The additional texture and the added weight could aid in the identification of certain points of reference such as: the legs, tail, mane and heads of the Tauros Trigeranus.

To anyone unfamiliar with the Tauros Trigeranus, it can be a confusing object to feel (it was a bull with two human heads as the third missing head had broken off), and therefore 19 descriptions corresponding to 42 comments resulted from this uncertainty. However, two similarities, both in a way similar to the lion column base, could have aided interpretive identification: points of reference such as a well-defined base assisting in orientation, as well as the animal-like visage, and to a lesser extent, cultural familiarity. A common trope in imagery is the lion, and knowledge of this could have assisted the formation of imagery as informed by a familiar gestalt of an object from Europe.

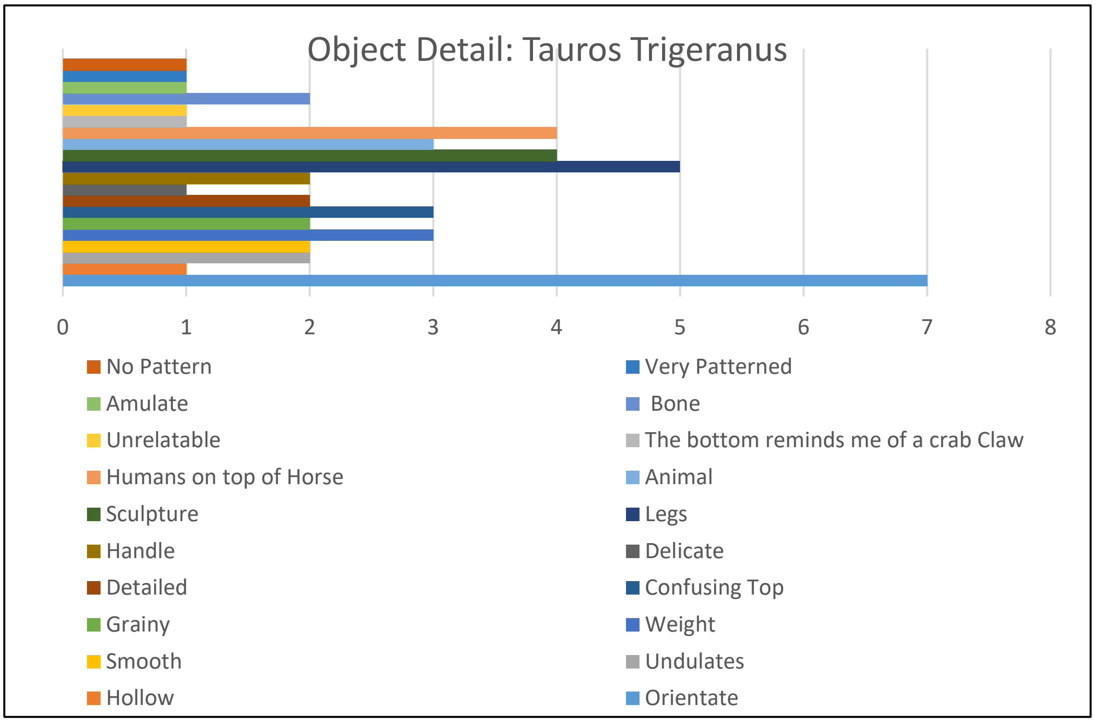


Figure 34 - Object details of the Tauros Trigeranus (PLA/Bronze 3DM)

As mentioned about the possibility for uncertainty, four respondents described the 3DM of the Tauros Trigeranus as 'humans on top of horse', while three others could not guess a specific animal and just gave the generic term 'animal'. One (Participant C) even described it as having a 'confusing top' and that 'It was too much' especially after the participant had counted four legs and noted a face of an animal. Another (Participant H) even claimed that there was no 'pattern' to it. Presumably this was in contradiction to what the participants could also feel through touch: the two human heads in the Tauros Trigeranus. Nonetheless, even with the expressed confusion in trying to identify the Tauros Trigeranus for some, all 12 respondents had great fun with the object, with seven deliberately placing or orientating the object onto the table and letting it balance on its own and of course, hearing it topple over onto the bubble wrap, while having their eyes closed. Although four respondents could not and did not identify the Tauros Trigeranus as a type of animal, with one (Participant E) saying that 'the bottom reminds me of a crab claw', the four enjoyed the chance to move the object around with their hands and feeling the shape. In fact, one third of the participants spontaneously counted the legs of the Tauros Trigeranus when handling the 3DM.

Participant E who was reminded of a 'crab claw' used the words 'the shape undulates' but also claimed that she could not relate the object to anything, crab claw notwithstanding. This suggested however that for Participant E, she wanted to reach an even greater approximation or accuracy in identifying the object. It must also be noted that none of the ones who claimed confusion or uncertainty in identifying the Tauros Trigeranus showed any frustration. In fact, all twelve seemed amused and to even relish the opportunity to handle the 3DM of the Tauros Trigeranus – with some even playing with it such as letting the 3DM balance on two of the legs. Stating the obvious, this enjoyment might have been triggered by the fact that all respondents knew that they were handling 3DMs of museum artefacts, plus it might be because this was a rare opportunity to have fun playing with the object.

Overall, the four experiments focussing on detail indicated that participants enjoyed and even relished the chance to handle the object themselves and had fun trying to guess, often correctly, what the object was. In fact, many participants were more than happy to offer their own unique descriptions and interpretation of what the objects felt like. The possibility that all had their eyes closed may have encouraged them to offer more than one description of the object must, however be acknowledged. Nonetheless the fact that respondents offered a range and wide variety of descriptions must not be discounted: they enjoyed the haptic engagement and interaction with the four objects in question and in total, offered 69 descriptions, albeit with many overlapping.

4.5.4 Part 3 - The Type of Object

To properly expand upon participant interpretation of the 'type' of object, it was thought necessary to divide this section into two parts: the first part introducing two variations upon a similar object in a visual and haptic experiment; and the second, a haptic-only experiment that culminated in an identification test. The two experiments were designed to elicit different interpretative schemes and biases; it was hoped that all experiments would expand upon and narrow the understanding of the type of object which would be useful for museums when selecting which of their original artefacts to duplicate as 3DMs.

The details of the objects used for this experiment on type are shown in **Table 15** below.

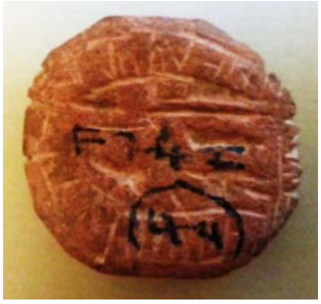
Object	List and Details of objects used in Experiment on Type	
Original Token		**Original Carthaginian Token;** borrowed from The University of Southampton NB: six respondents looked at the original
Replica Token		**PLA/Bronze mix Carthaginian Token;** using Fused Filament Fabrication, 3DM of the Carthaginian Token from The University of Southampton NB: the remaining six respondents looked at the replica
Stone Hand Axe		**Stone Hand Axe;** borrowed from The University of Southampton
3DM Samian Ware Bowl		**Samian Ware Bowl**; using Stereolithography technology, 3DM of a Samian Pot at the Poole Museum

Table 15 – Data Collection C: Experiment on Type

This experiment allowed for both visual and haptic interpretation, to aid interpretation and encourage better possible interpretive interest. Two iterations of a similar object were used; an original and one replica Token from Carthage. Exposure to these objects was not limited to any time because it was thought that interpretation would vary depending on exposure to the original or replica. Therefore, half the participants were exposed to the 3DM replica and the other half to the original (6 participants each) and were only told certain details after the event. Each participant was only shown one object as it was thought that exposure to both, through visual and haptic identification would affect and bias the interpretation of the other. The order of which participant would get which token was decided by an alternating order of the participants. Thus the first, third, fifth, seventh, ninth and eleventh participant handled the original token while the second, fourth, sixth, eighth, tenth and last participant touched the replica token.

For this experiment, three questions were asked: ‘Are there any details that you can see on the object?’; ‘Can you estimate the number of individual lines on the object?’; and, ‘Would you spend more time looking at the object?’. The answers given, as seen on **Figure 35** below, show that responses for the Original Token and Replica Token were different, with more details perceived for the former.

The answers to the three questions asked about the Replica Token, as seen in the top part of **Figure 35** below show the range of interpretation. In answer to the first question, ‘Are there any details that you can see on the object?’, all six respondents looked at and rubbed the Replica Token in order to obtain greater details through visual and haptic interaction. This resulted in three participants giving the answer of ‘writing’ and one each for ‘Lines’, ‘Faces’ and ‘Meaning’. This action of rubbing the Replica Token may have been provoked by its somewhat dull green colour, the appearance of which could have limited visual details. This was in contrast to the Original Token whereby the participants were able to offer more detailed descriptions such as ‘animal’ and ‘map directions’.

For the next question which asked, ‘Can you estimate the number of individual lines on the object?’, the participants handling the Original Token were able to offer a greater number of individual lines. In fact, three counted more than 50 lines with one giving up the effort of counting because too many lines could be discerned. This was in contrast to the 3DM of the token because the highest number reached was by one participant who counted at most, 30 to 34 lines. The details that were detected by the participants with the original token seem to suggest that the 3DM was not detailed enough to offer this type of information. In other words, without knowing more about the original token, participants may not be able to fully obtain more extensive information about the original artefact as suggested by those who had the opportunity to handle the latter.

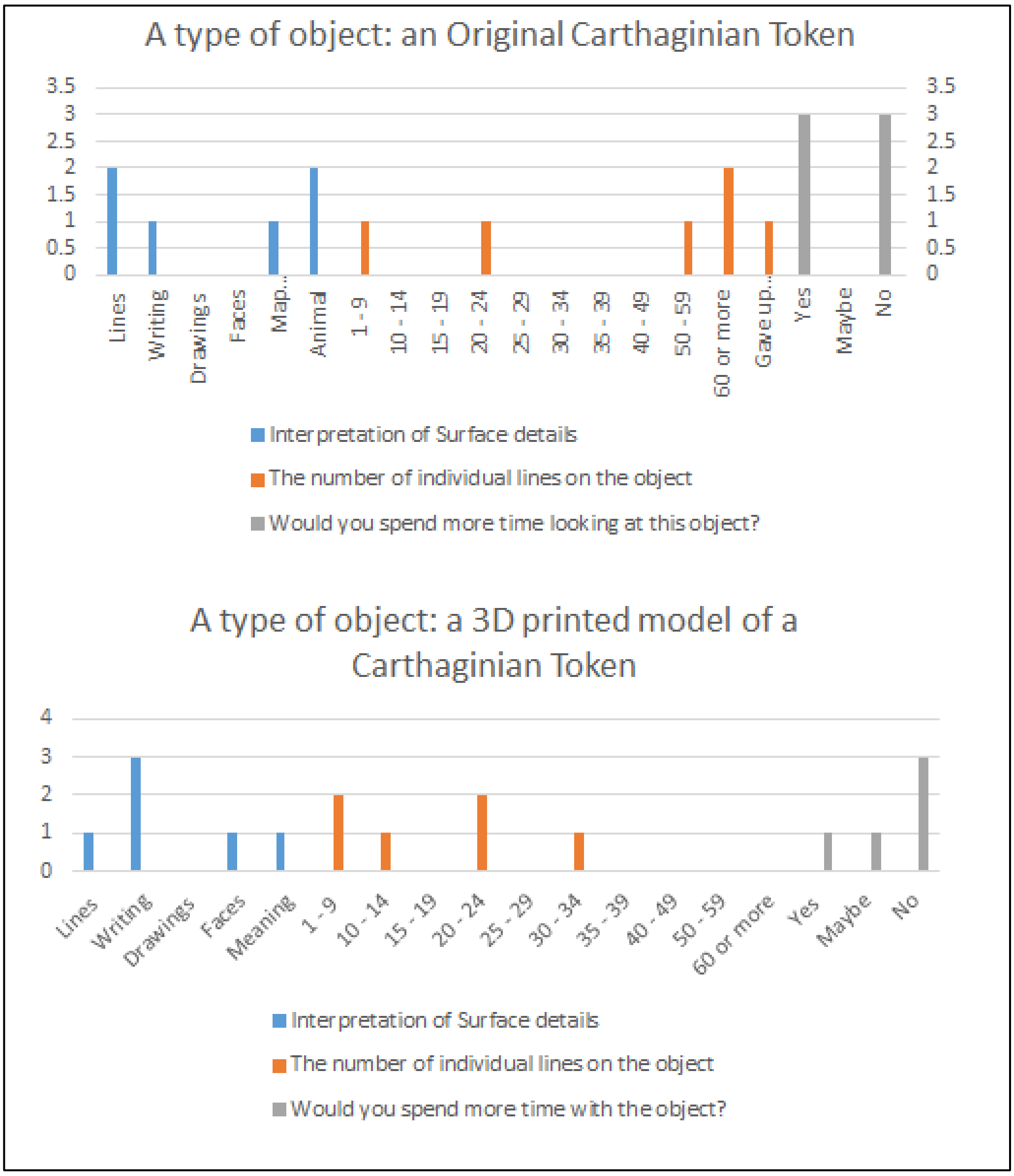


Figure 35 - Responses to two types of Tokens (PLA and Original)

Interpretation of the original seemed to display a polarity consistent throughout all three questions, suggesting somewhat a standard pattern of points of reference acting to focus interpretation. This suggested three issues: a greater interest in the original, possibly because of variation in surface colour; a lack of definition in the lines of the replica, either caused by the process of printing eroding certain details or the uniformity of the colour; or finally, the perceived continuation of a pattern on the surface of the replica.

The matter of interest limiting the interpretation of the replica may not be seen as a limiting factor in interpretation. A total of only one out of the six respondents said 'yes' to the question 'Would you spend more time looking at the object?' for the token. This was in contrast to three participants who having handled the original token, said that they would spend more time looking at it.

After handling the tokens – both original and replica – with their eyes closed, the 12 participants were then asked to close their eyes for the next two mini experiments on type. As the next two experiments were done with the participants' eyes closed, I re-introduced my touch criteria used earlier, and as previously mentioned, this was made of nine one-word descriptors with the tenth on 'other'. This was necessary so as to help participants select the choice which best fitted what they felt in their tactile interaction with both the stone hand axe and the 3DM Samian ware pot.

The first experiment mentioned earlier, was a Neolithic stone hand axe which was around the size of an adult palm and was understandably heavier than the rest of the objects handled previously. The second mini test was the 3DM of a Samian ware bowl made using SLA technology. For each of the two mini tests, the participants were asked the following three questions: 'What material is the object made from?'; 'How does the surface feel?'; and finally, 'Given that this is a piece of archaeology usually exhibited in a museum: what is it?'.

It is worth mentioning that the objects were conducted without the participants having any prior knowledge about the objects that they were handling: both were kept hidden from view. This was because the experiments dealt with 'Type' and were designed to provoke interpretation and categorisation. Asking the three questions, inspired in part, by sections one and two, this haptic-only experiment sought to obtain information if data gained through handling, could result in a name being given to the object. As can be seen, each of my four experiments sought to obtain information on each specific aspect or feature that could be derived from haptic-only engagement or from both haptic-visual engagement.

The responses given by the 12 participants are presented below and can be seen in **Figure 36**.

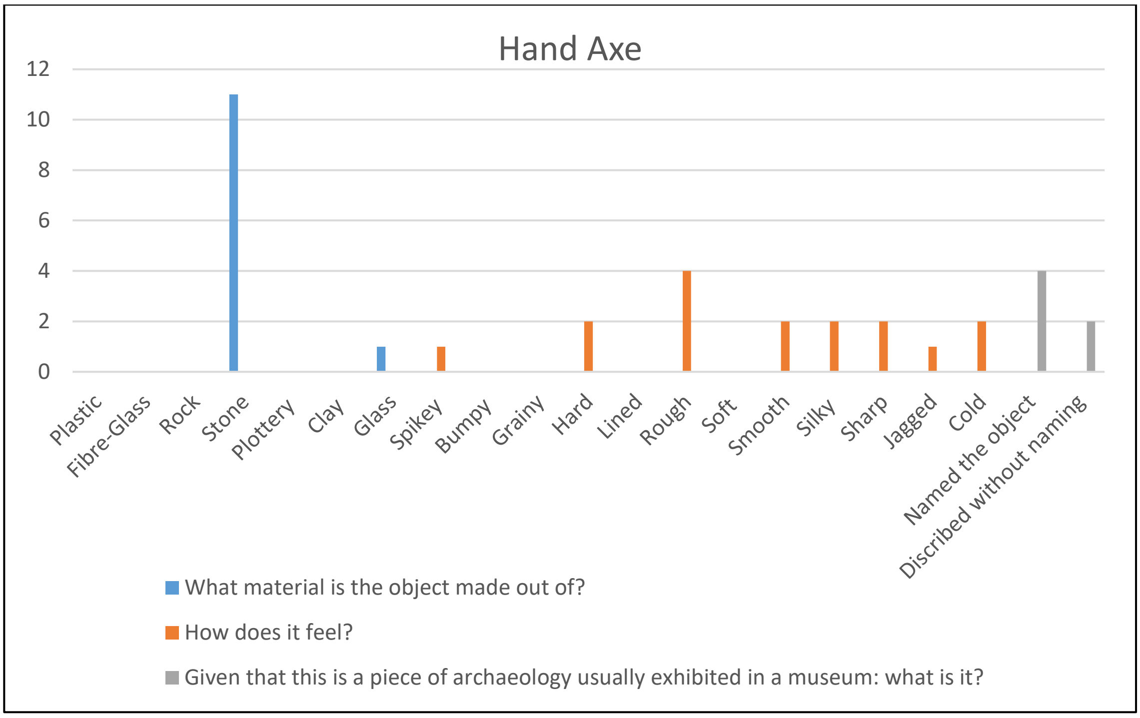


Figure 36 - Stone Hand-Axe: Identification on Type

Presented with an original Hand Axe, all 12 participants engaged with the object, with the lack of sight as an information source contributing to their curiosity. The fact that most participants, without delay, responded by saying that the object was made of stone, and even identification of the object, was not surprising given that stones are common and readily recognisable and therefore participants possess relative familiarity with this type of material.

Interesting however, was the range given for the feel, the original range of 9 one-word descriptors for my touch criteria was added to by three participants who concluded that the stone hand axe was 'Jagged','Sharp' and 'Cold' – the first two being qualities that suggested texture that was not uniform. Understandably, there was an overlap with the touch quality of 'hard' and 'rough' which two and four participants identified for me, respectively. Several also named the stone hand axe as 'fossil' (Participant E), 'flint' (Participant G, a lecturer), 'hunting or cutting tool' (Participant J, a lecturer), 'flint cutting tool' (Participant H), and even an 'arrow blade' (Participant D, a lecturer); while Participant A, the librarian, said 'flint, scraper or hand axe'. The majority who provided specific answers to what the stone hand axe felt like were the three lecturers, a librarian and two students, suggesting that education and familiarity with documentaries might have informed the answers.

After that, as mentioned, the participants still with their eyes closed were then given the 3DM Samian ware bowl to touch and handle. In other words, no one saw or had a look at the stone hand axe. This was deliberate because I did not want anyone to change their minds or switch their preferences: the primary purpose of having the experiment was to investigate if participants could identify an object based on touch of an unknown object i.e. the stone hand axe. As mentioned, the stone hand axe was deliberately chosen and borrowed from the University of Southampton due to the fact that the stone hand axe had unique features suitable for tactile engagement and stimulation such as both flat and sharp surfaces, as well as a solid feel to it while in some places, it was also both smooth and rough: qualities of textural features which participants identified for me. In fact, two participants mentioned 'smooth' as a feature of the stone hand axe.

Returning to the 3DM Samian ware bowl, the twelve participants had no difficulty identifying what it was – a bowl – although no one mentioned that it was the same bowl that was used in the first experiment on texture (where they also closed their eyes). This was deliberate – using the same bowl – because I wanted to see if participants could recall or relate an earlier handling activity which they had previously identified as a bowl or pot. No one mentioned this similarity and I did not prompt anyone to do so. This could be due to the fact that the participants had already handled eleven different objects, both original and 3DM.

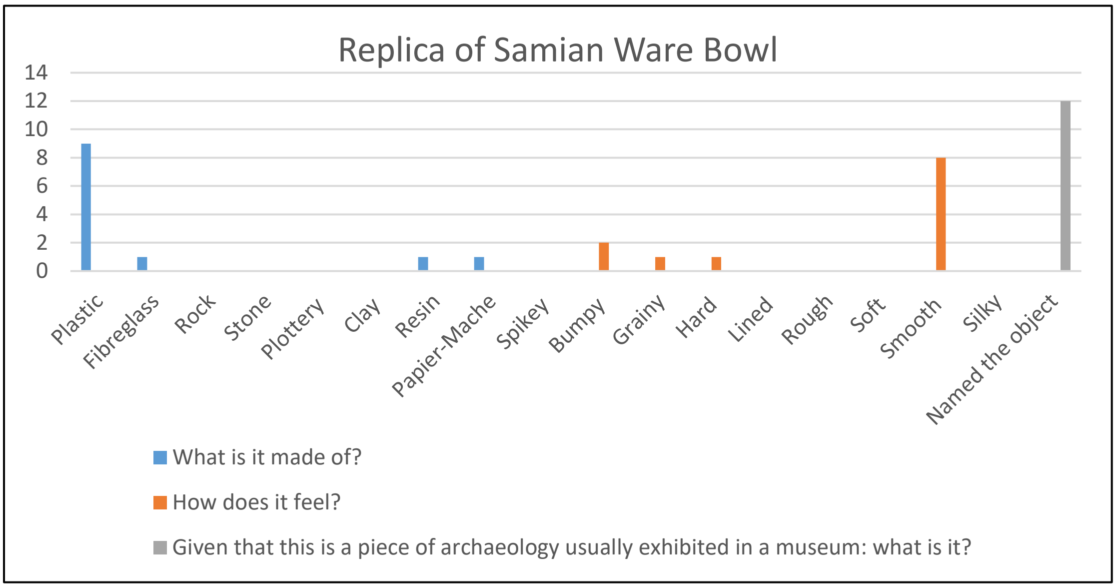


Figure 37 - Samian Bowl: Identification of Type

For the next question which asked, 'What material is it made of?', eleven out of the twelve concluded with three closely related materials: Plastic, Fibreglass and Resin. Their answers are shown in **Figure 37** above. Given the SLA 3DP process with the use of photo-reactive resin, all three answers were correct. Papier-mâché however, was an interesting conclusion perhaps showing the expectations as gained through familiarity in work or a reaction to a touch sensation that is reminiscent of Papier-mâché, although it must be admitted that the 3DM was definitely not similar to the touch or feel associated with papier-mâché. The association drawn could have been due to the fact that many objects commonly associated with papier-mâché are often bowls or plates.

The second question had already been asked in the first experiment on 'Texture': the question asked was the same in parts one and three, 'When you touch the surface of the object, how does it feel?' This question was asked with the same one-word descriptor in my touch scale or criteria to find out if participants could recognise through touching the surface of a haptically identifiable object. The answers, given by the participants, varied from those previously given in the earlier experiment on texture. The earlier experiment on texture on the same 3DM Samian ware pot (SLA replica) had participants offering six different one-word descriptors. However, when asked again, this time the focus on type, the twelve respondents converged to only four one-word descriptors which were 'bumpy', 'grainy', 'hard' and 'smooth'. Although the descriptors narrowed to four, there was one new descriptor which was 'bumpy'. This was due to the fact that two participants touched and felt the grooves of the 3DM Samian ware bowl. Their answers on type, together with earlier ones on texture, can be seen in **Figure 38** below.

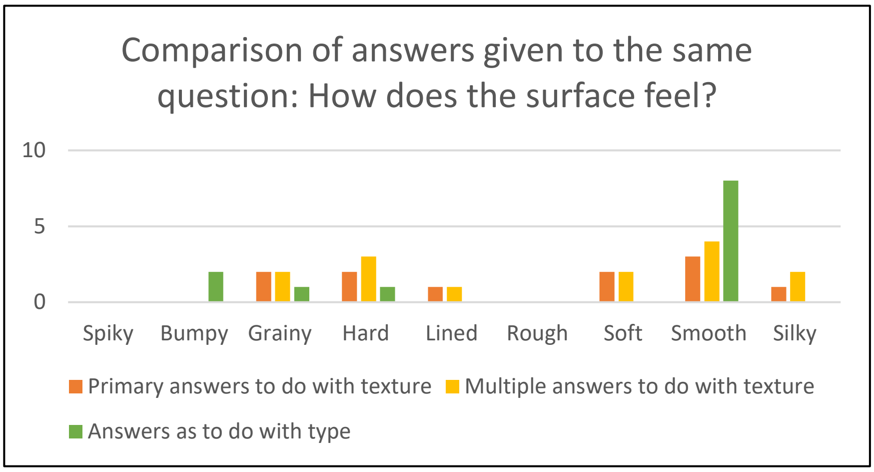


Figure 38 - Samian Bowl: A comparison of answers given to the same question the feel of the surface

Except for the appearance of 'Bumpy' that could have either been gained from 'Grainy' or 'Lined' elements, other considerations in this range seemed to have been transferred to 'Smooth'. This final experiment on type may suggest that respondents, through haptic interaction and engagement with different types of objects have learnt greater discernment or discrimination in their choices. In other words, participants seemed to have learnt or gained something from the experiments and therefore were not so scattered in offering their choices. In fact, as can be seen in **Figure 38**, all four choices selected by the twelve participants are all viable choices for the 3DM Samian ware bowl.

4.5.5 Part 4 - The Scale of Object

The aim of the last part of my experiment was to investigate whether the scaling of a 3DM could assist with identification. For this touch-only experiment (with eyes closed), the participants were presented with two distinct 3DP objects, a Shabti Doll and a Pot. Only the Pot had been used before. Both pot and Shabti doll were modified to direct focus onto specific details seen as important to understanding the role of scale in tactile identification. This can be seen in **Table 16**.

	Variety of Objects used for tests on 'Scale'	
1		**Samian Ware Bowl;** at 1× scale using Fused Filament Fabrication (FFF), 3DM of a Samian Pot at the Dorset County Museum
2		**Samian Ware Bowl;** at 1.5 x scale using Fused Filament Fabrication (FFF), 3DM of a Samian Pot at the Dorset County Museum
3		**PLA Shabti Doll;** at 1× scale using Fused Filament Fabrication (FFF), 3DM of a Shabti Doll at the Winchester City Museum (with the head cut off)
4		**PLA Shabti Doll;** at 2× scale using Fused Filament Fabrication (FFF), 3DM of a Shabti Doll at the Winchester City Museum (with the head cut off)
5		**PLA Eye Hieroglyph of Shabti Doll;** at 3 x and 6× scale using Fused Filament Fabrication (FFF), 3DM taken from of a Shabti Doll at the Winchester City Museum (only the eye of the doll was used – the rest were cut off)

Table 16 – Data Collection C: The 3DM used in activities to do with Scale

This experiment was divided into five mini experiments where the first was on a Samian Ware Bowl at original size (1x) ; the second was again the Samian Ware Bowl, though at one and a half times its size (1.5x); the third moved to the Shabti doll at original size (1x); fourth, again the same Shabti doll but at twice its size (2x) and finally, the fifth test which involved two objects - the concentration on one eye hieroglyph - at three times the size (3x) and at six times the size (6x). The deliberate scaling up of the objects was made in order to see how and at which scale would then prove either effective or ineffective for participants to identify or obtain additional tactile information. In addition, no participant was informed that they were handling the same 3DM albeit at different scales. With their eyes closed, only one participant (Participant H) seemed to have figured out that they were holding the same 3DMs of different scales in the last experiment.

For the first two tests using both Samian Ware Bowls of 1x and 1.5x, I asked the following two questions: 'Can you count the shapes?' and 'Can you recognise the shapes?'. This was in reference to the raised shape or patterns found on the 3DMs of the Samian Ware Bowl. The answers by the twelve participants for both different scales can be found in **Figure 39.** For convenience, I also offered a scale on the number of shapes: for example, 2- 4 shapes; 5 -10; 11- 15; 16 - 20; 21 – 25; 26 – 30 and finally, 'No defined shapes'.

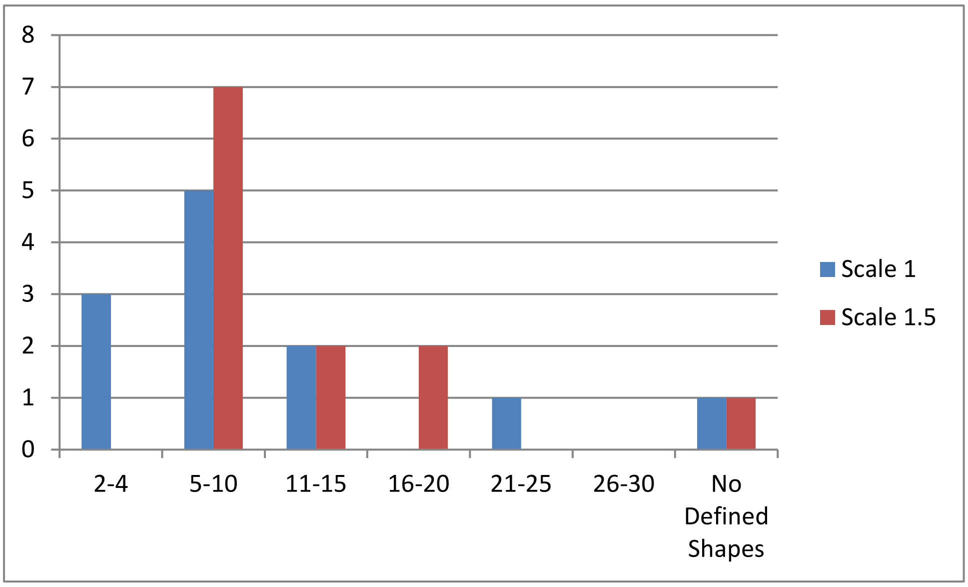


Figure 39 - Object/Shape identification of a 3DM Bowl at scale (1x and 1.5x)

The participants, asked to count the number of individual shapes on the Simian Ware Bowl gave differing reactions depending on the scale. Those who reacted with the conclusion that 'There were no defined shapes' were found to give one of two reactions: 'the material is too smooth to count individual shapes', and also that 'there is one continuous pattern' (Participant H). Conclusions concerning lack of definition fell by 43% and considerations re-distributed to the lower end of the range with 5 to 15 shapes being the identifiable range. In fact, for ten of the participants, when the 3DM was bigger at 1.5x, the ability to detect the number of individual shapes increased. For some, the increase was almost double. For example, for Participants E and G, this increased from 2-4 to 5-10; Participant C's increase was slightly more than double, from 3 shapes detected, this increased to 8 shapes at 1.5x. There would seem to be a correlation between the identification of shapes and the scale of the object where the bigger the object at 1.5x, the easier it seemed for the participants to identify the number of shapes except for two: Participants J and K. However, for the next question to identify the shapes at the same 1.5x, the same Participant J detected something which he could not previously detect at the original scale of 1x: a shape which zigzagged that he named as a 'pinecone' at the bigger 1.5x scale.

