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Model Dialogues: 3D models as active  
resources – an experiment in data  
enrichment of 3D modelled lithic artefacts

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## Abstract:

This thesis seeks to explore the potential for 3D archaeological datasets to become the 'living resources' advocated by Morgan and Wright (2018). This process is examined through lenses of object agency, object biography, Chaîne opératoire, formation processes and posthumanist theory with an aim to assess the capacity of digital approaches for enabling the self-reflexive 'slow archaeology' idealised by Caraher (2016). Finally, an analysis of the tensions between digital and traditional illustrative means was explored alongside considerations of data standardisation and metadata frameworks. The explicit questions this thesis seeks to answer are, what datasets can be used to enrich a 3D mesh? how does this palimpsest approach impact data analysis and interaction? can we identify the best practices for this approach? and can we identify broader considerations for future research?

The sample material used to explore these issues was a Mesolithic Core Axe currently held within the Lund University Teaching Collection within the Department of Archaeology and Ancient History. This was digitised using photogrammetric methods with the diverse theoretical issues mentioned previously used to identify information that could be utilised to 'enrich' the digital artefact in the form of multiple visual models. A hand-drawing was carried out to traditional conventions and projected onto the mesh as a new texture, and the illustrative tools and features of Agisoft Metashape, Meshlab and Blender were compared. The latter part of this research process involves an attempt to synthesise the various concerns above into a coherent and functional 3DHOP output before analysis and reflection of the chosen approaches is carried out.

*Keywords: Digitisation, Visualisation, Illustration, Slow Archaeology, Photogrammetry, Digital Archaeology, Agisoft Metashape, Meshlab, Blender, 3DHOP, Metadata, Formation Processes, Use-Wear Analysis, Chaîne opératoire*

# Table of Contents

Acknowledgements .....	3
List of Tables.....	4
List of Figures .....	4
Chapter One: Introduction.....	6
Theoretical Review .....	7
Chapter Two: Material and Methods .....	13
Materials .....	13
Methods.....	18
Chapter Three: Methodology.....	21
Macro Photogrammetry Session.....	21
Standard Photogrammetry Session and Modelling.....	23
Digital Illustration .....	27
Manual Illustration .....	33
Texture Mapping .....	37
Modelling Manufacturing Processes/Life-Histories .....	40
Use-Wear Analysis.....	45
Conceptualising Formation Processes .....	47
3DHop Output .....	49
Chapter Four: Discussion and Analysis.....	54
Digitisation: Affordances and Considerations .....	54
Questions of Consensus.....	58
Approaching Temporality.....	60
Reflexive approaches.....	64
Best Practices .....	65
Conclusions .....	65
Figures Sourcing .....	67
Bibliography and References .....	69
Appendix 1: Macro-photography Paradata .....	72
Appendix 2: Standard Photogrammetry Paradata: Artefact 1.....	75
Appendix 3: Artefact 1 Supplementary data Metadata.....	77

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## List of Tables

Table 1: Prospective Timetable of Research.....	7
Table 2: Chosen DCMI schema with definitions based upon those listed in Lubas et al (2013).....	12
Table 3: Description of software packages used.....	16
Table 4: Summary of research stages and associated tools.....	17
Table 5: Summary Definitions for the Approaches used in this thesis.....	18
Table 6: Helicon 7 parameters.....	21
Table 7: Standard Photogrammetry Camera Settings.....	24
Table 8: Gradual Selection Parameters.....	25
Table 9: Meshlab Z-Brush Parameters.....	31
Table 10: Meshlab Quadric Edge Collapse Decimation Parameters.....	38
Table 11: Selection of Schiffer's (1983) Simple properties of formation processes.....	48
Table 12: Pros and Cons of different illustrative approaches used.....	55

## List of Figures

Figure 1: Schema showing overview of prospective collected dataset.....	11
Figure 2: Sample Artefacts: Left = Core Axe ('kärnyxa'), Middle = Flake scraper ('Spånskrapa'), Right = Disc scraper ('Skivskrapa').....	13
Figure 3: Areas of Scanian flint deposits after (Högberg and Olausson, 2017, 31, FIGURE 22).....	14
Figure 4: View of photogrammetry set-up.....	15
Figure 5: Workflow diagram showing the process of photogrammetric capture to end report (Clarke et al., 2019, 3, Figure 2).....	20
Figure 6: Screen-capture of Helicon 7 showing stacking process with original selectively focused images on the left compiled to create the high-quality image on the right.....	22
Figure 7: View of first rotation showing how the artefact was placed vertically.....	23
Figure 8: Successful alignment of the first rotation showing camera placement and sparse cloud....	24
Figure 9: Warped, overlapping edges resulting from missing data.....	25
Figure 10: Final textured mesh of first sample artefact, the core-axe, showing the location of the alignment markers.....	27
Figure 11: Agisoft Metashape's predefined views in Orthographic mode of artefact 1 arranged according to Brøgger's (1906) standard axe views.....	28
Figure 12: Primary and Secondary Flake Negatives digitised using Agisoft Metashape's polyline tool.....	29
Figure 13: View of completed illustrated mesh showing the relatively illegible nature of the network of polylines produced.....	29
Figure 14: Artefact 1 processed through various Shaders on default settings in Meshlab.....	31
Figure 15: Using the Z-Brush tool in Meshlab).....	32
Figure 16: Primary and Secondary marks digitised in Meshlab.....	33
Figure 17: Initial preparation for illustration.....	33
Figure 18: Points of measure along the artefact's outline.....	34
Figure 19: Completed outline for both sides of the artefact.....	34
Figure 20: Drawing the ridges.....	35
Figure 21: Completed shading.....	35

Figure 22: Completed drawing showing lateral view .....	35
Figure 23: Completed Inked Drawing .....	36
Figure 24: Completed Digitised Drawing .....	37
Figure 25: Adding completed sketch as a reference in Blender .....	38
Figure 26: Marking the seams in UV editing mode in Blender .....	39
Figure 27: Completed mesh with hand-drawn sketch texture mapped to its surface.....	40
Figure 28: Spawning and manipulating a sphere mesh using a reference image as a background plane to approximate a flint node .....	41
Figure 29: Screenshot showing UV map above with the subsequent projected textured mesh below .....	41
Figure 30: Approximating a flint core with a low polygon mesh .....	42
Figure 31: Projecting a suitable texture.....	42
Figure 32: Nested meshes comprising axe, core and node respectively.....	43
Figure 33: Models arranged in Blender with a transparent, textured render and the central axe selected for visibility.....	43
Figure 34: Adding attribute data to each manufacture 'form' .....	44
Figure 35: Polyline schema of manufacturing forms in Agisoft Metashape with each polyline appended with associated attribute data .....	45
Figure 36: Brøgher's standard axe views with associated diagnostic morphological features .....	46
Figure 37: Distribution of Nørvsted axes in Eastern Norway and Western Sweden showing the Northern extent of Linden growth [dashed line] from data by Høeg, 1997 (Glørstad, 2011, 32, Fig. 12).....	47
Figure 38: Schematic diagram of planned 3DHOP output.....	50
Figure 39: Base Model successfully rendered in a basic 3DHOP html output .....	51
Figure 40: Sketch texture recored as vertex colours on the .ply mesh in MeshLab .....	51
Figure 41: Basic checkbox functionality.....	52
Figure 42: Final 3DHOP output .....	53
Figure 43: Various means of displaying flake negatives digitally: .....	59
Figure 44: Relational network of associated files for artefact 1, each with their own associated metadata showing how the connections traverse media types .....	60
Figure 45: Height map generated in CloudCompare based upon arbitrary categorization of z value 'surface' co-ordinates .....	60
Figure 46: 'Time-map' of artefact 1 with colour code plotting sequential overlapping of flake removal action .....	61
Figure 47: Three models combined in MeshLab to give an approximation of the arrangement of axe, core and raw material node for the core-axe [artefact 1].....	62
Figure 48: Stacked view of the three meshes with textures preserved corresponding to flint node, core and axe respectively .....	63
Figure 49: Breaking the illusion of the manufacturing form schema in Metashape.....	63
Figure 50: View of INHA's timeline approach to object life-histories, tracing the journey of a 5th century B.C. Greek Amphora from its source through various antiquities sales to a 19th century French Collection.....	64

## Chapter One: Introduction

*“Art hid with Art, so well perform’d the Cheat,*

*It caught the Carver with his own Deceit”* (Dryden and Scott, 1821, 124)

The story of Pygmalion imbuing his creation with life offers a salient analogue for the process of 3D digital documentation. On the one hand, the above lines convey much of the theoretical concerns with ontology and substance that have been identified with relatively new techniques such as 3D laser-scanning and photogrammetry. As Korzybski (1958) evocatively deconstructed Aristotelian frameworks of representation, stating that “A map is *not* the territory ... words *are not* the things they represent” (Korzybski et al., 1958, 58, my emphasis), Androshchuk (2014) highlighted the inherent process of *mimesis* in the context of archaeological recording practices with images acting as facsimiles of the material world gaining an assumed reality in the process (Androshchuk, 2014, 17). Despite these initial concerns however, there has been a growing scholarly consensus that believes that current research has not explored this capacity for information-rich ‘mimicry’ far enough and that current use of 3D techniques has tended towards the static and superficial. For example, Perry and Taylor (2018) have criticised the focus of studies upon quantitative approaches, neglecting the “richer qualitative analyses” (Taylor and Perry, 2018, 11) 3D modelling allows. Furthermore, Morgan and Wright (2018) have condemned the common practice of 3D models existing as merely the final output of research, not fulfilling their potential to act “as a living resource for ongoing interpretation” (Morgan and Wright, 2018, 19). Therefore, Pygmalion has additional resonance for the burgeoning discipline of 3D archaeology, offering an analogy for an ideal framework of practice in which data is figuratively transformed into something to be actively engaged with, with ‘living’ potential to inform and reshape research processes.

This thesis seeks to explore the potential for 3D artefact captures to be enriched in Pygmalion-like fashion. Initially expanding on some of the theoretical arguments mentioned above, ideas such as artefact biographies, Chaîne opératoire and formation processes will be discussed in connection with data capture and metadata frameworks to identify and inform the choice of suitable datatypes to add to the 3D artefact. Morgan and Wright (2018) explored the relationship between digitisation and more traditional archaeological media and this thesis aims to engage with this dichotomy by viewing hand-drawn illustration as another means of engaging with virtual artefact models. As such the chosen artefact will be illustrated using hand illustration conventions and the result mapped onto the 3D model. The aim here is twofold, experimenting with new interactive ways of engaging with archival manually drawn data; and to see if the more schematic output of traditional drawing forms offers additional clarity of information to be visible on the model.

Thus, the summary questions that this thesis hopes to answer are:

1. What datasets can be used to enrich a 3D mesh?
2. How does this palimpsest approach impact data analysis and interaction?
3. Can we identify the best practices for this approach?

#### 4. Can we identify broader considerations for future research?

With respect to methodology, following an initial campaign of photogrammetric capture using structure from motion a high-resolution model will be produced via a combination of *Agisoft Metashape* and *Meshlab* with the subsequent ‘additive’ datasets mapped onto the resulting mesh using Blender. This final palimpsest output will be converted into a *3DHOP* format and the dedicated framework available there explored to assess the model’s interactive and information display potential. As it stands the prospective timetable for research is as follows:

**TABLE 1: PROSPECTIVE TIMETABLE OF RESEARCH**

<i>February 1st – 15th</i>	Introduction and theoretical review
<i>February 15 – March</i>	Identification of desired supplementary data and artefact photogrammetry campaign
<i>February - March</i>	Production of model and 3DHOP output
<i>March - April</i>	Discussion and Analysis of results
<i>April - May</i>	Thesis Revisions, submissions etc.

#### Theoretical Review

The digitisation of archaeological material has had profound implications for frameworks of interpretation and practice and due to its relative ease and accessibility has had a multi-faceted impact across the spectrum of the discipline (Dell'Unto, 2018). As such there is an associated diversity of theoretical discourse related to the process of digital capture and given the nature of the material this has drawn inspiration from fields as varied as anthropology, philosophy, ontology and library science. Those immediately pertinent to the scope of this thesis include:

- Object Agencies and Posthumanism
- Object Biographies, Chaîne opératoire and Formation Processes
- Archaeological Illustration and Digitisation
- Metadata

To chart the new-found scholarly focus upon artefacts in the digital realm, we must explore changing attitudes to objecthood that developed in the latter part of the twentieth century. Cognisant of a consistent rejection of the fundamental principles of objectivity that the archaeological discipline had assumed to that point (Johnson, 2010), proponents of this critical self-awareness stressed a desire to return human experience and action to the centre stage of archaeological research (Johnson, 2010, 107). Having called into question the tangible connections that abstract cultural systems and networks prevalent in traditional processual archaeology had to the material and individuals at hand, scholars adopted anthropological concepts of agency, defined as “the issue of how we think about intentional action and the resources needed to act” (Johnson, 2010, 237). Far from resulting in a diffuse and chaotic independence however, agency is only visible within a given framework of reference. Thus, Barrett (2000) highlights *structuring principles* that enable, constrain and



direct an agent's actions with reference to "an embodied knowledgeability" (Barrett, 2000, 65).

### Object Agencies and Posthumanism

With these concepts of structuring principles discussed above, came the realisation that objects could also facilitate or hinder human actions. The increasingly self-reflexive archaeological discipline that questioned the objectivity of processualist thought, also stressed the colonial legacy of that Western scientific rationale. Whilst the antiquarian youth of archaeology is self-evidently colonial in nature, the collation of data sets and reduction of societies to cultural systems and labels at the expense of more ritualistic, emotive studies has been criticised as further projection of Western ideals, the fundamental processes of archaeology "at heart ... a colonialist endeavour" (Smith and Wobst, 2005, 5, my ellipsis). Scholars such as Shanks and Tilley (1987) emphasised the fact that archaeology is inextricably linked with modern social frameworks, "... is always a politics, always a morality" (Shanks and Tilley, 1987, 212). Coupled with this has been an equivalent scholarly unease at the ethics of objectifying people as elements of study. The natural solution then was to subjectify objects instead (Fowles, 2016).

This subjectification can be considered as reflecting a larger criticism of traditional academic dichotomies of culture vs nature. Archaeological practice has relied upon this distinction as an enabling factor for fieldwork, in that theoretically cultural debris, the focus of interest, should only be visible if it is categorically different to the environment (nature) that surrounds it. However, as early as 1985, Haraway criticised the simplicity of this argument, identifying three academically circumscribed divisions that needed dispensing with for the discipline to progress. Namely, human vs animal, organism vs machine and the physical vs the non-physical realm (Haraway, 1985). With such distinctions considered artificial and arbitrary, a new dynamics of interaction was developed, conceptualised as an entangled mesh of interactions (Hodder, 2011), a "flat ontology" (Sørensen, 2013, 8) that actively changes and adapts alongside Shanks' positing of a *Symmetrical Archaeology* that recognizes the equally potent agency artefacts and objects can manifest (Shanks, 2007). Sørensen identifies body accoutrements such as piercings, tattoos and specifically Bronze Age arm bracelets as cogent expressions of this object-based agency. Such items by definition of their fixed nature actively constrain their wearer's identity by displaying social norms not personal constructions of identity (Sørensen, 2013, 9). Certain objects in this case become linked to notions of the *lived body* with the organic supplemented with the mechanical, perhaps most starkly represented by prosthetic limbs (Sørensen, 2013, 10). Alaimo (2010), has eloquently encapsulated these abstract trends of thought under the aegis of transcorporealism whereby "the human is always intermeshed with the more-than-human world" (Alaimo, 2010, 2). Likewise, with the blurring of the physical and mental spheres advocated by Haraway (1985), material culture has been recast as a transformative media through which socio-cultural frameworks of belief are materially and "meaningfully constituted" (Hodder, 1982, 13). Thus objects constitute an incredibly rich vein of potential information about a multiplicity of socio-cultural processes, interactions and identities.

### Object Biographies, Chaîne opératoire and Formation Processes

Another aspect to consider resulting from the subjectification of objects, and one that offers perhaps a more material manifestation of the abstract theoretical concepts explored above, is the notion of *object biographies*. Hahn and Weis (2013) stress the fact that “cultural artefacts never stand still, are never inert” (Hahn and Weis, 2013, 1). Object biography is a theoretical framework that attempts to address this, based upon the seminal work of Igor Kopytoff (1986) it seeks to trace the life process of artefacts, how their use and status changes through time, and how these stages manifest themselves physically upon the object in question (Kopytoff, 1986). *Chaîne opératoire* has translated this into a more quantitative means by focusing upon the systems of manufacture and phases of construction that an artefact experiences, the “cultural transformations” (Sellet, 1993, 106) involved in the journey from raw material through used tool/object to broken/discarded. Thus, identifying manufacturing techniques, debris distribution and use-wear analysis become primary methods enabling a translation of these layers of object life-histories to be studied in a material fashion. However, Hahn and Weis (2013) have criticised the aptness of a biographical analogy in the context of artefact studies. Stressing the multiplicity of interactions and identities that objects endure through time as opposed to the linear simplicity an object biography implies, they instead expand object experience beyond its sell-by-date, to encompass the depositional and post-depositional processes and indeed, the new status artefacts gain as archival objects of study, “the after-life as a second life” (Hahn and Weis, 2013, 4).

Hitherto, our narrative has neglected the human end of the actor network of interactions of Hodder’s (2011) entanglement theory. However, with object biographies expanded to incorporate post-use contexts, scholars have developed frameworks to access the past intentions and agencies of the people who actually used and discarded the material objects visible in archaeological assemblages, namely *deposition formation processes*. Schiffer (1983) hypothesised three structural agents that affect assemblages; simple artefact characteristics such as size, density and shape, complex characteristics like quantity and distribution patterns and finally other factors such as sediment types and ecofacts (Schiffer, 1983). As an illustration of the value of such a forensic approach Schiffer points to ethnographic studies in Central American contexts which upon studying newly abandoned settlement sites, larger objects with little cost in their manufacture are discarded as waste but smaller, more cost-worthy artefacts are kept (Lange and Rydberg, 1972). Although self-evident in result, such studies also reveal how past networks of intention and cost values can be accessed through close scrutiny of artefacts in suitable contexts.

### Archaeological Illustration and Digitisation:

The plethora of potential object-specific information listed above can only gain visual primacy if the media used has multi-layering and connective capabilities. As such, digitisation offers a real means of collecting and visualising such a complex dataset. However, at this point, in clearly defining suitable features that can be singled out and mapped on the model, like use-wear marks and formation processes, there is a danger of being restrictive; limiting our engagement with the artefact being studied to a summary checklist of pre-vetted data types. One of the key benefits of archaeological illustration using traditional media, was that it

permitted a more reflexive and profound ‘dialogue’ with the object, acting as a “mediated expression of the archaeological resource ... an embodied expression of archaeological interpretation” (Morgan and Wright, 2018, 3 - 4). Furthermore, the practice of hand-drawing an artefact is restrained by the fundamental requirements of the information it must provide, each and every mark should have an economy of meaning acting as an intentional, interpretive act. This fact is emphasised by Adkins et al (1989) who rate the success of an illustration on the accuracy, clarity and abundance of information displayed (Adkins et al., 1989, 9). The accuracy of digitisation is well attested; however, it is the clarity and abundance of information that this thesis will seek to explore.

The processes involved in the act of digitisation has also offered a rich theoretical discourse predominantly focused upon the question and nature of authenticity in the digital record. Benjamin (1968) defines authenticity as “... the essence of all that is transmissible from [an object’s] beginning, ranging from its substantive duration to its testimony to the history which it has experienced” (Benjamin, 1968 in (Brida et al., 2012, 524)). With respect to how digital capture would distort this, Benjamin believed that “mechanical reproduction” (Conn, 2010, 27) would serve to disperse this associated aura. Despite this, we have seen above that by utilising 3D archaeology’s capacity for a multi-layered approach, we can perhaps return some of this ‘aura’ to the artefacts held in digital collections. Caraher (2016) has long criticised the drive for increased efficiency and standardisation embodied by many modern research practices, especially within the digital realm. Instead he advocates a self-reflective ‘Slow Archaeology’ that identifies “practices and tools that embrace the complexity of archaeological landscapes, trenches and objects” (Caraher, 2016, 423), very much part of the remit of what this thesis hopes to explore.

#### Metadata:

A fundamental issue is how to synthesize the diverse datasets above in a systematic and practical way, how to ‘enrich’ a 3D model (See Figure 1 Below). At a basic level this is a question of metadata. Metadata at its foundation can be defined as “data about data” (Liu, 2007, 3). Comprised of the separate elements that make up a digital object, metadata details information about the digital object itself including format type, creator/author, date produced etc. International partnerships such as the Europeana project have attempted to standardise and ensure the quality of digital heritage collections meta-documentation. For example the Europeana Data Model (EDM) was created to address the ontological complexity of defining the material object as distinct from its digital facsimile and furthermore this original model capture from the various online representations of it (Meghini et al., 2011, 5). An instance of the Europeana framework being used in an archaeological context, is the Europeana Archaeology Project (2020). A flagship project, Europeana Archaeology utilises the interconnectivity of the metadata schema in the Europeana system, aiming to improve “discovery of archaeological content through the use of *multilingual linked open data and geo data*” (Europeana, 2019, 2, my emphasis), as well as aims of public dissemination and data re-use. The greater potential for creative academic discourse and collaboration internationally is showcased by the litany of partner institutions involved, numbering some fifteen members in all. In terms of exploring how the format of the original dataset to be captured affects the construction of a metadata framework, the Terpsichore project has

sought to standardise the digitisation of intangible cultural heritage related to folk dances. The workflow they identified was “to digitize, model, archive, e-preserve and present” (Giannoulakis et al., 2018, 1). Both the Europeana and the Terpsichore projects used variations of the Dublin Core Metadata Initiative (DCMI) schema. Due to the level of standardisation and wide adoption DCMI enjoys, this is the schema this thesis will adopt.

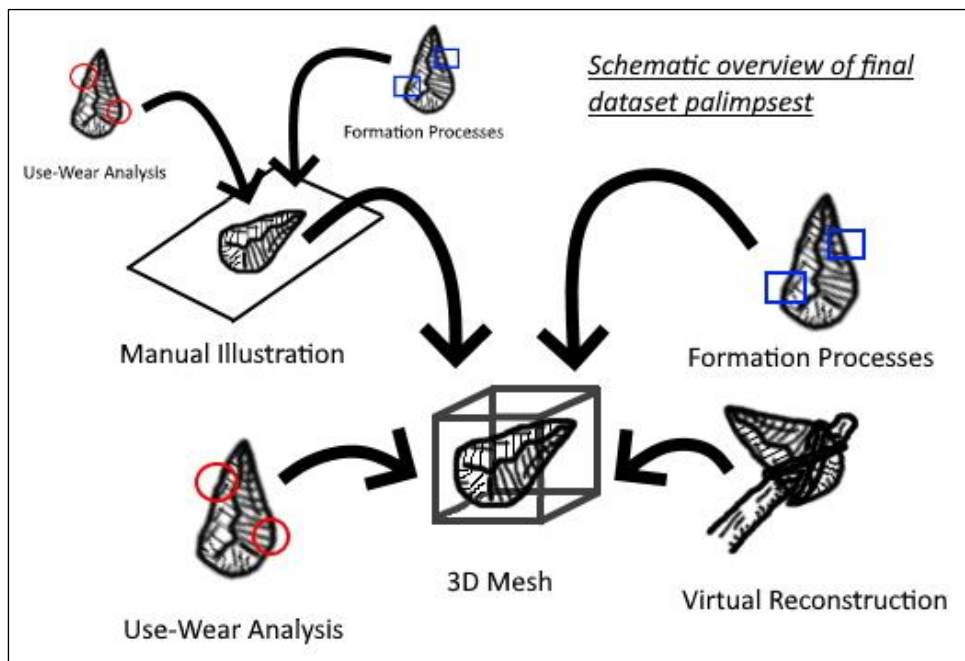


FIGURE 1: SCHEMA SHOWING OVERVIEW OF PROSPECTIVE COLLECTED DATASET

DCMI, or the Dublin Core Metadata Initiative in its nascent form consisted of fifteen elements or data types and can be traced to a 1995 conference in Dublin, Ohio chaired by the Online Computing Library Center (OCLC) and the National Centre for Supercomputing Applications (NCSA), the initiative sought to address “the rapid expansion of the internet [and] the plethora of information that was subsequently becoming available” (Lubas et al., 2013, 45, my parentheses) and the recognition that conventional indexing systems were ill equipped and outmoded for such a rate of change. The ontological complexities of digital data were recognized at this early stage in digital metadata studies, by establishing that a DCMI record would be singular not holistic in its representation, documenting a single version of a resource, for example a photograph of an artwork (Lubas et al., 2013). The further two basic tenets of DCMI ensured the accessibility quality of the data recorded, by emphasising the legibility and coherence of metadata even “if ... refinements or qualifications were stripped away” (Lubas et al., 2013, 46, my ellipsis); and striving for globally recognizable vocabularies and terminologies that were not too local or exclusive when describing the information or media being digitised, called the Dumb-Down principle and Appropriate Values principle respectively.

In terms of an anatomy of a DCMI schema, there are four basic components (Lubas et al., 2013, 48) comprising:

- **Properties:** Elements of a data set, the specific characteristics of a resource that are recorded.

- **Classes:** Categories of resources with shared properties, i.e. physical artefact, collected resources etc.
- **Datatypes:** Syntax rules regarding certain properties like dates, formats etc.
- **Vocabulary Encoding Scheme:** Acceptable terms used for elements such as subject and creator.

The original fifteen properties list established in 1995 has expanded exponentially as DCMI has developed beyond the web-created electronic resources it was originally intended to index, incorporating subjects as diverse as audio, video, physical objects and 2D media. For the purposes of this thesis however, these terms summarily based upon the initial list were whittled down to eleven usable elements, namely:

**TABLE 2: CHOSEN DCMI SCHEMA WITH DEFINITIONS BASED UPON THOSE LISTED IN LUBAS ET AL (2013)**

Title:	Accepted name of resource.
Alternative:	Other accepted names for resource.
Creator:	Person making the resource.
Contributor:	Person/Group providing assistance/additional information to resource.
Type:	Resource type/category.
Medium:	Resource Material.
Format:	File type, physical medium or resource proportions.
Extent:	Size of resource (e.g. File size MB)
Description:	Abstract account of chosen resource.
Date Created:	Date resource made.
Source:	Source collection of resource.

In adopting a metadata approach, it is hoped that the more ephemeral aspects of the artefacts such as formation processes can be conceptualised in a digital manner in the form of attribute tables, well referenced with regards to the source artefact, and that the rather abstract theoretical concerns above can be effectively situated in everyday praxis in terms of digitisation. Finally, under the aegis of exploring best practice, conceiving artefacts and the intended supplementary datasets as interlocking and enmeshed tables of metadata should guarantee systematic data rigidity and quality throughout the research process.

## Chapter Two: Material and Methods

Before detailing the processes involved during the thesis research, it is important to explain at length the materials and methods used. This is useful considering the rather diverse strands of research present and given the specialisation of a lot of the techniques, particularly the computing methods used.

### Materials

The material basis for this thesis can be split into several sections: archaeological, photogrammetric, modelling, processing and illustrative with a summary of the associated tools necessary for each step visible in Table 4.

The *archaeological* material consists of the sample artefacts from the teaching collection held within the Lund University department of Archaeology and Ancient History. Initially one artefact was the planned output both for expediency's sake and to permit more time to the creation of the additional datasets, a process which should be more labour intensive than the photogrammetry session. However, upon reflection the base amount of sample objects was increased to three. This develops the project beyond being a mere technological gimmick piece displaying one artefact, to a more robust evaluation of the applications of photogrammetry and 3D modelling interaction that permits a comparative analysis between multiple artefacts.

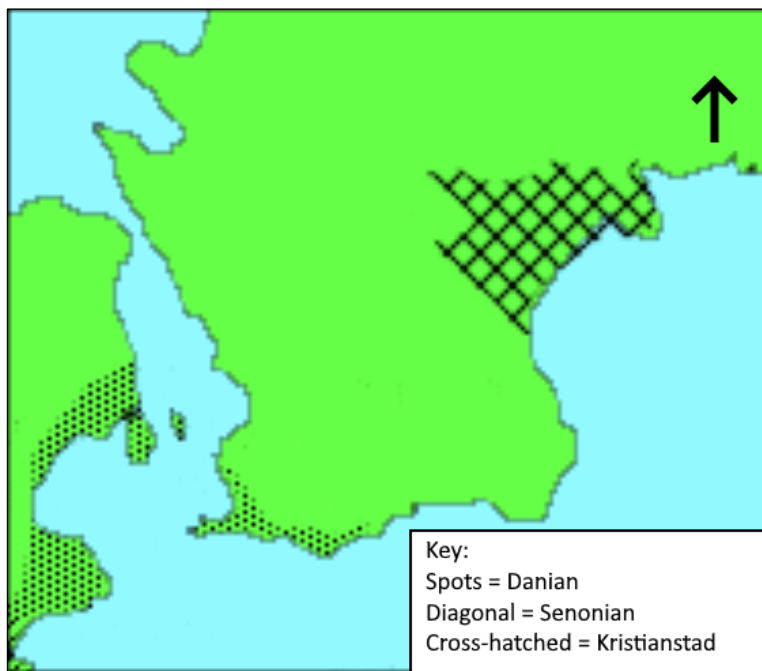
Such artefacts were chosen as they appeared to have decent records of use-wear marks on their surface upon cursory analysis. The tactility of the artefacts lends itself particularly well to a thesis of the current nature in that a lot of information will be visually imprinted upon the artefacts themselves. The chosen artefacts comprised three common Mesolithic tool-forms, a flake scraper, disc scraper and a core axe (Figure 2).



**FIGURE 2: SAMPLE ARTEFACTS: LEFT = CORE AXE ('KÄRNYXA'), MIDDLE = FLAKE SCRAPER ('SPÅNSKRAPA'), RIGHT = DISC SCRAPER ('SKIVSKRAPA')**



With respect to usable flint sources in a specifically Scanian context, those of the Senonian and Danian epochs, formed in the Cretaceous and Paleogene periods respectively, offered the raw materials for prehistoric societies and their tools (Högberg and Olausson, 2017). Generally existing as deep deposits, beds of these two flint types occur as outcrops (see figure 3) caused by isostatic rebound from the retreating ice fields. These notably occur around south-western Scania for Danian flint with isolated outcrops across the north-east and south of Scania for Senonian flint (Högberg and Olausson, 2017). There is also a flint-type unique to the environs surrounding Kristianstad distinctive because of its variation.



**FIGURE 3: AREAS OF SCANIAN FLINT DEPOSITS AFTER (HÖGBERG AND OLAUSSON, 2017, 31, FIGURE 22)**

Despite this seemingly simple picture of source regions for primary flints, Högberg and Olausson (2017) emphasise the fact that many secondary flints also were deposited in the topsoils of Scania by glacial activity and could also be found as coastal debris along its shores. The sheer quantity of available flints was effectively conveyed by an experiment carried out by Högberg in the till soil of a site close to Malmö. Concentrating on the contents of two sample squares 50 cm<sup>2</sup>, they collected some 3.5 kg of flint, with some 28 nodules with suitable dimensions for possible cores (Högberg and Olausson, 2017, 55). The point was made that usable flint nodules in such contexts would have been even more numerous than today, with modern numbers representing a small fraction of what would have been available, such flint stocks having been decimated by millenia of tool harvesting and production. Thus localised tracing of flint origin becomes tricky, especially considering Högberg and Olausson’s point that “literally millions of flint artifacts from prehistoric contexts in Scandinavia are known” (Högberg and Olausson, 2017, 28). However, disregarding questions of origin, such flint-rich archaeology offers the perfect context to explore past architectures of subsistence, manufacture and value, with use-wear analysis one of the key means of unlocking this.

*Photogrammetric* materials consisted of a Canon EOS 6D Mark 2 full frame camera, 24 – 105mm lens and tripod set-up. A light diffusion tent, namely the Foldio foldable studio was used to limit dark shadows and allow best surface capture. Finally, the artefact was placed on a turntable to aid systematic digitisation (see figure 4).

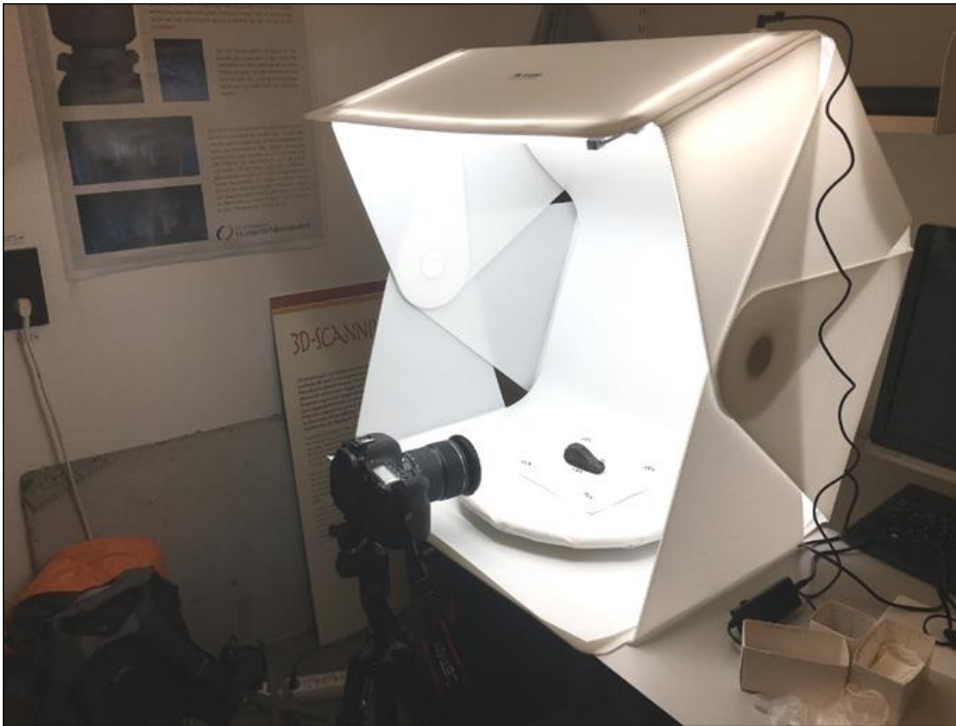


FIGURE 4: VIEW OF PHOTOGRAMMETRY SET-UP

The next stage in the research campaign is the actual *modelling* procedures in which the 3D data is produced. Materials for this are primarily software packages *Agisoft Metashape* and *Meshlab* (See Table 3) proprietary and open-source computer programmes respectively that use algorithms to stitch photographs together to form a 3D model. *Helicon 7* was used to combine multi-focused photographs together to form singular high focus images (See Table 5, Summary of methods).

Materials used to *process* the subsequent models were again the software packages *Meshlab* and *Blender*, both open-source programmes with a wide range of 3D data filtering and manipulation tools. Also utilised here were some of the features in *Cloud Compare*, another open source software package intended as an alternative to Agisoft Metashape. Final outputs of the models are intended to utilise a *3DHOP framework*.

The tools necessary for the *manual illustration* included cm squared graph paper, tracing paper, HB 0.5mm retractable pencil, black inking pens (0.5mm and 1cm), kneadable putty rubber, 30cm ruler, movable lightsource and a standard rubber.



**TABLE 3: DESCRIPTION OF SOFTWARE PACKAGES USED**

Software:	Description:	Features:	Version:	Publisher:
Agisoft Metashape Professional (64 bit)	Proprietary program that assembles 3D models using SFM and photo alignment algorithms.	<ul style="list-style-type: none"> <li>• Photo Alignment,</li> <li>• Sparse and Dense point cloud creation</li> <li>• Mesh Creation</li> <li>• Texture Generation</li> <li>• Data filtering etc.</li> </ul>	1.6.2	Agisoft LLC
MeshLab (64 bit)	Open-source program that generates, edits and processes 3D meshes.	<ul style="list-style-type: none"> <li>• Triangular mesh generation</li> <li>• Mesh filtering, fixing, texturing, measuring, inspection etc.</li> </ul>	2016.12	ISTI-CNR
Blender (64 bit)	Open-source program for 3D animation.	<ul style="list-style-type: none"> <li>• Texture mapping</li> <li>• Mesh modelling/editing.</li> </ul>	2.80	Blender Foundation
Helicon 7 (64 bit)	Proprietary program that generates focus stacked images	<ul style="list-style-type: none"> <li>• Focus stacking of images</li> <li>• Interpolation</li> <li>• Display options such as scientific scales etc.</li> </ul>	7.6.1	Helicon Soft Ltd.