In general, for the question concerning recognition of the shapes in the Samian ware bowl, it seemed that the larger scale had, in this case, decreased uncertainty: with some offering answers like 'cuboid' (Participant L); 'fish' Participant I) and 'ripples' (Participant F) as the shapes etched on the bowl. In other words, at the original scale which admittedly was small, many participants could not discern individual shapes and therefore, could not identify, or feel that they could confidently identify what the bumps and shapes were on the 3DM Samian ware pot at 1x.

Given the number and variety of figures on the surface of the object, the wide range was not surprising as interpretation of this information via touch resulted in greater individual approximations of what the participants expected. It is the fact that many participants counted more shapes at 1.5x, which is of interest here. This is because this suggested that more textural information and details could be gleaned at a higher scale. This was also supported by the earlier experiment which asked participants to count the number of objects with fewer objects being identified by participants at the original scale or size at 1x.

To reiterate, at a higher scale of 1.5x respondents not only counted more figures, their identification of shapes and figures also increased in accuracy. Thus, this leads to the suggestion that having bigger 3DMs might be beneficial for certain objects in a museum's collection as these 3DMs would or could aid in haptic interpretation. After all, as museums already provided magnifying glasses for some exhibits, the use of amplification in 3DMs by museums could be considered in the same category: as important aids to visitor engagement with the original artefacts, though in the case of the 3DMs, also greater visitor interaction through both touch and sight.

The next mini experiment was based on the Shabti Doll with the head deliberately cut off so as to direct focus onto the relevant details found on the 3DM itself. The two Shabti Dolls were 3DMs made out of PLA plastic where the first one was made at its original scale or size 1x while the other was twice as big at 2x. As this was still a haptic-only experiment, the participants were asked to keep their eyes closed (note: their eyes were closed during the previous experiment with the 3DMs of the Samian ware bowl at 1x and 1.5x). This last part of the experiment was to look at how participants adopted touch interpretation of a set of Hieroglyphics as presented on the front part of the Shabti doll at 1x and 2x scales. The answers given by the participants are shown in **Figure 40** below.

Presented to the participants sequentially, the same two questions were asked: 'Can you count the shapes?' and 'Can you recognise the shapes?' The information gained from the question, 'Can you count the shapes?' allowed for positive tactile identification of shapes which were indented on the surface of both 3DMs of the Shabti Doll at 1x and 2x. Presented with the to-scale model at 1x, the participants varied in their answers: one participant could only detect between 2 to 4 shapes, while another detected between 5 to 10 shapes and three detected between 26 to 30 shapes. What seemed most interesting is that seven participants claimed that there were no defined shapes that could be detected. However, when the scale for the front of the Shabti Doll doubled at 2x, the number of participants who detected shapes jumped to seven from four. In other words, at the amplification of 2x scale, participants felt more confident in detecting the shapes. This time three participants were able to count of 5 to 10 shapes, another found between 11 to 15 shapes and another between 26 to 30 shapes. Although this was a simple activity, the responses from the participants also indicated greater enjoyment from detecting and identifying the shapes, suggesting a possible link between achievement and enjoyment in this simple activity.

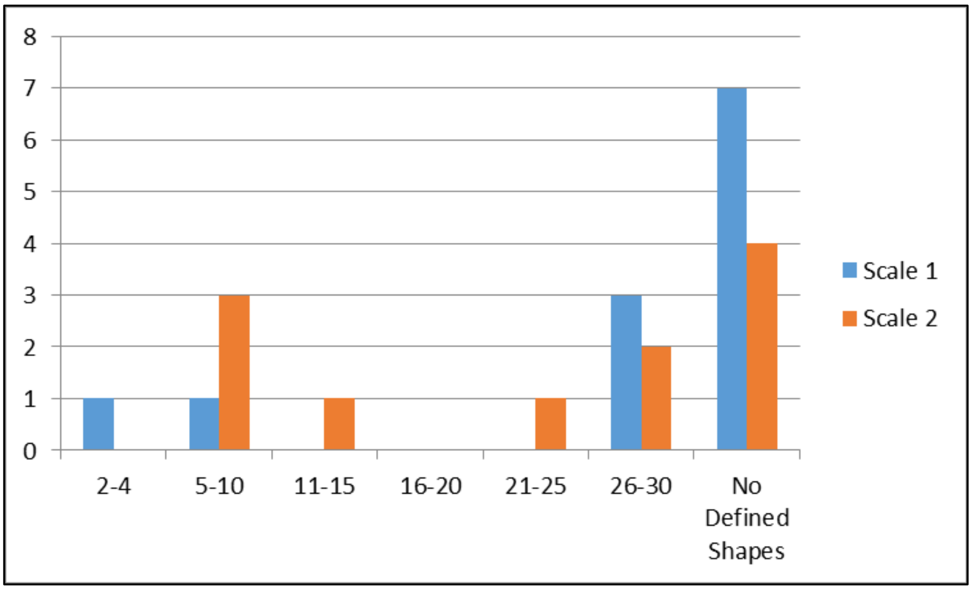


Figure 40 - Object/Shape identification of 3DM Shabti Doll (1x and 2x)

Also, at 2x scale, the answers for what the shapes looked like on the Shabti Doll became more specific with four participants offering answers such as 'Faces', 'Snake', 'Trees' and 'Floral', respectively. In fact, for Participant E, who claimed that the shapes on the 3DM Shabti Doll at 1x was not defined enough, just smiled and gave up, refusing to offer any answer; but at 2x, the smile became broader and this time, Participant E detected trees and offered the number of six shapes, presumably of trees. This was the same for another participant (Participant L) who, at 2x the amplification of the Shabti Doll said, 'There is more of a distinction [now there are] raised domes and rectangles'. It must be noted that for two participants who earlier were able to detect or identify the shapes at 1x, now refined their answers: Participant D who identified 'raised spears', now modified her answer to faces although she also decreased the number of shapes from between 26 to 30 at 1x scale to detecting 11 to 15 shapes. Participant I who earlier said that he felt a 'camel' at the 1x scale, now detected a snake among the shapes he felt which were within the range 26 to 30. It must be emphasised here that because the participants were not told they were handling the same 3DMs at 1x and 2x scale, this refinement or changes in answers on what they could detect through touch is significant: this showed that amplification had an effect on their answers. It must be stressed that there were changes in all the participants' answers from handling the same 3DM model at 1x scale to 2x scale. For some, this meant an increase in detecting the number of shapes, for others this meant a refinement in their ability to both detect and identify the shapes.

It would seem that the more accurate range was established with the doubling of the Shabti Doll at 2x scale. Participant interpretation of individual shapes seemed to have been limited somewhat by the introduction of a set of hieroglyphics at the original scale with seven participants unable to find any defined shapes at all. Similarly, the participants were just as uncertain about detecting the types of shape with one participant (Participant F) stating that it felt like the 'hide of an elephant' at the original scale. The amplification of the 3DM Shabti Doll to 2x scale, as can be seen, led to greater haptic discernment for the participants with Participant H mentioning that the shapes on the 3DM, in contrast to the earlier object handled, no longer seemed 'random'.

This greater amplification for both the 3DMs of the Samian ware pot and the Shabti doll may have benefitted the relatively simple task of counting the shapes on the surface of the 3DM; but identification was to have the greater interpretative impact or effect. As more of the participants offered a greater number of interpretative answers for the shapes at the higher amplification, many of them seemed to take pride in their ability to detect the shapes with one person out of twelve accurately mentioning hieroglyphics (Participant G) in the experiment with the Shabti Doll at 2x scale. This implies that at the original scale of the 3DM Shabti Doll, Participant G was not able to form any interpretive analysis but was only able to do that at the larger scale.

The final and last mini experiment involved two 3DMs which were made from the same Shabti Doll used previously. The 3DMs were on a chosen hieroglyph, the first at 3× scale and the next at 6× scale. The hieroglyph was chosen as something relatable given that it was from the previous Shabti Doll. This experiment asked the participants one question who in turn would haptically engage with the scaled 3DM, first with at the 3x scale and then at the 6x scale.

The Hieroglyph chosen was that of an 'Eye' as it was thought that a shape like this would, even out of context, be recognisable and thus possess relatable associations. As this was still part of the experiment on scale based on the Shabti Doll, there were perhaps two expected outcomes: a positive relation between scale and interpretation impacting upon identification; or the reliance upon points of reference, such as either identification of a relatable image or the identification that this was a continuation from the same Shabti Doll used earlier.

Just like the previous haptic-only experiment, this one on the hieroglyph of the eye from the Shabti Doll required the participants to have their eyes closed. Again, no information was given regarding the 3DM to be handled. Thus, participants were not primed to expect hieroglyphs and neither were they primed to retain information gleaned from the previous mini experiment. Just as in previous experiments, I asked the participants questions, this time it was only one question, which was 'What pattern is represented here?' for the two times I handed them the 3DM Eye Hieroglyphs at 3x and 6x, respectively. It must be stated here that the aim of this final experiment was not to obtain specifically correct identification but to investigate how participants react and how much effort they were prepared to expend, particularly as this was the last and final experiment. This must have been, for each participant, around the 35th minute that they were doing the haptic (with some visual) experiments with me. The answers which the 12 participants gave are shown in **Figure 41** below.

In the experiment, as mentioned, there was no focused identification. In fact, context was withheld as there was no suggestion as to what the object may be.

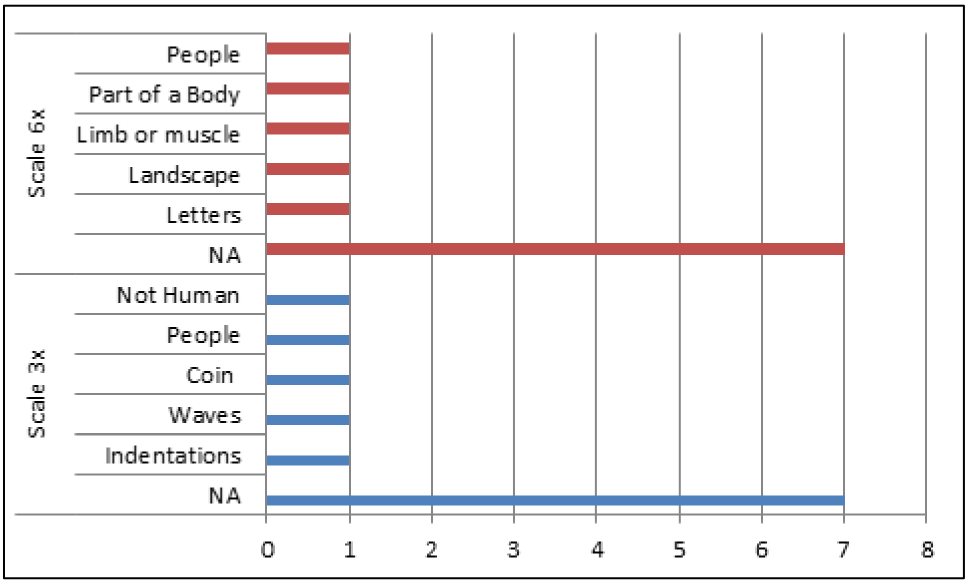


Figure 41 - Haptic Identification of Eye Hieroglyph (3x and 6x)

The participants were only given the 3DM Eye Hieroglyph to touch and then from their haptic engagement, offer their interpretation of the hieroglyph or what their touched revealed to me. Looking for answers closest to identifying the 3DM Eye Hieroglyph, the interpretation of the object as a 'limb or a muscle' as indicating a singular piece of anatomy is, perhaps, the closest. However, that was only possible as a guess at 6x scale. For the interpretation at 3x scale, seven participants could not figure out what the 3DM Eye Hieroglyph was and did not offer any guesses. This was the same at 6x scale. What was interesting, however, was the fact that four participants (F, J, H and K) did not detect anything at 3x scale and also 6x scale. However, for three participants (D, E and G) their first answer at 3x was no, but at 6x, it was ‘No [but now] more intriguing, more detail and variation’; ‘No [but there are] pinch marks’; and ‘Limbs and muscles’, respectively. Thus, for these three participants, the scaling at 6x of the 3DM Eye Hieroglyph proved to be ultimately more useful in the fact that it offered slightly more details for them to offer some form of interpretation. For participant I, there was no change in his answer which was ‘people’ for either at 3x or 6x of the 3DM Eye Hieroglyph. However, for Participants C and L, both changed their answers from their earlier one at 3x of the 3DM Eye Hieroglyph: from ‘coin’ to ‘landscape’; and from ‘wave’ to ‘part of body’, respectively. This is rather interesting because at the scaling up of 6x, for participants C and L, this amplification seems to offer, at least for them, greater and more specific information. After all, a wave is like a pattern but ‘part of body’ is object-specific. The same could be said about the ‘coin’ to ‘landscape’, presumably the latter having indentations simulating hills and valleys.

While amplification at 6x seems to suggest better and greater interpretive possibilities for six participants (four were convinced they could not detect anything with both 3DMs), two participants, however, seemed to have lost their ability to discern any shapes at the 6x scale of the 3DM Eye Hieroglyph. They were Participants A and B. For Participant A, at 3x scale she detected a few indentations but claimed not to be able to detect any object; this became worse at 6x because she was firm in her statement that she could not detect anything at that scale. Her answer was a straight ‘no, I cannot feel anything’. For Participant B, the first reply at 3x of the 3DM Eye Hieroglyph was ‘Not a human being’, but at 6x, the answer, just like Participant A, was also ‘No’ or ‘nothing’.

Information from these two participants is interesting: it is not always obvious that everyone would be able to detect more information and have greater interpretive abilities at higher scaling in the 3DMs, which is not unexpected. However, from the various experiments on scaling – the majority of the participants seem to be able to glean more information from the bigger models. For them, the ability to handle and to feel the bigger and more obvious indentations, bumps, grooves, etc. was a welcome addition to their own abilities to analyse and interpret from their haptic-only engagement with the 3DMs.

4.6 In Summary

The results from all three groups A – curatorial staff; B – museum visitors; C – Academics – display great interpretive variety, if not enjoyment with handling activities for the last two groups of B and C. The curatorial staff from Group A displayed wide knowledge of 3DPT and a desire to perhaps implement the technology as there was a growing awareness that this technology could benefit their museum. As such, information from the 11 museums which responded indicated positive reception towards how the uses of 3DPT could engage their visitors. In particular their responses, in the majority, showed that they were willing to apply 3DM in the foreseeable future by having both supervised and unsupervised interactive activities with 3DMs from their collections. In other words, the use of the 3DM, as a companion piece, acting to assist the visitor in object interpretation would, if conducted in-house and on a wide-scale, certainly add to object interpretation.

Data on Group B which were made up of museum visitors from two museums indicated that they were happy to engage with 3DM and showed interest in the technology as a whole, given that 42 people attended my public presentation on the general use of 3DPT but even better, indicated in the large majority that they were keen to have more handling opportunities with 3DMs. In particular, many even offered suggestions on what types and what added specifications to the 3DM would add to their enjoyment and interpretive engagement with the original artefact and 3DMs. Specifically, there was a group of visitors in one museum who could not wait to rush off to view the original artefact in the museum, which I had earlier borrowed to scan and print as part of my 3DM handling brief exercise with them. This data collection also revealed the value of having 3DMs nearby and accessible: two young children ran up and started playing with the 3DM of the bone comb. Bitgood (2015) refers to such activities as 'unprovoked' and therefore views them positively when they occur in the museum environment.

Data on Group C focussing on haptic-only and haptic-visual interaction, was from 12 academics who volunteered in my experiments and offered crucial information, previously unavailable on how texture, details, type and scale in 3DM could affect or influence haptic interpretation. Whilst each data collection group has its own motivation, 'A' to show potential application within the museum, 'B' reception and interpretation, and 'C' to show the interpretive impact in potential; all three indicate the complementary ability of 3DM to object interpretation within the museum for visitors.

Chapter 5: Discussion - The Potential of 3DMs in Museums

5.1 Introduction

As shown in Chapter Four, the potential for the use and application of 3DMs in museums was positively received by my three different groups of respondents. Indeed, the findings from these experiments indicate how the in-house use of models can be further developed to increase visitor engagement and interaction with 3DM and through this, benefit the original artefact's interpretation. Multi-sensory interaction with 3DM has shown that this can be a welcomed addition to the interpretation of original artefacts in museums. The addition can allow for experimentation with exhibitions, introducing a newly accessible interaction that elaborates upon the source of stimulus which are both tactile and visual. 3DMs are relatively accurate replica models of the original museum piece, and as such, are accurate models that allow for the introduction of a tactile dynamic. It is through this close interaction that the individual can learn about the original artefact through the interaction with the model. In practicality, interaction with the 3DM will be both tactile and visual and thereby similarities with the artefact need inclusion: the shape and texture of the object as well as a variety of details that ultimately has to produce a satisfactory visual representation, suggested in the findings on 'texture' for Pot D (Paper replica). It is how the museum further exploits this in exhibition that is the potential for these museums to offer a more participatory experience for their visitors. Museums could produce 3DMs that enhance certain details over others, alter the weight of the object to produce different reactions, or experiment with scales to enhance visitor interpretation.

5.1.1 Scale

As mentioned earlier in Chapter 2, touch can be remarkably specific in object categorisation and recognition (Klatzky and Lederman 1993; Gaissert and Wallraven 2013). As suggested by this research, tactile engagement can provide further information such as grouping and identifying objects; my data collection based on 3DM handling activities also indicate similar results (Klatzky and Lederman 1993; Gaissert and Wallraven 2013). Experiments in 'findings' point to how the handling of scaled 3DM can improve, if not add to object interpretation, with regards to the identification of shapes and patterns.

This was shown in my experiment on different scales of the 3DMs at 1x and 1.5x scaling and at 1x and 2x scaling and finally at 3x and 6x, using the 3DMs of a Samian ware bowl, a Shabti Doll and a cut-out of an eye hieroglyph, respectively. As reported in the previous chapter (The Scale of Object), the majority of participants were not only able to offer positive identification of shapes, they could also recognise and sometimes refined their interpretation based on their haptic interaction and engagement with the 3DMs at higher amplifications of 1.5x, 2x, 3x and 6x scaling. Thus, when handling the 3DMs at the larger amplification, participants were able to identify specific shapes such as faces, snakes, trees and flowers on the 3DM of the Shabti Doll at 2x scaling. This was the same for both the 3DMs of Samian ware bowl and the eye hieroglyph. Even when there was some confusion, the participants still seemed able to do better in the object counting exercises. Asked to count the figures on two versions of the Pot at scale 1x and 1.5x, and then on a front piece of a Shabti doll at 1x and 2x scale, the participants who initially had difficulty identifying shapes, exhibited greater counting abilities at the higher 3DM scaling, suggesting also better figure discernment when the 3DMs were made bigger. This time, the participants who had faced initial difficulty at 1x, mentioned that they could discern some shapes at the higher amplifications.

Having the 3DMs at higher amplifications meant that this decreased uncertainty in participants about identifying shapes, given the bigger indentations in the 3DMs which offered more textural information or details. This also led to greater enjoyment as evident through comments and smiles when the participants discerned or detected more shapes and were consequently able to offer more specific answers to the identification of shapes. As noted earlier in my previous chapter, my participants showed delight when they had achieved the objective of counting and identifying shapes and textures on the 3DM, all without being told what the 3DM was. In other words, haptic discernment and enjoyment increased with the higher amplification. It must be stressed here that all my experiments focussing on scale was done with the participants' eyes closed, meaning that no one was given any context as to what they were to haptically engage.

In this, it is possible that context could play a major role in influencing people's haptic engagement. If there were any influential context given, the visitor may respond in a way that has been primed with expectations such as, what shape or pattern to expect in the 3DM. Museum exhibitions will always present artefacts with a context, either this is provided by accompanying diagrams, related artefacts, or interpretive texts. With the provision of such context by museums through information regarding the artefact and scaled up 3DMs, my data suggests that this form of context could be added with activities which invite visitors to discern, identify or categorise shapes or textures found on the 3DM. This is because, as mentioned, participants in the visual-tactile and tactile-only handling experiments indicated enjoyment when they were able to discern patterns or shapes on the 3DMs.

It is also useful to note that the scaling up of the object, while largely beneficial in certain quarters, may sometimes provide extraneous features. It has been noted in experiments of scaling that the amplification of shapes sometimes feel ‘stretched’, and thereby take the shape or object out of its expected context (Gallace and Spence 2014). While a small number of my participants felt some confusion when the amplified 3DMs seemed to have patterns which appeared ‘continuous’ and hence merged, they were still able to discern and offer some form of analysis and identification of the shapes. This meant that the amplification offered more ‘context’ or information for them.

However, and this must be stressed, what was lacking for all my participants was a connection or context provided to them regarding the object being handled (with their eyes closed). In the museum, the scaled 3DM or 3DMs will be presented in such a way that interaction would require both vision and touch, and so context will definitely be present. The 3DM will be presented in parallel with the original, so visual context can be given to assist the demand of any object recognition required through touch.

An increasingly common sight in the exhibition of small pieces of archaeology is the addition of a magnifying glass. Meant to assist the view of either the whole or a single detail, this addition to the exhibition case is entirely complementary to the visual interpretation of the desired object. The ability presented in making 3DM is that it can be to scale **(Appendix E)**; and this presents an opportunity for the museum to highlight certain interesting object features or details. To make 3DM to scale is not unlike using the magnifying glass, and therefore vision as well as haptics in a multimodal way could benefit visitor appreciation.

In short, the idea of scaling up is similar to the idea of the magnifying glass helping the museum visitor discern a detail or the whole object. With a visitor focus, 3DM at higher scale has the ability to complement visitor artefact interpretation and even enjoyment if some form of encouragement could also be embedded in the display whereby visitors are invited to count, recognise, or discern some pattern; and to encourage engagement, the answer given could be somewhere nearby and not immediately obvious.

5.1.2 Shape

Object interpretation in my data collection came from Groups B and C where interpretations were reliant, for the most part, upon shape. Through the visual-haptic as well as haptic-only experiments, there remained a constant: the participants would hold the object, cradling it in the palm of their hand and identification would proceed. This action would orientate the object in such a way that for objects of a certain familiar shape, this would aid identification for my participants. In fact, as previously mentioned in Chapter 2, Newell et al (2000) found that shape orientation was used to achieve a viewpoint of the object through holding the object with the base on the palm. In other words, research suggests that cradling the object in the palm of the hand aids with object identification (ibid).

Besides cradling the object in the palm, familiarity with the shape of the object can be said to assist identification. This was shown when participants, with their eyes closed, handled two 3DMs which were that of an animal or were animal-like. This familiarity came in the form of the four legs in the 3DMs whereby participants in my Data Collection C on haptic experiments spontaneously counted the four legs of both the Tauros Trigeranus and the lion column base. Not only that, some even enjoyed trying to balance the Tauros Trigeranus on its legs. Understandably, even with their eyes closed, the participants started naming four-legged animals such as a horse, a bull, etc., as to what the 3DM could represent.

This was also the case in my earlier Data Collection B which was multisensory and therefore the museum visitors who answered questionnaires could see the 3DMs. Therefore, when asked to name the 3DMs which were that of a ‘Samian ware pot’, a ‘Shabti Doll’, and ‘Capitoline Wolf’, 39 identified the pot, 34 the doll, and 32 the wolf **(Figure 17)**. Sight played a major role in the identification of these objects although as one respondent noted in writing, as he/she did not have the chance to handle the objects, the section in my questionnaire was left blank suggesting that touch was very important for interpretation and identification, especially on more unfamiliar objects which I deliberately used with my museum participants.

When interaction was uni-sensory i.e. featuring only touch, points of reference took on greater significance. This was highlighted in my Data Collection C of both haptic-only and haptic-visual experiments. When participants, with their eyes closed handled the 3DMs and artefact, their handling indicated their desire to find as many points of reference as could be discerned through touch. As mentioned earlier in my previous chapter, there were many different tactile actions which my participants performed: using one hand as a support, the other to touch or both hands supporting with fingers feeling the object; and also with moving and orientating the object, sometimes placing or balancing the object on a flat surface. All of my participants engaged in these forms of tactile actions which was done to find as many points of reference as possible, and sometimes to just have fun interacting with the object as mentioned in my data collection on haptic experiments on detail.

In describing the object with eyes closed in my haptic-only experiment mentioned above, it is important to note, especially when considering the importance of shape familiarity that something familiar such as a 'base', 'neck', 'spout', or even a 'handle' **(Figures 31-34)** served as points of reference that assisted orientation and later, interpretation. In handling the objects, approximations were made where the object of participant interpretation went to the familiar, based upon shape: an 'oil lamp' became for one person a 'saucepan'; a 'lion column base' became for another, a 'Horse with a Saddle'; for eight people, the Shabti Doll was a 'face'; and for three people, the 'Tauros Trigeranus' was an animal. For the only participant who did not orientate the 3DM 'Tauros Trigeranus', merely holding it on the side, it reminded her of a 'crab claw'. In other words, these interpretations were based not just upon shape which led to recall or association from points of reference just made, but also based on orientation. In short, when more tactile actions were taken by my participants, interpretation for the object seemed to increase, suggesting a recall of memory and possibly reminiscence.

This is not surprising: Chatterjee et al (2009) stated that object handling provokes memories and it is those memories that are likely to retrieve something familiar from the individual. The shape interpretation as shown by participants in Group C indicated that when vision was taken away, tactile actions helped them to process information by collecting from points of reference whereby approximation based on shape took greater importance. This is perhaps not surprising given the hierarchy in haptic processing which favours shape over texture (Stilla and Sathian 2008) where the identification of shape will assist recognition (Cooke et al 2007). Shape recognition takes priority in this case over finer details such as texture for identification of object, particularly when sight has been removed.

The relative ease demonstrated in the recognition based on shape, also triggered two unexpected actions in the museum. One was from the 3DM of the Tauros Trigeranus and the other was on the 3DM of the Bone Comb. Both activities were unplanned and spontaneous, although upon reflection, not totally unexpected given what previous research on touch has alluded to: its manifold benefits.

In the case of my data collection in the museum, it inspired and encouraged eight museum visitors to rush and seek out the original museum artefact from which the 3DM of the Tauros Trigeranus was made from. As mentioned in my previous chapter, the original display was some distance from the 3DM in Dorset County Museum. Nonetheless, this did not deter the eight museum visitors who were enthused by the 3DM of the Tauros Trigeranus, who then returned after viewing the original artefact, and asked to handle the 3DM Tauros Trigeranus again. The second unplanned activity as mentioned in the previous chapter involved two young girls, who, emboldened by the fact that there was something which looked like a comb placed handily on a table and not inside a glass case, proceeded to reach for it and play with the 3DM bone comb, giggling and taking turns to comb each other's hair. The enjoyment, if not glee, observed in the eight adult museum participants and the two young children indicate the various ways that 3DMs can encourage additional acts without any prompting from anyone.

These two examples underscore how shape recognition can be important for the museum in encouraging engagement through a less formal and even fun environment. Recognised as an animal and a comb, the 3DM of the Tauros Trigeranus and the 3DM Bone Comb became subjects of a spontaneous activity. The difference between these 3DM objects is rather stark – one an animal with two human heads remaining, and the other a comb with some missing teeth - but both presented enough relatable points of reference that elicited immediate engagement. The fact that not just adults but children spontaneously jumped into a fun activity inside the museum is significant. Therefore, for a museum interested in increasing visitor engagement through having tactile activities with 3DMs, the types of selection from their collections should be a priority, particularly with respect to relatable points of association and reference, thereby making the end-product or activity inviting and highly accessible.

5.1.3 Material

The possible material to produce for 3DMs is ever increasing (Barnatt 2014), and the possibilities for museums are increasing with newer technology being developed. For the 3DMs I used in data collection, I limited my research to three types of 3DPT which were made using FFF technology, SLA technology and LOM technology. As mentioned in my previous chapter, each of these technologies use different materials such as PLA and ABS plastics, paper, and even a blend of plastics with metal (PLA/bonze in both the 3DM of the Carthaginian Token and the Tauros Trigeranus). In other words, the museum is spoilt for choice in material to be used where the only criteria being limited to: material which can be made malleable and mixed with a plastic base, of which the FFF technology allows (and which I have used in my data collection).

My discussion below is based on my use of the abovementioned technologies for the 3DMs. As stated in the introduction, I have deliberately limited my use to these three technologies because of its relative low cost and ease of use – scanning, post-processing and then printing – as well as the relatively shallow learning curve required to adopt the technology. Understandably, the material used for the 3DM was important in the forming of opinions as shown by respondents in both groups B and C. The 3DM used, for the majority, were made of PLA plastic (Shabti doll, samian ware pot, tusk fragment); two were ABS (samian ware pot, lion column base); two were made from a mixture of PLA/ Bronze (Carthaginian Token and the Tauros Trigeranus); and one was made of Paper (Samian ware pot).

The material for each type conveyed to the participants different information concerning texture, weight and sometimes shape. The choice of each material affected interpretation: with several participants indicating their preferences and sometimes their dislike. For example, one participant (Participant A) found the paper texture ‘furry’ which she associated with something positive although as mentioned, this description may have been due to the fact that the paper 3DM had been handled many times and the paper was felt to show signs of deterioration by the third day. Most of the participants also indicated their preference for the way the 3DM pots felt when made from PLA plastic and SLA plastic because the pots felt smooth and one (Participant L) even mentioned that due to the smoothness, it seemed 'shiny' – this was said in my haptic-only mini experiment. When feeling the ABS 3DM pot, participants discerned it as grainy and lined. It must be mentioned here that based on my data collection with Group C particularly on haptic-only activities, there did not seem to be any overt dislikes on any particular material used in the 3DMs which they handled and orientated.

However, when given the opportunity to handle the objects with their eyes opened, the one which seemed to elicit the highest disappointment was the LOM Paper Pot. This was because it was viewed as unlike any pot seen before given its stark white colour, and therefore falling short of their expectations. Thus, six out of the eight participants who had previously chosen Pot D (Paper) as their preferred pot when their eyes were closed, changed their minds when they opened their eyes with the reason for their new selection cited due to the colour and also because Pot D missed 'pot-like qualities' (Participant F). In fact, in my data collection for Group B, where I used a white ABS plastic for the 3DM of the Tauros Trigeranus, one museum visitor (D2) took an instant dislike to it, saying that it just looked 'tacky' and cheap.