3DHOP (64 bit)	Open-source HTML framework for interactive display of high-resolution 3D meshes.	<ul style="list-style-type: none"> <li>• Data measuring</li> <li>• Data display</li> <li>• Data management</li> <li>• Data enrichment</li> </ul>	4.2	ISTI-CNR
CloudCompare	Open-source software for creating 3D clouds and meshes	<ul style="list-style-type: none"> <li>• Data measuring</li> <li>• Data display</li> <li>• Data management</li> <li>• Data enrichment</li> <li>• Data alignment etc.</li> </ul>	2.10.2	CloudCompare

**TABLE 4: SUMMARY OF RESEARCH STAGES AND ASSOCIATED TOOLS**

Research approaches:	Materials and tools:
Archaeological (Generic)	<ul style="list-style-type: none"> <li>• Flint artefacts</li> </ul>
Photogrammetry (Stage 1)	<ul style="list-style-type: none"> <li>• Canon EOS 6D Mark 2 full frame camera</li> <li>• 24 – 105mm lens</li> <li>• tripod</li> <li>• Foldio foldable studio light diffusion tent</li> <li>• turntable</li> </ul>
Modelling (Stage 2)	<ul style="list-style-type: none"> <li>• Helicon 7</li> <li>• Agisoft Metashape</li> </ul>
Processing (Stages 3 & 5)	<ul style="list-style-type: none"> <li>• Meshlab</li> <li>• Blender</li> <li>• Cloud Compare</li> <li>• 3DHOP</li> </ul>
Manual Illustration (Stage 4)	<ul style="list-style-type: none"> <li>• 1cm squared graph paper</li> </ul>

	<ul style="list-style-type: none"> <li>• Tracing paper</li> <li>• HB 0.5mm retractable pencil</li> <li>• Black inking pens (0.5mm and 1cm)</li> <li>• kneadable putty rubber</li> <li>• 30cm ruler</li> <li>• Movable light source</li> <li>• Standard rubber.</li> </ul>
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## Methods

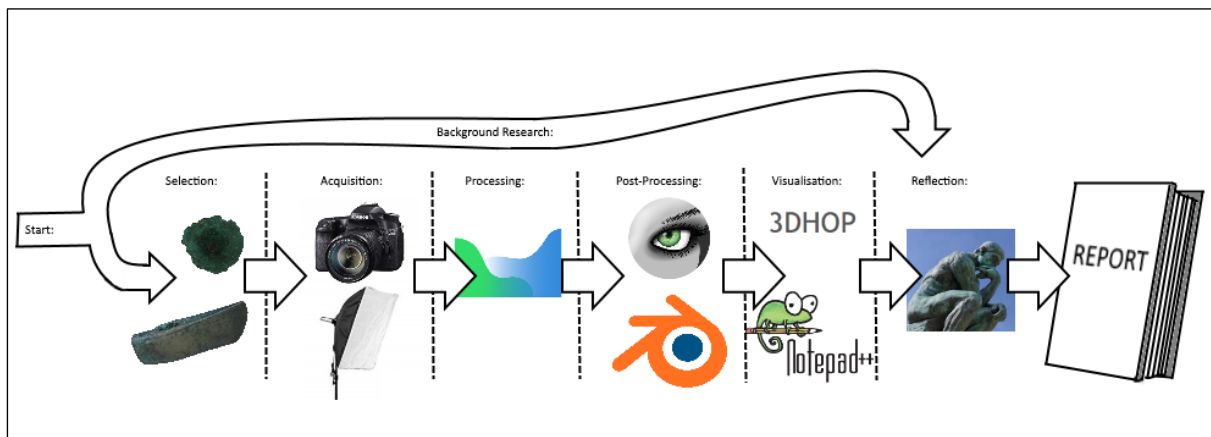
Before dealing with the research proper, it is prescient to briefly describe the methods used and expected workflow that will be utilised in carrying it out. For clarity, a brief definition of the different approaches used herein will follow:

**TABLE 5: SUMMARY DEFINITIONS FOR THE APPROACHES USED IN THIS THESIS**

Approach:	Definition:
<i>Photogrammetry or Image Based Modelling</i>	Defined as the reconstruction of “... the position, orientation, shape and size of objects from pictures [resulting in] ... coordinates of separate points in a three-dimensional coordinate system” (Kraus, 2011, 1). One of the most common methods fixes a camera and rotates the object to be scanned, taking a photo at regular intervals to capture a full 360-degree view of the object. Multiple rotations are then stitched together to make a 3D representation of the object.
<i>Focus-Stacked Macro Photography</i>	“Is a photographic technique that consists in capturing a stack of images at different focus planes for each camera pose” (Clini et al., 2016, 231) and combining them to form a high resolution, ultra-focused composite image.
<i>Modelling and Processing</i>	Involves the creation of a 3D model in the form of a cloud of points (Point-Cloud) or textured 3D mesh and the subsequent filtering and manipulation thereof.
<i>Sparse/Dense Point-Clouds</i>	Are the clouds of three-dimensional points generated by the photogrammetry algorithm.

<i>Meshes</i>	Are the transformation of the above point-clouds into 'water-tight' objects by connecting each point with a line and filling the spaces in-between with planes.
<i>Textures</i>	The surface information of the object such as colour that are mapped onto the mesh object producing the final model.
<i>Digital Illustration</i>	The use of polyline or polygon tools in software programs to delineate or emphasise certain features on the artefact.
<i>Manual Illustration</i>	Can be defined as an interpretative form of representation, with lithics drawing " a technical representation [offering] information through graphical conceptualisation on the shape and ... the method and order in which the flakes were removed from the artefact" (Raczynski-Henk, 2017, 11, my parentheses and ellipsis).
<i>Use-Wear Analysis</i>	Is the "analysis of the surfaces and working edges of artefacts to detect signs of wear, damage, or residue caused by their use" (Darvill, 2009, 249).
<i>Formation Processes</i>	Are those which have "affected the formation and development of the archaeological record"(Champion, 1980, 51). These are not limited to the human activities during use, but also natural and post-depositional processes. As such it is a means of conceptualising how time affects artefacts, linked to ideas of object life histories and chaîne opératoire.

The workflow of these diverse approaches can be seen in Figure 5 below:



**FIGURE 5: WORKFLOW DIAGRAM SHOWING THE PROCESS OF PHOTOGRAMMETRIC CAPTURE TO END REPORT (CLARKE ET AL., 2019, 3, FIGURE 2)**

Comprising of two strands the main route consists of the practical photogrammetry campaign, manual illustration and mapping of visual datasets. The second route follows the literature research to identify this supplementary data, mainly use-wear analysis and formation processes with both strands combining at the visualisation stage. The results will then be analysed with respect to the theoretical frameworks discussed above, and a reflection on possible future research will be proposed.

## Chapter Three: Methodology

The following chapter details the research procedures carried out from the initial photogrammetry and modelling campaigns through to the illustrative and enrichment approaches outlined above. Although to some degree sequential, with each research stage building upon the previous, the different approaches within this section can also to some extent be characterised as a series of separate experiments in which the capacities for display of different visual information are assessed.

### Macro Photogrammetry Session

Initially the aim was to use macro photography to capture the highest possible artefact detail enabling faithful reconstruction quality in the resulting mesh. Artefact 1, the kárnyxa or Core-Axe was used to explore the feasibility of this approach. Figure 4 above displays the camera and light tent set-up used. In terms of camera parameters, as mentioned above a Canon EOS 6D DSLR camera with a 24 – 105 mm lens was used. Although this lens is not intended to take macro photographs, it can be used for decent macro captures provided suitable camera/object set up and focal adjustments are used. ISO levels was set at 120 following the protocols outlined in Lastilla et al (2019) which advocated an ISO level of around 100 sufficient for “adequate to good light conditions and small enough to avoid grain and noise” (Lastilla et al., 2019, 701) with white balance locked to a reference photo of the turntable and tent set-up without the artefact in situ, and a modifier of  $\pm 2^{2/3}$ . Aperture was set at F8 and the lens was set at a value of 50mm, with the centre of the artefact around 30cm from the camera lens. The camera was fixed on a tripod and the ‘front’ portion of the object closest to the camera brought into sharp focus with the rest blurred and a photo taken. The object was then ‘swept’ across through a steady manual increase in focal length with photographs taken at each increment until the furthest point of the artefact from the camera was in focus. Each ‘sweep’ consisted of approximately 10 to 15 photos before the artefact was rotated and the process repeated. Care was taken to note down the camera parameters and photograph id numbers for each photo per sweep (Appendix 1). Rotation 1 of the artefact took 15 ‘sweeps’ in all with a total of 183 photos. The entire macro capture consisted of three rotations of the artefact in various views and resulted in 579 photos.

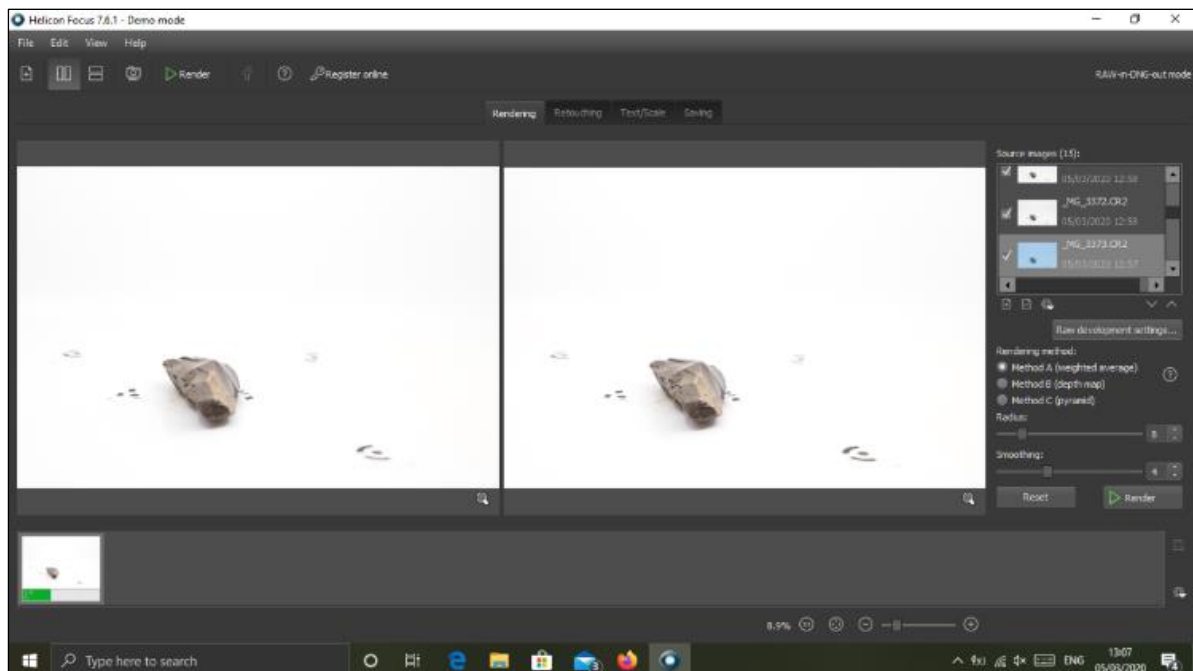
The photos were then imported per ‘sweep’ batch into Helicon 7 which compresses each batch of photos into a macro image stack with a high level of consistent focus across the artefact (Figure 6). Photos were imported into the program in raw format to avoid any resolution loss as a result of jpeg compression.

The software parameters used were the default settings:

**TABLE 6: HELICON 7 PARAMETERS**

Rendering Method:	Method A: Weighted Average
Radius:	8 (Default)
Smoothing:	4 (Default)

This was due to inexperience with both the software and the process of macro photography. For example, the rendering method used: method A, “computes the weight for each pixel based on its contrast, after which all the pixels from all the source images are averaged according to their weights” (Lastilla et al., 2019, 702). Whereas method B identifies the sharpest pixel in the images used and creates a resulting depth map, preserving contrast and colour better (Lastilla et al., 2019, 702). The resulting macro photos were exported in DNG format to preserve resolution with each rotation comprising of 15, 18 and 16 stacked photos respectively. In terms of future considerations, tethering the camera to a remote shutter control and an automatically staggered focal adjustment set-up would increase sharpness of the capture by reducing the blur associated with manual adjustment. The necessity of having an automatic set-up would be emphasised when the photos were imported into Agisoft Metashape for 3D processing.



**FIGURE 6: SCREEN-CAPTURE OF HELICON 7 SHOWING STACKING PROCESS WITH ORIGINAL SELECTIVELY FOCUSED IMAGES ON THE LEFT COMPILED TO CREATE THE HIGH-QUALITY IMAGE ON THE RIGHT**

The photos were then imported, again in DNG format to Metashape in three chunks corresponding to the three rotations of the artefact, cameras calibrated and optimised, before photo alignment was carried out with high generic selection. However, many of the photos failed to calibrate correctly and as such the resulting meshes produced were fragmentary and skewed. Macro photography can either be carried out automatically, with the camera placed on a slide and the focal adjustments made by mechanically moving the camera forwards towards the object or with lens adjusted manually in the manner described above. The former serves to preserve the camera parameters, allowing the algorithm in Agisoft Metashape to correctly estimate camera positioning and distance from object. The latter results in different camera measurements between each photo which throws the algorithm into confusion. A workaround for this issue can be to manually mask

the blurred parts of each photo in order to mitigate the camera calibration issues (Clarke et al., 2019), however as the main crux of this thesis is to explore actively engaging with data and creating a digital palimpsest, standard photogrammetry capture was decided upon in the aims of expediency.

### Standard Photogrammetry Session and Modelling

Following the issues involved with the macro-photography capture, standard photogrammetry methods were used. In order to comply with best-practice and to ensure a high standard of data capture, the technique and equipment summaries published by the Swedish National Heritage Board proved useful (Riksantikvarieämbetet, 2019) as well as the methods and parameters outlined by Sapirstein (2018) that focused on small artefacts of a similar size ratio to the sample artefacts chosen in this thesis, less than c.10 cm in length. The camera, turntable and light-tent set up remained the same as the macro session, but the use of a remote trigger was also used to reduce blur from camera shake via the IOS App Canon Camera Connect and ultimately a Canon RC-6 remote control. Finally, after struggling to get a decent alignment via having the artefacts placed upon the side, kneadable putty rubber was used to prop the artefact up in a 'standing' position (see Figure 7).



FIGURE 7: VIEW OF FIRST ROTATION SHOWING HOW THE ARTEFACT WAS PLACED VERTICALLY



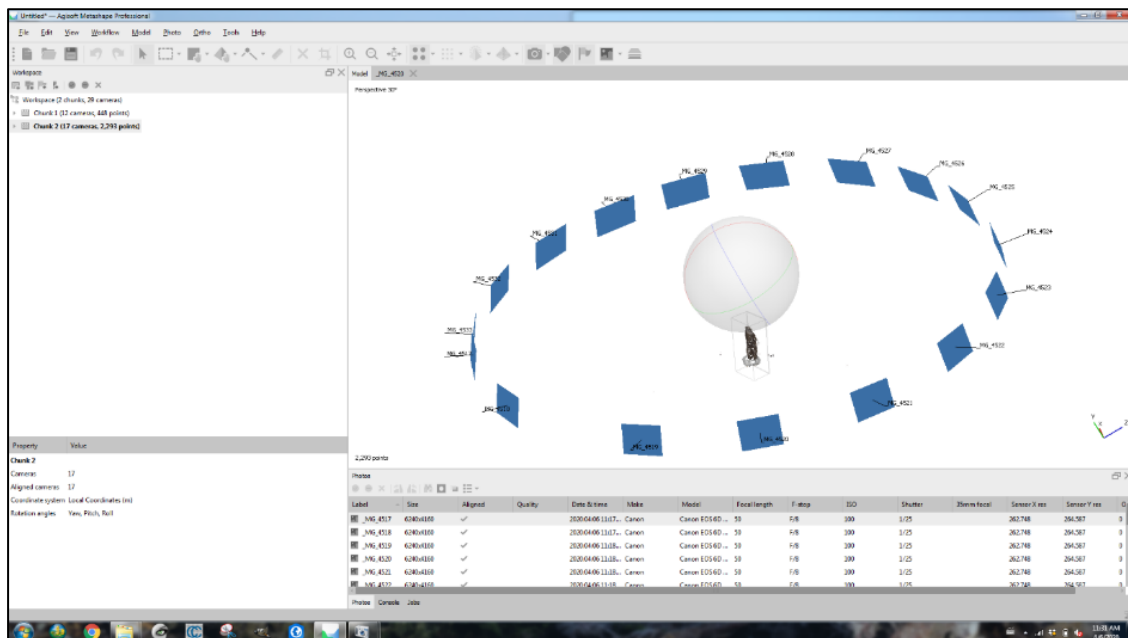
This facilitated a quicker capture in that the two sides of the artefact are photographed simultaneously with no need for the stitching together of two separate models for each side, a time-consuming process. However due to the putty rubber stand, a separate rotation capturing the area obscured by the support had to be carried out and the two chunks aligned. The camera parameters used can be seen in Table 7 below.

**TABLE 7: STANDARD PHOTOGRAMMETRY CAMERA SETTINGS**

Focal Length:	50 mm
Aperture:	F8 +/- 2 1/3
ISO:	100

The section below deals primarily with the first sample artefact, but the methods and processes involved would be the same for all three artefacts and for the sake of expediency and to avoid repetition further information on those two would be included in the Agisoft Metashape Process Reports for the respective artefacts within the Appendix.

In terms of workflow the photographs for each rotation were imported into Agisoft Metashape as separate chunks. Firstly, the image quality of the photographs was calculated to ensure a robust calibre of photographs were being used to generate the model. Above 0.5 is generally the standard measure for image quality in Metashape, and the rotations used were checked against this benchmark. In terms of the first artefact, the next step was to calibrate cameras so that the software can correctly estimate the lens used and distance between the object scanned to the camera sensor before photo alignment on a high setting with adaptive camera fittings taken into consideration was carried out (See Figure 8 below).



**FIGURE 8: SUCCESSFUL ALIGNMENT OF THE FIRST ROTATION SHOWING CAMERA PLACEMENT AND SPARSE CLOUD**

The resulting sparse cloud was then corrected via camera optimisation and then converted into a dense cloud on high settings resulting in a cloud of some 1,121,884 points. Whilst

initially this capture looked quite good, upon closer inspection, the edges of the axe and the top of the blade were missing a lot of data which became more apparent after manual noise deletion when a mesh was generated with a custom face count of 150,000 displaying subsequent noise and warping at these edges (Figure 9). In order to combat this, the mesh and sparse and dense clouds were deleted, and the process begun again in earnest. However, in order to ensure that the software had access to the maximum quality of axe edges data as possible, the photographs in the chunk were masked manually by a combination of the magic wand, magic scissors and add to mask tools, with only the sample artefact visible for alignment. Following this, the photos were aligned with the same parameters as the first attempt, and the produced sparse cloud subjected to gradual selection and deletion with the parameters recorded in Table 8.