The material used with the 3DMs of the 'Tauros Trigeranus' and the 'Carthaginian token' for Data Collection C was Bronze mixed with PLA plastic. This certainly gave the 3DMs some weight, but this was unintended, the main intent was the roughness of the surface texture to benefit tactile discernment. The haptic-only experiment on Type alternated between the use of the original and the 3DM, with the result that greater context seemed to be ascribed to the 3DM with the patterns on the obverse and the reverse of the token described as 'Writing' as opposed to 'Lines' or 'Animals'. Thus, the use of the Bronze/ PLA plastic offered more surface texture than even the original clay Carthaginian token. This may be something which museums interested in veracity or verisimilitude may want to note: certain textures offered greater interpretation than perhaps warranted. As the data showed, colour and visual appeal matter. The stark white colour of the paper pot and the white ABS plastic Tauros Trigeranus seemed underwhelming for several people – both museum visitors and my academics. This was because there appeared to be a mismatched between expectations and visual input.

Certainly the types of material used will have a bearing upon interpretation indeed. It must be admitted that due to the fact that museum visitors who responded to my questionnaires and the academics knew that every 3DM was a replica of a piece of museum archaeology, and presumably would have adjusted their expectations to expect for example, in metal, some form of patination, or visible signs of ageing for others. It is the fact that as different materials were used, these expectations were not met and so, may have produced reactions like 'It feels cheap'. To reiterate, for museums to ensure that negative reactions do not occur or to minimise any negative reactions in their visitors, visual appeal (in the form of colour) must be considered so as not to alienate more visually discerning or sensitive visitors.

5.1.4 Weight

To haptically engage with the objects, the participants for this data collection in groups B and C, all picked the object up, held it in their hand and undertook some form of orientation. Orientation was undertaken by every participant in 'C' with fewer doing this in 'B'; this may be because for my museum visitors, they were conscious not to take too long as they politely passed the 3DM to the next person. Nonetheless, for everyone involved, it was natural to orientate the object which they frequently did using a point of reference, as with the 'Lion Column Base' in my haptic-only experiment on detail. This, they did with the identification of a 'Base' by holding the object and feeling the bottom. In so doing, all inevitably could feel the weight of the 3DM.

The 'Lion Column Base' was, for its size, considerably lighter than another 3DM, which was the Paper Pot or Pot D in my haptic-only experiment reported in the previous chapter. Made using the 3DPT called LOM, Pot D was a solid paper model whereas the 'Lion Column Base' as manufactured using FFF technology, was ABS plastic and was hollow, hence its lightness. Orientation of this 3DM was helped by quite a discernible base, as this was the only extended flat part of the 3DM. However, for the 'pot', orientation was not such a benefit, with participants thinking the lid was the base. However, Pot D benefitted from its solidness which had weight, and this resulted in a textural preference for participants. In fact, for eight participants in my haptic-only experiment, out of the twelve, these eight picked up paper Pot D and used its weight as justification for their haptic preference. Although as previously noted, six from the eight switched their preference when sight was involved.

Overall, the weight, or relative lightness of the object, was observed to add or detract from the interpretation of the object. In the case of the paper Pot D, the weight served as justification that it felt 'real' suggesting that the weight of the paper 3DM met certain expectations. In general, my twelve participants in Data Collection B, when asked the question, 'When you touch a replica object, is there one word that comes to your mind?' were keen to express their surprise as to how light the object was. The 3DMs felt solid and sometimes, bulky but in the form of hollow plastic, some of the 3DMs did not meet either tactile or visual expectations, a factor which may have contributed to the many comments on how light the 3DMs were. For museums interested in having a comprehensive tactile activity as part of increasing interaction for visitors, the benefit of weight in 3DMs could be an important factor particularly if the original artefact was heavy in the first place. It must be noted that current advances in 3DPT can now allow for the addition of weight onto the 3DM.

The focus on the whole body of the object, rather than the individual detail is interesting and not unexpected. It is, as suggested by previous studies which I have mentioned in Chapter 2, object recognition which takes the form of hierarchy where object categorisation (Gaissert and Wallraven 2015), object orientation (Newell et al 2010) and identification (James et al 2007) are processed separately depending on input (Linden 2015 p.69). In fact, Cooke et al (2007) state that shape recognition has priority and for the individual, this naturally aids their ability for quick identification where classification falls into categories, either as something known or something familiar, or as an unknown. The shape of the object took priority, and was made in a process which was quick, relatively accurate and effortless when exposed to the general or familiar. However, when confined to touch-only recognition for detailed-specific objects such that the participant has not encountered before, it is likely for the participant, to either reach an approximation from points of reference that are either concrete or abstract in processing the information. Therefore, in haptic-only activities, my participants reached for the element of weight as their overriding priority in their preference for certain 3DMs over others, but when visual-haptic stimulus was allowed, then vision seemed to override the priority of weight.

For the museum then, the curatorial staff must consider which prioritisation takes place when selecting the artefact from their collection and which 3DPT can best produce the required 3DM. Put simply, would weight be an overriding factor or colour or texture in their consideration for selecting something? Alternatively, would weight have more importance in the 3DM of a plate or spear? These are considerations which museums ideally should take into account in their bid to provide greater haptic interaction, engagement and appeal for their visitors aside from considerations of low cost.

5.2 Reception to 3DMs and 3DPT: Overview

As mentioned in Chapter 2, the ‘Touching the Past’ project held at Plymouth Museum (Pitt and Hurcombe 2017) showed that the general public can be and was receptive to the use of 3DMs in museums. The museum, which exhibited ‘Whitehorse Hill’ artefacts, sought feedback from its visitors where comments received were overwhelmingly positive (ibid, p. 122). Of the positive reactions to the exhibition, the enjoyment derived from the addition of touch in the museum exhibition was repeatedly made. Visitors emphasised that ‘looking and touching at the same time’ was important to their appreciation of the exhibition and that for some, it made the ‘awareness of the object’ (ibid) even more appealing or pronounced. One negative comment received for the exhibition, cited by Pitt and Hurcombe is interesting: that it seemed to be a ‘Waste of money, the real thing is not plastic’ (ibid p.122). However, this can easily be rectified with a change in material for the 3DM, as previously discussed. This would then help reduce if not avoid negative responses from the public whose expectations of replicas have not been met. It must be noted that currently there is even Gold/PLA mix besides the Bronze/PLA which I had used for the Tauros Trigeranus. With the inexpensive Gold/PLA mix, museums with Roman gold coins can print out one or two such coins, at 6x scale, roughly the size of an adult palm, which costs around £4 each.[36]

The positive reactions for the abovementioned exhibition seemed to have been mirrored in reception to 3DM by groups ‘A’ and ‘B’. Practical exhibition of 3DM as companionable pieces presumably would be undertaken for two reasons: to provide fresh interpretation of the object and to encourage an increase in attendance. This is important given the challenge to increase or maintain visitor numbers, mentioned previously in my introduction. One way to stem any drop in museum visitation seems to point to greater visitor appreciation and in the case of the ‘Touching the Past’ project at the Plymouth Museum exhibition, having haptic interaction seemed to have garnered highly positive comments and feedback particularly pertaining to visitor enjoyment and appreciation. My data

[36] Amplification might be a consideration for museums: both for greater interpretation by visitors as well as reducing instances of museum visitors accidentally slipping such 3DMs into pockets. In fact, in one conversation with a curator, she mentioned about excitement during handling activities particularly on small objects, and how easy it was for individuals to forget they were handling museum objects and therefore museum property, and to slip it into pockets. Curators have been known to do this, signs of Lord Emsworth, it would seem; unfortunately, while curators always returned the objects, visitors were not always as scrupulous.

collection on museum visitors bears this out: as a response to the question, 'If this technology were used to exhibit replica models would you be likely to return to the museum?' Out of 41 replies, only 4 were negative with 37 as positive or 'maybe', which we can take to be receptive to the idea of handling 3DMs in the museum.

To museum visitors the question, 'Do you think that being able to touch these replicas would be a useful aid to understanding the object?' resulted in 27 positive, 7 said maybe and 1 negative. In other words, an overwhelming majority favoured touch to enhance their museum experience via learning more about the original artefact. In fact, as mentioned previously, one participant (W3) in Winchester City Museum asked if this technology could be made 'accessible to schools', and if admittedly, quite flattering, my presentation could be repeated, 'to schools? (Primary KS2[37])'. Clearly, this museum visitor not only appreciated the handling activities, he/she could see its potential and worth, particularly for educational purposes with younger students.

I have reported in detail about my data collection C in Chapter 4, which was done in a series of experiments, each taking around 45 minutes for individual volunteer participants. I will not repeat the findings here but must note this important fact: twelve people volunteered, who were both staff and students, indicating their interest in handling activities particularly on 3DMs of museum artefacts. This clearly indicates them being receptive, if not curious and interested in the experience of handling objects, and by extension, the idea of 3DMs being exhibited in a museum which are handle-able. In fact, this positive receptivity may have encouraged or increased the probability of more curious and playful haptic engagement, resulting in, for example, attempts made, while their eyes were closed, to balance the Tauros Trigeranus on its legs or turning and orientating the lion column base. Even the Carthaginian Token was handled with glee as participants took pride in trying to feel as many lines or patterns as possible. Ultimately the positive reception of the academics proved to be beneficial to the data collection as all twelve were, on every aspect of the handling exercises, forthright in their opinions as they shared what they particularly appreciated and liked in their handling experience and, also which feature i.e. weight, colour, texture, etc., made more of an impression on them. In

[37] The primary school educational level of Key Stage 2 covers the age range of 7-11.

other words, data from the academics showed positive reception towards tactile engagement and interaction with 3DMs.

From museum visitors and academics, another group of stakeholders which I investigated was the curatorial staff in museums. Of the 11 questionnaires returned through post or email, the majority of museum curators showed a positive attitude towards the use of 3DM in their museum, particularly with regards to visitor experience. This was indeed a positive reception which bore similarities to research from 2014 in which museum curators not only expressed positive views regarding digital technologies but were already applying them in the curation of museum exhibitions (Maye et al 2014). Earlier work had already seen curatorial attitudes to the direct application of technologies as interpretative instruments for stand-alone exhibitions (Petrelli et al 2013 p.9). Indeed, in the application of 3DM as well as any 3DPT, focus and end purpose must factor into the application within the museum (Lindauer 2006; Rowland and Rojas 2006). Thus, in consideration of practical application, perhaps informed by their experiences of the practicality of museum exhibitions and visitor engagement and behaviour, the museum curators of ‘A’ became more cautious about having actual handling activities, with nine museums indicating that they would hold supervised activities with 3DMs and seven indicating that they would take one step further by having unsupervised handling activities. Two museums rejected both supervised and unsupervised handling activities: one cited budgetary concerns (issues of manpower and loss of 3DMs, perhaps) as the reason for not investing in 3DPT, and therefore not having handling activities and the other suggested that it was low on its current priorities. However, it must be noted, this did not rule out the possibility that 3DPT would be used in the future; just not in the immediate future for these two museums. It must be stressed that these two museums, as previously reported, which said no to both supervised and unsupervised activities, both ticked yes to producing ‘replica objects for sale’. In other words, different museums with their variety of priorities – conservation, documentation, and exhibition – have slightly different views on how 3DPT could be applied to their museums; and as shown, many were positive towards how 3DMs could be utilised to fit into their museum mission. In short, the willingness to adapt and change for future purposes, as indicated by the curatorial staff, is highly encouraging and points to a positive reception to the use of 3DPT and 3DMs.

In addition, the eleven curatorial staff from museums indicated prior knowledge regarding 3DPT, where four stated 'University' as their source of information about the technology despite only one university-run museum among the eleven which responded to my questionnaire. The other sources were: through Professional context, Training Course, Project, and newspapers with three museums indicating that their knowledge of 3DPT came from 'Television' programmes. This relatively wide selection of sources suggests that museum curatorial staff were not unaware of 3DPT, but were, in fact, realistic about the potential of 3DPT for their museums; and therefore, suggesting their positive reception was at the 'Slope of Enlightenment' as theorised in Gartner's Hype Cycle for Emerging Technologies **(Appendix D)**.

Each of the museums had replicas of artefacts in their collection, and as previously mentioned, these were made from a variety of different materials and were put to a variety of uses by the individual museums. The relative fragility and expense of replicas made from 'Basketwork' or 'Electrotyping', would undoubtedly, have limited the potential uses of those replicas as they would have been treated with great care, if not extreme caution. In other words, no museum with these replicas would risk harm or damage to them. A 3DM, however, would be hardy, cheap and replicable **(Table 2, p. 63)**, and can also be made using a variety of materials **(Table 5, p. 99)**. In fact, one museum – The Royal Albert Memorial Museum in Exeter - did have two 3DMs made of its 'Hameldon Bronze Age Dagger', as previously mentioned. While one replica is in storage, another is on display to the public albeit kept behind glass and therefore out of reach of visitors.

It was perhaps unsurprising that a question concerning the price of a replica went unanswered by most museums. The museum in Exeter, however wrote down the cost of its bronze cast replica of the 'Hameldon Bronze Age Dagger', made in 2010 and costing £250. As previously mentioned in **Chapter 4**, the original was destroyed in WWII and this replica dagger is now on public display and therefore is unlikely to be used for handling. A 3DM printed of Bronze/PLA (Appendix E) of the estimated dimensions 9 by 9 by 8cm would cost around £3 in material to print using FFF technology. Given the relative scarcity of 3DMs currently in museums, it is not surprising, that the replica of the Hameldon Bronze Age Dagger which cost £250 would be exhibited behind glass, as an artefact. This – kept out of reach by visitors - would not have happened if the 3DM using Bronze/PLA had been manufactured using FFF technology, and then available for visitors to handle. Presumably because it is still a dagger, there may be concerns about such handling activities, but the potential benefits of exhibiting 3DMs remains unchanged.

Returning to the answer by museums about how they could or would potentially utilise 3DMs in their museums, all bar one, were overwhelmingly in favour of 3DMs as a form of income generation. This point will be discussed later in the next chapter. At this stage, I just want to highlight the fact that because museums can appreciate this financial potential stemming from the sales of 3DMs, this is highly encouraging. Beyond the financial aspect, the potential sales of the 3DMs would only lead to greater interest by visitors, and even an increase in access to and knowledge regarding the original artefact. This positive reception towards sales, also highlight the practical and rather functionalist perspective adopted by the curatorial staff, evident in their answers to my questionnaire. After all, in their running and management of the museums, these stakeholders are concerned for the future of museums in the 21st century, with new visitors pointing to the trend that they are now clearly interested in multi-sensory engagement and entertainment ('novelty chocolate handaxe anyone?' – Royal Albert Memorial Museum) for their leisure activities.

Unsurprisingly, to the question which asked museums about the projected application of 3DM, every museum said that the adoption of 3DPT in the production of 3DM would 'benefit what the museum is already doing' **(Table 6).** This is interesting as this seemed to suggest that despite the eleven museums indicating caution or being cautious in their use of 3DPT and 3DM, they would still apply the use of 3DPT and 3DM to suit their individual institution. This, I would assert shows the benefits and flexibility of 3DPT to suit different purposes. In this case, even though this was posed as a hypothetical question, their answers still indicate the potential of 3DPT to meet the different priorities of the museums particularly as their curatorial staff have asserted that any use of 3DPT would be to support the museum, particularly in its bid for conservation and documentation purposes.

In 'The Original's Companion', the data collection was designed to include three different groups of museum stakeholders – curatorial staff, museum visitors and academics – and who have responded positively to the adoption and use of 3DPT, even when phrased as a hypothetical question. I see this positive reception as highly encouraging for any museum, not yet engaged or involved with 3DPT, but which is keen to enlarge its visitor footfall and to increase visitor engagement and appreciation through more tactile handling activities.

5.3 Exhibitions with 3DMs

In an exhibition, it is desired that 3DMs are there to add touch-based interpretation to the engagement with the artefact. The ability of the museum-based companionable 3DM is to encourage extensions of interaction in engagement, interpretation and learning about the object. However, in the discussion just presented, we see that the application of 3DMs in each museum is likely by degrees to be different, which may present an alteration in the presentation, exhibition or indeed the type of 3DPT used. The analyses on responses by Group A by curatorial staff show that they view 3DMs as a complement to the museum as a whole, not just the individual museum-owned artefact. It must be stressed again that curatorial staff play a crucial role in how 3DMs and 3DPT would be adopted and applied in the museum. Notwithstanding that, the curatorial staff also indicated keen awareness about visitor experience, appreciation and satisfaction.

Thus, actual data from museum visitors is important as this may encourage more museums to adopt 3DPT if the technology can be shown to encourage greater visitor interaction and even higher levels of satisfaction derived from greater haptic engagement. My last group, Academics, was chosen because of their willingness to participate in my admittedly extensive experiments on touch which dealt in different aspects of handling activities. In short, data from these three groups of stakeholders offer vital information, previously unavailable, for my research aimed at increasing or enhancing the interpretive benefits to museum archaeological artefacts through visitor tactile engagement with 3DMs.

Therefore, the following three sections will be devoted to discussions on how visitor tactile engagement with 3DMs can be beneficial to museums, informed from both theoretical and functionalist perspectives.

5.3.1 Visitor Engagement: Exploratory Three-part Activity

As previously mentioned, the 3DM of the Tauros Trigeranus was used with my questionnaire at two museums with actual museum visitors: Dorset County Museum and Winchester City Museum. The original artefact of the Tauros Trigeranus was on display at the Dorset County Museum, and in light of the occurrence of the ‘Exploratory Three-part Activity’ this is of interest here. To reiterate, part of my data collection included the introduction of the general uses of 3DPT through a 20-minute presentation by me, followed by the questionnaire which was handed out to the audience along with four different 3DMs. As mentioned, there were eight museums visitors, throughout the day, who, after my presentation and having completed my questionnaire, rushed off to check out the original artefact of the Tauros Trigeranus. I did not have to mention that the 3DM was made from the Tauros Trigeranus that was on permanent exhibition in the museum: one of their museum volunteers took it upon herself to happily inform the museum visitors and audience present.

The 3DM of the Tauros Trigeranus used was part of the data collection for questions 4, 4.1 and 4.2 which also sought the application of personal knowledge or informed interpretation as to the provenance of the original artefact. Of these eight, having been informed by a museum volunteer that the object was somewhere on display within the museum, these eight were curious and motivated enough to see the original. In other words, eight out of the 29 museum visitors at the Dorset County Museum, or 28% of the museum participants considered the 3DM interesting, educational and possibly entertaining to evaluate both original artefact and 3DM of the Tauros Trigeranus. More importantly, these eight returned to me and sought out the 3DM again to touch, orientate and even feel its weight or relative weightlessness. In other words, just having handled the 3DM of the Tauros Trigeranus, was sufficient reason for them to seek out, learn more and assess the original artefact of the Tauros Trigeranus. Or, as mentioned previously, these visitors viewed themselves as ‘explorers’ (Semmell, 2016) and in their quest for knowledge, verisimilitude, etc., they went off to discover for themselves how the Tauros Trigeranus 3DM compared to the original. This is important information, particularly for curatorial staff keen to know how such visitors can be catered for, as well as placement for details on how and where to exhibit both 3DM and the original artefact. The lack of proximity, in this case, between 3DM and original artefact encouraged spontaneous activity among visitors.

As observed in the participants, the exploratory activity would feature certain steps, of this there were two variations. This activity featured the handling of the 3DM, the search for the original to make observations and take notes, and then the return to handle the 3DM in order to compare it to the notes taken on the original. The use of notes taken was rather interesting as there was a limit seemingly placed on interaction that depended upon the individual. As observed, the notes for comparison with the original of the 3DM were either taken in the form of a digital photograph of the original to compare with the 3DM, or as a combination of a photograph as well as written notes.

All of this was done to compare the 3DM and not the other way around, presumably the act of holding the 3DM served as a temporary form of note taking. This was however an informal and unprovoked activity (Simon 2010, p.34) that was an exercise in curiosity and motivation to know and learn more about the original artefact. The ability to compare and upon returning, to evaluate the 3DM for its perceived difference from the original, was an activity that was seen as deserving of their time during their visit. This was part of their leisure activity, indicated in part by smiling faces of the individuals and group chatter; indeed this was the type of unprovoked and informal activity previously mentioned in **Chapter 2** and expanded upon by Hood (2004) as indicating attitudes held by museum visitors of viewing visits as leisure activities.

This exploratory activity to seek out the original of the Tauros Trigeranus, demanded that each participant expended energy and used time, an act which in practicality took each participant around 10 minutes, but as Bitgood (2013, p.123) noted, this investment in time spent by the museum visitor is crucial as it signified greater engagement and involvement. More importantly, Bitgood also stressed that such investments in time would consequently attract and hold the museum visitors' attention thereby adding value to the 'prompted engagement' (ibid). The concept of 'prompted activity' which looked at how museums encouraged its visitors to be more engaged and involved, has direct relevance as to how museums can engage visitors with original artefacts through 3DMs. In this case of the eight museums visitors with the Tauros Trigeranus – original and 3DM - there was no prompting made by me at all. It was the museum volunteer who initiated the 'prompted engagement' and must have been nearby throughout the entire day at the museum.

I would like to stress that in no way did I suggest or hint to the volunteer to initiate the information by giving any 'prompted engagement'. This extra step undertaken by the volunteer to offer 'prompted engagement' also indicates the importance of (personal) recommendations in the museum. All could see that she was a volunteer, from the badge prominently pinned on her top and I would speculate that her enthusiasm and interest might have also encouraged museum visitors to spend more time engaged in both visual and haptic interaction with the

Tauros Trigeranus – original artefact and 3DM. Again, this may be something that museums should consider regarding the use of ‘prompted engagement’ as mentioned by Bitgood, and how volunteers can play important roles in visitor engagement and involvement vis-à-vis 3DMs. In this case, this took the form of verbal suggestions about where the original artefact could be found; but in general, for the museum, this can take the form of prominent signs for interested museum visitors which can help direct them to the original artefacts, if the 3DM is not placed in the same room.

To state the obvious, haptic engagement with the 3DM encouraged a visual need to observe the original artefact. The ability to get close to the 3DM was exploited by the eight individuals who then continued their haptic and visual interpretation of the Tauros Trigeranus at the Dorset County Museum: clearly, they did not want to prematurely end their exploratory experience and engagement with both 3DM and original artefact of the Tauros Trigeranus. Previous interaction with the 3DM had included various museum visitors who answered my questionnaire by picking up, playing with and orientating the 3DM, and then speculating that the 3DM was a charging bull, a horse, or even a zodiac sign. However, this extra investment in time by the eight museum visitors, showed a development of activity that suggested a deeper interaction and engagement, which ultimately led to more analytical interpretation of the Tauros Trigeranus.

The 3DM of the Tauros Trigeranus, as discussed earlier, was a product of Fused Filament Fabrication (FFF), and therefore made of hollow ABS plastic as opposed to the original which was made of solid iron. However, despite the difference in weight, colour and texture, the 3DM was not seen as an ephemeral curio or novelty but as a model to develop further understanding of the original Tauros Trigeranus, especially in the case of the eight museum visitors. They also felt compelled to return not only to handle again the 3DM, but to discuss with me their impressions and therefore their interpretation of the Tauros Trigeranus. This motivation to share their views and hence their interpretation is important as this shows not only the depth of their engagement but their desire to let others know about their interpretation. For the museum curators, this is rather encouraging: and as many already have a book for visitor feedback at the entrance; maybe they could also include a similar book for these similarly interested museum visitors to share and record their interpretation of 3DM and/or original artefact for others to read, appreciate and offer comments as well.

Out of the data collected, this 3DM of the Tauros Trigeranus came closest to what my framework ‘The Original’s companion’ was designed to fulfil: a 3DM complementary to the artefact exhibited. With tactile engagement in the museum, the 3DM handled by the visitors served to alter their interaction with the original artefact. As observed on the one full day I was given for my data collection, it was not only people who knew the location of the original artefact who participated, but also first-time museum visitors who took notes on the 3DM, and only knew that the artefact was exhibited somewhere else in the museum but did not know the exact location of the object. The adoption of this unprovoked activity as mentioned is analogous to the behaviour of visitors-as-explorers (Semmell 2016): the visitor’s act of tracking down the original artefact and then returning to compare it to the likeness of the 3DM, which presented a clear objective or quest for them and thereby enhancing their museum-visitor experience.

In the exploratory three-part action that emerged: first, visitors would see the 3DM, then secondly, go and seek out the original artefact, and finally, return for a comparison; in the first and last action, the 3DM played a complementary role in object interpretation, whilst changing in status by being ascribed analytical valuation and/or re-valuation.

The first action which took place while one 3DM was being printed: everything learnt about the object was distant. In this case, despite the action that was taking place - the printing of the 3DM - the interaction with it was along the standard museum exhibitions paradigm where the visitor as actor, in displaying interest, could only learn about the object at a distance. In other words, the object was viewed as a plan or a map that offered guidance on the type of artefact that can be inferred or seen from the 3DM.

The third action, was however, slightly more nuanced, as this was not solely distance learned, but in fact, was a combination of distance-learnt information and haptic re-evaluation whereby both adding to individual interpretation and even appreciation. Participants would evaluate the veracity of the 3DM to the original artefact because distance-engagement was enforced for the original artefact, but there was no barrier for the 3DM: they would, in fact, pick the 3DM up and re-orientate it, all the while re-evaluating the 3DM as their fingers felt the texture, shape and surface details of the 3DM. In this case, their final (third action) would complete their gestalt model: they could fill in the gaps, evaluate and then re-assess based on earlier expectations; ultimately adding to their whole engagement, experience and appreciation of the original artefact which was mediated by their haptic interaction with the 3DM.

A three-step activity like this would not happen with the adoption of a 3DM project which only serves as display stand-alone models. The 3DM as suggested by 'The Original's Companion' would likely promote such an activity but, it would require the 3DM to be seen as worthy of comparison and evaluation. What this does suggest, however, is that when presented with a piece of archaeology and a 3DM, the visitor opting to extend their curiosity in the artefact, will readily interact with the model. Therefore, museums should make such 3DMs available and easily accessible for visitors. As mentioned by Chatterjee et al (2009) interaction by visitors may take a few different forms: in this situation, the 3DM, in tactile interaction, can only increase and develop appreciation of the original artefact. As mentioned earlier, there is now less of a barrier for the museum visitor: in handling the 3DM, tactile engagement and interaction are now offering new details of information, previously not available, except through visual inspection of the original artefact.

In another form, Chatterjee et al (2009) also noted the reticence of some museum visitors in tactile interaction, although their research was conducted with original museum artefacts. Should any museum visitors have such reticence and hence greater reluctance to handle original museum artefacts (for a variety of reasons such as fear of damage, etc.), having the 3DM would eliminate such potential reticence or fears. Also, for some museum visitors, I observed that they would at first be likely to offer criticism of the superficial similarity or dissimilarity of the 3DM and only after this, would they feel it right to pick up and interact with the 3DM. In this sense, the museum visitor's ability to criticise and offer evaluative comments served to break-down any formal barrier to interaction with the 3DM.

In this situation, two aspects were similarly altered: visitor appreciation of the piece of archaeology and the typical behaviour in museum exhibitions e.g. reading text and observing displays or what was commonly referred to as the 'nature of museum protocols' which presumably exhibited such activity before the advent of 3DMs. Such accessibility to object can affect and have some influence over participants for the duration of their visit through encouragement and motivation to initiate further engagement. Therefore, the adoption of a standard 3DM project along these lines presents the potential of influencing long-term museum protocols, which can add to visitor engagement and even enjoyment of their museum experience. After all, making conditions conducive for more exploratory three-part activities will only serve to benefit museums and their mission to inform, educate and help the public appreciate their heritage.

5.3.2 Fun with Creativity or Haptic Play

I have been discussing and offering data on adult museum visitors. The discussion here is from the observation of the two young girls which I observed at the end of my last presentation at Dorset County Museum, while I was in conversation with one of my museum visitor respondents, with a small group clustered around the table with the 3DM Tauros Trigeranus. This informal interaction occurred when the two young children ran up to the 3DM bone which was conveniently left on a table - I had not yet packed it away. It was immediately obvious that the two young children had identified the 3DM as some sort of comb, which they then began to take turns playing by brushing each other's hair and giggling all the while: no words were exchanged by them in that spontaneous activity, only giggles and the action of combing for the other. The action was not prompted by the adult who accompanied them (presumably one of their parents) to interact with the 3DM. As mentioned, their actions with the 3DM of a piece of archaeology were carried out spontaneously and without supervision.

Engaging with the model comb, the children's interaction can only be described as play (Roussou 2004): it was fun for them to pick up the comb and brush each other's hair. This activity was much more personal (Simon 2010, pp.9-10), unlike the activity which the adult museum visitors undertook with the 3DM of the Tauros Trigeranus, as previously discussed. The fact that this 3DM could encourage a spontaneous and fun type of engagement could be due to a range of factors: concerning ease of access, identification, weight, material, size and colour.

It must be reiterated that during data collection for Group B, the 3DM of the Bone Comb was not used for object interpretation exercises. The 3DM was instead used as an example of what LOM technology can achieve or cannot achieve, as previously reported. Not having referred to the 3DM of the Bone Comb in my questionnaire, there was understandably less interest shown by the adults in the inaccuracies found between the model and the original artefact which was also on display at the same gallery where the original Tauros Trigeranus was displayed. The lack of interest shown by the adults, therefore, may have literally created space for the children to exploit at the table. However, the ability to access and exploit handling of the object, does not automatically suggest interaction.

In interaction, identification was crucial. Neither the original nor the 3DM bore great similarity to 21st Century combs; however, identification as an object of worth and utility was still possible for the children. This 3DM presented sufficient points of reference, bearing similarity in vision as well as touch as to what may be expected in a comb; a row of teeth and a handle may have assisted this identification. Given that this interaction from the initial interpretation of the 3DM resulted in the combing of hair, it seems that this 3DM satisfied the children's visual and tactile requirements: it looked and felt like a comb, so maybe, it was a comb.

The 3DM and the original artefact of the Bone Comb do not present great dissimilarity but are subtly dissimilar as to be quite plain in comparison. As stated earlier there were necessary elements concerned with use or function of the object: there were sufficient numbers of points of reference. Other variables that we may consider that aided recognition and the appeal of the 3DM Bone Comb were weight, material, size and colour. The issues of weight and material are closely related for this 3DM, an example of LOM technology this is made out of many layers of paper which creates a model that is a block of paper. The 3DM of the comb from this process was solid, and because of the manufacture using paper, presumably felt nice to the touch (as stated by Participant A on touching another 3DM paper replica made using LOM). The 3DM Bone Comb was the same scale as the original artefact: this was no larger than 10 by 4 by 1 cm. As the handle was the longest part of the comb, it is reasonable to think that this presented a prompt in this engagement; there was something to hold (Bitgood 2013).

Interaction with this 3DM was interesting: for adults, the difference clearly, as with all models, pointed to its approximate gestalt of the original (or lack of) and as a consequence, was ignored by the adults who flocked to the 3DM of the Tauros Trigeranus. To the young children, it was clearly an object which invited play. This informality, spontaneously acted out by the children, as an object of play was not only interesting, but indicated how 3DMs can be both an object of playful novelty and learning. Interpretation, it must be stated took place: just not the same type of interpretive analysis undertaken by the adults earlier on the 3DM Tauros Trigeranus. For the young children, it seemed to be instinctive and was developed based on their schema for interaction: in part this may have been due to their curiosity which led them to approach and find out what the adults were doing, clustered around one end of the table.

The observation of this informal and spontaneous interaction or activity with the 3DM Bone Comb highlights the potential offered by 3DMs in museums. Clearly, these 3DMs are not just tools for learning and appreciation of our historical past: they can just as easily provoke or inspire creative play. I have adopted the term 'haptic play' to refer to this type of spontaneity, activity and interaction shown by the two young children with the 3DM Bone Comb. It, therefore, is useful here to return to my adult participants from Group C who also engaged in acts which can be termed as haptic play: balancing the object and waiting for it to fall, as it inevitably did and then chuckling because of the object falling. Thus, I would define 'haptic play' as any act or activity in object handling as one 'performed beyond touching for formal identification or information.' As such, and possibly stating the obvious, 3DMs can be entertaining and used as objects to inspire play and possibly creativity, additional benefits which can only be complementary to the original artefact. As indicated, the curiosity shown by the children added to their haptic interaction which I have called here 'haptic play'. This led to much fun and enjoyment for these two children, evident in them picking up, and using the 3DM Bone Comb as a real comb for their hair, and also as a toy for them to play with each other. Needless to say, the literature on play has already shown its link to creativity and relaxation, for both children and adults, which I will not go in-depth here. At this point, I just want to state how this spontaneous activity derived from the 3DM Bone Comb could and did become one tactile engagement and interaction which proved entertaining, fun and enjoyable for some of the younger museum visitors.

5.3.3 Proximity to Original Artefact

The simple matter of holding an object seems to have beneficial qualities; for the individual, this stimulates the mind (Chatterjee et al 2009) and provokes a development in interaction. Chatterjee et al, was of course, referring to object-related reminiscence that was part of a series of unguided handling activities in a hospital: by holding the object, this act alone allowed the individual to reminisce and even derive some positive physiological benefits (Chatterjee et al 2009, p.168; Camic et al 2017). In the museum, there are two possibilities how this related reminiscence can occur: the visitor could be directed or guided in their interactions with the 3DM, as companion to the original artefact; or they could engage on their own any interaction with the 3DM. Thus, the museum could provide a focus, leaving any interactive activities open for spontaneity, or allow the choice for either types for museum visitors (Grace et al 2013).

The two objects mentioned – the 'Tauros Trigeranus' and the 'Bone Comb' – both became the focus of visitor activities. The two were, to an extent, formalised, the aim of the former being to compare and contrast the 3DM and the original, and the aim of the latter to experience using the comb. The ability to get close to the object was paramount, as this made the efforts and the eventual goal much more accessible to museum visitors. In activity, the effort required for interaction was outweighed by these prospective goals. Therefore, whatever the degree of effort required, such as picking up and manipulating the 3DM, this accessibility was offset by the increase in the degree of the individual's interpretation (Bitgood 2013).

The matter of holding an object and bringing it close and within range for a private view, or play, acts to focus attention onto the object of desire. Desire, however, in this form of closer interaction, presents the link to ownership (Chatterjee et al 2009, p. 167, Peck and Childers 2003). Given the personal nature of this close interaction, it is to be expected that a particular bond will be formed between the object and the actor. Ultimately this may be problematic for the museum as the actors may not want to return the object as Chatterjee (2009) found. However, it must be noted that Chatterjee et al's research was focused on participants in hospitals who were very ill, and therefore vulnerable, suggesting the likelihood of them developing possessiveness towards the object handled which had given them therapeutic benefits.

It is the attention shown to the 3DM that suggests a close bearing to the individual's interest or attraction (Bitgood 2013 pp.41-43), and the motive of curiosity (Spence and Gallace 2008). To focus attention specifically on the object held offers an option to further develop knowledge surrounding the object (Owen 1999). This ability to get close to the 3DM, to view as well as touch the object, offers a new potential dynamic in object interpretation.

Any difference in degrees of interpretation can also be seen in variations of distances in all three groups. Group A was, in method of dispersal, distanced and therefore, necessitated projected interpretation. This took a holistic view of the topic with variables of exposure, prior-knowledge and imagination all surrounding 3DPT, dictating the practical utility of 3DM within their particular museum.

In Group B, object interpretation was multi-sensory, combining touch and sight. Multisensory interaction allowed for a degree of closeness that benefitted the personal interpretation of 3DM. Getting close to the 3DM encouraged not just greater analytical interaction but also informality of interaction with the addition of play, observation and haptic interaction.

Group C had a degree of closeness to the 3DM that whilst allowing for the greatest engagement, was limited to mainly unimodal touch-only interaction as the participants were asked to close their eyes. Individual interpretation was produced through dependence upon the identification of points of reference (Lacey and Sathian 2014) and as mentioned earlier, this could be as simple as feeling the base of the 3DM, orientating the object and finding as many familiar points of reference or shapes as possible. To reiterate, among the four tactile elements investigated, my experiments showed that shape took precedence but when vision was allowed, colour took priority as this was used to match expectations formed from tactile engagement.

All these discussions – regarding the different groups in my data collection – considered the 3DMs being in a set location. But this need not be the case. The potential offered by 3DPT cannot be ignored. Any form of scanning and processing, to make digital copies of artefacts is already making possible a wealth of data, if not a treasure trove of valuable information. Projects like MicroPasts (British Museum 2014) and the collaborative efforts of museums to digitise specific collections (Marshall 2018) have already made such new data available to the public.

It must be acknowledged here that with advances in 3DPT and the creation of specialised databases in the public domain for open-access, online museum visitors who are able to download and print the 3DMs from data uploaded by museums could potentially enjoy this privilege. This has been made possible through databases used by museums such as ‘Thingiverse’, ‘Shapeways’ and ‘Scan the World’, where some museums have specifically advertised in these databases, in the hope of encouraging an interest in their collections and thus visit. In fact, at the time of downloading and printing the 3DM Lion Column Base from ‘Thingiverse’ in 2013, the institution that had scanned the object and uploaded it, Parma Museum expressed this wish to increase visitor interest[38]. In this case – proximity with regards to both 3DM to the original artefact – for these end users, it would not be directly applicable, as their visitor experience would have changed: they are no longer in public space and subject to museum visitor protocols but in their own individual home, which I acknowledge here.

5.4 Interpretation Revisited

In the interaction with 3DM there was significant overlap in the findings for Groups B and C. The data provided by both suggest a variety of factors in the interpretation and recognition of artefacts which I discuss in more detail here.

5.4.1 Time

If the object, either the 3DM or artefact, is held in the hand or in some way haptically engaged for more than a few seconds, then it was found that there was little to no relation between time and the discerning of object detail (Klatzky and Lederman 1992). In practice, little relation was found by unimodal interaction with the object and greater object discernment. There was however a relationship between interest or curiosity shown to the object in-hand and the time the person was willing to examine the object.

Questions asked for Groups B and C did result in some interesting numerical data. Group B was asked direct questions concerning their opinions on the use of 3DPT within the museum, and the experience of handling and interacting with 3DM.

The relation of interest with time can be inferred from data collection of Group B based on the question, 'Would handling a replica of an archaeological artefact increase […]?' which could be seen as indicating future intent. As the answers suggest, there are benefits from handling the 3DMs. My question allowed for multiple answers and thus out of 41 respondents, 32 said that they would 'spend more time with the artefact'; 38 would 'return to the museum'; and that 28 would show 'Interest in the original', with 32 stating that they would 'like to know more about the peoples who made the original'. In other words, interest derived from

[38] However, accurate as of August 2017, this 3D scan has been removed by the institution. This was previously mentioned as footnote number 1 on page 10 and later footnote number 35 on Table 14 on page 162.

handling the 3DM suggested that museum visitors would return and spend more time on the original artefact. Put simply, there is a beneficial relationship between the artefact and the visitor.

Sometimes when the original artefact had few visual details and texture on the surface, thus having relative tactile dullness, the 3DM would similarly acquire these features. One of my mini experiments on ‘Type’ was designed to elicit deeper reflective answers based on 3DMs which have few textures such as the original Token from Carthage and its companion piece 3DM. In studying the original Token from Carthage, the participants were at first more likely to ascribe it with pictorial depiction as in a face, animal or map as opposed to the 3DM where participants’ interpretation was to try to give this meaning. The 3DM was perhaps given a personal relevance, with most answers such as ‘writing’, ‘meaning’, ‘lines’: an attempt in other words, to understand the 3DM. Naturally, they were curious and spent time feeling the grooves for the indented lines on the token.

In asking the participant to count the lines represented on the surfaces of either the original Token or 3DM; the original Token gave rise to a range that presented extremes. The minimum being within the range ‘1-9’, the maximum was ‘60 or more’ whereas for the 3DM, the range was rather clustered at the lower end of the spectrum with the majority of answers given for ranges ‘1-9’ and ’20-24’. The conclusions of both parties were rather curious: for the original we have the majority concluding at the higher range, with individual answers 55 – 100 and for the 3DM, 1 – 24. This seems to suggest that the greater the number of individual lines, the less likely there is to be a single or a repeated pictorial representation. However, both numerical conclusions seem to be counter to this assumption; could we in fact conclude with time being a factor affecting and confusing the participants, or forcing a reflection in interpretation with this multimodal interaction? The lack of visual stimulus would suggest that this focused the individual on interpretation from the haptic stimuli.

5.4.2 Expectations

It must be said that museums largely rely on visitor goodwill and interest in order for footfall to occur. Therefore, in part, the museum has the responsibility to encourage visitor interest and even enhance visitor experience by conveying readily accessible information in order to aid the visitor in their interpretation of the exhibited object (Pearce 1990). In any museum, there are many examples of this; an explanatory text, a display, a collection, or a single piece of archaeology can mean different things to different people: individual motivation coupled with expectation will affect the individuals' specific interpretation, and indeed their wider interaction (Hood 2004).

Informed through a balance between their current surroundings and their own background history, Groups B and C brought their own expectations to these object handling activities. The range of interests and backgrounds influencing Group B were greater than with Group C; open to the public, the museum visitors in Group B were from different backgrounds whereas Group C was formed of academics in the humanities, specifically from the arts. Therefore, it could be expected that the broader demographic range as presented by Group B would, in the section of object identification offer a variety of answers based on the assumption that their expectations were different given their different backgrounds.

Using the 3DM of the Tauros Trigeranus, Group B offered a range of answers while Group C kept to descriptions of single entities, or groups of elements although the examples given by Group C appeared more imaginative: animal', 'skeletal', 'legs', 'Crab claw', 'humans on top', 'Shiva statue' and 'Amulet'. For Group B, examples of answers were 'Zodiac sign' and 'Bridal Gift'.

Interpretation of objects, for Groups B and C was informed by individual expectations in which education, societal and professional roles were shown to play a role. The individuals of Group C were academics at the Winchester School of Art and their expectations corresponded with something of artistic value. Their answers therefore described a part and offered an approximation of the object; this was directed by unimodal (haptic-only) interaction, limited by exposure. Understandably, an imaginative picture was gained, through haptic manipulation which was positively or negatively impacted by their expectations. In the case for this Group C, expectation, and developed by imagination, had the greatest impact on their object interpretation. For some, the description of a part or a single element, required approximation through expansion or elaboration, producing something tangential, but related to expectations of what the 3DM represented: by naming specific objects or giving specific references, such as 'Amulet' or 'Shiva Statue'.

Expectations by Group B were likely to be directed by object interaction that was multimodal. The variety of experiences represented by the group, therefore, resulted in a great range: where it must be said, interpretation demonstrated a specific but not necessarily topic-specific knowledge which, whilst providing definitive interpretations, was guided by perceived expectations. Definitive 'whole' objects have been given, to this extent through the combination of haptic and visual stimulus; this complementary exposure would seem to be expansive to offering up object-specific information. Though, given the lack of topic-specific prior knowledge as well as a lack of exposure to related artefacts, answers from Group B were object-specific, that is: 'Bull', 'Cow', 'Goat', 'Boar' although two out of the 41 mentioned 'Bridal Gift' and 'Zodiac Sign'.

Expectations, especially the expectations of the encounter, clearly affected object interpretation. However, the extra meaning ascribed by both Groups B and C, 'Shiva Statue', 'Amulet', 'Zodiac Sign' and 'Bridal Gift' further demonstrate the personal nature of interpretation (Wachterhauser 1986) in which, experiences via previous exposure to various influences, are likely to offer and even attribute context to interpretation. The ascription of a wider and more personal narrative is particularly interesting for the museum. Interpretation of the 3DM is influenced by the experiences of the individual and therefore any information resulting from interaction is personal. Interpretation in the context of the person is focused between the 3DM and the individual (Owen 1999). Thus, the individual in the ascription of context to the 3DM will apply personal information; this information may be from educational or experiential sources but this is reliant on the retrieval of memories (Eldridge et al 2000; Rugg and Wilding 2009; Linden 2015). Despite this interpretation being dependent upon the individual - the 3DM cannot interpret itself - this does not mean that the individual invents their own interpretation. Instead, this results in focussed interpretation which is specific to that object. Interpretation may therefore result from a variety of personal sources: like memories, education, experiences and reception to the 3DM; but equally in a museum setting this will be influenced by the museum as an external source: such as any written interpretation as well as the presence of the original artefact. Given this focused and personal interpretation as indicated by Groups C and even B, which was encouraged through touch-based interaction, this form of interpretation can be encouraged and directed by the museum particularly in offering context to the original artefact.

Indeed, interpretation of the 3DM is focused and given the nature of any touch-based interpretation, the conclusions are subjective but not unguided. As mentioned previously in **Chapter 2.4** the occurrence of touch as a sense (Linden

2015) means that understanding of shapes and textures is seemingly instant and as a natural process would seem to occur without effort (Keltner 2010). However the process of understanding what has been touched beyond the obvious is not necessarily effortless; indeed, it is the ascription of context – and in the case of Groups B and C – the retrieval of memories that appeared to require a degree of effort (Eldridge et al 2000; Rugg and Wilding 2009; Gallace and Spence 2014), of which the respondents were keen to expend.

5.5 Approximation to Original Artefact

The process of replication, processing, production and perhaps re-production that is scanning, post-processing and printing **(Appendix E)** alters the veracity of the desired object in comparison to the original. Therefore, the companionable 3DM, would, by minute degrees, be altered as a simulacrum (Baudrillard 1929/2010). The 3DM will not, ultimately, be a replica but will exhibit a very close approximation that will in turn be a complementary tool. The problem that Baudrillard indicates is that of trust (ibid 1929/2010) and with the use of 3DM as a complementary interpretive tool in a museum, there is a need for the maintenance of trust between the museum and the visitor. The goal is not to produce anything in total exactitude, something that would be impossible for the current 3DPT. 3DM that, through subtle difference in material quality, maintains a border between complementary and complemented. Therefore, to be used as a device in a museum, which is a space for the public where the distinction between original and exact replica could be narrowed, the maintenance of this difference works to positive effect for the museum visitor. What this suggests for the museum visitor, is the chance to develop analytic skills in comparing the 3DM with the original as well as an opportunity to become engaged with the artefact.

Understanding, interaction and interpretation of museum archaeology, as can be seen through responses from Groups B and C were altered with this difference. This alteration affected some aspects of understanding surrounding visitor object appreciation as well as institutional use of the museum. Focussing on the 3DM, the fact is that its use within a museum, as a companionable piece to a collection, may bring up legal and ethical questions. What becomes apparent, with the use of 3DM as companionable complementary pieces to museum archaeology, is that the status of the 3DM is altered, and with that, the terms of interaction with the object and the institution.

To briefly consider this altered state, the 3DM is not a piece of archaeology it is an expressed interpretation of the artefact and is exhibited under the framework of ‘The Original’s Companion’. Companionable to the artefact, it is through this association that this altered object begins to gain value. Indeed, the individual museum visitor who interacts with the 3DM and associates it as a companion to the original begins to ascribe it value as my data indicte from Groups B and C, suggesting some transfer of value from the original artefact to the 3DM. Thus, the 3DM acts as a proxy to the distanced original artefact through the tactile interaction of the individual.

5.5.1 Subjectivity

Variety in object interpretation is as wide as it is personal to the actor. An object by itself cannot tell observers what it is, where it was made, for whom it was made, or for what use it was put to; and so visitors, as the interactor, must add context into it. Without guidance, this context is individual and personal, limited or expanded by factors such as interest, imagination, and schemas of interaction. To apply greater context in ascribing meaning, as with how museum visitors and the academics named the 3DM of Tauros Trigeranus as the ‘Shiva Statue’, ‘Amulet’, ‘Zodiac Sign’ and ‘Bridal Gift’, this suggests examples of memory retrieval and application of individual context. However, whilst there may have been effort in the retrieval of a personal memory that was relevant in the context ascribed by the individual to the 3DM, this also suggests an effortlessness in the identification of certain features. The ‘Shiva Statue’ therefore followed the identification of shape with the addition of heads and legs; whilst the ‘Bridal Gift’ the shape and extremities combined to be interpreted in the context with which something similar to that would be used.

To put it simply, the data from tactile impulses, as subject to a natural physiological process (Linden 2015) were unconsciously interpreted and this required no effort; it was the ascription of context – in this case memory retrieval – that was conscious and required effort (Eldridge et al 2000; Rugg and Wilding 2009; Linden 2015). These examples of the interpretation of the 3DM of the Tauros Trigeranus were specific to the individual and consequently personal.

However, this subjectivity in interpretation does not mean that the individual makes up or invents their own interpretation; instead individual interpretation will be informed from a variety of sources derived from sight and touch. As we saw with the data collected, a wider variety in interpretation of 3DM and objects was observed in Group C as opposed to Group B: where the former lacked sight, the latter included sight and therefore interpretation gained further focus. This interpretation, in short, allows museum visitors to appreciate a private viewpoint in which the actor gives a personal context to the object by retrieving a memory, and suggesting an origin, based upon prior experience. Therefore in the context of The Original's Companion, the personal interpretations that surround the handled 3DM and the impersonal interpretations that surround the artefact can complement and elaborate upon each other, with or without the accompanying text on the artefact.

To look at variety in interpretation, the pre-determined range given for texture in Group C can demonstrate variety in a matter that is highly subjective. A range of nine elements were first introduced in the 'Texture' experiment as: 'Spiky', 'Bumpy', 'Grainy', 'Hard', 'Lined', 'Rough', 'Soft', 'Smooth', 'Silky' with the tenth being 'other'. This range was not graduated in scale, but instead offered options on haptic feedback on which the individual would, as with reality, choose multiple overlapping criteria. The addition then of a tenth element, 'other', was welcomed as 70% gave multiple responses and around half responded to 'other' with interpreted haptic responses of 'fluffy', 'furry', or 'cold'.

In a way similar to the addition of contextual meaning and purpose seen above, the addition of the 'other' criterion demonstrated the personal link as well as the variety in object interpretation. The range of nine elements was never going to be wholly sufficient as to satisfy the question asked, but instead was designed to cater as much as possible for tactile description without causing confusion in the admittedly broad range of touch-based interpretations (Linden 2015). One element may have overlapping qualities with another, or share some qualities as indicated by another element, but the choice of multiple one-word descriptors was still useful for my participants because they selected the word from the criteria which suited them most or fitted their schema, even the choice of 'other' whereby they would decide if the one-word descriptors matched their haptic-only interpretation of the object for both 3DM and original artefact.

5.6 In Summary

Being able to handle an object, like a 3DM, and get close to it suggests that with haptic and visual exploration, a picture of the object is formed in the mind. The picture formed is sometimes an approximation which is built from points of reference that have been found by the actor. Informed by these points of reference, the actor then develops an interpretation that is private and therefore personal (Peck and Shu 2009). This interpretation is subjective and as such, this interpretation held by the museum visitor, will go on to guide and direct their interest and actions in the museum, as discussed in what I have described as the exploratory three-part action: where visitors would handle the 3DM, then seek out the original artefact and return to re-assess and re-evaluate the 3DM often by handling it again, informed by their visual re-evaluation of both objects. As indicated by my data collection in Groups B and C, curiosity, interest and even motivation to learn have all triggered actions which affected greater engagement and involvement, and hence by inference, greater appreciation of the museum experience.

Spence and Gallace (2008) point to the actor who handles an object which has their attention drawn to it which then generates active interest in the artefact. The interpretation of the object is dependent on whether it makes the biggest impression upon the individual (Simon 2010), but often that is limited by accessibility in museums to the artefact. A predominantly single-sense approach to object interpretation will produce results that may overlap with a multi-sensory approach to object interpretation, but this will ultimately be limited by restrictions in the individual's personal gaze especially when artefacts are viewed behind glass. The barrier comes down when haptic interaction is offered, as suggested by literature and my data collection. Upon haptic interaction and engagement, comes greater analytical interpretation (e.g. rushing to seek the original Tauros Trigeranus displayed in order to compare and evaluate, etc.) and sometimes, having fun with haptic play as previously defined, such as combing hair with the 3DM Bone Comb and giggling; or balancing the 3DM Tauros Trigeranus and hearing it fall and chuckling at the action, amusement as a side bonus.

Offering multi-sensory interaction would be beneficial to both museum and its visitors when interaction with 3DMs is encouraged – supervised or unsupervised. It is through the addition of tactile interaction that interpretation and further planned or unplanned interaction with 3DM benefits both the visitor and the museum as visitor appreciation and learning can increase from the exhibited objects.

To consider the current innovative uses of 3DM in the museum, there are many considerations which the museum can easily apply or adopt that can offer greater haptic engagement and interaction for their visitors: namely through selection of artefacts based on shape that provides sufficient points of reference (animal-like; relatable); colour for visual appeal and meeting expectations; context; weight of 3DM PLA or ABS filament/resin/paper to match or approximate original artefact, etc. In museums which have adopted the use of 3DM, visitor reception was overwhelmingly positive, demonstrating how this positive reception to 3DPT and 3DM can increase appreciation and even footfall. This is indeed highly encouraging news for increasing visitor appreciation of archaeology using 3DPT.

Chapter 6: Considerations Legal and Ethical

6.1 Considerations that could change everything

In the consideration of current ethics and ethical thinking about 3DM artefacts, discussions on possible guides for museums must depend on contemporary documents and new studies which, admittedly have not always kept up to date with advances in technology. However with this said, an updated and overarching framework was given by the European Union in 2013, known as the 'Public Sector Information Directive' or more commonly as the 'PSI Directive' (European Parliament 2013), it is an update amending 'the re-use of public sector information' that was published in 2013 and came into application in 2015 (ibid). This, the PSI Directive, presents a framework that offers guidance that regulates the daily functioning of museums particularly with regard to the digitisation, storage, distribution and museum use of artefacts (ibid 2013; nmdc 2014). Such an overarching framework shall therefore be considered as this applies to every publicly funded museum in the UK (nmdc 2014, p.1). However consideration must be given to codified sources from the UK, as bodies offering theoretical and practical guidance, such as the Museums Association in 2015: this will be discussed alongside legal matters with a particular focus on Intellectual Property (IP) laws (Bentley and Sherman 2004) as well as documents that offer a framework for the use of digital images, such as the 'London Charter' (Denard 2009).

Before any discussion - legal and ethical - on 3DP and 3DMS can take place, it is important to know the current definition of IP and what it stands for: the term intellectual property (IP) refers to 'a loose cluster of legal doctrines that regulate the uses of different sorts of ideas and insignia' (Fisher 2001, p.1). These are inclusive of copyright, patent, trademark and property rights which are in place to protect the originality of the concept or object.

6.2 3DM: Related Law and Ethics

Museum protocol on the adoption and standardisation of 3DM as an interpretive tool to museums means that legal and ethical guidelines regulating the exploitation of in-house 3DPT and 3DM must be applied. Current museum ethical practice directs the use and halts any abuses that may occur, wittingly or unwittingly, that can undermine museum collections and dilute notions of ownership, in particular on Crown ownership of collections.

It must be noted that current museum ethical guides are already spelled out in a document called ‘A minimum standard for museums’ which was published by the International Council of Museums (ICOM), the international body whose members include museums from around the world (ICOM 2006, p.3); in addition, for museums in the UK, they are also bound by the regulatory principles of the UK Museums Association (MA), with membership and accreditation to the national body as sufficient inducement to meet or surpass the minimum guidelines set out by the association. The legal understanding of the use of museum collections is further developed upon by the ‘PSI Directive’ (European Parliament 2013) as this views the digitisation and the museum use of collections as public sector information, the definition:

> ‘…data, documents, images and electronic files created by a public body during the course of its core business. In a museum context this may include…collections management records, or images in which the museum owns the IPR’.
>
> (nmdc 2014, p.1)

In the daily practice of the museum, if digitisation or any of the above applies, then this necessitates that the museum applies measures in accordance with the ‘PSI Directive’. Though as mentioned in the above, considerations concerning the museum ownership of Intellectual Property Rights (IPR) for any artefact within the museum collection can be an issue. A museum’s collection of archaeology is formed of a group of artefacts whose provenance can be either known or unknown; this is subject to laws on IP as well as rules on ethics. Ultimately, ethical thought may determine that an object in a collection is conserved for the future and exhibited with adequate public orientated interpretation (ICOM 2006). However, IP will inform the museum as to the property rights dictating the scale of interpretation and indeed museum exploitation (JISC 2014).

Digital information is currently shared between museums, regulated by an understanding of the established guiding rules of IPR (European Parliament 2013; Morrison and Secker 2015; nmdc 2014). Understanding of copyright and the ownership rights of the museum allows the sharing and dissemination of information; this is complemented by the 'Creative Commons' licences[39] that have seen further development upon the understanding of digital aggregation and ownership rights (cc 2018a; NMC 2015, p.22). These licences provide formal understanding between museums that allow for the easy adoption and adherence to a framework for the loaning of artefacts and collections (Bauer 2015; Malaquias 2016). These guidelines have been reached in the consideration of tangible artefacts and currently regulates the sharing of artefacts. The Creative Commons guidelines, however, as we shall see, only suggest a course of action and therefore may be contravened. Many museums around the world have their own digital policy governing the sharing of artefacts **(Appendix F)**; however, with the growth in museums sharing copies of their digitised artefacts on aggregator sites like 'Thingiverse' (MakerBot 2012), 'Shapeways' and 'MyMiniFactory', there may be a case for an extension or development in current legal understanding (Koseki et al 2010) particularly with the implementation of the PSI Directive (European Parliament 2013).

Indeed, the project 'Heritage Futures 2015 – 2019' conducted research with the remit of looking into the development of heritage use by museums (Harrison et al 2016 p.1). Within this project four areas were of interest - uncertainty, transformation, profusion, and diversity – and were to be regarded as a concern to the future of heritage management (ibid). However, as mentioned by Harrison, it is the potentially broad range of practices in heritage that may possibly hamper any effort to develop within any heritage establishment (Harrison et al 2016, p68-70). In the use of digital collections it is the possibility of dispersal that is most disruptive, with a potential to halt or waylay museums and public access to 3DM or digital models (nmdc 2014). As such, consideration has been given by various research projects, as well as guiding frameworks like 'The London Charter' on the dispersal of digital photographs (Denard 2009), but even this, in consideration of digital models, would need development. The PSI Directive, implemented in 2015 (European Parliament 2013) does not revoke the framework of 'The London Charter'; it instead augments clauses concerning the aggregation and application of digital images inside and outside of a museum setting (Denard 2009; nmdc 2014; European Commission 2015).

[39] Adoption of any of the six creative commons licences is strongly recommended for any public sector body; such as a museum. In fact, in order to help decision making concerning the readiness of a cultural body to adopt a Creative Commons Licence, there are tools courtesy of online databases that assist with decision making, such as provided by IPR Support and the Creative Commons website (cc 2018a; IPR Support 2018).

The previous chapter expanded upon the benefits and potential uses of 3DPT and 3DM in museums as shown by data collection Groups A, B and C and this is important as there are certain instances where concerns over practice can potentially contravene current IP as well as ethical guidelines and so prevent its adoption of and implementation in museums.

6.3 Sales

To take an example from Group A for all but one of the eleven museum curatorial staff: 91%, said that they would have 3DMs sold in their museum gift shop. The curatorial staff from the museum which owned the replica of the 'Hameldon Bronze Age Dagger', and presumably with the dagger in mind, suggested also and possibly half in jest, 3DM sales made of chocolate – 'Chocolate Handaxe anyone?'.[40] Whereas this preference for selling the 3DM could be seen only for museum income-generation, we could also see this as increasing the interest and educational desire to know more about the original artefact and 3DM. In fact, as mentioned previously, sales of 3DMs from 3D printable digital scans is the current norm for profit and not-for-profit open-access online platform aggregators such as 'Thingiverse', 'Shapeways', 'Scan the World' and the British Museum-founded 'MicroPasts Project' (British Museum 2014). This selling of the digital image/file/likeness or 3DM for income generation is subject to guidelines outlined by PSI Directive (European Parliament 2013). However, like many museums, the PSI Directive has encouraged museums such as the British Museum to publish their own guidelines on how this directive affects their daily activity with respect to the re-use of digital images in publishing, aggregation and income generation (British Museum 2017d).

Whereas control of who downloads and prints the object from these online aggregators is limited (to those who have a printer and are interested in the object), the museum selling the 3DM inside the gift shop has an understandably tighter degree of control as they can select and print the 3DM as well as sell to the (presumably) interested museum visitor. In other words, the sale of 3DMs by the museum may limit the potential consumer base (European Economic and

[40] 3D printing using chocolate is increasingly popular but in the museum context, this raises a whole host of health and safety issues for the museum, unless of course they partner with a catering company or chocolate manufacturer which would open even more issues on third-party copyright and fair-use. It is important to note that such considerations of 3DMs pertain to the image and not the artefact.