**TABLE 8: GRADUAL SELECTION PARAMETERS**

Reconstruction Uncertainty:	10
Reprojection Error:	0.3
Number of Images:	2
Projection Accuracy:	10 %

Again, a dense point cloud was generated with settings on high and the edge-quality of the model assessed. The issues with the edges and noise is perhaps due to the material of the axe itself, being made of a dark and reflective flint. As such there was some scattering of points due to the high reflectance of the surface and the depth of the colour in the shadows resulted in data loss. These issues would prove problematic for the second rotation too.



**FIGURE 9: WARPED, OVERLAPPING EDGES RESULTING FROM MISSING DATA**

As the artefact was propped upwards with putty rubber on its hafting side, a second rotation of the artefact had to be carried out with the axe flipped so that its blade was now resting in

the support. However, following the camera calibration and image quality estimations outlined above, and alignment in high settings and camera optimisation, only one side of the artefact was aligned. All the photos involved were above 0.5, so the quality of the input data was of no issue. To attempt to force the program to align the photos to some degree further alignments were made in medium and subsequently low settings to no avail.

To combat this issue, a campaign of manual masking was carried out like that of the first rotation. This resulted in a successful alignment and following a process of gradual selection with the same settings as the previous rotation, a dense cloud was generated on high settings. However once again there were some issues generating the blade edges with the sides of the axe overlapping with themselves.

As previously mentioned, the dark colour and reflective nature of the artefact's surface was problematic and whilst the models above had been generated with the JPEG format of the photographs taken, a new alignment and modelling campaign was undertaken using the RAW photograph files which had a higher white balance preserving much of the surface data missing in the JPEG shadow areas. Whilst this worked with modelling the rotation with the blade up, the blade down had issues with the reflected light on the flint's surface being too bright, again resulting in data loss.

Gradual selection to the same parameters summarised above in Table 5 also compounded this loss of data, with too many surface points filtered out. As a result, the solution was to experiment with the image brightness and contrast levels of the photos and carry out no gradual selection campaign in order to maximise the surface capture. Initially both rotations were subjected to the default system estimated levels of brightness and contrast which resulted in very dark photos. Mitigating this involved manually changing the models to 80 % brightness and 150 % image contrast for the blade down rotation and 200 % brightness/ 100 % image contrast for the blade up capture. This resulted in an approximate colour match for both rotations which were merged via marker based methods to form a full dense cloud of the axe subsequently processed into a textured mesh on ultra-high settings to preserve as much surface detail as possible (Figure 10).



**FIGURE 10: FINAL TEXTURED MESH OF FIRST SAMPLE ARTEFACT, THE CORE-AXE, SHOWING THE LOCATION OF THE ALIGNMENT MARKERS**

### Digital Illustration

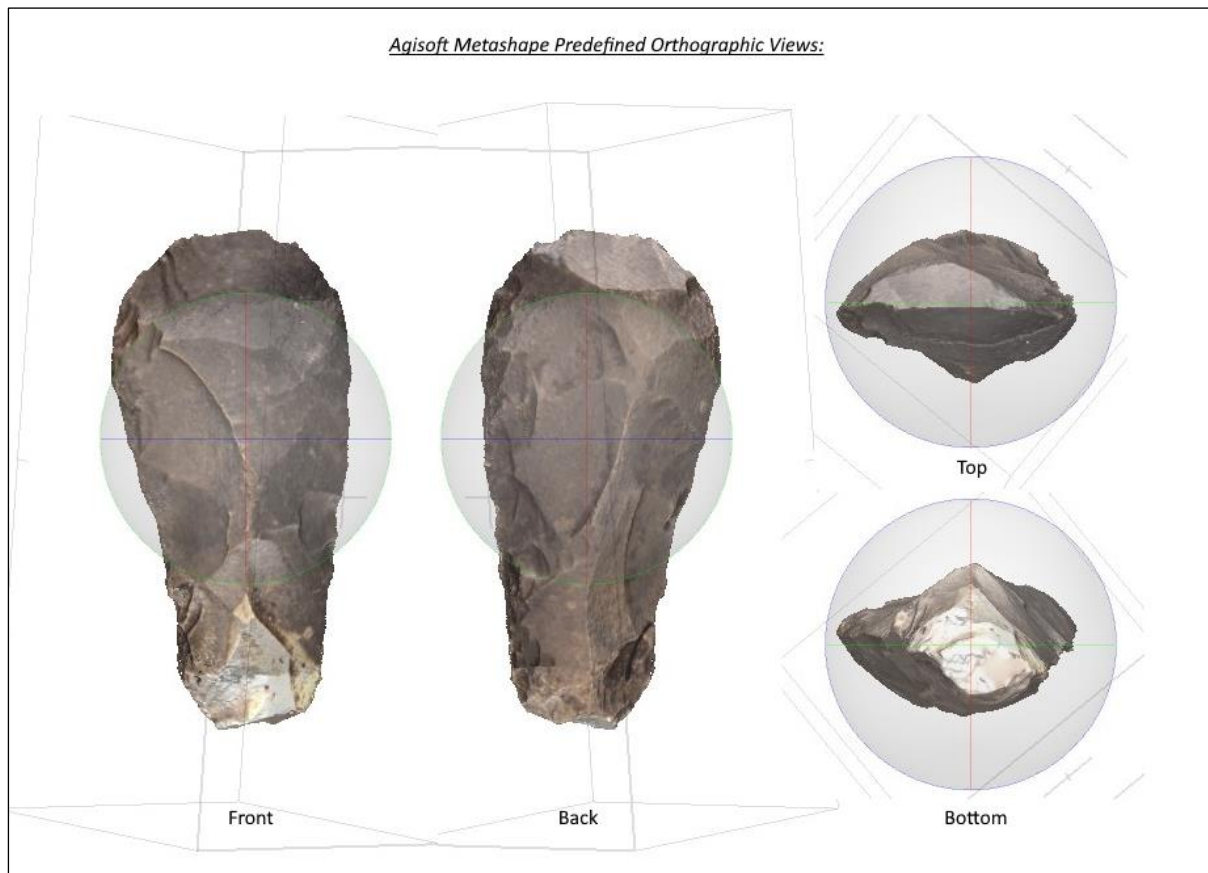
Before carrying out the use-wear analysis, it seemed prudent to explore means of illustrating the models in order to have a base framework upon which to situate the additional use-wear supplementary data. Although this section was initially planned to involve purely manual illustration, with the idea being to map the completed drawing onto the map as a texture, the scope of exploration was expanded to include an attempt to assess the illustrative capacities of Agisoft Metashape and Meshlab. As such the process would be much more actively enmeshed within the 3D models themselves, allowing for the investigation of issues as diverse as digital affordances, data visualisation and engendering engagement in a reciprocal conversation between the artefact as 3D model, illustration, and actual material object. As such it was hoped such a comparative approach would herald a practical discussion of the sort of reflective, slow archaeology hypothesised by Caraher (2016).

### Agisoft Metashape

Having generated a usable textured mesh, the next step was to explore the illustrative capacities of Metashape's polyline tool to act as a case study against which to compare traditional manual illustration.

Firstly, the completed chunk with textured model was duplicated. Following this the model had to be orientated to standard illustration views in orthographic mode with the blade as the top, hafting butt as the bottom, with the topside as front and the underside as the back view following Brøgger's (1906) standard axe views. To do this, orthographic view was entered using the workflow Model -> View Mode -> Orthographic. Next the view was orientated into the 'Top' view using the predefined view mode shortcut 7. Then the orientation of the model was readjusted to the aforementioned standards using Model-> Transform Object -> Rotate Object with the blade edge running horizontally across the axe.

The process was repeated until the axe was correctly aligned in all predefined views (See Figure 11).



**FIGURE 11: AGISOFT METASHAPE'S PREDEFINED VIEWS IN ORTHOGRAPHIC MODE OF ARTEFACT 1 ARRANGED ACCORDING TO BRØGGER'S (1906) STANDARD AXE VIEWS**

Whilst the image above shows the quality of 2D illustration that Metashape can encompass, it neglects the unique and immersive quality that 3D datasets embody. Therefore, this thesis sought to explore enrichment of the existing dataset by way of Agisoft Metashape's polyline feature. In order to have a base level of enrichment data and measure Metashape's facilities for data classes and categorisation, it was decided to digitise primary flake negatives associated with constructing the axe, the so called 'roughing out' phase, before digitising any secondary flake negatives visible.

The workflow for this process was as follows. Firstly, the model was adjusted to a front orthographic view. Next a new shapefile with an added polyline file called "Flake Scar front (primary)" and all of the flake scars associated with the roughing out of the axe shape digitised with a blue polyline. A second polyline file was made, and the illustration campaign was then undertaken with the secondary flake negatives digitised in yellow, titled "Flake Scar front (Secondary)". Next the model was orientated into a back orthographic view using the shortcut Ctrl+1 and the process repeated (See Figure 12). In terms of the practicalities of this illustration process, it is advisable to disable the shapefiles for the completed side when commencing upon the second side as the multitude of digitised features can make visibility

quite tricky (Figure 13) with a total of 28 primary "roughing-out" marks and 51 secondary marks identified.

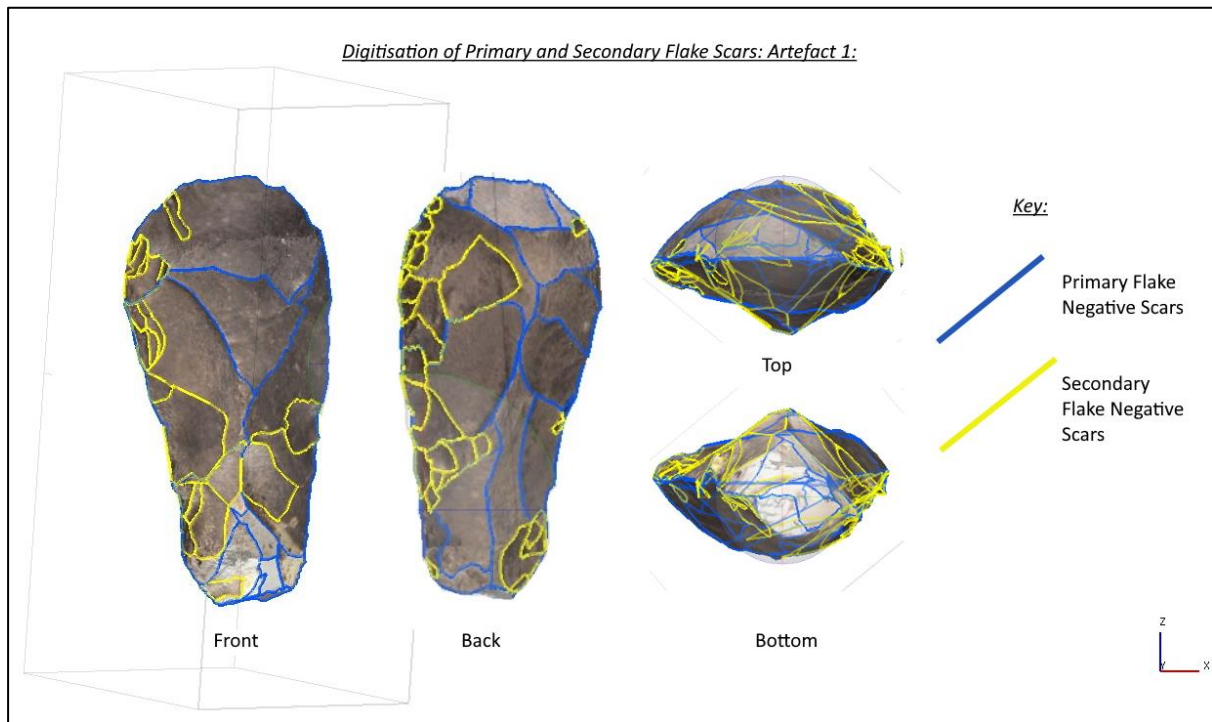


FIGURE 12: PRIMARY AND SECONDARY FLAKE NEGATIVES DIGITISED USING AGISOFT METASHAPE'S POLYLINE TOOL

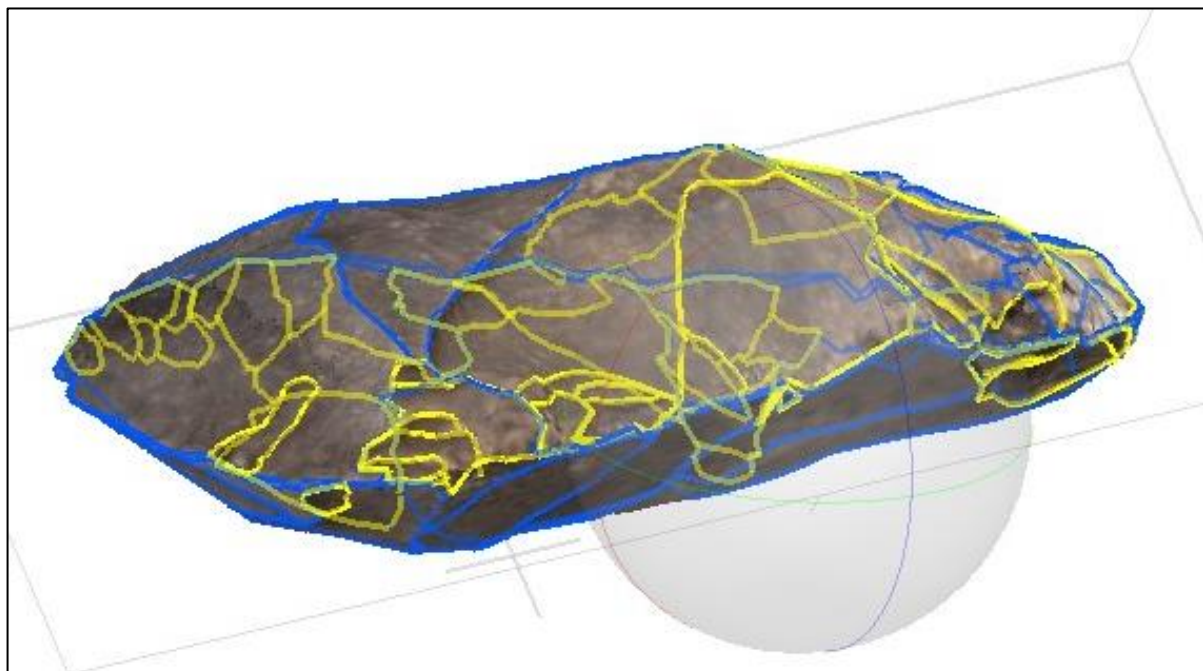


FIGURE 13: VIEW OF COMPLETED ILLUSTRATED MESH SHOWING THE RELATIVELY ILLEGIBLE NATURE OF THE NETWORK OF POLYLINES PRODUCED

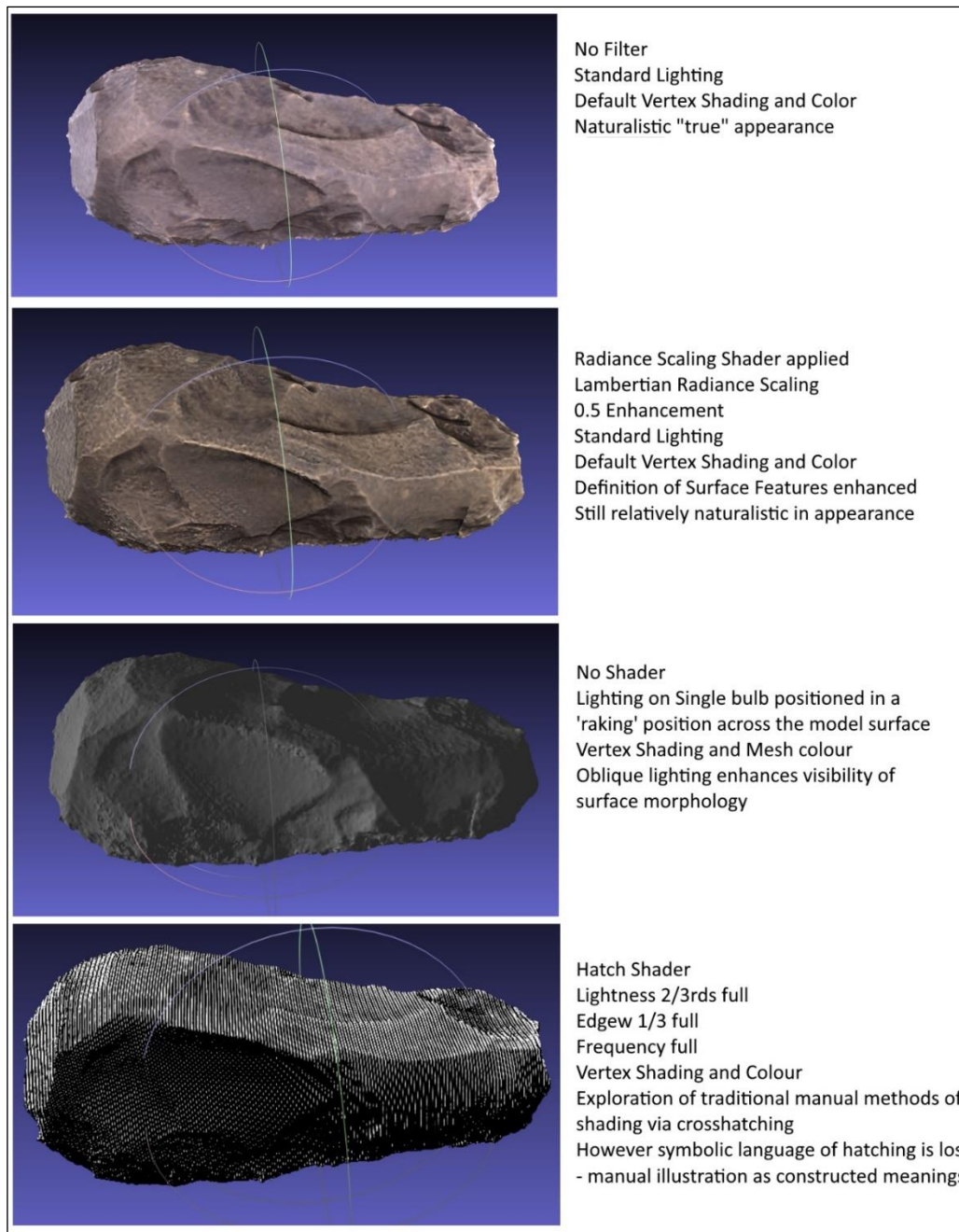


Whilst these features were digitised initially in standard orthographic views, the ability to rotate and zoom in on the model helped immensely in terms of reading its surface. Despite this there are definite limitations to this approach, with a lack of surface and feature snapping and lack of undo function major issues, but these will be discussed further in the Discussion and results chapter. It is important to note however, that such meta-level concerns were never under the purview of what Agisoft Metashape was intended to do, with the exportation of the model into ArcGIS Pro a possibility if true in-depth feature class enrichment is required.