Social Committee 2015) to visitors rather than anyone with a printer, but this would serve to maintain a tighter degree of control over access to their collections while still encouraging interest in the artefacts. In this case, there is no transfer of ownership in such sales.

The sale of replica models from museum collections is quite prevalent in museum gift shops: these are models created for that purpose and between those for exhibition and those for sale, a clear distinction is almost always drawn. Indeed, unless prohibitively expensive, the models for sale will often be generic to the type of artefact, while the models used in exhibition will be specifically of an artefact, made to a high standard and behind glass and out of reach. Guidance on the matter of the use of income generation is given by article 13 of the PSI: 'for the re-use of documents…for their reproduction, provision and dissemination' (European Parliament 2013) and is provided through consideration of the PSI Directive 6.14:

> 'Where charges are made by the public sector bodies… shall not exceed the cost of collection, production, reproduction, dissemination, preservation and rights clearance, together with a reasonable return on investment. Charges shall be calculated in line with the accounting principles applicable to the public sector bodies'.
>
> (European Parliament 2013)

In other words, these charges by museums can be "beyond minimal costs" (nmdc 2014, p.2). But in income generation, what must be considered is the in-house activity, through a museum Gift Shop. With a definition of commercial sales through trading companies as a 'museum trading company' (nmdc 2014, p.3) the PSI Directive does not apply to sales. The PSI Directive does however apply to how the museum approaches and provides information to these trading companies (ibid), stating that 'transparency' needs to be shown – in article 3 under 'principles governing charging' - in the dissemination of digitised cultural materials (European Parliament 2013). Indeed in the selection by the museum of any trading company, it is incumbent on the institution to ensure that fair-play is observed and that all the collections whose intellectual property rights remain with the museum remain accessible to the public (European Parliament 2013; nmdc 2014).

When also considering 3DMs for income generation, the resulting possible similarity between the model and the artefact in the museum's collection should be considered. Indeed, this issue of sales, if the 3DM were to be an exact replica of the artefact, could possibly contravene ethical guidelines as set out by ICOM 8.14:

> 'Members of the museum profession should not participate in directly or in-directly in dealing (buying or selling for profit) in the natural or cultural heritage' (ICOM 2006, p.13).

If a 3DM were to be sold by the museum and exhibiting the same features of a 3DM that was currently used as a companionable piece to the artefact on exhibition, as outlined in the framework of 'The Original's Companion', then this would threaten to contravene ethical guidelines as set out by ICOM. To reiterate, the similarity of the 3DM, one for sale, the other for use in the museum, may give the impression that the museum were selling off part of their collection, thereby disposing of previously used 3DM for a profit. Of course, there may be extenuating circumstances which can be considered to circumvent these guidelines – such as restricting or limiting the number of sales of such replicas with laser-etched marks to show that it is not the original, etc. – and many more such circumstances in a theoretical exercise. Therefore, the discussion below would be limited to what may likely happen in a museum, keen to expand their haptic engagement for visitors.

Stating the case first, to use 3DMs as a complementary device, as outlined by my framework 'The Original's Companion', would be an acceptable way of exhibiting a model as an interpretation. But to sell another 3DM of the very same 3DM that has been exhibited with the same veracity – scale, weight, colour, etc. – would enter a grey area. This is because with the museum placing a value upon its 3DMs (by selling it) may seem to inadvertently be placing a value upon publicly-owned heritage (MA 2015, p.3), and thereby introducing commoditisation into their collection (ICOM 2006, p.10). The danger therefore, would be to potentially undermine the trust between the museum-as-authority-cum-heritage-guardians, and the visitor, who has entrusted guardianship of their heritage to the museums. For some members of the public, they hold the museums to a high standard and expect museums to uphold the highest principles, given their privileged status as institutions of local and national heritage.

To sell 3DMs, as nearly all the museums would want to do as indicated in my data collection Group A, could have positive as well as negative effects upon the museum as well as the museum visitor. Thus, to avoid potential negative effects, 3DMs to be sold would have to be changed from the original such as: scaled down; printed with a different material i.e. plastic/resin/paper; even a different colour or weight; and possibly having a museum mark as a form of branding (Poltorak and Lerner 2002). The sales of 3DMs could, as previously mentioned, encourage interaction through interest by museum visitors, and a desire to learn about the original artefact through owning and looking after a 3DM. These positives, however, may be disregarded if the museums choose not to alter 3DMs, and simply presented and sold the 3DMs as unaltered, an act which would raise ethical eyebrows for individual institutions, as the Museums Association has written in the ethical guidelines:

> 'Treat collections as cultural, scientific or historical assets, not financial assets' (MA 2015, p.13).

Therefore, unless changed in scale, weight, colour etc., the sale of 3DMs will look like the sale of cultural collections. Understandably, given the reach and potential of 3DPT, it is possible for this to happen i.e. the production of 3DMs to approximate features of the original artefact. Take for example a 3DM of one of the Mayan pots from the Nebaj area, such as the pot on display in 'Museo de Arqueología' in Guatemala. I mention this because the museum does not have the financial reach of the British Museum and should someone 3D scan one of their beautiful, intricate pots and then re-construct it to fill in the missing shards, would this even be theft or infringement of the moral rights of the museum? And should the perpetrator be discovered via foolish posts on social media, can the museum make a claim for the re-constructed model under terms of ownership of the original? And even if they did, is it worth the effort for a small museum? Of course, this is just hypothetical – although given the rapid pace of technology – this is likely to happen in the near future unless better checks and balances are put in place.

Nonetheless, these potential drawbacks should not deter museums from making investments in 3DPT in order to increase visitor engagement and involvement with artefacts. The positive benefits to the use of the 3DMs as objects to be interacted with, as sources of interest and of learning should not be forgotten but instead encouraged.

6.4 How the Law Can Intervene

To consider the application of IP laws, we may extend the above previous usage and sales scenario. Academic literature on IP about the understanding of the many uses of 3DPT and subsequent use of 3DMs within an established museum is admittedly limited as the majority of articles and discussion mainly consider the potential role of 3DP in the industry and online platforms (JISC 2014), and of specialised digital visualisation (Denard 2009). The potential use by the museum of digitised models as well as 3DM has legal limitations in application. Digitisation and aggregation are covered by legal frameworks that specifically govern who has access to, controls, downloads, modifies a digital model, or indeed whomsoever prints a 3DM (Denard 2009; cc 2018a).

Creative Commons licences are legal guidelines that govern the sharing and third-party use of digital models, of which there are six iterations: there to ensure the copyright and permissions, as wished by the originating institution, are met (cc 2018a). These licences protect the artefact or indeed the digital image when on loan between institutions or when the image or model is shared with unknown third-party clients (ibid). As Creative Commons licences deal with digital licencing, certain museums have adopted this in order to regulate the use of their digital data (Bertacchini and Morando 2018). Databases that are online recipient hosts of this digital information like 'Thingiverse' or 'Shapeways' are in fact, responsible as publicly accessible aggregator databases (MakerBot 2018; Shapeways 2018). As publicly accessible and therefore responsible with sharing this data to third-party sources, online aggregation databases operate under a variety of licences from within the Creative Commons (cc 2018a). Indeed, whereas Creative Commons Licences apply globally to the museums as well as third-party re-use and aggregation of cultural materials, it is also incumbent upon museums in European member states to adhere to the treatment of cultural heritage as outlined in the PSI Directive (European Parliament 2013; European Commission 2015). Thus, a museum that is part of a European member state (**Appendix F, British Museum, National Museums Scotland and National Archaeological Museum Naples**[41]**)** is required to meet the standards for re-use of information as

[41] As reported in 2012 by an EU statistical body 'ENUMERATE', the total percentage of museums that offered public access to their digital collections stood at 31% for cultural institutions (this includes museums, libraries, and archives); however this falls to 22% in the consideration of only Archaeology Museums (Stroeker et al 2012 p.4). Though this number is in itself an increase according to the 2013 report, 'Public and Commercial Models of Access in the Digital Era', only 5.5%

outlined in the guidelines of the PSI Directive (nmdc 2014; European Commission 2015).

To produce a 3DM, the museum would have to consider their moral rights or those dictated by the owner, as well as the property rights over the original artefact (JISC 2014). Unlike the earlier hypothetical example with the Mayan Pot, this discussion looks at what museums can or cannot do under the guidelines with 3DMs. Applying laws concerning IP would require the museum to examine the provenance and terms of donation of the original artefact, and to consider the ultimate use of the 3DM (ibid; Malaquias 2016). In this scenario, the museum would first have to examine and determine the terms of the original loan or donation, the novelty of the object and the cultural significance regarding final use (JISC 2014).

However, given the current state of property rights in IP, there is, in fact, little to stop an object on loan from being replicated as a 3DM, unless specifically requested. The digital object, should one be made, is in-part governed by the standards of practice outlined by ‘The London Charter’ (Denard 2009) as:

> ‘The Charter defines principles for the use of computer-based visualisation methods in relation to intellectual integrity, reliability, documentation, sustainability and access’ (Denard 2009, p.2).

A loaned object once replicated will therefore, be subject to the sustainability in preservation as a digital model on a computer (ibid, 5.2 p.10). However, on this point the London Charter is in direct contrast with British Museum policy. In the article ‘The British museum account 2006-2007’, the author reminds us that the guiding act of 1963 ‘prohibits disposal of collection objects unless they are duplicates’ (British Museum 2007, p.4); in which case, – are not these visualised digital images essentially attempts to duplicate part of the artefact – what would happen therefore to the printed 3DM? Ultimately, the responsibility for any conservation and/or any addition to museum policy towards the 3DM or duplicated object will be incumbent upon the instigator of the action rather than placed on the museum. Though, if loaned to a museum rather than donated, the moral rights of the owner of the object must be considered and legally, has

of European Museums in 2009 had made their digitised materials publicly available (Feijoo 2013, pp. 116-117).

authority over the object and how it is to be digitised, manipulated through post-processing and produced as a 3DM.

The next question surfaces: who is able to enforce these rules? As can be inferred these are merely guidelines and based on trust that individual museums would police themselves. This may be made harder because many museums do not have resources to employ or train a separate Compliance officer on IP in their curatorial team. However, any uptake or adherence to a code of practice concerning digitisation, or 3DM, will be determined by the digital policy of the individual museum (Bertacchini and Morando 2018) that is possibly guided by a broad governmental strategy. Indeed, the digital strategy of the museum varies accordingly (ibid), as demonstrated in the selection of six museums and corresponding government strategy in **Appendix F**.

Each of the six governments have overlapped with the other governments in digital strategies (Mimler 2018); this is especially apparent in European Museums, for example, to look at **Appendix F** the 'British Museum', 'National Museums Scotland' and the 'National Archaeological Museum Naples' all have developed a digital framework that has in some way evolved from their consideration of the PSI Directive (European Parliament 2013). With this development in Europe and in the rest of the world, the six museums represented in **Appendix F** present some differences in the focus as well as application of the museum-based use of 3DM. Consideration of these digital policies – though limited to six national museums in **Appendix F** – is not representative of the totality of museum ambitions when considering the use of 3DM. However the positive application of policy directing the use of digital technologies in digitisation and online aggregation as well as the in-house use of 3DM for projects and exhibitions indicates a positive future outlook for the use of digital technologies which suggests further expansion in this area in their use of 3DPT.

The Creative Commons licences (cc 2018a), as mentioned earlier, much like The London Charter (Denard 2009) are concerned with any recipient use of the digital image and/or use of the digital model. However, unlike the latter, the Creative Commons licences specifically name and thereby rule out certain third-party uses for their digitised materials. There are six types of Creative Commons licences and each licence tier caters to different categories of use. The two most common types that are likely to be used by the museum as well as the aggregator sites 'Thingiverse' and 'Shapeways' are Creative Commons 3.0: this is known as 'Attribution 3.0 Unreported' or 'cc BY 3.0' (2018b), and Creative Commons 4.0, known as 'Attribution 4.0 International' or 'cc BY 4.0' (2018c). Covering the use of digital images, these licences work to govern how these images are shared with other people, and how they are remixed, changed or introduced as a novelty by those recipients (cc 2018c). An example from the British Museum website informs us that:

> 'the British Museum wishes to encourage dissemination about our collection and expertise that we publish on our website … we increasingly intend to release content on our website under a Creative Commons Attribution-Noncommercial-ShareAllike 4.0 International (cc BY-NC-SA 4.0) licence'.
>
> (British Museum 2018)

Whilst this 4.0 licence does not govern every item published on the British Museum website, this means that those that are governed are not-for-profit and can be downloaded and used with the correct attribution given (British Museum 2018). An extension of these licenses is in effect on other open-source aggregation sites, which will be discussed later. For two online database websites 'Thingiverse' and 'Shapeways', they are, however, governed by different types of the Creative Commons licence: the former encouraging adherence to the 'CC BY 3.0' licences (MakerBot 2018) as used by certain museums allowing for-profit pursuits, as well as sharing and augmentation but proper attribution must be given (cc 2018b). 'Shapeways', however, has adopted 'CC BY-NC-SA 4.0', this is for non-profit where sharing is allowed and attribution must also be given.

Returning to our discussion, the museum's moral right over objects and loaned objects which have been replicated would need another closer look at the most recent document on this issue: namely the '3D Digitisation and Intellectual Property Rights' (JISC 2014). The document provides a scenario (ibid, p.10) which is the closest for a museum and may provide an insight into the situation of the authority of the museum to commission a replication in order to produce a 3DM. The moral right, concerns works in which the originator is alive but where the object desired is not under copyright (JISC 2014, p.10). For guidance on this matter of ownership we may turn to the PSI Directive: a digital image that is produced and aggregated by the individual museum possesses the intellectual property rights of ownership, it is therefore incumbent upon the owner to ensure the upkeep of certain standards (European Parliament 2013; nmdc 2014; British Museum 2017d). However, it is with practical application and the later digital aggregation that when a copy is derived from the source by a third-party it is outside the scope of the PSI Directive (nmdc 2014; British Museum 2017d). With that said, the intellectual property rights from in-house projects or educational outreach activities are owned by the institution or the individual that has digitised and exhibited the 3DMs (nmdc 2014; cc2018a).

If, for example, the museum wants to exhibit the various stages of making stone arrowheads and needs to create a 3DM of the newly made piece of archaeology, then where there is no chance of copyright infringement, the originator would have to be notified if only to obtain the moral rights (ibid). However, if the originator is no longer living or if the 'originating source for the material' is publicly owned, then in such cases, the rights would have to reside with the institution where the artefact is housed and thereby the possible application of IP consideration, or if presumably the museum, the Creative Commons Licence (JISC 2014; cc 2018a). In the latter, does this mean that the museum is allowed to wilfully 3D print out the object? In this sense what role does the museum play: as the purveyor of heritage objects for display, the guardian of national and local heritage or both?

In short, the museum polices itself and this may become a contentious issue when museums begin to extend the role of 3DM beyond educational and haptic engagement within its walls. Finally, what about issues of data from 3D scanning of the original artefact: the museum, as guided by the PSI Directive is encouraged to make this information publicly available online (European Parliament 2013), and this can be achieved through the museums' own website or on a database, such as 'Thingiverse' or 'Shapeways'. The contentious issue is in the re-use of this online data by the public; and as there is a wealth of data lying dormant in the museum's database, the issue is twofold: what should be uploaded and what can be done with this data?

The Museum in the UK that wishes to upload and share digital files is encouraged to refer to the PSI Directive, though they are given the discretion to decide which materials to make publicly accessible: and although that is left up to the museum (nmdc 2014), it is still incumbent upon them to ensure certain provisions in the protection of digital heritage: such as in income generation and that proper attributions are met (European Parliament 2013 Guibault 2018).

The next section looks in detail at how IP laws can be applied or cannot be applied in certain cases.

6.5 Intellectual Property (IP) Law

In the replication of archaeology using 3DPT, we must consider IP as offering regulation on the different ways that digital 3DMs as well as printed 3DMs can be used. For example, the process of making a 3DM includes many processes such as: digital image capture, information storage, post-processing and printing **(Appendix E)** at which at any level, control may be given to a second or third-party agent contravening IP (Weiser 2003, p.560).

Whether the museum storage of the digital image of the 3DM is held on a private computer, or one with a common access network, is important as it will assist to ensure the control and the ownership of the object. It is the consideration of sharing, and therefore, aiding in the aggregation of this material with other parties, that must therefore be guided by IP concerns. As discussed above, where the museum has intellectual property rights over digitised collections it is for the institution to show discretion in the aggregation of such data (nmdc 2014) but this cannot be without restraints and the onus also falls upon them to ensure the maintenance of IP and protection in use of digital materials (Weiser 2003; Guibault 2018). PSI Directive notwithstanding, it has made allowances for this: the museum is not obligated to share all data that has resulted from digitisation programs; but instead, it is left up to the discretion of the institution on what to make publicly accessible (nmdc 2014).

All these practices such as data capture, sharing of data, and replication, depend on the handling and permission to handle the data from the owner of the IP, whether by a first, second or third-party source. Any museum replication of archaeology will be subject to restrictions and safeguards imposed by the IP laws (Fisher 2001). However, as noted above, flouting can be done as no one is actively policing the issue of replication, particularly those of 3D photos taken without prior permission in museums.

The rise of 3DP perhaps necessitates the protection of the collections that are part of the museum, leading to a development in the focus of laws surrounding IP laws which are inclusive of copyright, patent, trademark and property rights. It is the period of technological advancement resulting in the comparative ease of replication, storage, possible aggregation and potential modification of the original item by a third-party that has forced development in what had previously been seen as a ‘grey area’ in the law (Bentley and Sherman 2004). This seems to have been highlighted in the case of the head of Nefertiti’s statue, (mentioned previously in Chapter 2) which was reported to have been secretly scanned at the Neues Museum in Berlin and then uploaded for open-access use by the public. There was public outrage due to the fact that something precious had been seen as stolen and that public heritage can be easily transferred into private ownership. And this may be one of the many reasons why the British Museum's 'MicroPasts Project' has shown care when it comes to uploading digital artefacts to its database. To download and print a 3DM of an artefact that was uploaded as part of the museum's 'MicroPasts Project' means that the individual is required to sign in to the host website 'Sketchfab' and agree to abide by the licence of the 'Creative Commons 4.0 International' or (CC BY 4.0) with attribution as the sole restriction (cc.4.0 2018; British Museum 2018). In this case, public reception to the 'MicroPasts Project' has been warm and welcoming, and seen as a fantastic way to digitise national heritage as well as promoting engagement with the collections of the British Museum.

Returning to our earlier discussion, the closest comparison to 3D Printing and data protection can only be found in the 'London Charter's' four-page guidelines called the 'Computer based visualisation of cultural heritage' (Denard 2009) which 'aims to introduce greater rigour in the methods of digital visualisation of heritage' and is meant for the field of digital archaeology (Denard 2009, p.2). The guidelines scrutinised the implementation, purpose, uses, methods and the outcomes of digitisation projects in heritage orientated institutions like museums (ibid), and thus seeks to promote intellectual property rigour as well as to further focus development on sustainable computer-based visualisation (ibid, p.4). Again, this must be noted: it is merely a guideline. It must be mentioned here: the PSI Directive seeks to make such data publicly available with as few restrictions as possible, though there are certain caveats given; such as is written under 'Transparency' in Article 8 of the PSI Directive: museums may issue appropriate restrictions to the re-use of data through certain licences; however this must not restrict public access (European Parliament 2013, p.7). Article 8 of the PSI directive is just one of the caveats that is written in order to offer a level playing field in Europe, and indeed under 'Practical Arrangements' states that

> 'Member States shall make practical arrangements facilitating the search for documents available for re-use' (European Parliament 2013, pp.7-8).

For the museum, the data mentioned above includes public access to its data as well as public re-use of its metadata including online access to its digital aggregated materials (ibid).

In practice, for the successful production of a 3DM, once three-dimensional data has been taken of the original object, the resultant model must be in the computer and readied for printing. This means that the resulting model must be held on software, commonly known as post-processing software - that is neither from the capture software nor the printer – which cleans, processes and stores the digital model for printing. Once a digital representation is captured, it is then transferred to the post-processing software to prepare the model to print (Lipson and Kurman 2013, pp.100 – 102). However, in the case of the digitised model artefact, this can sometimes smooth out anything that the computer deems an erroneous detail which can potentially change the look of the artefact. The potential is there for this change of the superficial look of the model, and where accurate visualisation of a printed model is concerned, this is then a breach of principle 4.4 of the 'London Charter', (unless clearly specified by the museum):

> 'It should be made clear to users what a computer-based visualisation seeks to represent, for example the existing state, an evidence-based restoration or a hypothetical reconstruction of a cultural heritage object or site, and the extent or nature of any factual uncertainty' (Denard 2009, p.8).

It is this post-processing software's ability to add or take away details from the digitised computer representation and the subsequent effect upon the 3DM produced, which raises concern over the change to the original (JISC Legal 2015, p.3). During the process, resulting in the printing of an artefact, there will always be an addition or subtraction to the model produced: this could be in any stage of the process, but with the addition of time and greater competency, these differences can be rendered close to nil. In the ethical and ideal sense, such processes are protected with no possibility of any infringement.

However, 3DPT gives the museum the ability for aggregation of formerly private collections and by introducing them to the public, this has given rise to the debate between two camps: one which supports the "commons"; the other, the "proprietary control" camps (Weiser 2003, p.560). This may still be pertinent, even now, and concerns the practice of reverse engineering; in practice, the essence of the 3-dimensional capture process before 3D printing of the model. Aggregation of these collections is currently not regulated although sharing of the museum collections does not, as of yet, warrant firm legal action.

In the document by Papakonstantinou and Hert (2012) called, 'Legal Challenges posed by online aggregation of Museum Content: the cases of 'Europeana' and the 'Google Art Project', they write that 'museums are, in most cases, publicly-owned holders of vast amounts of information that are, by definition, open to everyone' (ibid, p.314). Though the above is in consideration of large multi-national institutions that deal with heritage, the individual museum may indeed be challenged to meet the administrative and resource requirements incurred when uploading their digitised materials (Clough 2013; European Parliament 2013) under the PSI directive in force since 2015. In fact, one new inclusion is the opportunity for redress as provided under clause 28 of the PSI Directive (European Parliament 2013). The option of redress can therefore be taken by the public upon a dispute or disagreement with the 'public body', in this case the museum and as mentioned by the 'National Council of Museum Directors' under ' Redress arrangements':

> '…there will be an independent body which will have the power to make binding decisions over such disputes' (nmdc 2014).

Further distinction by the UK Ministry of Justice on 'The RE-use of Public Sector Information Regulations 2015' states that:

> '…where a public sector body refuses a request for re-use it must notify the applicant, give reasons for the refusal and inform the applicant of its internal complaints procedure and other means of redress' (Raab 2015, p.14).

However, one caveat does apply to the practical daily operation of the UK museum, as under regulation 5.1 part b, the regulation of redress for the museum does not apply when: 'a third party owns the intellectual property rights in the document' (Raab 2015, p.4).

Therefore the implication for this issue of redress to be offered by the museum in all partiality is limited by the IPR of the museum collections. Besides the legal implications, as mentioned, there is the possibility that museums, in addressing such redress or disputes by some members of the public, may find this additional administrative task onerous and burdensome (Janssen and Hugelier 2013).

A study into the open-access nature of these projects has seen digitisation increasing, in line with control of the content either from the institution or the provider (European Commission 2015). This, in practicality, means that for the original 3DM, the rights would be held by the originating museum. In theory and practicality, this is so for every museum artefact. Under standard collections policy, a donated artefact that is subject to digitisation does not see the rights of IP changing hands; nonetheless, the museum still needs to address caveats that may preclude these actions. However, as noted in our hypothetical case of the Mayan pot, once something is out of place in the discussion i.e. 3D scans being out of the control of the museum, then it seems to be a situation of a 'free-for-all' with no restrictions and no adherence to any non-binding guidelines. As can be seen, this is again a huge potential minefield for the small museum, protective of its collections and yet eager to adhere to the spirit of the PSI Directive (2013).

However, as stated by Mendis et al (2015), 'there is a lack of empirical evidence' (ibid, p.1) in determining whether IP must adapt to new and potentially exploitative uses of 3DPT (ibid). In one argument, it is recommended that current IP need not change given that limitations in replication and printing of the current stock of 3DPT available does not necessitate legislation (ibid, p.5) and may, in fact, stifle public interest and creativity (ibid, p.6). However, Mendis et al also gave a caveat to their recommendation, writing that with the next technological breakthrough this could all change (ibid, p.8). In practice for a museum, any 3DP replication is currently to be undertaken and judged in the same way as photographic digitisation. This is dealt with by section 32 of the 'Copyright, Designs and Patents Act 1988' as 'Things done for purposes of instruction or examination in the Copyright, Design and Patents' (Crown 1988). Whilst the artefacts digitised must be made freely accessible on either the museum website or on a publicly accessible aggregator, such as: 'Shapeways' (British Museum 2018) or the Natural History Museum (iDigBio 2018), they are regulated, and the accessibility of these sites is ensured through the EU PSI Directive (nmdc 2014). However this guideline itself does come with the caveat that "Museums can apply a degree of discretion to what they make available" (ibid p.2) and therefore presumably, it is up to the individual museum to decide what constitutes public interest as well as the degree of accessibility for digitised collections/images/3DM that is eventually uploaded to a publicly accessible database. The data that is uploaded though should be publicly accessible and thus rendered in common 'readable' data. The data stored and made accessible, as mentioned by the European Union PSI Directive, Article 5.1 should ensure the current and potential 'interoperability' of contemporary as well as future technologies (Papakonstantinou and Hert 2012; Rosati 2013; Janssen and Hugelier 2013; European Parliament 2013). In other words, besides the need to ensure its data is uploaded for public access, there is also a real fear of the very probable ability of technologies for making digital capture easier, cheaper, and more accurate, and hence to easily produce 3DMs of artefacts on display which are of museum-quality: something that museums have to take into account.

The museum in digitising collections and producing 3DMs will have to consider the implications of IP through the whole process of data capture, storage, processing and printing of 3DMs. These are considerations that may prove onerous for certain museums: limitations may cast doubt on whether standards can be met which may prevent the museum from developing its collections (Janssen and Hugelier 2013, p.5). However, this is not to discount collaboration, as museums that do not meet certain requirements on the digitisation and aggregation of online as well as online data may seek to collaborate with other museums and institutions, like libraries and universities in digitisation projects, in order to have them hosted in 'Europeana' or the 'Archaeology Data Service' (Clough 2013, p.64; Trognitz et al 2016; Beagrie 2014). The future may not hold such limitations to museum digitisation, for reasons similar to the amendments made to the PSI Directive of 2003 (European Parliament 2013); it is predicted that future technology as well as the aggregation of data will increase exponentially (Freire et al 2017). At the moment it is because of the possible burden in ensuring that the requirements of the PSI Directive are met, that museums which otherwise have viewed the 3D digitisation and printing of 3DM projects as attractive may be deterred (ibid). However future developments concerning the interoperability of software (Clough et al 2017, p.215; Europeana 2018), and the rapid development of digitisation and storage technologies may encourage museums to digitise and print 3DM given a shallower learning curve. At the moment it can be seen that development in the potential production of 3DM has not kept pace with technology (Malaquias 2016; Freire et al 2017). Notwithstanding all these intentions it must be remembered that in any use of digital technology for the digitisation of collections, according to the Smithsonian Institution:

> 'Digital Technology should first and foremost enhance and reinforce the in-person visitor experience' (Clough et al 2013, p.63).

Functioning under the framework of 'The Original's Companion', it is the aim of the application of the 3DM to enhance the visitor experience. As an expression of data the 3DM is companionable to the original that is designed to benefit interpretation. Therefore, museum provision of 3DMs in public exhibition, promoting accessibility and engagement can, as shown in **chapter 4**, enhance visitor engagement with archaeology, and underscores the use of digital technology in the first place: as stated by Clough et al which is to enhance and reinforce the in-person visitor experience in the museum (2013).

6.6 Ethical Line

The subject of ethics and ethical guidelines as laid down by regulatory bodies such as ICOM and Museums Association as well as some national policies are the only ones to offer guidance on the treatment and exhibition of artefacts within museums, and 3DMs are no exception. The regulatory principles as laid down by the UK Museums Association (2015) concerning the exhibition of artefacts have it that:

> '[to] acquire, care for, exhibit and loan collections with transparency and competency in order to generate knowledge and engage with public collections' (MA 2015, p.13).

Ethics, or a code of ethics lays the foundation, and in part, sets boundaries emphasising an underpinning modality for museums (Edson 1997); however, as shown, the guidelines or ethics by ICOM and MA, while useful, are still broad and open to abuse. Thus, how should the concerned but participatory museum use 3DMs ethically, not to mention, how is it to share its data for re-use as per the PSI Directive?

6.6.1 To Digitise and Use 3DM

Within a museum, the decision to exhibit 3DMs would be three-fold: selection, heritage attraction and complementary conservational needs. This ultimately would boil down to the ethical considerations of a museum-focused visitor narrative and object-focused conservation through digitisation.

However, to maintain a visitor focus, the issue of choice in the selection of the 3DM would be made. The process of digitisation would not indeed begin until the object has been considered for any visitor-centric appeal, either in ability to elaborate upon exhibition narrative, the analysis of displayed objects or used to demonstrate a specific method resulting from historical and archaeological interpretation. This would fit with guidelines from the Museums Association - as suggested earlier in the chapter – so as to maintain its ability to generate knowledge (MA 2015, p.13; ndmc 2014; Guibault 2018).

The second and third issue: heritage attraction and digitisation, are in fact, dependent upon the first selection within the museum. Is the object popular enough to have a 3DM as an extra layer of interpretation, or perhaps, does an object require a 3DM as further explanation to bring out its concomitant artefactual wealth? Indeed, the final consideration: is the artefact in need of digitisation and should the 3DM try to show what the original artefact previously looked like when it was new?

Public consumption of 3DM will be to see them as interpretive models as the companion to the original and possibly distinct in material, colour, weight and even scale from the original, to which the 3DM is companion. An interpretive division between the original and the 3DM will need to be maintained in order to nullify any potential to mislead the public. This is a viable possibility, as indicated by 36% of curatorial staff from my data collection from Group A[42] of curatorial staff, who believe that the public may be misled by the side-by-side exhibition of the original object with the 3DM. However, and this must be acknowledged, it is a problem in some museums that present and display exact replicas, but do not label them as replicas or 3DMs. As ICOM states:

> 'Museums should respect the integrity of the original when replicas, reproductions or copies of items in the collection are made. All such copies should be permanently marked facsimiles' (ICOM 2006, p.9).