### Meshlab

The illustrative features of Meshlab are different, lending themselves less to schematic representations of specific features of the artefact, and more to enabling greater interaction and inspection of the model itself. For example, the program features a litany of different shading and lighting formats that can be used to emphasise the coherence of surface features (Figure 14). In addition to this, Meshlab features a paint function that can be used to actively annotate the model. Unlike the polyline tool native to Agisoft Metashape however, this does not create a separate entity file for the digitised features, but actually paints onto the surface of the mesh itself. As such, categorisation of surface features is beyond the scope of the program, however the broad spectrum of interactive tools and functions of Meshlab, engenders a real sense of experimental engagement with 3D data outside the bounds of systematic categorisation, lending itself to intrinsic questions of illustration and visualisation. A digital petri dish for self-reflexive archaeological practice.

For example, the fourth panel in figure 14 displays the use of the “Hatch” Shader to generate a pattern of cross-hatching across the model’s surface. In this way the digitised artefact acts as an approximation of traditional means of illustration standards through the medium of cross-hatched features and details. And yet, upon subjection to this shader, our understanding of the surface information of the artefact is in no way improved beyond perhaps clearer recognition of large ridges and negative features. Cross-hatching in the context of manual drawing is imbued with symbolic meanings with each mark a considered act of intention weighed against the information it conveys. Raczynski-Henk (2017) lists some 21 different hatching conventions and symbols for hand drawing lithics, each conveying specific information about different surface features, stating that the legibility of illustrations depend “entirely on the strict application of the relevant conventions” (Raczynski-Henk, 2017, 15). Whilst it is inappropriate to compare a digital model and a 2D drawing as both are fulfilling very different purposes, the issues above are still important to consider with respect to the often unconscious constraints computer programs place upon the nature of the questions we ask/how we interact with digital material, and the suitability of established conventions given the new and unprecedented means of data display now available. One means of circumventing this issue of convention, and preserving the information contained therein, is to manually draw the artefact on paper, digitise that drawing via scanning, and then map it onto the 3D mesh as a new texture.



**FIGURE 14: ARTEFACT 1 PROCESSED THROUGH VARIOUS SHADERS ON DEFAULT SETTINGS IN MESHLAB**

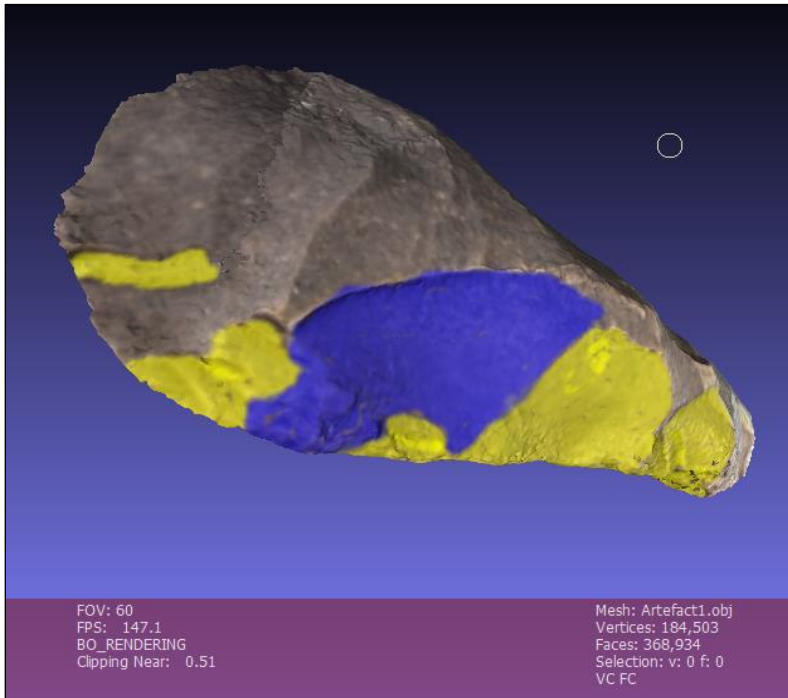
With respect to exploring the more schematic illustrative means of Meshlabs Z-Paint tool, a session digitising the primary and secondary flint scars was carried out using the brush parameters seen below in Table 9.

**TABLE 9: MESHLAB Z-BRUSH PARAMETERS**

Opacity:	50
Hardness:	50 (Default)
Size:	8 - 20

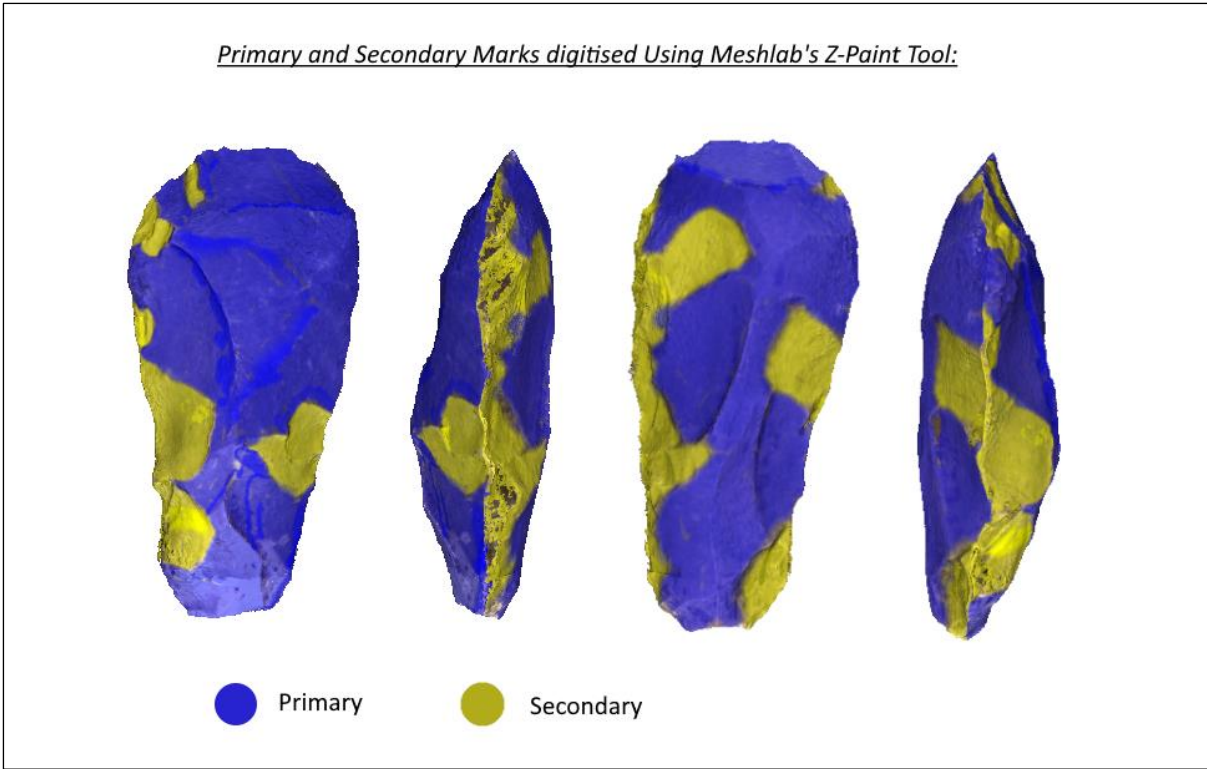


The keynote colours used were the same as those used in the Agisoft Metashape polyline campaign with blue for primary and yellow for secondary marks (See Figure 15). Conceptualising the marks as plains as opposed to linear boundaries made reading them on the surface a bit easier at the expense of individual resolution for each mark. Instead marks from the same category bleed into one another producing a very simplistic schematic overview.



**FIGURE 15: USING THE Z-BRUSH TOOL IN MESHLAB)**

It is interesting comparing the two schemas produced, noting the differences between the marks digitised. Perhaps the best solution involves a combination of the two programmes, utilising Meshlabs different shader features to enhance visibility of the marks while digitising them. The Z-Brush tool again had a distinct lack of an undo function, and upon exiting the tool to re-orientate the model, the chosen parameter and colour values had to be re-entered. Despite this, we can see that simple diagrammatic representation of surface morphology and features can be produced (See Figure 16). Future efforts could involve perhaps a gradient coloured categorisation of features displaying the entire life history of the artefact, from raw stone surface, primary roughing out marks, secondary 'retouch' marks, use-wear marks and even damage associated with post-depositional processes like frost/fire cracking if visible. An attempt to approximate this based upon a more critical reading of the sequence of overlapping marks was carried out using a colour coded gradient from blue to red representing earliest to latest marks in temporal sequence. This is discussed more in the conclusion.



**FIGURE 16: PRIMARY AND SECONDARY MARKS DIGITISED IN MESHLAB**

### Manual Illustration

Manual illustration of the artefacts relied heavily on the standardised procedures documented in 'Drawing Lithic Artefacts' by Yannick Raczynski-Henk (2017). Materials consisted of a retractable pencil, kneadable putty rubber, ruler, squared graph paper (cm<sup>2</sup>), tracing paper, a handheld light (mobile phone) and black inking pens with 0.3mm and 0.5mm nibs respectively. In order to prepare the page for the drawing, any information about the sample artefact was written at the top, including find number, a small scale bar was drawn in the bottom left-hand corner, and a horizontal line was drawn close to the bottom as a baseline from which to take longitudinal measurements.

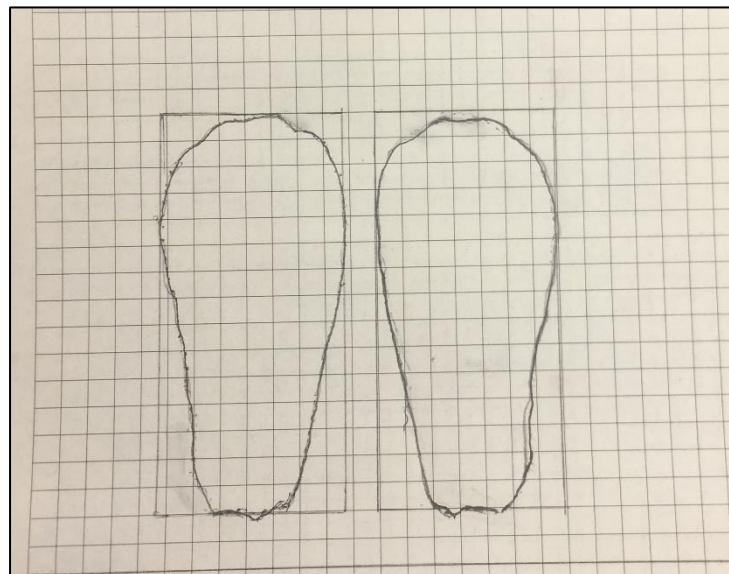


**FIGURE 17: INITIAL PREPARATION FOR ILLUSTRATION**

The artefact was then placed dorsal side up upon a support of putty rubber so that it wouldn't wobble when taking measurements; and a rectangle drawn around it encompassing its maximum extent (Figure 17). A rectangle of the same dimensions was then drawn in preparation for the ventral side. Measured points were then taken along the outline of the artefact using a ruler edge as a plumb line. The extendable lead of the pencil came into the fore at this point, able to go 'under' the artefact to record the correct extent of the outline (Figure 18). The outline having been transmitted to the paper via points, the next step was to join the points together ensuring that "the dots do not become vertices" (Raczynski-Henk, 2017, 28) joined by straight lines but are bridged fluidly (Figure 19) with both faces of the axe drawn in this way. The intersection of the ridge lines with the artefact's edge are indicated using lines to aid the next drawing stage with this the artefact then placed to the side of the drawing in order to facilitate this. The ridges are then drawn in via a combination of sight and measuring ridge intersection points from the baseline (See Figure 20).



**FIGURE 18: POINTS OF MEASURE ALONG THE ARTEFACT'S OUTLINE**



**FIGURE 19: COMPLETED OUTLINE FOR BOTH SIDES OF THE ARTEFACT**



FIGURE 20: DRAWING THE RIDGES

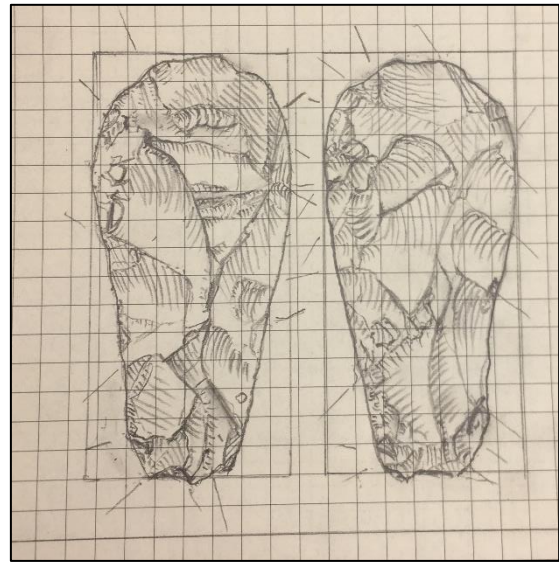


FIGURE 21: COMPLETED SHADING

The same process was carried out for the reverse side and then the shading commenced, with hatching dependent upon the direction of slope and the artefact lit from the top left by means of a phone torch which was occasionally moved to increase slope visibility. The final sections to draw included a cross-section of the widest point of the artefact, and a lateral view. The cross-section was quite problematic, again involving propping the artefact blade-down into the kneadable rubber support and taking points with the pencil and ruler.

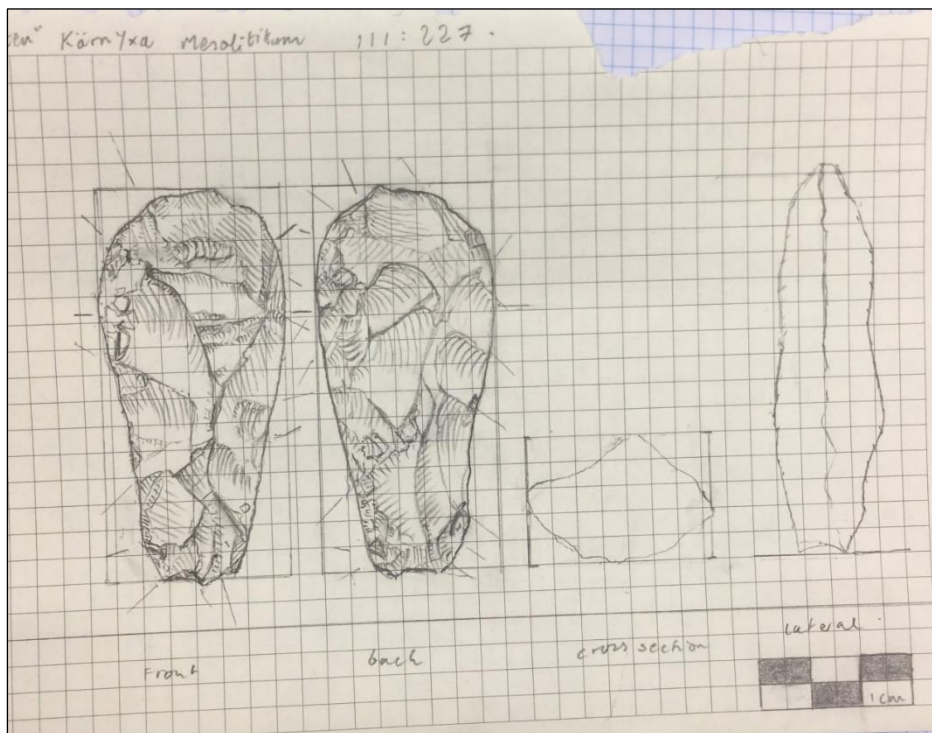
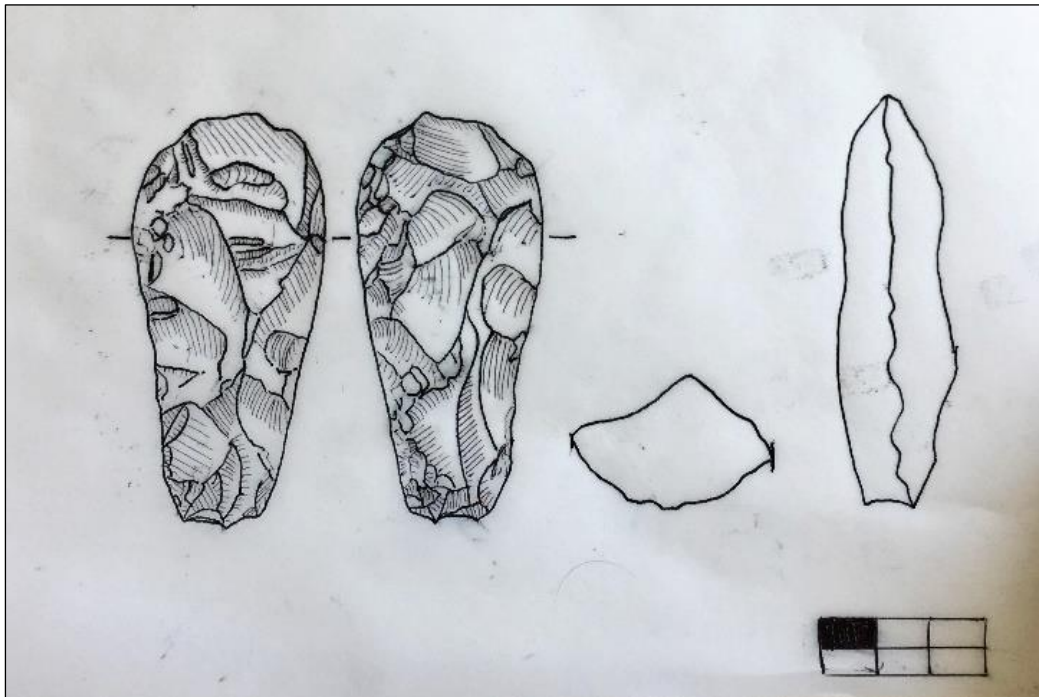


FIGURE 22: COMPLETED DRAWING SHOWING LATERAL VIEW



There was an issue of artefact stability here with the object tending to wobble when attempting to take measures with the ruler. This continued into the process drawing the lateral view, which was undertaken using the same workflow and methods (See Figure 22 above).

The next stage in the drawing process is to ink the pencil drawing so that the maximum visual information is displayed. To do this a sheet of tracing paper was placed over the drawing and the artefact traced in black ink using a 0.5mm nib for the outline and ridgelines, and a 0.3mm lens for the hatching and detailing as is standard practice (Figure 23).

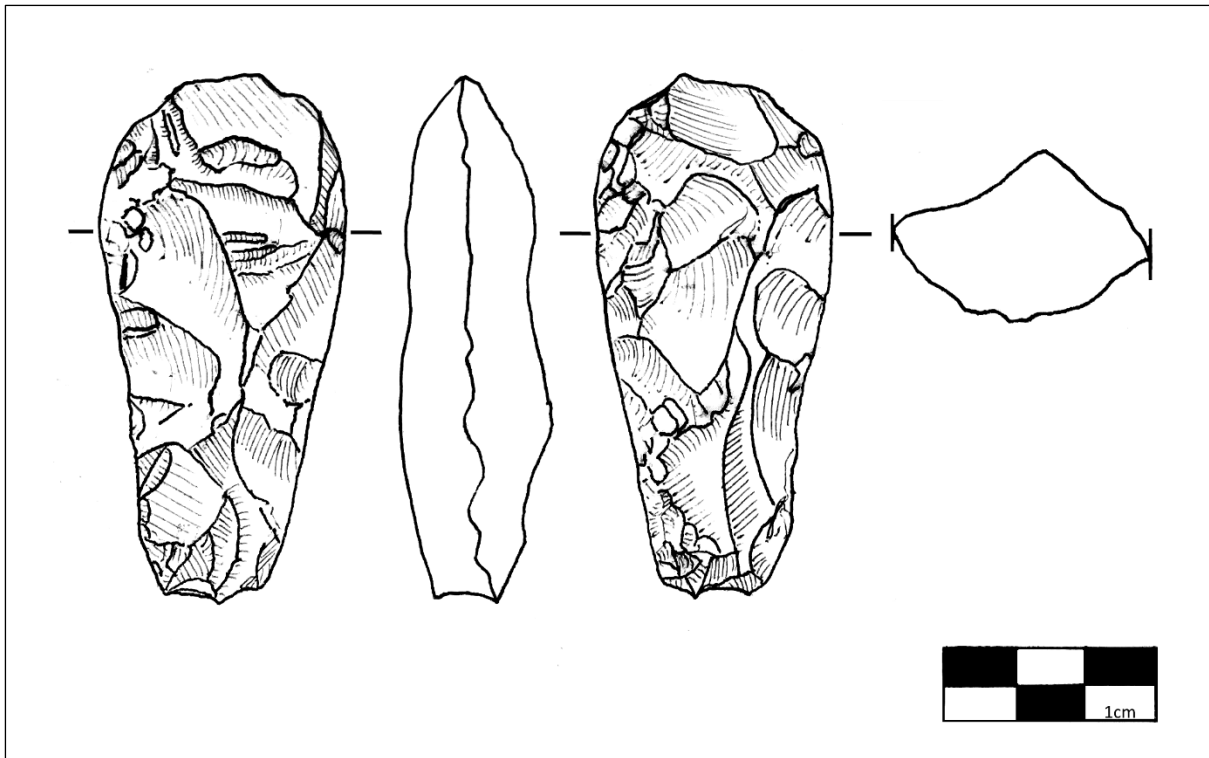


**FIGURE 23: COMPLETED INKED DRAWING**

So that the image fulfils publication standards, and again to ensure maximum clarity of visual information, the inked drawing was scanned into a computer and opened as a .JPEG image in the open source program Paint.net In order to simplify the image it was converted into greyscale format using Adjustments -> Black and White. Then the image levels were adjusted to convert the background to a true white and enhance the contrast of the lines via Adjustments -> Levels with the settings:

- Input: 179 and 0
- Output: 255, 1.21 and 0

Next any blemishes and specks were manually removed using a white brush tool before the views of the artefact were re-orientated to conform to standard display practice. Finally, the contrast of the image was increased to enhance the linework to the maximum extent possible with a contrast increase of 40 percent with anything higher resulting in loss of the hatching. The completed image was then saved as a bitmap .BMP format which converts the image to binary (See Figure 24).



**FIGURE 24: COMPLETED DIGITISED DRAWING**

Despite the relatively smooth procedures outlined above, there were some issues encountered, namely a smudging of the ink when brushed by the hand, primarily the 0.5mm pen chosen and a general lack of experience when it comes to representing slopes and features. Also, the suitability of using a 0.5mm pen given the small size of the artefact may be questionable with smaller ridges and negatives harder to draw, although the feasibility of using smaller nibs is arguable. Having said that, the drawing generated appears clean and comprehensible with the next step in the process involving mapping it onto the 3D model produced earlier.

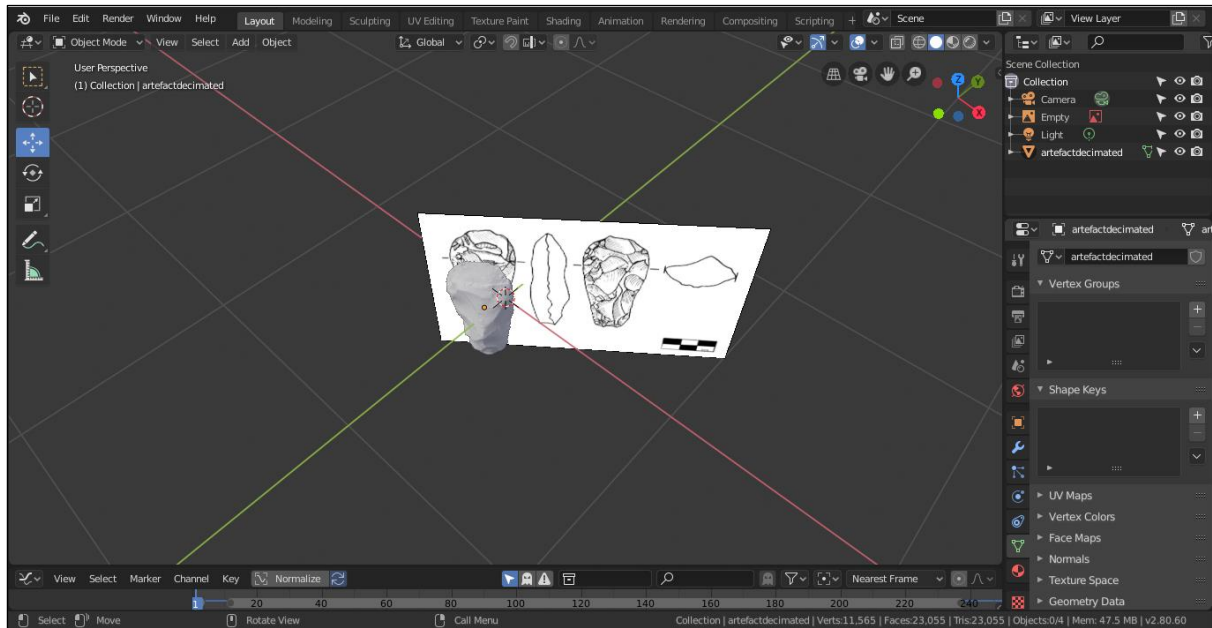
### Texture Mapping

Upon importing the completed 3D model of artefact 1 into blender, the model was centred to the point of origin via selecting the model, left-clicking and choosing 'Set Origin' -> 'Geometry to Origin'. However upon moving into UV editing mode and trying to select edges to make the first seam necessary for 'unfolding' the model in order to project the drawing as a texture upon it, it quickly became apparent that the base model was too high in polygon count to effectively unwrap and remap, having some 368, 934 faces. Due to the fact that the crux of this stage was to explore the interactive intersection of the 3D model format and 2D drawing from a data visualisation perspective as opposed to a data measurement perspective, it was deemed necessary to simplify the model to a large degree to accommodate this schematic remapping of textures. Therefore, the model was imported into Meshlab and duplicated, thus preserving the high-resolution original model. Then the mesh polygon count was lowered to a manageable amount via Filters -> Remeshing, Simplification and Reconstruction -> Simplification: Quadric Edge Collapse Decimation ultimately resulting in a model with 11,528 polygons after five iterations. The parameters used were:

**TABLE 10: MESH LAB QUADRIC EDGE COLLAPSE DECIMATION PARAMETERS**

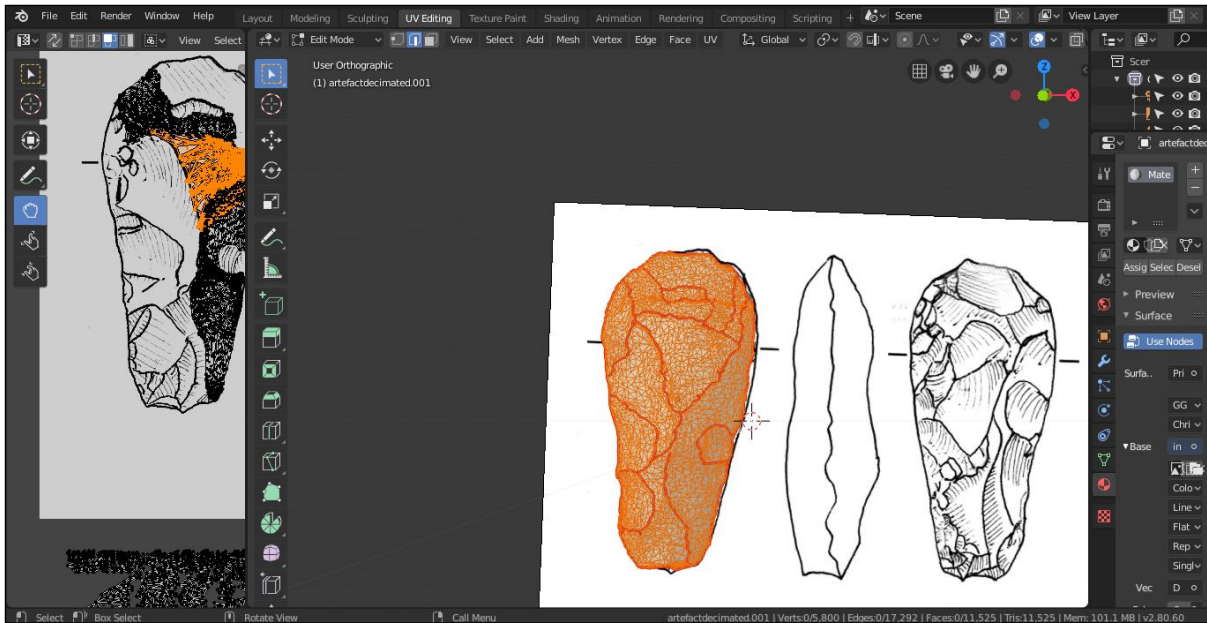
Quality Threshold:	0.3
Boundary Preserving Weight:	1
Preserve Typology:	Enabled

This decimated model was exported as a shapefile to Blender and the final processed sketch (Figure 24 above) added as a reference image plane in .JPEG format to expedite the texture seam mapping process (Figure 25).



**FIGURE 25: ADDING COMPLETED SKETCH AS A REFERENCE IN BLENDER**

The view mode was changed into an orthographic view and the rendering of the artefact changed to wireframe mode, rendering it 'translucent' and allowing the reference image to be seen through it. This facilitated better alignment of the model and sketch. Finally, all the default seams (mapped to all polygon edges in the mesh) were selected using the shortcut 'A' and the seams removed using -> UV -> Clear Seam. The new seams were mapped out according to both the reference image of the sketch, and the topology of the model surface itself (See Figure 26), however the simplified nature of the model in terms of its relatively large polygons resulted in a very angular approximation of the seams relative to both the model and the sketch. To visualise the mapped textures in 'real time', the rendering mode was changed to 'solid' and output changed from material to image texture.

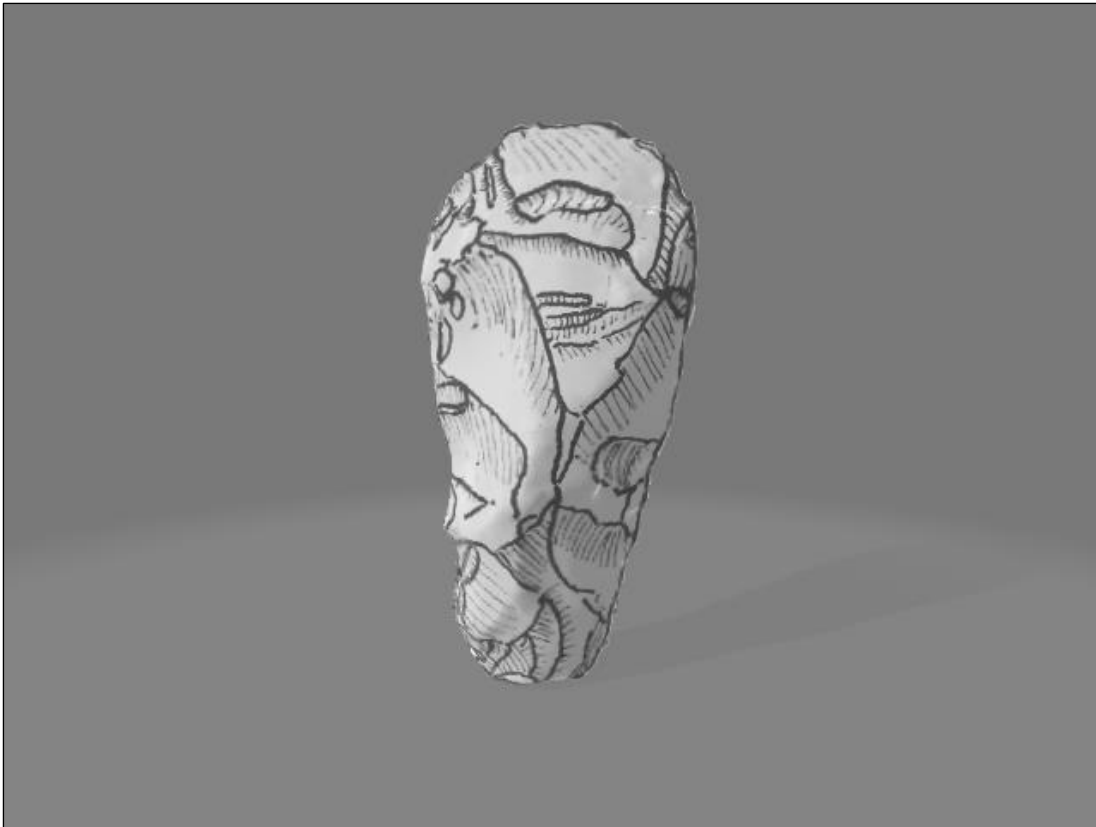


**FIGURE 26: MARKING THE SEAMS IN UV EDITING MODE IN BLENDER**

The constituent parts of this texture map were also hard to distinguish upon unwrapping being overlapped and interlocking due to the complexity of the seam network. An aspect of this thesis seeks to explore new means of interacting with traditional illustration. As such, exact mapping is not necessary, being impractical due to the limits of the software and model used. Therefore, the map was reduced to one seam along the edge of the artefact with two separate parts corresponding to the dorsal and ventral sides of the axe.

Default unwrapping and Smart UV unwrapping caused the texture maps to be distorted and warped, partially visible in the left-hand side the figure 26 above. The simplest means of projecting the texture was to carefully select all the polygons on one side of the mesh, orientate the camera so that the mesh matched approximately the size and position of the corresponding side in the reference image, and then use Blender's Project From View tool to estimate the best means of unwrapping the artefact. This avoided any warping and large resizing and enabled mapping of the obverse side without having to 'flip' the texture map. Then any match issues along the edges were resolved by resizing and the 'grab' tool in the UV Editor, resulting in a model augmented by the drawn texture (Figure 27). There were some issues with blurring at the edges of the model but given the nature of trying to map curves on a triangular mesh, and for the purposes of displaying the possibilities of this approach it was deemed adequate.