If an exact replica is presented, then to simply mark it as a copy is a minimum requirement which can still be open to misrepresentation by the museum or misinterpretation by the visitor. That is why in the current state of 3DPT using FFF technology which I adopted for this research, no such 3DM can be an exact replica of the original artefact. In short, the current state of the 3DM would have a clear division between itself and the original artefact. Further opportunities to mislead can be reduced by changes in scale, colour and material, as previously discussed in **Chapter 5**. However it is useful returning to the issue of authenticity and worth of 3DM as it gains this through association with the original artefact; indeed, handling the 3DM acts as a proxy for handling the original. As

[42] This was in answer to question 3.3: 'In displaying original objects side by side with replicas, do you think that the museum is running the chance of misleading the public?'

mentioned, in handling activities participants responded as such: they were given access by proxy that was privileged and previously denied to all but a few selected persons. The 3DM was therefore handled with the same trepidation that the original artefact would warrant, in which the ability for tactile engagement with the 3DM produced in the individuals a sense of awe. So, while the 3DM may have been ascribed worth, it is still a replica and is unlikely to be misrepresented by museums, consigning concerns of authenticity and fakes as just journalistic endeavours on a slow news day.

6.6.2 Storage

There are requirements for both physical and digital storage, both being a priority for the museum in the proper housing and categorisation of collections (Edson 1997). If it is to be presumed that this will be treated as another object in the collection, then the conservational duties of the museum will have to consider both the physical storage of the 3DM and digital storage of the model. The production of a 3DM will at first, necessitate digitisation, and this process will mean that the digital copy will become the property of the museum, and like cataloguing by the museum, this will be stored and maintained for future use by the museum (Clough et al 2017) and public re-use under the PSI Directive as mentioned earlier.

The issue of digital storage can be considered another ethical flashpoint. The desired outcome for the museum is the production of 3DM; this requires a process of digitisation and model representation. This is a digital representation of a piece of museum-owned archaeology that by itself is owned by the museum, and the parties concerned will be responsible for the upkeep and conservation of even the digital image. In fact, the same ethical guidelines for the acceptance and long-term care of physical artefacts, as suggested by Museums Association, will be directly applicable to the museum's storage of digital images:

> '[to] Accept or acquire an object only if the museum can provide adequate, continuing long-term care for an item and public access to it without compromising standards of care and access relating to the existing collections' (MA 2015, p.14).

Once the digital model can be manipulated and indeed can be treated as an object, its use will come under the guidelines above and should therefore, in conservation, be treated as a part of the collection: both subject to patronage and care. Data storage is very important, and file for a 3DM is data heavy, with great variation between digital file types. A photograph of a Samian ware pot viewed as a JPEG is 528KB but when viewed as a complete colour model as an OBJ file then it is 24,139KB (24 MB) or as a white STL file then it is 16,621KB (17 MB). Given the fact that the two 3D file formats given are those most commonly used by 3DPT, consideration should be considered as to the capacity for digital storage in the museum. This type of data storage may then need specialist conservation (Barnatt 2014). Indeed digital conservation should be just as rigorous as the conservation of the physical object, as greater use through handling activities, will bring with it a greater need for conservation.

At this point, we need to mention the 'EU Directive on the Re-Use of Public Sector Information: Guidance for museums' on Storage of digital images, as this states that any image the museum uses for income generation must be made publicly accessible (European Commission 2015; Guibault 2018) which has overlapping similarities to the guidelines on public-access as given by the 'Museums Association' (2014). Thus, museum data that arises from the digitisation of collections is required, to a degree, to be made publicly accessible to online audiences as well as visitors (ibid; Clough et al 2017, p.161); in this decision, discretion is therefore left with the museum that has digitised its collection (nmdc 2014). Although as earlier noted, should anyone feel that the museum is carrying its discretion too far by not making such data accessible, they now have the option to seek redress under the PSI Directive as museums are guided to clearly make visible the way for public access to this information, and to indicate clearly how complaints and/or disputes would be addressed[43].

6.6.3 Manipulation of the Digital Image for Interpretation

Returning to the issue of 3DPT: 3DM encourages interaction that is active, close, and tactile; a museum that uses 3DM will want this to be encouraged. It is a temptation to modify the digital image of the 3DM to increase visitor interpretation and that should perhaps be taken into consideration as well.

Potential problems in the 3DM can arise in the decision-making behind the exhibition of modified models. The modification of digital models, such as

[43] In point of fact, 'the complaints process will only apply to issues of re-use, and will not consider complaints about access, which are dealt with [separately] under [a different] access legislation (The National Archives 2018, p.29).

scaling for magnification, or editing the digital image to draw tactile focus to one particular detail, may initially be carried out with the intention of producing 3DMs designed to direct the tactile interest of the museum visitor. With that said, it does not follow that the museum has the right to modify the digital image in any way that they desire. As the digital object is part of the museum collection and 'The Original's Companion' is associated with the original, treatment of the image and the 3DM in re-use by the museum as well as third-party users, bears similarities to a piece of cultural heritage.

As a representation of part of the collection, once processed and visualised as a model, this becomes part of the digital collection; and concurrent ethical limits are to be placed upon what can be done with this piece of heritage. Therefore, any reinterpretation of the original piece of archaeology, by producing a complementary 3DM, needs to be sympathetic to the understanding of the knowledge represented in the simulation. Indeed, the intended result will be the most influential factor: as a piece of heritage where interpretation for the intent of exhibition must:

> "Ensure editorial integrity in programming and interpretation. Resist attempts to influence interpretation or content by particular interest groups, including lenders, donors and funders" (MA 2015, p.10).

Therefore, in interpretation, and in the case of the digitised copy and digital manipulation in post-processing, the museum has to consider two dependents: the object as a piece of heritage, and the audience as recipients. This is a relationship in which the 3DM will fulfil the role of the connector and allow the engaged visitor, as the handling actor, to play the role of the recipient.

In the interpretive context of seeing the museum purely as a place that interprets the artefact for the illumination of the individual (Taborsky 1990, p.50), we can see how a relationship between the artefact and the individual develops. To see the distanced artefact, and its surrounding interpretive text, the data interpreted or further interpreted, becomes information ideally given without obstruction to the (receiving) museum visitor. It must be stated, the 3DM is not key in this relationship, but it is assistive: the veracity of the model joining the connections between the distanced artefact, the bare-bones interpretation of the text and the comprehension and processing, in the context of the actor as recipient. As a representation of the original, the 3DM in the exhibition is an interpretation. However, unlike other interpretative materials, the model by production, becomes akin to a piece of heritage and therefore, it is subject to ethical standards (MA 2015). To be clear, as part of an exhibition, in this relationship, the 3DM can never take the place of the original artefact, and instead is a 'joiner', acting to assist interpretation and allowing interpretation from the original. It is therefore, this assistance in knowledge transfer (Roberts 2004) that increases the importance of the veracity of the model, because otherwise a distorted picture of the historical artefact may arise.

In consideration of this relational aspect (Taborsky 1990) between the object, 3DM and the museum visitor, we can begin to appreciate the use of 3DMs as assistive in providing the visitor with tactile information that they otherwise would not get. In certain cases, however, there may be magnification of the 3DM with scaling, increasing discernment of the whole, or part of the 3DM. In a similar way, the editing of the digital image may serve to draw tactile attention to one or more details of the 3DM: such manipulation may be done to bring out the full interpretive benefit of the museum artefact for the engagement and edification of visitors.

Within this equation, this type of modification must be considered, if downloaded by a third-party where the model is subject to whichever licence is attached to it (Janssen and Hugelier 2013), and this licence can vary in potential and leniency. The licences of the Creative Commons, previously mentioned, offer various grades of restrictions and leniency; modification of a digitised artefact can be described as introducing a 'derivative' and thereby contravening the most restrictive creative commons licence 'Attribution-NonCommercial-NoDerivs' known as 'CC BY-NC-ND' (cc 2018a). Allowing for aggregation between third parties, this rules out any modification of digital file or 3DM as well as any attempt at income generation (cc 2018a). However to look at **Appendix F** it can be seen that online materials are regulated by Creative Commons Licenses that offer the ability for aggregation, commercial activities as well as the introduction of derivatives (ibid). As can be seen, there are key issues to be considered for a museum intent on providing an exemplary exhibition with 3DMs.

The following discussion proposes a theoretical scenario which may work in the current context of ethical guidelines and IP laws while offering a full potential haptic engagement for museum visitors using existing collections.

6.7 Unwrap the Mummified Animal – A Hypothetical Exemplary 3DM Exhibition

Take for example, a proposed museum exhibition: ‘Unwrap the Mummified Animal’, operating in a museum and guided by the framework ‘The Original’s Companion’. This would see the full 3-dimensional replication of a 3DM taken from a Mummified Animal. This would feature the replication of every aspect of the Mummified Animal: the wrappings, body and every bone that would be done in order to replicate a complete Mummified Animal. The proposition of this type of exhibition is, at the moment hypothetical as this would represent an extreme in the application of 3DPT as well as 3DM. However, when we consider examples of scanning, there are two such examples where virtual 3D models have been recreated; both of which present considerable overlap with the proposed scanning project necessary for the exhibition ‘Unwrap the Mummified Animal’.

The first example was undertaken for the BBC programme ‘Attenborough and the Sea Dragon’, this featured the scanning and digital reconstruction of an Ichthyosaur by the University of Southampton (2018). The scans of the Ichthyosaur fossil were taken using a micro-CT scanner taking scans of the almost-complete fossil (BBC 2018). This produced a fully realised digital model that could be processed, reconstructed and finally animated. Computer Tomography scanning, known as CT scanning could achieve this, as this used x-rays to scan the embedded parts of the fossil, thereby the entire skeleton could then be individually modelled, processed and animated (Southampton University 2018). CT scanning of this fossil allowed for the reconstruction and recreation of an entire Ichthyosaur, as every bone, scale and tooth were digitally realised (BBC 2018). Our exhibition entitled ‘Unwrap the Mummified Animal’, would bear similarities in the fact that CT scanning would likely be used in the reproduction of every bone and wrapping of the animal. Ultimately, this would result in the production of an accessible 3DM, where every part of the 3DM would be detachable and a fully realised piece on its own.

The second example was undertaken by the British Museum and featured the 3D scanning of a mummified Crocodile (The British Museum 2017c). The scanning of this Crocodile was also undertaken using a CT scanner to produce a number of scans as well as a virtual 3D model for exhibition as part of the temporary public exhibition ‘Scanning Sobek: mummy of the crocodile god’ that ran from 10th December 2015 – 21st February 2016 (ibid). As a product of the scanning of this mummified Crocodile, there is in fact 3DM to download and print on the aggregator website My Mini Factory (Scan the World 2016). As it is the body of the 3DM that can be downloaded and printed and not the detailed bones or indeed anything inside the model that was shown by the CT scan (The British Museum 2017c) it will be different from the proposed 'Unwrap the Mummified Animal' as the 3DM aims to provide as much interaction as possible based on the use of multiple 3DMs which would collectively make up the 3DM of the mummified animal.

The above examples of the scans show that with the application of the correct technology, the full 3D scanning and the presentation of an interactive virtual model for exhibition is possible. However, to print the full 3DM representation of an animal with which the visitors can interact, raises questions that for some may seem ethically ambiguous[44]; there are in fact current examples for similar projects and museum exhibitions. At this point, it must be stated that, this only suggests that a 3DM of a Mummified animal, such as a cat, dog, crocodile etc. be made, and not a human. The examples of projects and exhibitions, in order to test 3D scanning and 3DPT abilities are, as previously mentioned in Chapter 2: Allard et al (2005), in the replication of a 3DM from a female Mennonite skeleton for museum exhibition in Manitoba (ibid, p.1); Tschopp and Dzemski (2012), in their replication of a Sauropod neck for reconstruction and exhibition in a museum, and from the 'Medelhavsmuseet' (2017), which in collaboration with 'The interactive institute Swedish ICT', produced 3D scans from a Mummified Ancient Egyptian called 'Neswaiu' (RI.SE 2014).

All three examples, used a variety of technologies over a period of time, and required a steep learning curve, but important to our proposed 'Unwrap the Mummified Animal', these show that this type of exhibition is possible for the museum using current technology. At this stage, it is useful to note that unlike the use of the Mennonite skeleton, my proposed 'Unwrap the Mummified Animal' is from an animal and not from any human remains and therefore unlikely to cause as much controversy.

To reiterate, the proposed exhibition 'Unwrap the Mummified Animal' is used to represent an extreme application in the use of 3-dimensional technologies

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[44] I am referring to fringe animal rights groups; however, it must be noted that there is no case of animal abuse at all and should be taken as similar to displays of taxidermy. However potential protests from these groups should not be discounted.

(scanning and printing). This exhibition thus proposes that a museum-quality 3DM be made of every part of the Mummified Animal which would then be exhibited. The exhibition would have a visitor focus, and would be fully interactive with museum visitors, able to construct or deconstruct the 3DM as in taking it apart like a jigsaw. As we have seen with the examples of Allard et al (2005), Tschopp and Dzemski (2012) and the Medelhavsmuseet (2017), at the present moment such an exhibition can be achieved by using the current technologies available.

It must be noted at this point, that with the digitisation of any animal from a museum collection, as is being proposed, it is incumbent upon the facilitator to use discretion in the use of the data, not just in the printing of 3DM but in the storage, maintenance and any online aggregation; all of this to remain in-line with the PSI Directive in force in the UK since 2015 (European Parliament 2013) which emphasises accessibility for all. Therefore, in consideration of the exhibition and the aggregation of data, it behoves us to think about the extent to which this data can be made accessible to the public. For museums with this 'Unwrap the Mummified Animal' Exhibition, the museum will produce an excess of data and metadata; and therefore, while it will be under their discretion on what to make publicly accessible, the spirit is to make the data and metadata available, albeit without possibility of any infringement.

6.7.1 Why a Mummified Animal?

The popularity and fascination of the Egyptology Gallery continues to be an attraction for visitors (Moser 2006): there is something about the society and culture that fascinates museum curators as well as museum visitors. It is this fascination by museum professionals, as well as the interest shown by the museum visitor that seems to drive an interest to know more, and thereby, spur museum re-interpretation through representation and innovation (Moser 2015). The association of ancient Egyptians with the mummification of animals may not trigger as much interest in the public as actual human mummies, but in comparison with the representation of human remains, the 'Unwrap the Mummified Animal' would bypass the contentious issues associated with exhibiting human remains, and worse still, allowing tactile interaction with one (that is why the 'Medelhavsmuseet' in Sweden only allowed tactile interaction with the 3DM amulet). Therefore, the choice of a mummified animal, whether it is of a cat, dog, crocodile, or any of the other species that was mummified, is intended to increase the representation of the practice of animal mummification, ideas of animal symbolism and even the study of animal anatomy.

Besides the fascination with mummification for the public, it is the access to these collections of mummified animals that makes this type of exhibition using 3DPT and 3DM viable and highly possible. This is because mummified remains of animals from Ancient Egypt are rather common in museum collections with many 18th and 19th century British explorers donating their finds to their local museums (Stevenson 2013). It is not just national museums in large cities that were to benefit (Ibid) but also small-town museums like Torquay Museum (Torbay Council 2017) which, in common with large city museums, were in receipt of Egyptological collections from generous collectors such as Flinders Petrie, who donated his finds to many towns in England and Scotland (Stevenson 2013; Torbay Council 2017). Given a local significance, the museum, having been in receipt of such Egyptological artefacts, will find scanning and then printing the 3DM of the mummified animal for production and exhibition relatively simple with the first major hurdle gone – that of access to the mummified animal in the first place. In fact, given the PSI Directive in force, databases such as the Archaeological Data Service (ADS) have published clear guidelines on the different types of 3D formats to allow interoperability (ADS 2016) and assist museums interested in uploading their data on such sites, besides the individual museum keeping the data in-house (Trognitz et al 2016).[45]

To select and reuse an object from the museum stores would introduce reinterpretation and increase representation of the topic such as mummified animals within the museum. This publicly accessible reinterpretation of the animal in the exhibition ‘Unwrap the Mummified Animal’ would present a deviation from the reinterpretation of human mummification (Moser 2015) through the examination of human remains, and instead focus on the culture, societal roles and beliefs surrounding the role of animals in Ancient Egypt. In addition, the more scientifically-minded museum visitor may appreciate the techniques used in the preservation of the animal while admiring the skeletal remains of the animal. This is also likely to appeal to younger museum visitors who would now have a tactile role in the inspection of Egyptology.

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[45] As offered by the ADS digital archiving service, there are 15 file formats in which data can be uploaded as well as an overview of parameters supported by the 3D data formats; in addition ADS also offers guidelines on 14 issues for consideration for file-level metadata of 3D models.

6.7.2 Ethical Considerations

'Unwrap the Mummified Animal' as a proposed museum exhibition, may also raise some ethical considerations. The exhibition would require careful thought in the replication of: the bandages and the individual bones that would constitute the 3DM. The exhibition would represent a development in the accessibility towards what can be classified as 'grave goods', and therefore, the possibility of unlimited visitor interaction with the 3DM should be curtailed due to two possible ethical considerations.

The first ethical consideration concerns the method of scanning and the resulting multiple images. If we accept the mummified animal as an artefact, then everything that is being 3D scanned must comply with the guidelines as set out by the Museums Association. To produce a 3DM of a mummified animal would be to ultimately produce three replicas: the 3D scanned images, the digital model, and the physical 3DM. In keeping with the current Museums Association guidelines on the ethical treatment of digital archaeology, the two digital representations, and the modifiable 3DM would have to display accuracy and similarity to the original.

As this proposed exhibition 'Unwrap the Mummified Animal' aims to represent the mummified animal with as much accuracy as possible, the above should only serve as guidelines and not limitations. However, the museum to retain this integrity (ibid) would have to be mindful of what control to impose over the image, the digital model, and the printing of the 3DM. Therefore, the museum will have to ensure that it considers the issue of control and how it is to be maintained in the long-term; over rights of access and what constitutes acceptable for open-access; as well as storage of the digital images, models and 3DMs in their entirety should the public seek redress after having been denied re-use of the data or metadata.

The second ethical consideration is regarding the concept of representation and its potentially sensitive context. The topic of access to the exhibition for visitors which features a re-production of a mummified animal for public exhibition and interaction needs also a close scrutiny. ICOM which has considered this, has offered guidelines on the exhibition of sensitive materials and as stated:

> "Human remains and materials of cultural significance must be displayed in a manner consistent with professional standards, and where known, taking into account the interests and beliefs of members of the

> community, ethnic or religious groups from whom the objects originated. They must be presented with great tact and respect for the feelings of human dignity held by all peoples." (ICOM 2006, p.9)

The museum, therefore, will have to consider strategies in limiting the possibility for any transgressions of the dignity of the original animal as felt by the museum visitors. Considering the interactivity of the exhibition of the 3DM in 'Unwrap the Mummified Animal', the museum might want to regulate access to the 3DM in several ways. The first way could be the placement of the 3DM in the exhibition located in a room where access is limited in which interaction is through supervision by a trained member of staff in attendance. To limit access into the room where the exhibition, 'Unwrap the Mummified Animal' would take place may reduce offending sensibilities due to great care being taken over the interactive activities. Another way the museum could avoid any perceived transgressions against the animal artefact is by offering a thoughtful and sensitive rationale, either by visual or oral presentation, or even a text, of the aims and objectives of exhibiting and allowing interaction with the 3DM of the animal in 'Unwrap the Mummified Animal' exhibition.

The museum that adopts 'Unwrap the Mummified Animal' proposal, will have to be mindful of these ethical concerns. Ethics in this case, impinges upon some aspects of the museum exhibition, from replication and production and may include how representation of the exhibition is conveyed to visitors, in order to garner positive reception from the public. To meet ethical guidelines over 'Unwrap the Mummified Animal', the museum therefore must consider its control over access to the digital data and metadata, as well as any resulting physical 3DMs while also taking into account the right of the public for access and redress under the PSI Directive: in other words, balancing all these against its ethical considerations.

6.7.3 How would the 3DM be made?

To meet the desired exhibition, as well as the potential level of interaction of the museum visitor with the 3DM as proposed by 'Unwrap the Mummified Animal', the 3DM made would be manufactured using different types of 3DPT. This combination of technologies would take examples from previous museum and clinical projects. Exhibitions of 3DM have shown us that the 3D scanning, reconstruction and printing of 3DM for exhibition purposes can be achieved (Allard et al 2005; Tschopp and Dzemski 2012; RI.SE-Interactive 2014). In addition, clinical experiments such as the printing of a Frog skeleton, Dogfish tissue (Thomas et al 2016), Rat skull (Phol et al 2017), or indeed bones of an Ancient Egyptian Mummy (McKnight et al 2015) all for research purposes, show us the accuracy that can be achieved in the correct application of 3DPT. In short, the printing of the 3DM must be conducted in a way that appreciates the wear and tear on the 3DM, from handling activities and the frequency of use with the 3DM as suggested in my experiment with LOM; as after three days of handling exercises the soft paper texture had begun to deteriorate and felt 'furry' because no additional coating was used.

In scanning to produce the digital model to be printed, a combination of technologies that include laser scanning, photogrammetry and CT scanning to retrieve the 3D information could all be used as per the example of the Medelhavsmuseet exhibition of the mummified remains with the 3DM amulet (2017, RI.SE 2014). The variation in 3DPT should be used in order to retrieve as much detail as possible and meet the practical demands of the exhibition (Allard et al 2005). In practicality, three technologies of 3DM could be used: SLA to recreate the density, strength and durability of the bones; FFF to print any detailed ornamentation or small bones; and LOM to give flexibility in the printed and coloured reproduced wrappings. In fact, to use 3DPT to retrieve and recreate as much detail as possible, the individual technologies could be used to recreate a desired textured feeling.[46]

The printing of a 3DM animal from a digital model of mummified remains would require time and money to be invested; indeed, this may present a relatively steep learning curve for any museum. However, given the current abilities of the present technologies and examples of previous museum projects, it seems that this can be achieved, particularly if done in collaboration with nearby universities.

6.7.4 Probable Reception of Visitors

The exhibition 'Unwrap the Mummified Animal' is designed for a visitor-focused interactive exhibition. This potential museum exhibition would be designed so that the visitor could re-construct and deconstruct the model by joining together or removing each individual bone and wrapping. The museum could also run

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[46] I used all three 3DPT in my data collection with Groups B and C. As mentioned earlier the technologies that I used were Fused Filament Fabrication (FFF), Stereolithography (SLA) and Laminate Object Manufacturing (LOM). Each resulted in a certain textured feel and interpretation. All are discussed in the findings chapter in Chapter 4.

specialist activities alongside which are designed to increase knowledge on the original and 3DM as well as Egyptology, Ethnography, History, Archaeology, Museology, Biology, Cryptography, and Art etc.

Reception to this exhibition, as with any activities surrounding the 3DM, is likely to be mixed. It will be the role of the museum to encourage the possibly reticent visitor to interact with the model (Chatterjee et al 2009). It has been previously observed that when touch is allowed through handling activities, either outside or inside a museum, the interactor will need time and possibly encouragement to become used to the level of interaction.

We can, in fact, take the reception received by the Plymouth City Museum and Art Gallery, which used 3DM for its 'Whitehorse Hill' interpretation as a guide (Pitt and Hurcomb 2017). Reception to their exhibition was overwhelmingly positive with only one negative remark as, 'waste of time and money' (ibid). However, the difference between their exhibition and what is proposed for 'Unwrap the Mummified Animal' is all to do with scale. This exhibition is not to be accompanied by any other technology; in fact, it is to be exhibited under the framework of 'The Original's Companion' and so, it is to be exhibited as complementary to understanding the original artefact. Direct comparison with the original may run the possibility of provoking negative reactions; however, these remain in the minority so long as there are strategies adopted by the museum to encourage positive reception and reduce any negative sentiments.[47]

As can be seen, visitors upon entering the room with the exhibition would have the experience of both visual impact and tactile engagement. As we have seen with data collection from Group C, expectations of the 3DM should be matched with the original artefact, which can be done through various criteria: texture, shape, weight and colour. This would help to encourage visitors to have as much positive interaction, interpretation and involvement as possible and could help to promote the exhibition as a worthwhile exploration through tactile-visual interaction and experience in the museum.

[47] As received from Data Collection Group B, only one participant (D2) commented harshly on the addition of 3DM in the museum feeling that 3DM 'SHOULD NOT BE ALLOWED IN MUSEUMS, BUT KEPT TO A CHILD'S TOY CHEST (sic.)'. See Chapter 4, p. 143. As mentioned, the majority response was positive and enthusiastic.

The ‘Unwrap the Mummified Animal’ exhibition would be an interactive museum exhibition of a 3D scanned and printed 3DM that the museum visitor could construct as well as deconstruct. With tactile engagement possible through the handling of every bone from the skeleton and every wrapping or ornament of the body, visitor interpretation would be developed upon and academic curiosity extended by the museum. The museum would have many roles in this exhibition, from selecting the object, to producing the 3DM. As noted, the museum should retain control of access to its physical representation within its doors. However, the museum should also consider the goal and the eventual uses of the final exhibition of the 3DM, with special consideration given to the ethics and reception of the exhibition of a 3DM of a mummified animal and how it treats metadata of its 3D scans. This is depicted in **Figure 42** on the next page which looks at the whole 3DPT process for the museum, with the in-visitor experience as the primary focus.

With the current technology available, such an exhibition is more than possible. For the museum that is able to produce such 3DM and successfully run the exhibition ‘Unwrap the Mummified Animal’, this presents vast potential for the development and degree of visitor interaction within the participatory museum.

The Original's Companion in Practice: Unwrap the Mummified Animal

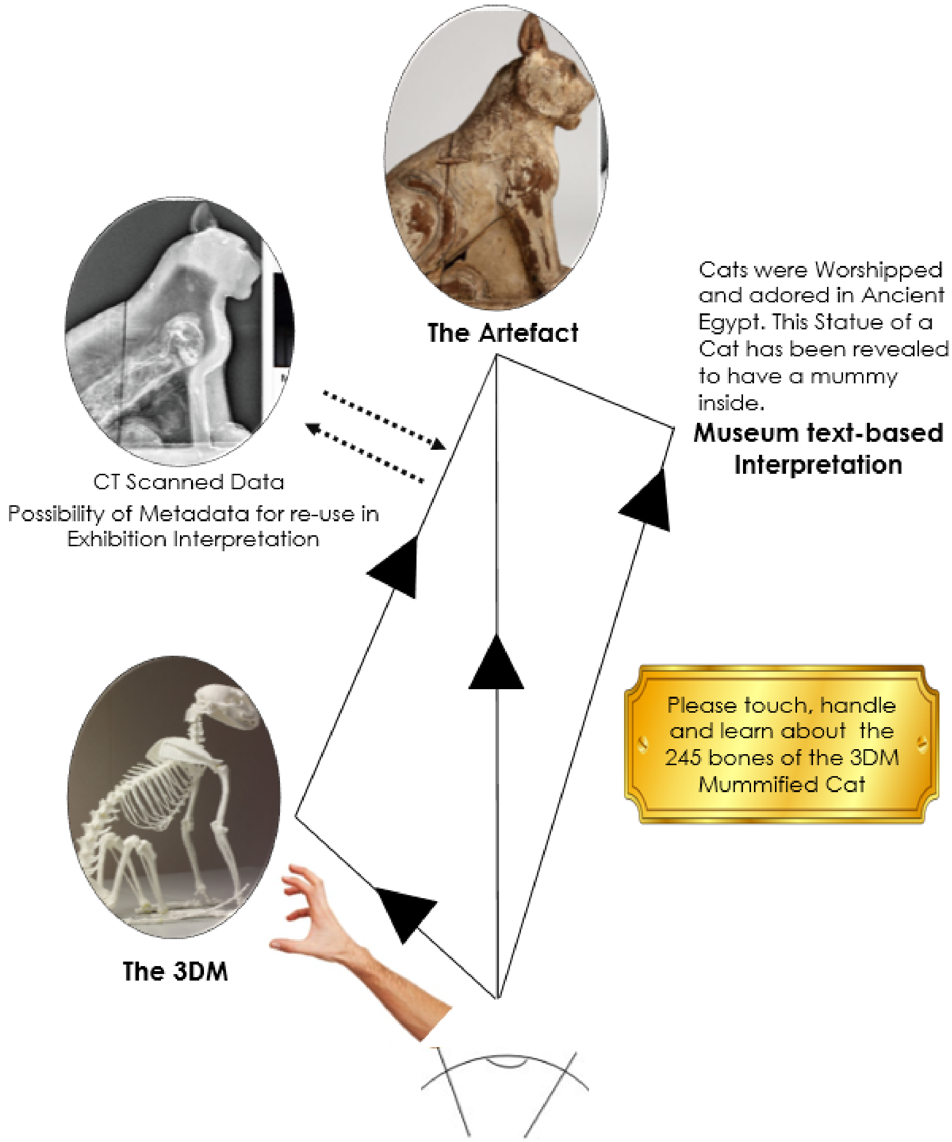

Figure 42 - Unwrap The Mummified Animal Exhibition[48]

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[48] The artefact pictured is of a statue that has undergone a CT scan as part of the University of Manchester Museum 'Gifts for the Gods' Exhibition. This statue is one of 800 such pieces that the museum hold in their Egyptology collection.
The 3DM pictured is not from the exhibition; and in fact, is the result of a 3D printing project by the artist Jonathan Seeney who posted a video online about his project. The Cat known as 'Alan' was reconstructed from a mixture of 2D scans, photographs and drawings; this was then printed using Fused Filament Fabrication.
All of the photographs used for the hypothetical Exhibition of 'Unwrap The Mummified Animal' are in the public domain, are open-access and have been downloaded from Google Images. The images are from: BBC Earth, this features the image of the artefact as well as the CT scan (Hogenboom 2015); and Jonathan Seeney who is the artist behind the 3DM of 'Alan' the Cat (2014).

6.8 In Summary

The processes undertaken by the production and use of 3DM inside the museum with the potential legal and ethical concerns indicate a way for future development in this understanding for both theory and practice. Currently, a direct use of 3DM is not considered either by ICOM (2006), MA (2015) or the ‘London Charter’ (Denard 2009) although as noted in **Appendix F**, some museums have begun to apply their national guidelines governing loans which can cover, in some instances, the use of 3DPT and 3DM. Nonetheless the concept of IP, is rarely touched upon or raised with respect to 3DMs of museum artefacts. In consideration of intellectual property rights, the law, as it stands can likely apply rulings surrounding copyright and property rights, but neither of these impinge exclusively with 3DPT or 3DMs. Patent law does impinge upon the technology but will likely never overlap with the museum remit of making and using 3DMs. The ‘London Charter’ (Denard 2009) and the European Union PSI Directive (European Parliament 2013; nmdc 2014) do offer guidelines on the way 3D images should be treated; but as discussed, this is not necessarily binding for the former and strictly enforced for the latter although offering guidance on the re-use of digital imaging in the museum.