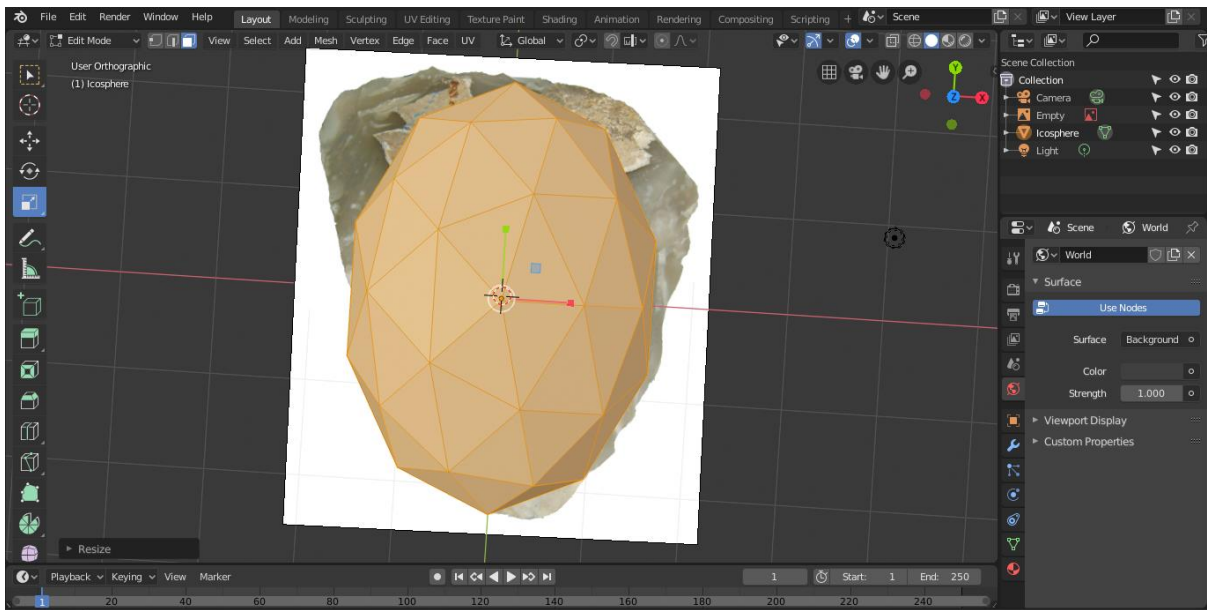


**FIGURE 27: COMPLETED MESH WITH HAND-DRAWN SKETCH TEXTURE MAPPED TO ITS SURFACE**

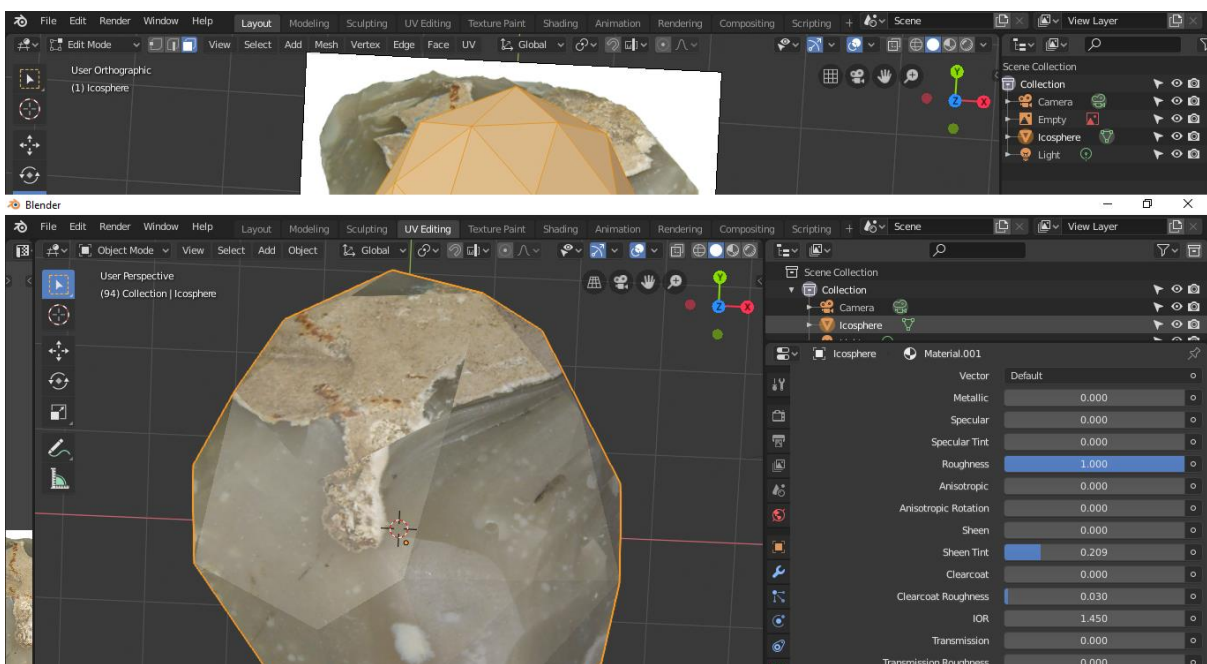
### Modelling Manufacturing Processes/Life-Histories

Hitherto, the aims and questions being asked of the modelling and illustrating processes have been fairly straightforward, modelling and recording visual data of surface features, an approach that the three-dimensionality of digitisation lends itself well to. The next section however, deals with conceptualising and modelling how the sample artefact changes over time, from raw material to product. To be truly scientifically engaging, the composite models should be drawn from a known workshop site, in which associated flake positives, negatives, rough-outs, cores etcetera are present and carefully scanned. This is beyond the potential of this dissertation which instead looked to model a simple schema of representation for the manufacturing life-history of the core-axe. This was conceptualised as a three-stage process comprising raw flint node, core and finished tool.

The first step was to model generic approximation of a Flint Node. This was carried out in Blender. First a reference image of flint node was added in orthographic view-mode via Add->Image->Reference. Next, as a starting point, a sphere was spawned via the workflow, Add->Mesh->Icosphere. This was then manipulated through various tools in the Edit and Sculpt modes to form an elongated, irregular sphere (See Figure 28) vaguely resembling a node of flint. A chosen reference texture, in this case Miorcani\_flint.jpg was added as a texture file in UV editor and projected using project from view, readjusting the UV map to suit. The texture was rendered visible through switching the Render -> Solid parameters from Material to Image texture, navigating to the required texture file accordingly (Figure 29).



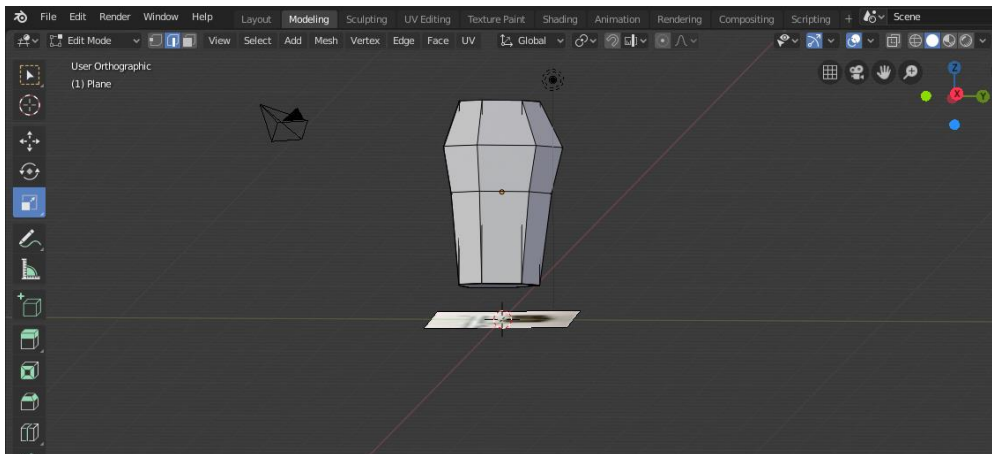
**FIGURE 28: SPAWNING AND MANIPULATING A SPHERE MESH USING A REFERENCE IMAGE AS A BACKGROUND PLANE TO APPROXIMATE A FLINT NODE**



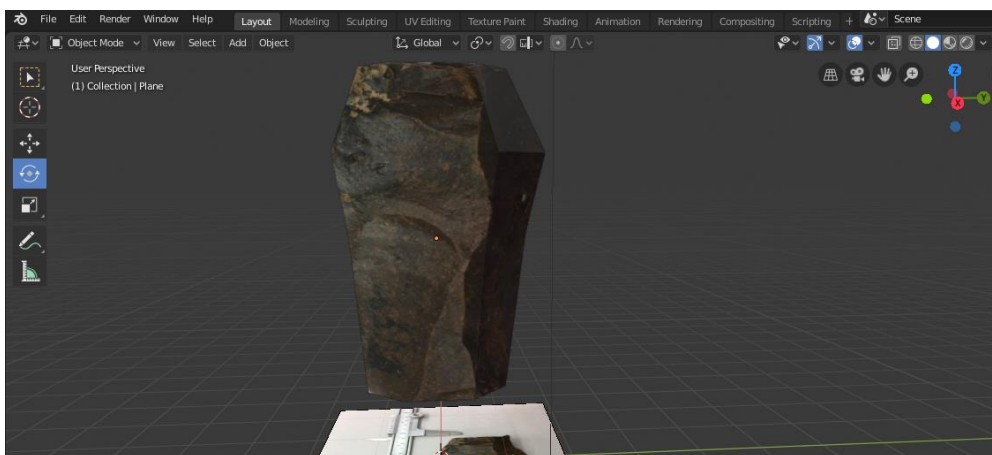
**FIGURE 29: SCREENSHOT SHOWING UV MAP ABOVE WITH THE SUBSEQUENT PROJECTED TEXTURED MESH BELOW**

Step two involved modelling a representation of a flint core. As above, a suitable reference image was added in orthographic view. In this case IMG-0949.jpg, a photo of a core taken during the selection phase of suitable artefacts in the Lund University teaching collection. A usable base mesh had to be constructed from scratch in this case by adding a plane and then extruding edges to form a hexagonal tube, a basic core. Then all edges along the top ‘opening’ were selected using edge select in Edit Mode, right clicked and New face from edges selected to fill void. This process was repeated for the bottom. Next, two horizontal loop cuts were added in Edit Mode, cutting through the object approximately half-way up and 1 quarter of the way from the top and scaled out to approximate the bulbous core in the reference image

(Figure 30). Finally, the mesh was unwrapped and the reference image was projected as a texture using project from view, scaling and positioning uv map accordingly (Figure 31).



**FIGURE 30: APPROXIMATING A FLINT CORE WITH A LOW POLYGON MESH**

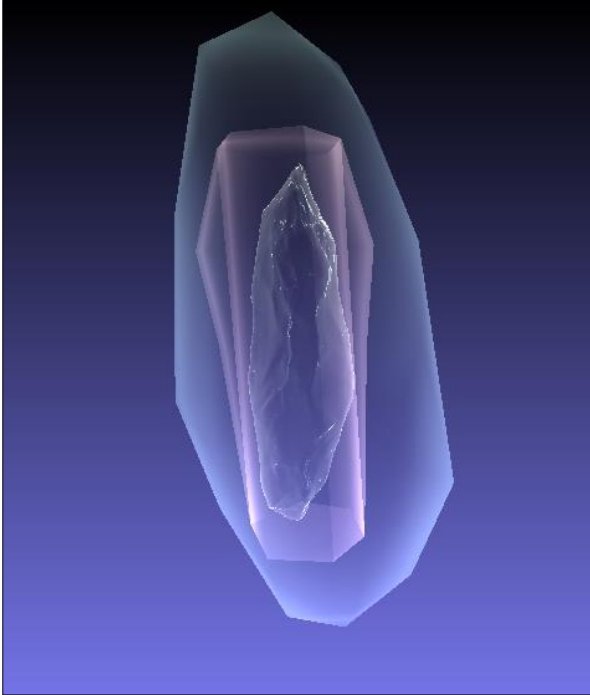


**FIGURE 31: PROJECTING A SUITABLE TEXTURE**

The final phase in visualising the manufacturing processes of artefact 1 involved combining them nesting doll fashion in Meshlab. Both textured meshes were exported as .obj files with associated .mtl texture files and imported into Meshlab along with Artefact 1\_Decimated.obj. To aid visibility of each mesh, an x-ray shader was implemented through Render->Shaders -> Xray.gdp, rendering the models translucent. Next a combination of the workflows Filters -> Normals, curvature and orientation -> Transform: Rotate, Transform: Scale and Transform: Translate was used to orientate the models inside each-other (Figure 32) ensuring preview option was enabled to facilitate easier rotation and translation.

*Textures used:*

- [https://upload.wikimedia.org/wikipedia/commons/e/ed/Miorcani\\_flint.jpg](https://upload.wikimedia.org/wikipedia/commons/e/ed/Miorcani_flint.jpg) [accessed: 27/04/2020]
- IMG-0949.



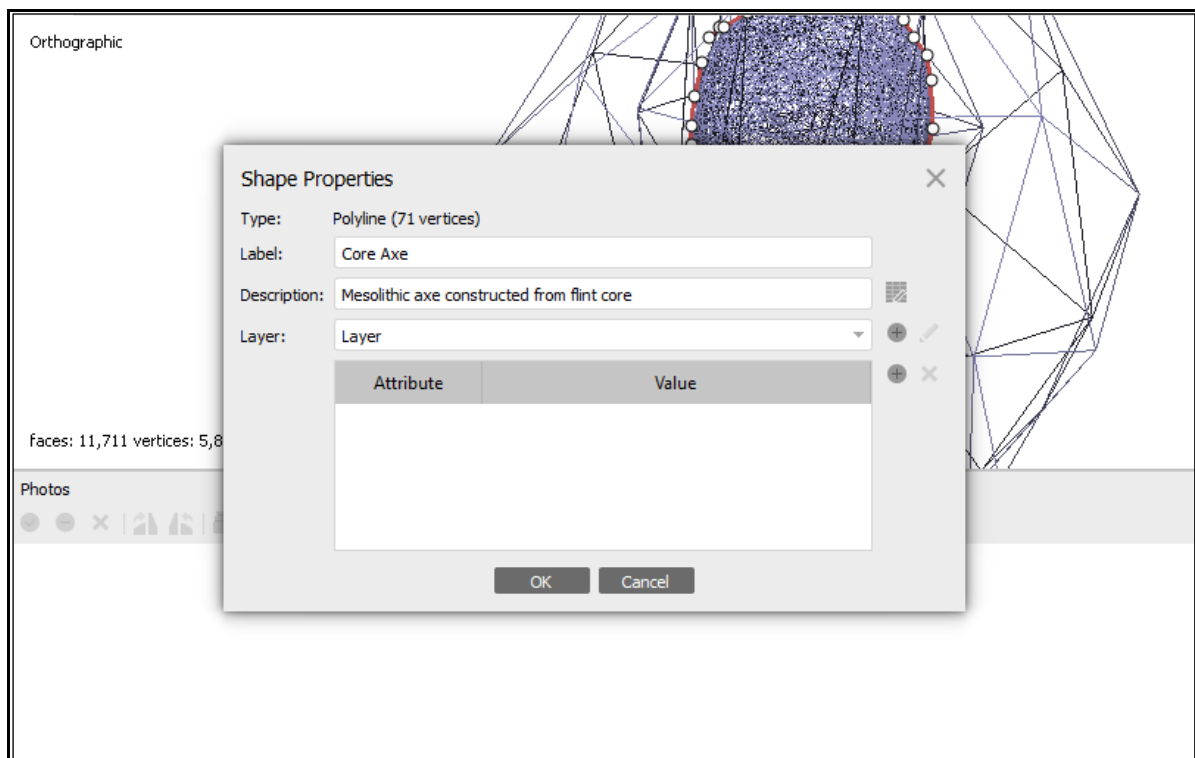
**FIGURE 32: NESTED MESHES COMPRISING AXE, CORE AND NODE RESPECTIVELY**

Although this allowed the spatial relationships between each manufacturing stage to be seen, preserving the information held in the textures would be more visually striking. Therefore, the three models were imported into blender, arranged ensuring textures were correctly mapped and visible, before “Show Whole Scene Transparent” was selected, allowing both the interior meshes and their associated textures to be seen (See Figure 33).



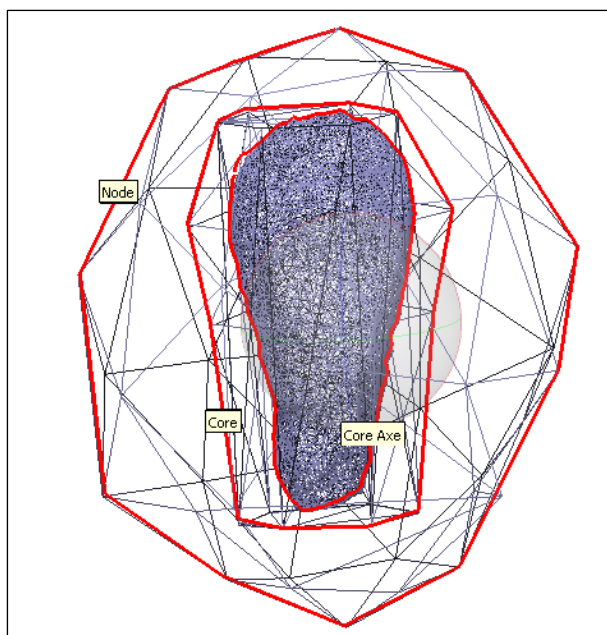
**FIGURE 33: MODELS ARRANGED IN BLENDER WITH A TRANSPARENT, TEXTURED RENDER AND THE CENTRAL AXE SELECTED FOR VISIBILITY**

To add a quantitative element to this, it was decided to export the models to Agisoft Metashape in order to utilise its polyline and attributes tools. The composite model was merged via the shortcut “Ctrl + J” and imported into Metashape. The view was changed to wireframe view so that the edges of the interior models could be digitised and the polyline tool was selected. Working from the outside in, labels and a brief description were appended to each polyline (See Figure 34).



**FIGURE 34: ADDING ATTRIBUTE DATA TO EACH MANUFACTURE ‘FORM’**

This resulted in a schematic record of the sequence of manufacturing forms the core-axe took before becoming the axe visible today (Figure 35).



**FIGURE 35: POLYLINE SCHEMA OF MANUFACTURING FORMS IN AGISOFT METASHAPE WITH EACH POLYLINE APPENDED WITH ASSOCIATED ATTRIBUTE DATA**

It is also worth noting here that the native cross-section tool in 3DHOP would allow the user to interactively ‘discover’ the internal modelled manufacturing forms in the composite model, adding an active dynamic to engaging with the data produced.

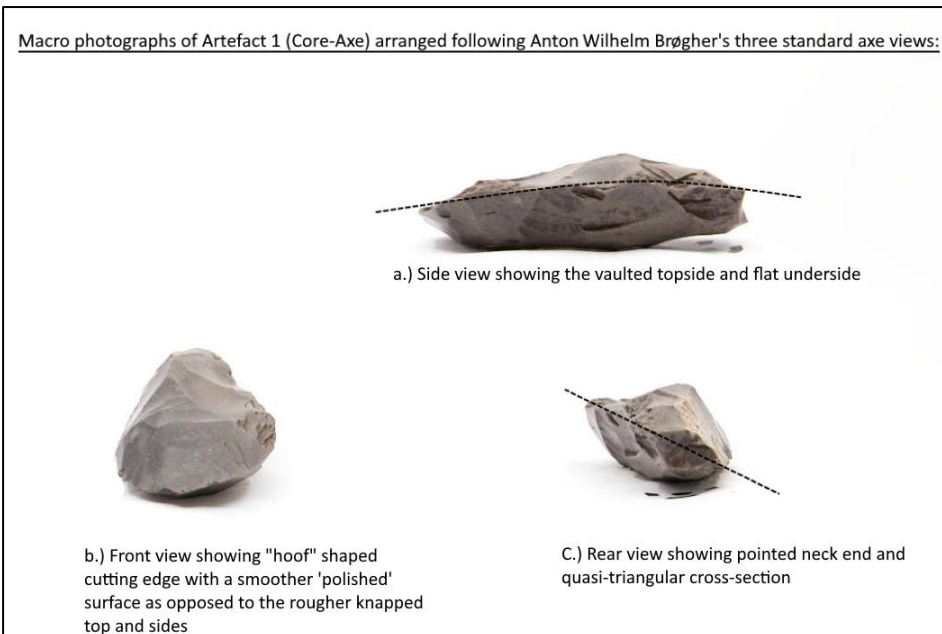
### Use-Wear Analysis

The collation of supplementary use-wear datasets for the artefact consisted of three parts, namely a background literature review of the prevailing theories on how each of the selected artefacts were used and the materials they processed, and the resulting use-wear marks expected. The identification and ‘mapping’ of these marks will be a circular process with ongoing reference to different artefacts datasets, namely via reference to the physical artefacts themselves, photographs taken in the initial photogrammetry campaign and the 3D models produced. Finally, these results would be implemented into a 3DHOP format as clickable hotspots on the 3D meshes themselves.