However, no current work has reported on the potential museum use, either of the digital or physical 3DMs. The production of the 3DM definitely opens up the debate into the potential abuses which includes: the use of the 3DM in the museum, the loss of control or the delegation of the activity to a third-party, or even the modification of an image to produce a 3DM that is not representative of the original.

Similar to this, will be the issue of ethics when the museum considers income generation in its gift shop. The museum that prints 3DMs that are for sale, as well as the museum’s use, will surely have to change aspects about the item for sale such as: scale, material, colour, material and/or weight. This may be to limit the veracity of the 3DM or indeed to amplify areas of certain details to encourage tactile focus. This form of digital manipulation is currently governed via understanding from guidelines of digital manipulation of images as set out by the ‘London Charter’ (Denard 2009). If the museum does not make suitable changes or modifications to their 3DMs, then they would run a risk of deceiving and misrepresenting the museum in its role as the guardian or steward of local and national heritage.

As 3DMs become more widely used by the participatory museum, and their application within the museum grows, so will the literature on the subject (JISC 2014; (Pieraccini 2001; Denard 2009; Morel-Deledalle 2010). The current pace of ethical and legal thought has not gained the momentum that it deserves, and it seems that future guidelines with clearer specifications may arrive as a reaction to future applications. As shown, there are many possibilities and potentialities with the use of 3DPT and 3DM and their inclusion in museums would indeed increase visitor involvement, engagement and interaction.

Chapter 7: Conclusion

In the last few years, several museums have since closed while the rest have had their funding reduced; in other words, it is now becoming imperative for museums to show their relevance to the public, and to attract new as well as returning audiences. The aim of this thesis is to investigate the application of 3DPT and the use of 3DMs in museums that would not only benefit the interpretation of archaeological artefacts but offer museums the opportunity to engage more with their visitors. As mentioned previously, 2016 is now seen as the start of declining trends in museum visitor numbers (DCMS 2017). Thus, this research presents useful data, previously unavailable, which offers new directions on museum praxis, which can help to increase visitor engagement and involvement as a participatory museum, and possibly help to stem falling museum visitor numbers which is admittedly part of a wider trend towards visitor attractions receiving fewer visitors.

This study began by offering a systematic overview of 3DPT and how it has been applied in different industries such as health sciences, engineering, construction and architecture. As noted about relatively new technologies, there was and still is a certain degree of media hype for 3DPT, in spite of its use as a printer since the early 1980s. Currently, the most popular and viable use in 3DPT for museums is the 'Desktop printers', of which the FFF technology has also been used in my study so as to offer both practical and functional perspectives on how museums can apply this technology. Therefore, my research on the effects of 3DPT and 3DM in the museum to benefit archaeology has included studies surrounding museology, archaeology, history, psychology and sociology, to help us understand the variety and depth of interpretation as originating from this degree of haptic interaction with 3DMs.

Research has shown the importance of tactile interaction which can aid interpretation through orientating an object; identifying objects through classification and grouping, while also linking haptic interaction with positive emotions and even healing. However, all these previous experiments and studies, as noted in 'Chapter 2 – Scientific and Theoretical Overview', were conducted using a variety of objects and not museum artefacts; or if museum artefacts were used, they were conducted on patients outside the museum context; or they were studies not meant for exhibition but exploring the potential of 3DPT in producing museum-quality objects. Nonetheless these studies are useful because collectively, they offer insights into the benefits of haptic interaction and involvement seen from a variety of perspectives – biological and physiological feedback; the psychological and sociological underpinnings, and even on the empirical and philosophical discussions on the sense of touch. In other words, the long literature on haptic engagement and tactile interaction indicate its importance particularly from the perspective of the museum keen to increase visitor footfall.

7.1 'The Original's Companion' in Praxis

As such, my research through my methodological framework 'The Original's Companion' investigated three important museum stakeholders, based on the concept which I have borrowed and adapted from Anderson (2006) which I call the 'imagined audience', and which have direct relevance to curatorial staff. The other stakeholders were museum visitors and academics. Thus, in my framework, the museum stakeholders were divided into three groups which comprised curatorial staff from 11 museums, 42 visitors from two different museums and 12 academics, so as to obtain a wider range and depth of interest held by them regarding 3D Printing and 3D models of original artefacts. Therefore, findings from each group were important because taken collectively, this crucial information from the three groups offered a comprehensive overview of how 3DPT could be introduced, received and positively accepted, as well as key information on the types of 3DM which would encourage a more engaged, involved and even exploratory audience within the museum.

As stated in my introduction, I had deliberately limited my use to the three most popular 3D technologies because of their relative low cost and ease of use – scanning, post-processing and then printing – as well as the relatively shallow learning curve required to adopt the technology. Understandably, the material used for the 3DMs in my research was important: thus the 3DMs used, for the majority, were made of PLA plastic (Shabti doll, Samian ware pot, tusk fragment); two were ABS (Samian ware pot, lion column base); two were made from a mixture of PLA/ Bronze (Carthaginian Token and the Tauros Trigeranus); and one was made of Paper (Samian ware pot).

For the first group of stakeholders, I reported my findings from surveys returned by the eleven curatorial staff who indicated that the application of 3DPT would benefit their museum's mission and activities, and that they were largely positive about the introduction of 3DPT and 3DMs. More importantly, these curatorial staff mentioned that the production and use of 3DM would benefit the way their museum was seen or viewed in their community and thus were receptive to having 3DMs as an interpretive tool in the museum. Although the large majority of them viewed 3DPT in the role of conservation and documentation for their own museum collections, these curatorial staff were also in favour of having supervised and unsupervised handling activities with 3DMs in their museums. Almost all the museums were in favour of sales of 3DMs in their museum gift shops, thereby highlighting the importance of funding and generating income for their museum management.

These answers collectively indicate the positive reception by curatorial staff towards 3DPT and the use of 3DMs and imply a greater role for them, given sufficient budget and time. On the whole, the curatorial staff showed cautious optimism towards how they would deploy 3DPT and 3DMs in their museums, if they were not yet already using the technology. This positive reception by the curatorial staff is important because they are the ones who would be the adopters of this innovation within their museum. In fact, this positive reception to 3DPT seemed to have been confirmed by my own experience in my fieldwork collecting data in two museums – Dorset County Museum and Winchester City Museum - which not only gave me full use of their collections to conduct 3D scanning and printing of their original artefacts, but also requested for a public talk to be held on the current uses of 3DPT, prior to administering my questionnaire on their museum visitors. This positive reception can increasingly be seen in a growing number of museums – both local and abroad – which have begun to use 3DPT and 3DM in their exhibits. Reasons for the museum adoption such as conservation, education, etc. as suggested in studies (Maye et al 2014; McDermott et al 2014) are also mirrored in my data on curatorial staff.

Another set of data collection occurred in two museums that were located in different counties: the Dorset County Museum and the Winchester City Museum. In running the handling activities, overwhelmingly visitors were receptive to having greater tactile interaction with 3DMs. Through their tactile engagement with 3DMs, museum visitors indicated that identification was relatively easy for them, as well as encouraging them to offer more analytical interpretations based on their tactile handling of the 3DMs. They were happy to engage with the 3DMs and showed interest in the technology as a whole, with 42 members of the public attending my scheduled presentation on the general use of 3DPT. Even better, the majority indicated that they were keen to have more handling opportunities with 3DMs in museums; and more importantly, that they would spend more time or visit the museums specifically to see the original with the 3DMs. In particular, many offered suggestions on the types and what additional specifications to the 3DMs that would add to their enjoyment and interpretive engagement with the original artefact and 3DMs. In fact, a variety of answers that were elicited indicated keen enjoyment and interest in their visual-tactile engagement, with words offered such as 'Wow', 'Amazing', 'Awesome' as their single-word reactions to their handling of 3DMs. Museum visitors who answered my questionnaire also took the opportunity to pick up, play with and orientate the 3DM, speculating that the 3DM of the Tauros Trigeranus was, among a variety of answers, a charging bull, a horse, or even a zodiac sign. The wealth of answers showed their interest which also triggered or encouraged their interpretive analysis.

This interest and engagement also led to a specific sequence of behaviour that were repeated by the museum visitors which I have named as the 'exploratory three-part action'. First, visitors would see and handle the 3DM; then secondly, go and seek out the original artefact in groups of two or more; and finally, return for a comparison. In the first and last action, the 3DM played a complementary role in object interpretation, whilst changing in status by being ascribed analytical valuation and/or re-valuation. These visitors clearly viewed themselves as 'explorers' (Semmell, 2016) on a group adventure and therefore, were having fun being on a mission or quest to find out more about the original artefact.

Not just the observation of the 'exploratory three-part-action' another type of behaviour was also observed at the museum: this time on non-participants who were children. The two children involved ran in, saw the 3DM bone comb, conveniently left on the table, and immediately picked it up to play. Giggling and obviously enjoying themselves, they brushed each other's hair. As mentioned previously, no words were exchanged in that interaction by the young children. This spontaneous activity, which featured the immediate identification of the 3DM as a comb, led to much fun and enjoyment. Its use as a toy showed the link between this engagement and both creativity and relaxation; therefore, taking on important relevance as a valuable source of haptic play; an action which I have defined earlier as 'an act performed beyond touching for formal identification or information' (p. 212). Hence this spontaneous activity, derived from just picking up the 3DM Bone Comb, itself proved to be entertaining, fun and enjoyable for some of the younger museum visitors, indicating the many possibilities for a variety of 3DM tactile interaction activities in museums.

The next key group of museum stakeholders, the academics, provided the last link in my investigation for a more holistic and comprehensive data on how 3DMs can be utilised by museums to offer interpretive analysis for their visitors as companionable to the original artefact. This time, experiments were conducted on 12 members of both staff and postgraduate students, which offered crucial information, again previously unavailable, on how texture, details, type, scale and colour in 3DMs could affect or influence haptic interpretation.

In the experiment on texture, some of my participants even ascribed qualities to the 3DM using words such as 'safe and hardy'; 'pleasurable texture' as it felt 'flinty like shale [from a] beach' while yet another, likened the object to 'furry' in the positive association, suggesting that, memory, particularly pleasant ones, were recalled when engaged in tactile activities. More importantly, participants also indicated that, if visual cues did not meet expectations, or were not what they imagined the object to look like, then any tactile preferences mentioned earlier, made through haptic-only interaction, were subsequently disregarded. In other words, vision would override their tactile preference.

In addition, participants would also seek to touch for discernible points of reference so as to identify the object; and in tactile handling, participants would orientate the object as mentioned by Newell et al (2000) to achieve an object viewpoint through holding the object with the base on the palm. Besides cradling the object on the palm, familiarity with the shape of the object often assisted identification. In addition to having preference for weight in the 3DMs, the participants also showed their pleasure and enjoyment whenever they felt something which was like an animal; implying that animal shapes provided the highest points of reference and positive association for them. Sometimes, the participants also engaged in haptic play particularly with the two animal-like 3DMs, similar to the two young children mentioned, such as trying to balance the object on its legs and then hearing it fall onto the bubble wrap and chuckling, as they were amused by their haptic play with the 3DM. It was also found that when 3DMs were scaled up from the original size of the artefact, haptic discernment interpretation and enjoyment increased with the higher amplification, particularly at 1.5x and 3x due to the fact that participants could increase their ability to detect more patterns or lines. This suggested the role of including task achievement activities for haptic involvement and engagement for museum visitors.

7.2 Accessibility and Interpretation in Museums

In the interpretation of 3DMs, accessibility plays a big role. Under the framework of ‘The Original’s Companion’, to pick up and handle a 3DM is crucial; and the benefits to the visitor and the collection are fantastic. Touch-based interaction with a 3DM is also a highly personal interaction, and one which encourages informality if not greater involvement for the individual. Limits to museum visitor object-interpretation are often caused by limits placed upon access which can take many forms, namely glass barriers. Thus, such barriers like vision-only distanced interaction will not likely result in personal object interpretation. Therefore, accessibility in allowing for handling an object is understood to share a personal link allowing for specific object meaning to be given to its handler.

Touch-based interpretation of the 3DM can find ready application within the museum. There is a link between accessibility and interpretation such as to touch or grab the artefact and interact with it and thereby indicating analysis or interpretation had taken place, as my examples of the 3DM Tauros Trigeranus and the 3DM Bone Comb showed i.e. the young girls had interpreted the latter as a comb and acted accordingly. Both models - 3DM Tauros Trigeranus and the 3DM Bone Comb - met certain criteria: they exhibited relevant points of reference, they were the expected shape for the object. In other words, by allowing touch in the museum and having tactile activities with 3DMs of original artefacts, curatorial staff would have metaphorically removed the hitherto limiting glass barrier which had previously prevented any close engagement between visitor and original artefact.

With the introduction of 3DMs as companionable pieces to the original, varying reactions will not rest solely on just reception toward the 3DMs but on the interpretation of the artefact. Stating the obvious, sight-only interaction requires effort in analysing an object and in reading the accompanying text; unlike visitor-orientated object interpretation, which, although requiring a degree of effort, is decreased with close tactile-interaction with the 3DM. The effort, required in this case for interpretation, however, lessens with the addition of touch as opposed to sight-only. This addition of touch produces a personal interpretation in which the actor gives their own context, using personal interpretation to fill in the gaps left by previous vision-only stimuli. This context given to the 3DM is personal and related to the memory retrieval of the individual (Rugg and Wilding 2000; Spence and Gallace 2008). As such, the ascription of context to the object may not be as effortless, but the initial reaction from touch stimulus is still effortless. Indeed, to touch an object means that, however briefly, a physiological reaction will be set in motion and this will give automatic and unconscious focus to initial object interpretation (Linden 2015). The information first receive from the object does not need to be thought or processed for long in order to gain understanding because such interpretation is immediate. Thus, the addition of tactile engagement is vital for increasing greater museum visitor interpretation and possibly providing higher levels of enjoyment. Therefore, the application of 3DM is important to the museum because the companionable nature to the artefact encourages extensions of interaction within the museum, by encouraging engagement, interpretation, learning, and even offering health benefits and challenging perceptions of archaeology.

7.3 Touch as a New Praxis in Museums

To appreciate the generative potential of the application of 3DPT, benefits in the museum's exhibition use of 3DM will need to expand beyond the removal of the glass barrier between the visitor and the artefact, as mentioned. The absence of touch interaction from a museum severely limits visitor object interpretation. The museum use of 3DM thus represents the synthesis of three overlapping issues: application, accessibility, and interpretation. The museum can do a lot with 3DMs, and as these are complementary devices to the artefact, such adoption will benefit visitor interpretation.

Discussions on the functional aspect of the addition of touch as a new praxis in museums must also include practical details for its adoption. In a museum's selection of a 3DM, the museum must also decide what the primary purpose is behind the use of the 3DM. The 3DM could be placed as part of an exhibition, supportive of a narrative; as an educational resource; or anything else that the museum decides for its use. However, in interpretation, reception and interaction, this should be undertaken with the public at the heart and centre of the project or in any consideration on 3DM, as visitors are the ones to interact with both the original (vision-only) and the 3D model.

Application by curators, as seen in my study suggests an extension in the use of handling activities by staff. These include sales of 3DMs, supervised object handling and/or unsupervised object handling activities and also specialist educational activities with 3DMs. However, these same curators would have to be mindful that successful museum application of these 3DMs would be subject to reception from visitors, as discussed previously in my chapter on the ethical use of museum artefacts.

Novel and intuitive interpretation of 3DPT could be exploited by the museum exhibit given the flexibility of 3DMs to aid visitor object identification and tactile discernment. Manipulation of 3DMs through the amplification and scaling of either the whole or part of the digital copy have resulted in interpretive benefits; application of this in the museum context, is analogous to the use of a ‘haptic’ magnifying glass that could increase interaction with previously inaccessibly small objects, for example, in the appreciation of details in a coin.

The aim for the museum therefore, in its application of 3DPT, is for long-term permanent use of 3DMs rather than short-term exposure; and thus, the museum that uses 3DMs would need to be mindful of how they would be utilised and the correct message conveyed to the public so as to avoid any forms of misrepresentation or misleading the public. It is the potential informality of interaction with readily accessible 3DMs that the museum could include as part of their planning for tactile activities in order to obtain positive reception from the museum visitor, both adult and child visitors alike.

As this thesis shows, the application and adoption of 3DMs can offer tremendous benefits to the interpretation of artefacts of archaeology as exhibited in the museum. The individual museum, while deciding how it will apply these models, can offer more types of engagement for the museum visitor. As noted, 3DMs will introduce more than touch to the museum: they introduce a novel way of exhibition that can easily gain permanence while for the visitor, they represent a form of interaction that previously was forbidden, with original artefacts kept behind glass. With the use of 3DMs, this new form of tactile interaction and involvement has been shown to offer insights, increased interpretation and learning through a more informal and inclusive form of engagement for museum visitors.

Current experimental application has seen 3DPT’s potential to benefit the interpretation and engagement of visitors with 3DMs of original artefacts. This technology is a fantastic vehicle for increasing and deepening further understanding in archaeological interpretation by non-specialist visitors, and therefore, the use of 3DMs should be more than just a mere stationary addition to the exhibition: it should be a new praxis for museums. After all, by embarking on a 3DPT project, the museum is also developing upon its remit to conserve, preserve and protect artefacts whilst sharing valuable data with larger audiences, in this case, via digital means to inform and educate generations to come.

7.4 Directions for Further Research

There are a number of areas in which further investigation could be explored vis-à-vis tactile engagement in museums on 3DPT. The first of which would be the investigation of the use of 3DMs inside a museum for public engagement which is carried out within museum premises. This could take the form of an observation within the museum, in which certain artefacts would be accompanied by companionable 3DMs as well as certain placements of 3DMs in order to investigate how this may encourage the instances of 'haptic play' and the museum 'exploratory three-part-action' as observed in my data collection. In addition, my framework necessitated a whole-day presence in both museums during half-term holidays. Reactions and behaviour from museum visitors may differ from behaviour during normal weekdays or weekends. Thus, such refinements may further offer insights into what my own data has shown.

A second area of research would feature another round of data collection on curatorial staff taking into account newer 3DPT and presenting a set of questions based upon my current data on 'The Original's Companion'. Questions could be asked in line with new developments and accuracy in 3DPT since the start of my research. These questions would offer the latest data based on the most current 3DPT. However, as noted, my research was based on the three most common 3DPT in use, where the price has fallen accordingly while offering higher quality printing outcomes.

Finally, further refinements in my haptic experiments would be useful particularly on scale, texture, colour and weight which can now easily be adjusted as of 2018 instead of when I first started my investigation in 2012. Then using existing 3DPT technology, as mentioned in Chapter 4, colour was an issue in my use of 3DMs along with the lack of weight in my plastic PLA and ABS 3DMs. Also, I only recruited academics for my haptic-only and visual-haptic experiments; whereas investigation into direct museum visitors inside museum premises might or could offer more direct application and relevant data, instead of having to draw extrapolations or inferences, as I did with my group of academics in the university. Nonetheless, as mentioned, my data offers useful information, previously unavailable and points to promising results for museum praxis, and a re-consideration of the role of museum visitors who have been shown to be exploratory, engaged and highly interested in the options for tactile interaction within museums.

I am also reminded anew of my initial reaction when given the opportunity and chance of handling original artefacts e.g. Shabti Doll, Samian ware pot, Tauros Trigeranus, Mammoth Tusk fragment, Carthaginian Token, etc. I realise how privileged I am but this was due to my status as a researcher, something which many museum visitors do not have. With the use of 3DMs, museum visitors now would at least be given a chance of handling the original artefacts by proxy and that is why my group of visitors used words such as ‘wow’, ‘awesome’ and ‘amazing’ to describe their experience of handling the 3DMs of the original artefacts.

Appendix A: Questionnaire for Curators

Data Collection Group A

1. Have you heard about 3-dimensional rapid prototyping?

Yes ☐ No ☐

1.1 If you answered yes; where did you first see/hear about this technology?

____

____

____

1.2 Are you aware of any times when this technology has been used to further peoples understanding of archaeology?

Yes ☐ No ☐

If you answered yes, would you care to add anything?______________________________

____

____

1.2.1 If so could you provide an example; such as a name of a Newspaper, radio programme or a journal title?______________________________

____

____

1.3 Have you ever used a 3-dimensional rapid prototyping machine?

Yes ☐ No ☐

If you answered yes, are there any details that you would like to add?
(For example; the machine type or place where you first used this technology.)

____

____

____

Collections and copies within the museum

2. Does the museum collection contain any objects that are too fragile to exhibit to the public?

Yes ☐ No ☐

2.1 If you answered yes, do you believe that if it were possible to display all or some of these objects that there would be public interest? ____________________

____

____

2.2 Currently does the museum house or exhibit replica objects within the collection?

Yes ☐ No ☐

2.2.1 If you could identify one or two of these objects, would you please provide a few details of these objects; such as:

- The name of the Object____________________

  ____

- The location of the original____________________

  ____

- The method to which one or more of the replicas were produced __________

  ____

- The date/s that the replica/s were made ____________________

  ____

- The price of the replicas ____________________

  ____

- Is the replica is on: Public display ☐ Loan ☐ Storage ☐ Reserved for educational purposes ☐

The application of 3D printing in a museum

3 Certain museums in England already use 3D rapid prototyping to produce replica objects for sale and for educational purposes. On the other hand if a greater number of museums were to invest in this technology there may also be the potential to increase museum foot-fall. With these in mind, do you think that it would be your particular Museums interest to invest in this technology?

____

____

3.1 If the museum could produce 3 dimensional rapidly prototyped replica objects do you think that this would encourage the museum to:

- Allow unsupervised object handling within exhibition rooms Yes ☐ No ☐
- Allow supervised object handling in the exhibition rooms Yes ☐ No ☐
- Increase the number of specialist educational activities Yes ☐ No ☐
- Produce replica objects for sale Yes ☐ No ☐

3.2 If the museum has one, what is its mission statement?____________________________

____

____

3.2.1 If the museum began to produce replicas of its own collection through 3-dimensional rapid prototyping technologies do you think that this would complement:

- The museums mission statement? Yes ☐ No ☐
- The work that the museum is already doing? Yes ☐ No ☐
- The preservation of fragile artefacts? Yes ☐ No ☐
- The way the museum is seen in the community? Yes ☐ No ☐

Would you like to add anything in response to any of these questions?

____

____

3.3 In displaying original objects side by side with replicas, do you think that the museum is running the chance of misleading the public? Yes ☐ No ☐

Appendix B: Questionnaire for Museum Visitors and Presentation Slides

Data Collection Group B

QUESTIONNAIRE

1. Did you visit the museum to see this demonstration? Yes ☐ No ☐

1.1 If you answered no, would you please write what you came to the museum to see?

____

____

1.1.1 Is this a return visit to the Museum? Yes ☐ No ☐

1.2 How often do you visit museums? Once a week ☐
Every few weeks ☐ A few times a month ☐
Every six months ☐ Once a year ☐
Every couple of years ☐ Never ☐

2 How old are you? 18 or Younger ☐ 19-24 ☐
25-33 ☐ 34 – 44 ☐ 45-54 ☐
54-65 ☐ 66-76 ☐ 77 or over ☐

3 Before the presentation had you heard about 3D printing?
Yes ☐ No ☐ Do not know ☐

3.1.1 Where did you first hear about this technology? ________________________

____

3.2 Did you understand this presentation? Yes ☐ No ☐

3.2.1 Do you have any questions about either this technology or the presentation?

____

____

Hands on

4 Do you recognise these items?

1 Yes ☐ No ☐ What is it? ______

2 Yes ☐ No ☐ What is it? ______

3 Yes ☐ No ☐ What is it? ______

4.1 When you see this replica what do you think?

1 What is it a replica of? ______

2 Where does the original come from? ______

3 What date would you give the original? ______

4.2 When you touch a replica object:

1. Is there one word that comes to mind? ______
2. Do you think that being able to touch these replicas would be a useful aid to understanding the object?

   Yes ☐ No ☐ Maybe ☐

4.2.2 Is there anything that you wish to add?

______

______

5 If this technology were used to exhibit replica models would you be even more likely to return to the museum? Yes ☐ No ☐ Possibly ☐

6 Would handling a replica of an archaeological artefact increase

The time you spend with the artefact? Yes No

Would this affect your interest in the original? Yes No

Would you like to find out more about the peoples who designed the artefact?

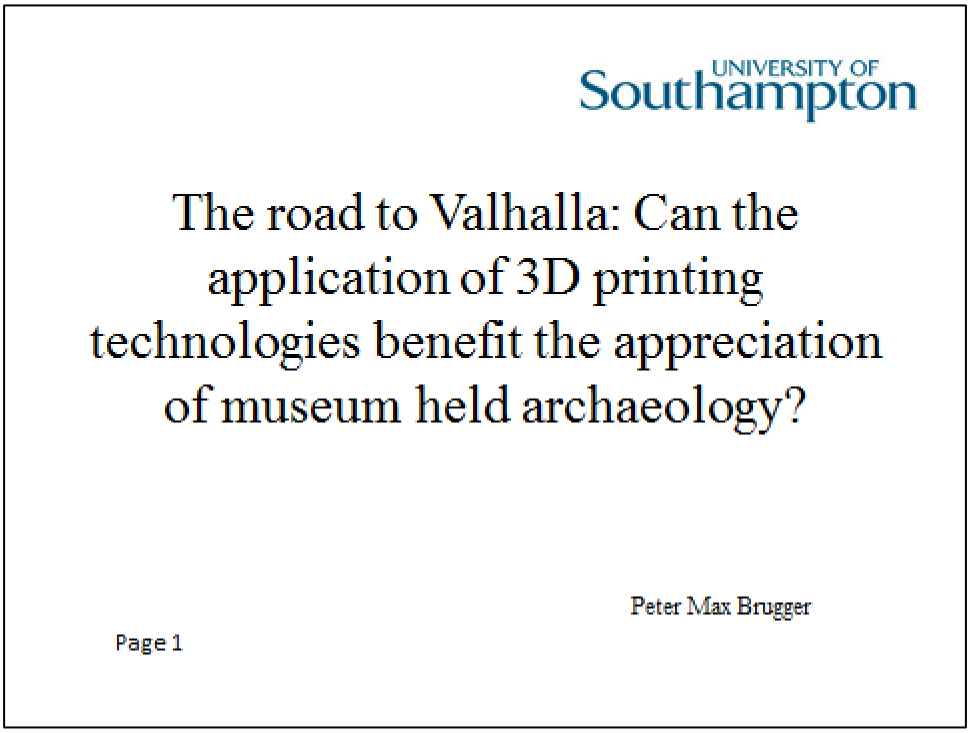
Yes No

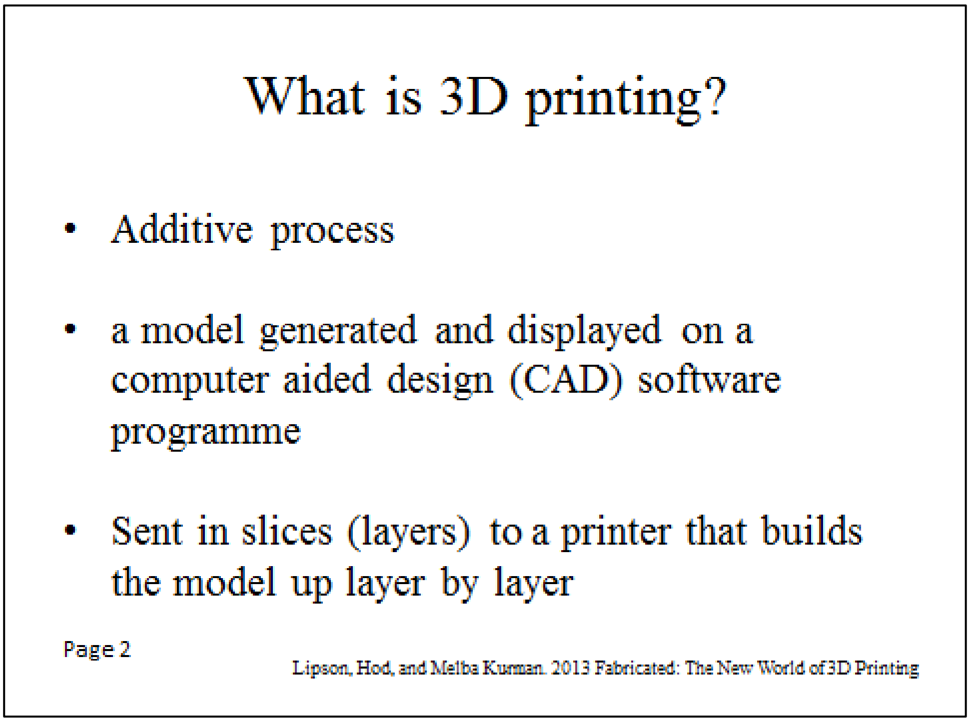
Would you return to visit the museum again? Yes No

<u>Presentation given at Dorset County Museum and Winchester City Museum.</u>
(20 minutes; prior to administering the questionnaire each time)

Topics Covered:

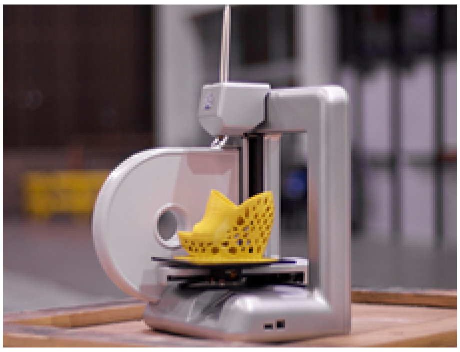
- An introduction to 3DPT
- An introduction to the current uses of 3DPT
- An introduction to my study (before handing out the questionnaire)





The Cube 3D.

- Fused Deposition Modelling/Fused Filament Fabrication
- Uses either ABS or PLA plastics
- Molten Plastic is laid on a Bed



http://cubify.com/cube/

Page 3

The MCOR Iris 3D printer

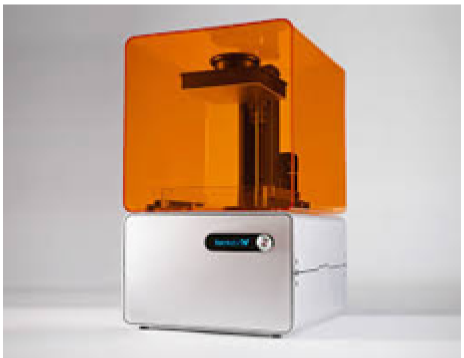
- Laminate Object Manufacturing
- Paper Models printed in Full colour
- 3D model cut sheet by sheet

Page 4

http://www.mcortechnologies.com/3d-printers/iris/

Formlabs

- Stereolithography
- Liquid resin reacts to light
- Layer by Layer



http://formlabs.com/

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Prosthetic Hand as reported by Emma Bryce for the Guardian.

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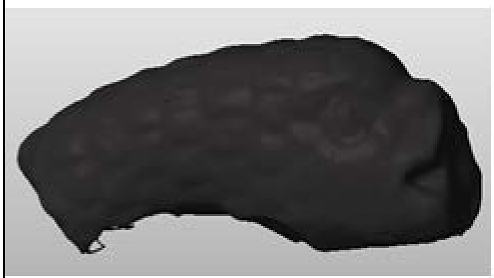

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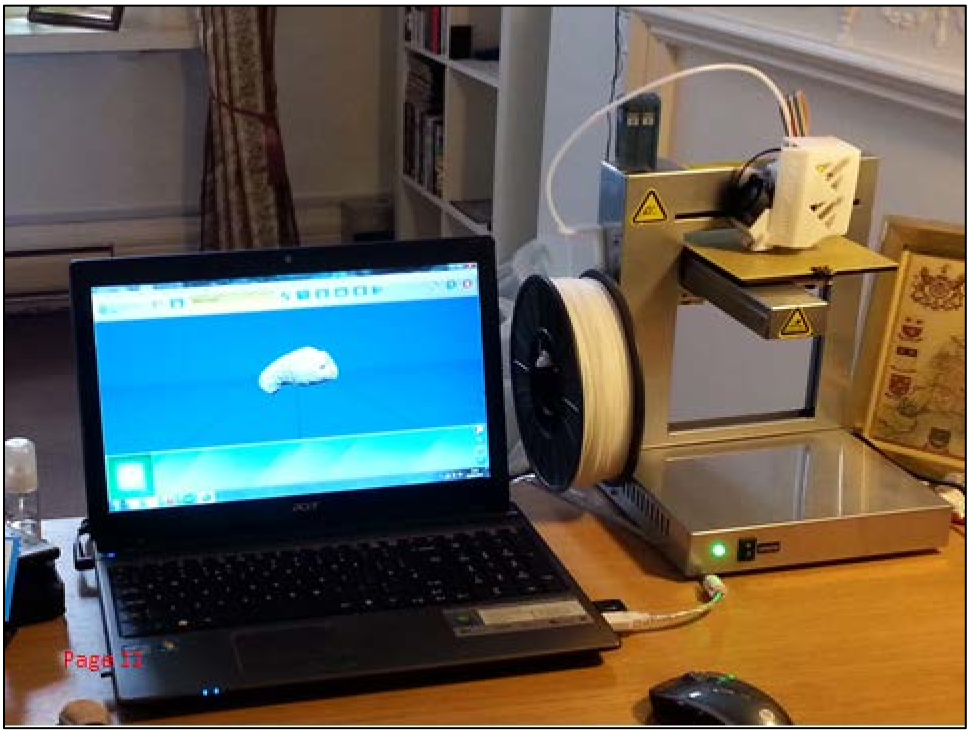

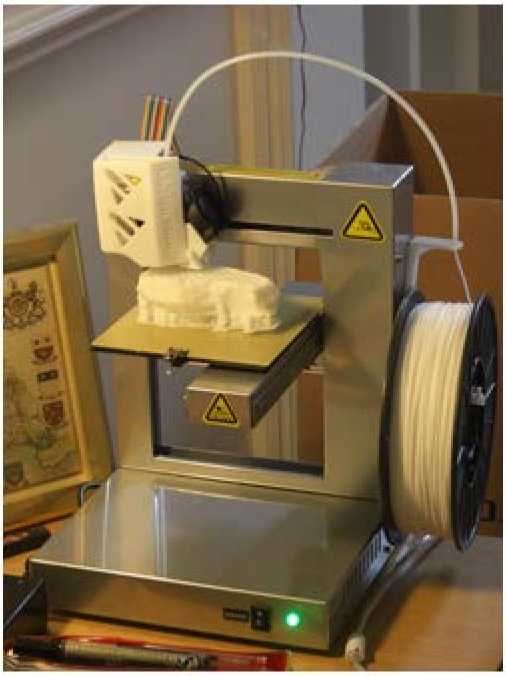

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3D printers, every home should have one

Page 14

A consultative Library of Objects

Professor Huxley on the British Museum quoted in The Museums of the Future, 1891

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http://www.pcmag.com/slideshow_viewer/0,3253,l=289174&a=289174&po=1,00.asp

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Thank you very much

Peter Max Brugger
pmb3g12@soton.ac.uk
07811 010637

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Appendix C: Questionnaire for University Academics

Data Collection Group C [for use by facilitator only]

Part 1

What the participant should know

[SCRIPT] In a moment you will be asked to handle two pieces of archaeology. These will however be presented to you in two groups with the original object accompanied by its 3 dimensionally printed replica. For the purposes of this experiment it will not be important to tell you which is original, instead I am looking for you to respond to touching the surface texture of the object.

There will only be 1 question asked after you touch each individual object: When you touch the surface of the object how does it feel?

There are 8 objects and I will place them on the table one at a time in front of you. As this test is touch only I request that you only touch the object with 1 hand and that you please close your eyes.

A. PLA

Spikey Bumpy Grainy Hard lined Rough Soft Smooth Silky Other

B. Original

Spikey Bumpy Grainy Hard lined Rough Soft Smooth Silky Other

C. ABS

Spikey Bumpy Grainy Hard lined Rough Soft Smooth Silky Other

D. Paper

Spikey Bumpy Grainy Hard lined Rough Soft Smooth Silky Other

Which one did you like the feel of the most and why? ____________________

____

A. PLA

Spikey Bumpy Grainy Hard lined Rough Soft Smooth Silky Other

B. Original

Spikey Bumpy Grainy Hard lined Rough Soft Smooth Silky Other

C. ABS

Spikey Bumpy Grainy Hard lined Rough Soft Smooth Silky Other

D. Paper

Spikey Bumpy Grainy Hard lined Rough Soft Smooth Silky Other

Which one did you like the feel of the most and why? ____________________

____

Appendix C

Part 2

What the participant should know

[SCRIPT] In this experiment you will be presented in turn with 4 objects. You can pick up and handle each object but you will be restricted to 20 seconds during which you will be required to keep your eyes closed. After handling each object, you will then be two questions these will be the same for every object:

Can you describe this object please?

Are there any features or patterns that stand out on this object?

After handling the object, **[NOTE] the questions shall be repeated**.

When answering each question feel free to say as little or as much as you want.

lamp

Were they looking at the object as though they could see it?

Column Base

Doll

Statue

Part 3

What the participant should know

[SCRIPT] This experiment will be divided into three sections. In each section you will be asked to handle one object and describe it – in the first test, when you handle the object, you can look at it and pick it up; in the second and third tests though, your interaction with the object will come with two conditions: to place the object in the palm of your hand and describe it whilst your eyes are closed. All three of the questions will ask you to describe the object whilst you are holding it.

Token

Are there any details that you can see on object?

- Lines ☐
- Writing ☐
- Drawings ☐
- Faces ☐
- Other ________________

Can you estimate the number of individual lines on the object?

1-9 10 – 14 15 – 19

20 – 24 25 – 29 30 – 34

35 – 39 40 - 49 50 – 59

What Colour is the object? Brown Red Black Green Blue

To touch is the object? Rough Smooth A bit of both

Would you spend more time looking at it? Yes Maybe No

Object 2

What material is the object made out of? Plastic Fibre-Glass Rock Stone Pottery Clay

How does the surface feel? Spikey Bumpy Grainy Hard lined Rough Soft Smooth

Silky Other

Given that this is a piece of Archaeology, usual exhibited in a museum: What do you think it is?

Object 3

What material is the object made out of? Plastic Fibre Glass Rock Stone Pottery Clay

How does the surface feel? Spikey Bumpy Grainy Hard lined Rough Soft Smooth

Silky Other

Given that this is a piece of Archaeology, usual exhibited in a museum: What do you think it is?

Part 4

What the participant should know

[SCRIPT] This experiment is about scaling up objects to increase the potential for detail recognition. You will soon be handed objects that are scaled-up. You will need to close your eyes and feel for various details. For each object there are two questions:

Can you count the shapes?

2 – 4 5-10 11 – 15 16 – 20 21 – 25 26 – 30

Can you recognise any shapes?

Yes No What are they? ______________________________

Can you count the Shapes?

2 – 4 5-10 11 – 15 16 – 20 21 – 25 26 – 30

Can you recognise any shapes?

Yes No What are they? ______________________________

Can you count the shapes?

2 – 4 5-10 11 – 15 16 – 20 21 – 25 26 – 30

Can you recognise any shapes?

Appendix C

Yes No What are they? ______________________

Can you count the shapes?

2 – 4 5-10 11 – 15 16 – 20 21 – 25 26 – 30

Can you recognise any shapes?

Yes No What are they? ______________________

Can you describe one detail of this object? ______________________

[SCRIPT] In a moment I will present you of two versions of the same object, these objects will only differ in the fact that they are scaled up from an original artefact. I will present them to you one after the other to handle and thorough touch alone to identify the shape or object that is engraved on the surface.

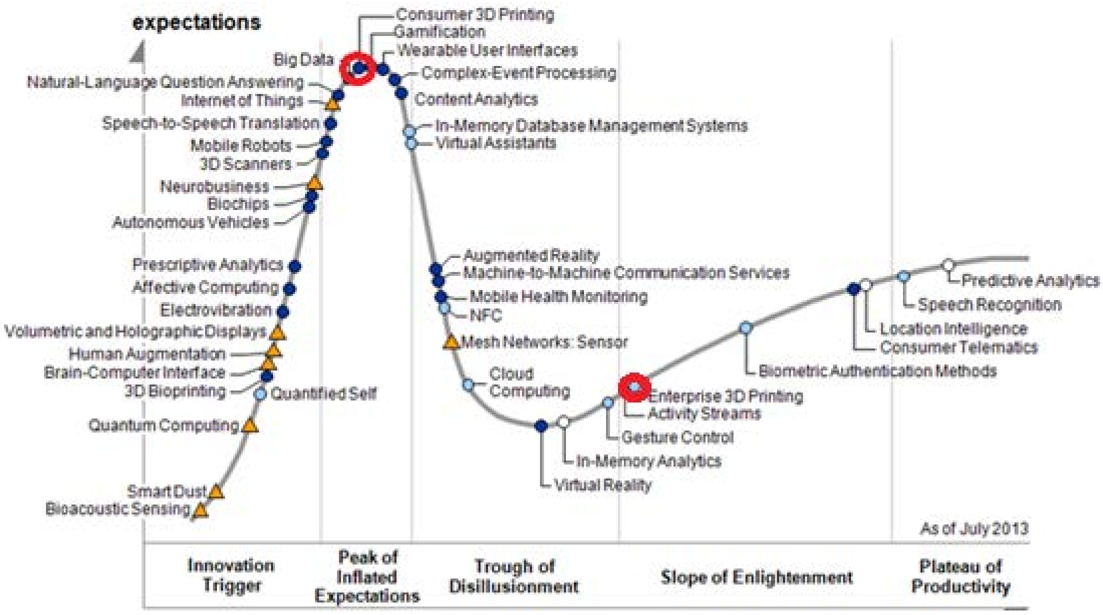
Now I will ask you to close your eyes and I will hand you the object.

Scale × 3 ______________________________________

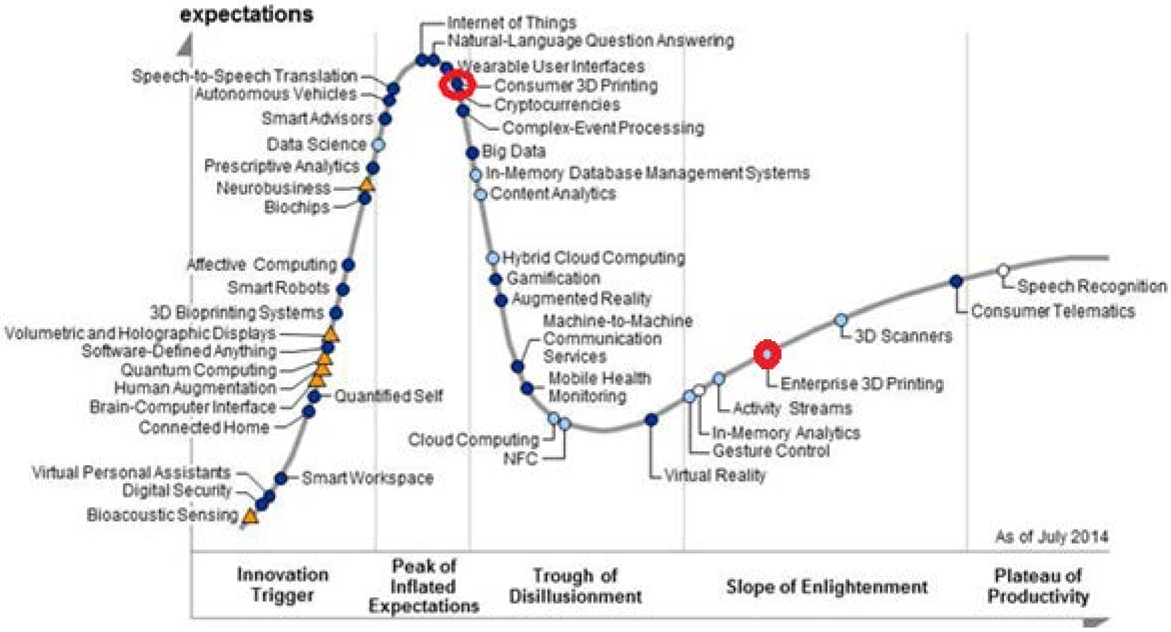
Scale × 6 ______________________________________

Appendix D: Gartner's Hype Cycle of Emerging Technologies

The difference made in one year from hype to disillusionment in the media



Consumer and Enterprise 3DPT in 2013 as plotted on Gartner's Hype Cycle of Emerging Technologies, published by J. Shofield (2013). Gartner, Inc.



Consumer and Enterprise 3DPT in 2014 as plotted on Gartner's Hype Cycle of Emerging Technologies, published by C. Stamford (2014). Source: Gartner, Inc.

Appendix E: Digitisation and Printing Stages for a 3DM

A 3DM to be made needs to go through a few stages: Digitisation, this includes scanning of the original; post-processing, meaning that the digital model is processed through software programmes; and finally printing using a 3D printer. It is for this reason that the aim of this appendix will describe the steps taken to produce a museum quality 3DM.

There have been projects undertaken, such as the ‘Use of Hand-held laser scanning and 3D Printing for Creation of a Museum Exhibit’ (Allard et al 2005), and ‘3-Dimensional reproduction techniques to preserve and spread paleontological material - A case study with diplodocid sauropod neck’ (Tschopp and Dzemski 2012). However, in these cases the focus was on the technical ability to replicate, whereas the focus of this thesis in to produce a 3DM under the methodology of ‘The Originals Companion’.

Any digitisation project that a museum is likely to have undertaken was quickly understood to only include digital photography. Therefore, to produce any 3DM, 3-Dimensional data had to be taken from an original source. This represented a learning-curve, requiring selection and many practical and technical choices to be taken that have bearing over the final 3DM. Selection in this case entails, the object to replicate, technology for digitisation, and post-processing software, and the technology for 3DP. Indeed, of the technology used, a dedication of time, and good will of the participating museums. Originally there were three participating museums, these were: Dorset County Museum, Winchester City Museum and Poole Museum. Data Collection however for ‘Group B’ was undertaken at the Dorset County Museum and Winchester City Museum and the data collected from the touch only experiments of Group C used the resulting 3DM.

To best complete the task and show the practicality of this technology and the addition of 3DM within a museum it was decided that three criteria be satisfied: The technology used is either cheap or free; the technology must be easy to use; the technology must be of a high quality. It was not easy to balance these three criteria but it was thought that given the nature of the museum and ever shrinking budgets as well as the scrutiny the 3DM would come under; a balance was necessary.

Object Selection

Figure 43 - Roman Samian Ware as exhibited by the Dorset County Museum

In order that we achieve clarity we shall focus on one object, a Roman Samian Ware bowl as exhibited in the Dorset County Museum. This bowl was exhibited alongside two bowls, two vessels and several beads, all burial gifts for a sixteen-year-old girl. The process of selection was important, the size of the object chosen needed to be substantial enough in size that those handling the 3DM could interact and observe detail at 1-1 scale but with the possibility that scaling could also reveal additional information. The goal of replication being the suitability of the 3DM for handling activities of University Academics ‘C’ the potential familiarity or un-familiarity of the actors with the source material needed to be considered and in this case a Samian Ware bowl was believed to be something that would have close to near universal recognition by the museum going public. The crucial question that replicating the Samian bowl to make a 3DM was, would producing this 3DM benefit the interpretation of, or interaction with the original artefact?

As we can see from the photograph **(Figure 43)** the bowl is exhibited behind glass as one of a collection. The dimensions of the bowl are 9cm height, 9cm deep, 8cm wide. On a practical note, the uniform matt texture of the Samian Ware eased the precautions for replication, therefore unlike other artefacts, fewer precautions concerned with glare from overhead lights had to be taken. Ultimately the digitisation process – as described in the next chapter – was undertaken using the ‘Next Engine 3D’ Scanner, whilst ensuring proper etiquette was observed, for example, when on the rare 2 occasions when object handling was necessary; the Digitisation process proved to be made straight forward due to selection.

Appendix E

Digitisation

The task was to scan the object, for this a 'Next Engine 3D' scanner was used. To use this scanner a dark and quiet room needed be found to undertake the process, this was to limit possible glare and light reflection as well as limit the possibility of interruption, such as the inadvertent jogging of the scanner. A

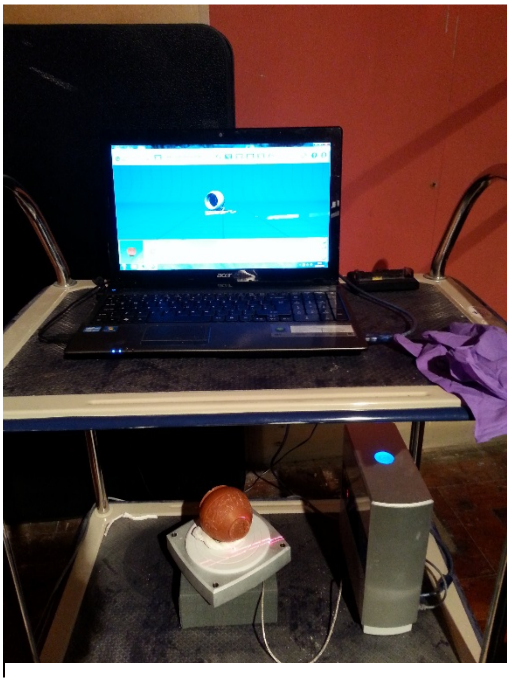


Figure 44 - Scanning using the 'Next Engine 3D'

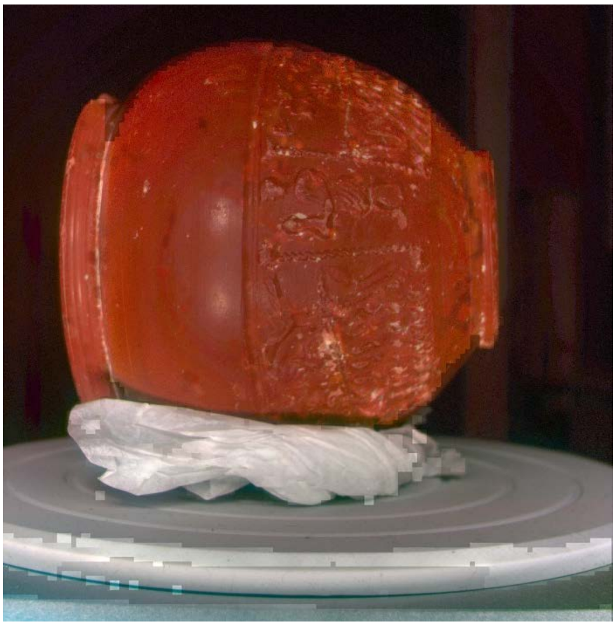


Figure 45 - A cross-section of the Samian Ware Bowl resting on the Turntable of the 'Next Engine 3D' scanner

storage cupboard was chosen **(Figure 44)**, this was not used as a collections store but a store for chairs and was lit thereby it was beneficial to use a tray to limit any glare on the object.

The process of scanning was relatively simple but required a dedication of time and therefore patience. With the object below resting on the turntable of the 'Next Engine 3D', the artefact would be revolved 360 degrees. In scanning, the turntable would turn the object by degrees at defined intervals and at every stage taking a series of photographs and a scan **(Figure 45).** A process that was expected to require two scans with the object being repositioned to piece together a fully digitised model. As the scanner was very sensitive a few attempts were necessary and a process that over time I was able – through trial and error as well as luck – to get to 40 minutes originally took me 4 hours 20 minutes. Finally, I could piece together a digitised model that could be sent to post-processing software.

Post-processing

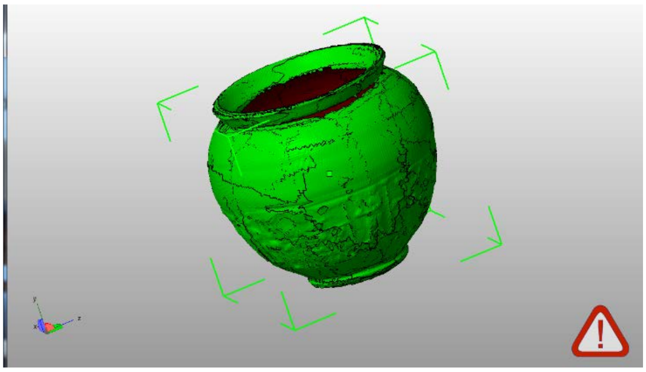


Figure 46 - The model sent to Netfabb to be repaired

A fully digitised model was ready to be sent to post-processing software. The software used for this was free open-access software versions of 'Netfabb' and 'MeshLab'. These pieces of software were east to use and were accessible. The goal of sending the model to these pieces of software was to get this ready to be sent to a 3D Printer as this would make the 3DM. In getting this ready for to print the model, it was necessary to send the model to 'Netfabb' first **(Figure 46)** and then after repairing the model to 'MeshLab' **(Figure 47)** as the final to be polished and later to be sent to a 3D printer. Dealing with two file formats 'Surface Tessellation Language' (STL) and 'Object File' (OBJ), the difference being STL deals in monochrome and has a storage capacity of 39 Megabytes and the latter keeps the colour and storage of 72 Megabytes.

Using the software closes possible holes in the meshed surface of the pot and ensures that this can be printed. The software smooths the model and is designed to get rid of various inaccuracies, but this is unfortunately extended quite readily to the details that want to be preserved. A median needed therefore to be found that would allow this to be printed whilst not eroding vital details.

Figure 47 - The final model as seen on 'MeshLab'

Appendix E

Printing the Model

Most of the models exhibited to Groups B and C were, like this 3DM, printed using Fused Filament Fabrication using a printer known as an 'UP 3D'. The printing process was rather fast at 3 hours 6 minutes. The quality chosen was high as listed as 'fine' but you could choose fast or normal. Sent for printing **(Figures 48, 49 and 50)** the process was simple. The model was divided into 557 layers to print from the spool of 'Olive Green' PLA plastic. The 3DM cost £1.29 to print.

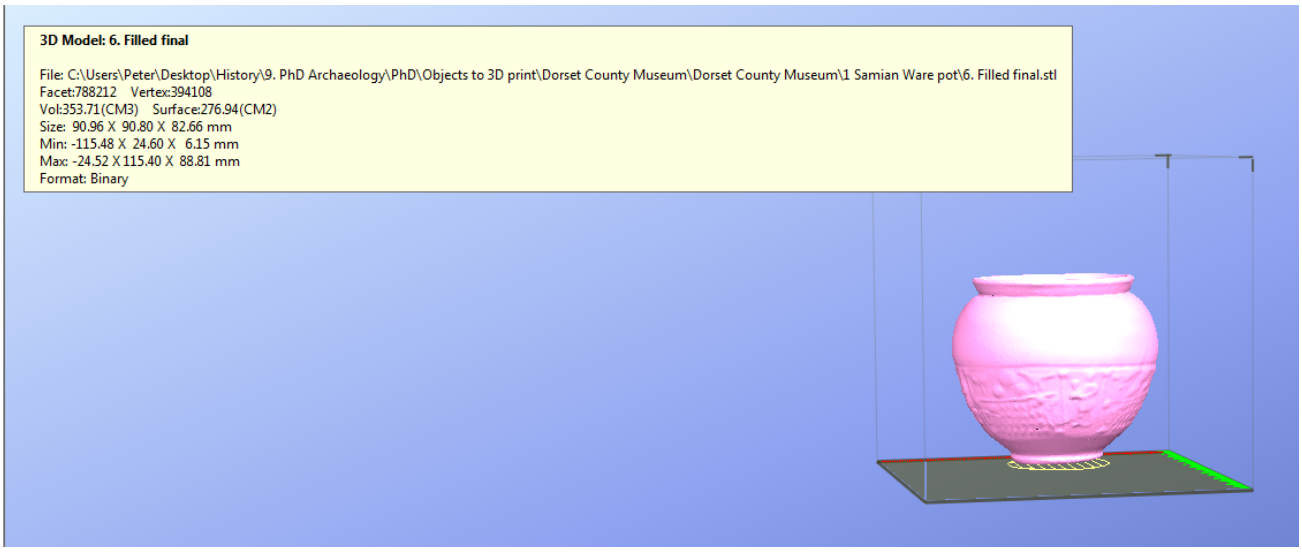


Figure 48 - The digital model as sent to the 'UP 3D' printer

The only limitations where that the printer bed as well as the frame limited any final print to 5 by 5 inches but unless printing to scale this was not a setback.

Figure 49 - The final 3DM

Figure 50 - The 3DM printed on the 'UP 3D'

Appendix F: Six Examples of Digital Policies

Museum Name & Sources used	**Digital Loans Policy & Public Access to Digital 3DM**	**Government Loans Policy**
British Museum (British Museum 2007, 2016 & 2017) (European Parliament 2013) (Hancock 2015) (DCMS 2018) (Creative Commons 4.0 2018)	• Loans policy is under The British Museum Act 1963 • Digital co-operation is necessary for research • Copyright and permissions are governed under the Creative Commons 4.0 • Sketchfab – governed by Creative Commons 4.0 1. Copy and redistribute in any format 2. Remix/transform the material 3. Attribution must be given 4. This in Not for profit and must be kept as such 5. Any item with introduced novelty is still governed by creative commons 4.0	DCMS: • Objects on loan must be protected • The sharing on digital artefacts must be increased • These objects should be loaned to museums and the public
National Museum Scotland, Edinburgh (NMS 2015 & 2016) (European Parliament 2013) (Creative Commons 4.0 2018) (Scottish Government a 2018) (Scottish Government b 2018)	• Loans policy under The National Heritage (Scotland) Act 1985 • Cataloguing of Digital Collections will be done in CIS and the materials/artefacts will be treated the same way as any museum artefact. This will be in-line with the Museum's Digital preservation policy. • Sketchfab - governed by Creative Commons 4.0	Scottish Government • Museums are part of the 'Digital Economy' in loaning artefacts • Shared technological platforms as part of a public service • Develop a sharing infer structure • Digital Champions Programme established 2013 1. Sharing knowledge & Skill 2. Championing Digital Technology
Smithsonian Institution (Smithsonian Institution 2009) (Smithsonian X 3D 2013) (Creative Commons 4.0 2018) (Digital Government 2018) (NHM Imaging 2018)	• Smithsonian Commons governs digital loans – begun with the establishment of a 2010 pan-educational brief • Facilitate a dialogue with a world-wide community • Develop platforms for participation and innovation • Digitisation and the diffusion it brings alters the model for learning that the museum has previously been run • Copyright and permissions are governed under the Creative Commons 4.0 • Sketchfab - governed by Creative Commons 4.0	USA • Digital Government 1. Encouraging Digital sharing to benefit livelihoods 2. Public focused innovation
National Archaeological Museum Naples	• Loaning can only be for research or exhibitions purpose	Italian Government

(MANN 2018) (MANN 2016) (European Parliament 2013) (Team Digital 2018) (Piacentini 2015	• If for exhibitions abroad there must be a return date • A planned digital strategy will increase sharing for research and exhibition in Universities and museums • A targeted selection of loans will have 3DM produced to be lent for scientific purposes	• Greater digital sharing for academic research • Greater accessibility through the establishment of guidelines • Three-Year Digital Plan to increase national and global sharing • The Digital plan comes under the Ministry of Cultural Heritage and the completion of project is projected for 5 years from 2015
Western Australian Museum (Western Australian Museum 2015) (Museums and Galleries New South Wales 2018) (Government of Western Australia 2018) (HO 2015) (DTA 2015)	• Lending objects to museums, Universities and other institutions for the purposes of exhibition and research • Loaned objects must be not-for-profit of community-based organisations • All loaned artefacts on loan are subject to copyright and cannot be replicated or copied in any way without the permission of the loaning museum	Australian Government: Digital Transformation Agency • Encouraging the creation of digital visualisation and 3D printing apps, in GovHack 2015 • Public focused not-for-profit digital marketplace
Auckland Museum (Auckland War Memorial Museum 2016) (Auckland Museum 2018) (Creative Commons 4.0 2018) (ICT gov.NZ 2015) (data.gov.nz 2015)	• Sharing digital content in a variety of formats • The establishment of 'Enquiry centres' as digital hubs of learning, research and information exchange • Universal access to a digital experience during and after a museum visit • Copyright and permissions are governed under the Creative Commons 4.0 • Sketchfab - governed by Creative Commons 4.0	New Zealand Government • Exploit new innovative technologies for greater accessibility • Greater access of agencies to innovative technologies • Establishment of 'Digital nz' searchable database for 29 million cultural artefacts, inclusive of museums, archives and libraries

Table 17 – Comparison of Six Museum Digital Policies with their Corresponding Government Strategies

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