#### Artefact 1: The Core-Axe/kärnyxa

Literature research of this artefact type sought to identify works primarily dealing with similar artefacts from Scandinavian contexts. According to Knutsson and Knutsson (2020), accessible flint resources are limited to “a small portion of southern- and westernmost Sweden and Norway” (Knutsson and Knutsson, 2020, 106 - 107) with the wide dispersion of flint artefacts throughout Mesolithic Scandinavia illustrating the inter-regional networks of people and materials at play during this period. In terms of core-axe morphology itself, (Glørstad, 2011) has highlighted several diagnostic features including a triangular cross section and ‘hoof’ shaped axe edge summarised in figure 36 below (Glørstad, 2011, 22 - 23) based upon illustration standards established by (Brøgger, 1906).

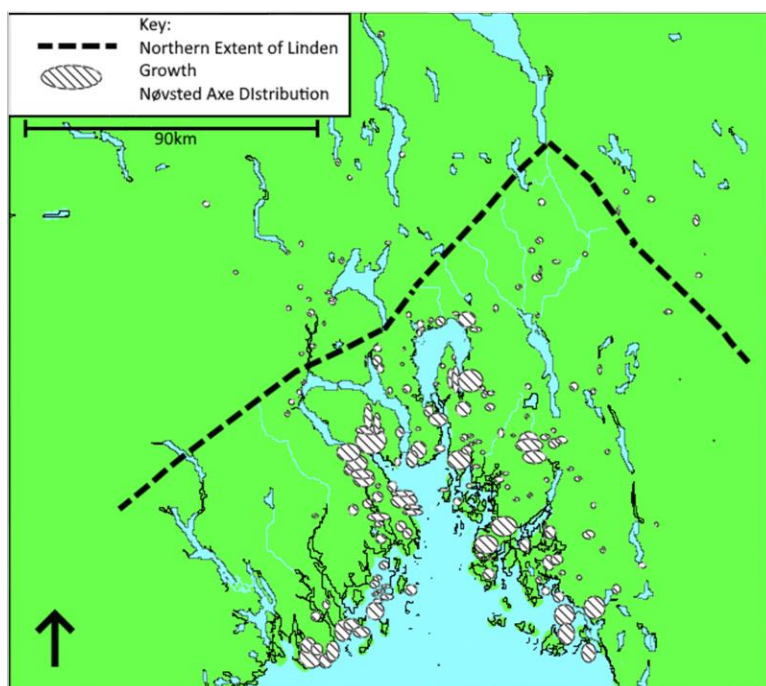




**FIGURE 36: BRØGHER'S STANDARD AXE VIEWS WITH ASSOCIATED DIAGNOSTIC MORPHOLOGICAL FEATURES**

With respect to what materials core axes were used to process, Knutsson and Knutsson (2020) identify the working of raw wood (Knutsson and Knutsson, 2020, 110) with (Glørstad, 2011) emphasising the shape of core-axes as being particularly suited to gouging, going on to suggest core-axes as tools in the production of dugout canoes (Glørstad, 2011, 31). This hypothesis is strengthened when the coastal, lacustrine and riverine-concentrated distribution (See Figure 37) of one of the most popular core-axe forms, the *Nøvsted* axe is taken into consideration (Glørstad, 2011). Furthermore, although no Mesolithic dugout canoes have been found in any *Nøvsted* contexts, the spread of the wood-type used in their construction, Linden, was limited to the northern limit of *Nøvsted* findspots (Glørstad, 2011, 31) (see Figure 37 below).

It is important to note that although similar in form, the sample artefact is smaller than the *Nøvsted* axe-form, being c. 8cm long whereas Price (2015) emphasises that standard core-axes "range in length from roughly 10 to 20 cm" (Price, 2015, 61). As such it is unlikely to have been involved in the production of objects as large as a dugout canoe but could feasibly have been used in the working of smaller wooden objects.



**FIGURE 37: DISTRIBUTION OF NØVSTED AXES IN EASTERN NORWAY AND WESTERN SWEDEN SHOWING THE NORTHERN EXTENT OF LINDEN GROWTH [DASHED LINE] FROM DATA BY HØEG, 1997 (GLØRSTAD, 2011, 32, FIG. 12)**

In terms of the actual residue woodworking leaves on flint artefacts, those macro features that are readily visible without the aid of a microscope fall into the scope of this thesis. These are macro impact marks, fractures and striations (Marreiros et al., 2014). The working of semi-hard and hard ligneous materials results in quadrangular and trapezoidal scars and semi-circular scars bridge all worked material types (Claud et al., 2019). If the sample artefact was indeed used to process wood, these features should be present.

The approach set out above shows how Use Wear analysis is a readily available means of artefact enrichment, with the Nøvsted axe case study providing a compelling example of potential information on tool use and resource access held within use wear marks. However, issues with time constraints and the relatively low resolution of the base model derailed the main research aim of this approach, which was to assess the capacity for circular reflexivity with regards to identifying the marks on both the original artefact and the 3D model. Being able to readily identify such marks on the 3D mesh surface would also have increased the information 'value' of digitised artefacts. As such the attempts made at sequencing flaking activity represents perhaps a broad extension of this approach, with the Nøvsted example illustrating the more refined information available from Use-Wear analysis proper.

### Conceptualising Formation Processes

Research for this section comprised a reflexive consideration of the processes of digitisation above, as well as identification and exploration of metadata schemas, formation processes and aspects of data science. As summarised within the introduction, a seminal work by Schiffer (1983) categorised formation process traces as existing within three potential groups: Simple properties, Complex properties, and Other properties. Given the contextless nature of



the sample artefacts chosen it is apparent that research of this kind will be constrained to the most relevant simple properties only (Table 11).

TABLE 11: SELECTION OF SCHIFFER'S (1983) SIMPLE PROPERTIES OF FORMATION PROCESSES

Trace:	Description:
<i>Size</i>	Can affect how artefact is deposited: e.g. cleaning activities 'sort' objects by removing larger material whilst missing smaller objects (Schiffer, 1983) linked to the <i>McKellar theory</i> that objects of a smaller size "are more likely to become primary refuse in activity areas" (Schiffer, 1983, 679), a process identified in ethnographic analogues. Size affects <i>loss potential</i> and in terms of larger artefacts, <i>recycling potential</i> , especially pertinent to lithics. Size preference has also been identified in artefact <i>dumping</i> versus those that are <i>curated</i> – larger, <i>low cost</i> objects versus smaller, <i>specialised forms</i> . <i>Post-depositional</i> processes such as trampling, ploughing, animal scavenging and water and wind activity serve to sort artefacts on a dimensional basis, with smaller objects tending to sink and larger artefacts being uplifted.
<i>Density</i>	Has relevance to the <i>sorting actions</i> of water and wind referenced above. Increased density also serves to increase artefact <i>endurance</i> to decay and weathering processes, particularly with respect to bone (Schiffer, 1983, 681).
<i>Shape</i>	Again, affects how artefacts respond to fluvial and aeolian processes.
<i>Use-Life Factors</i>	The processes involved in the artefact's active life such as <i>breakage</i> or <i>usability</i> that affect the nature of its deposition, markedly expressed in the whole, usable objects found in burial, domestic and hoarding contexts versus those often broken artefacts in secondary deposits (Schiffer, 1983, 681). <i>Use-wear analysis</i> also comes into play here, as well as <i>replacement costs</i> of objects.
<i>Damage</i>	Although akin to Use-Wear analysis, non-cultural processes of damage are also included here. For example, Odell (2001) emphasises the negative affects trample damage can have on our understanding of artefacts. Citing experimental blind-test approaches he stressed the fact that edge damage sustained in the process of trampling can "be incorrectly interpreted as use-wear [and] mimic retouch" (Odell, 2001, 54). Abrasions and striations can occur when material is buffeted about in water, with a loss of ridge definition and smoothing recognized too.

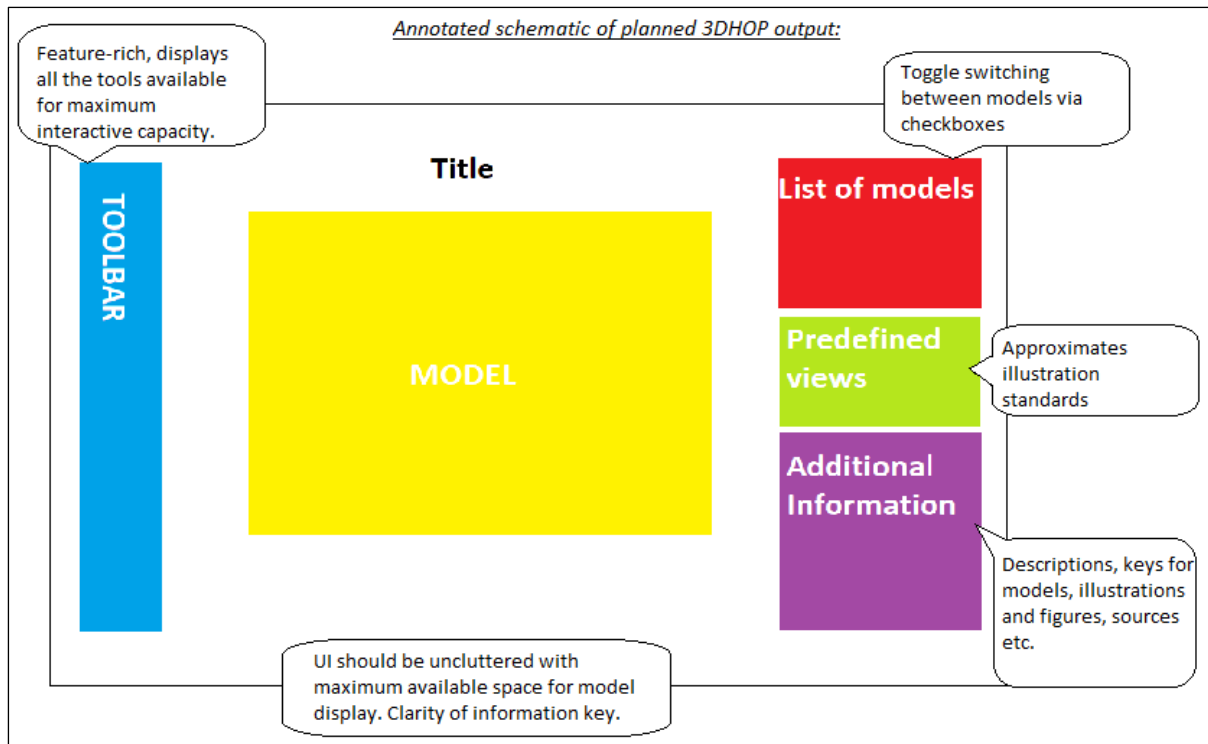
As can be seen in the summary table above, even simple formation process traces are ephemeral and complex embodied in a litany of surface features and dimensional information, as well as various factors during the course of the object's life history. Instead of attempting to identify the trace of these processes on the sample artefact itself, this section of research deals with the key issue of how to conceptualise formation processes within a metadata framework standard? Some of the property types listed above could perhaps be

served by the *Format* field in the DCMI schema, in that this allows for the physical proportions of the artefact to be recorded. The *Description* field could perhaps be used to indicate shape and density information, although density could perhaps be better suited in the *extent* field. This complexity of field suitability effectively conveys the innate tensions involved in trying to adapt frameworks intended for digital works to other more abstract media types. Visually distinctive information such as those in the Damage and Use-Life Factors are more suited to be digitised and modelled using a combination of the different digital and manual illustrative techniques discussed above. In this case systematic call-back of formation processes would manifest itself more in the network of relationships between models digitising use-wear marks, different natural damages and records of other cultural aspects based upon experimental archaeology like ascribing cost and labour value rather than the individual traces themselves.

There are two ways of approaching this issue of digitisation. One is to avoid the intricacies of media type and correct metadata fields altogether by attaching an attribute table to the artefact models in question with perhaps a schema similar to Table 11 above into which the relevant information can be recorded. Although relatively simple, this approach fails to engage with the uniquely visual nature of a lot of the traces of formation processes, something that a computer-based methodology uniquely provides. Careful implementation of a tagging system with 'formation process' as a unique identifier across multiple models, media types and relevant metadata fields could allow nexuses of formation process information to be accessed and displayed via simple query searches. This is linked to concepts of a *semantic web* which standardises web resources via a structured language (Resource Description Framework). Instead of prioritising the object over related information, RDF brings the subject information to the fore, allowing for more efficient querying and recall of relevant information linked to the resource object. Likewise, projects such as the Wikidata Query Service have sought to standardise the query terms and frameworks used in data call-back, recursively improving accessibility of the information network as a result. Thus, in this way formation processes are used as a structuring principle for synthesising multiple digital datasets and media-types.

### 3DHop Output

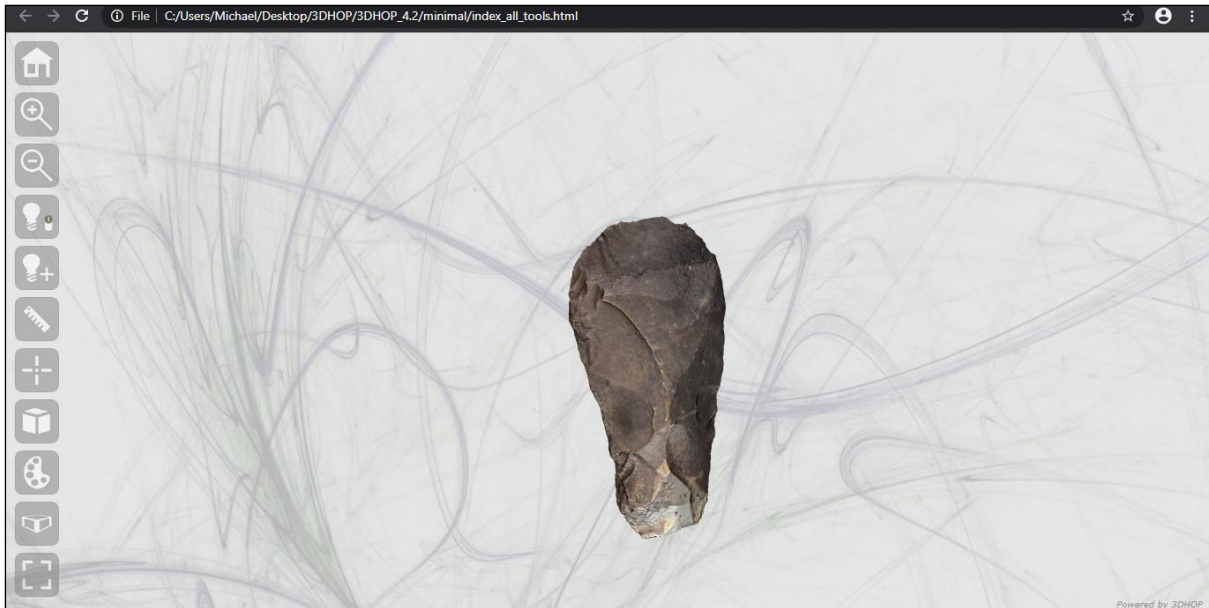
The final stage of the research process was to collate the various models and visual data above into a synthesised 3DHOP output, allowing for dynamic display and engagement with the artefact digitised. Prior to code the 3DHOP output, a rough annotated schematic was drawn up plotting the layout of the 3DHOP page (Figure 38). This served to offer a template for the coding process and to attempt a design which prioritised maximum information clarity and display.



**FIGURE 38: SCHEMATIC DIAGRAM OF PLANNED 3DHOP OUTPUT**

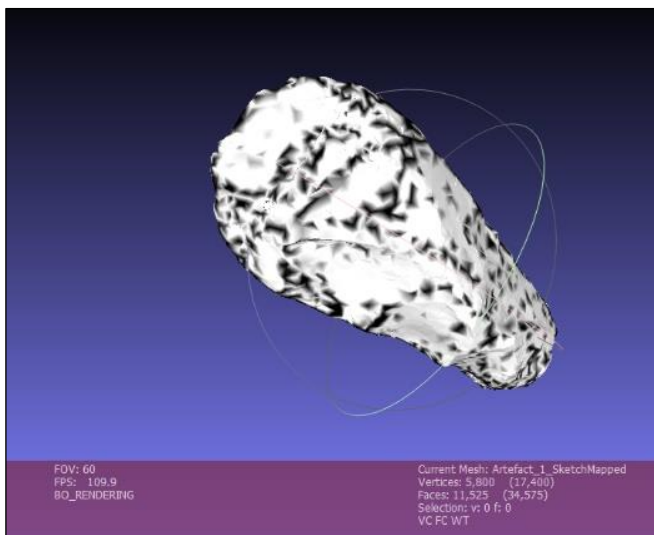
### Data Preparation

To allow the 3DHOP layout and functionality quality to be assessed locally, a Google Chrome desktop shortcut was created, and the properties changed to allow access to local files. This way both the 3DHOP framework code and relevant model data could be accessed and displayed in a web-page output. 3DHOP models are reliant on the Nexus format (.nxs), a format primarily used for its file mapping capacities. As such the base models and supplementary model forms must be converted. In order to do this, the models were converted into a .ply format from .obj in MeshLab, ensuring the vertex colour checkbox was ticked. This was then converted into the required .nxs display format via copying the .ply file into the 'Build\_Nexus' convertor packaged with the Nexus software download. The subsequent base model nexus was then saved into the 3DHOP models folder before being converted into .nxz format, a compressed file for easier 3DHOP rendering and viewing via 'nxsbuild'. The default 'index\_all\_tools.html' file was altered in Notepad++, with the mesh pathway url being set as "models/Artefact\_1\_Base.nxz" allowing the model to be visible when the html file is opened in the Chrome shortcut created earlier (Figure 39).



**FIGURE 39: BASE MODEL SUCCESSFULLY RENDERED IN A BASIC 3DHOP HTML OUTPUT**

Upon attempting the same process with the sketch mapped artefact model a few issues regarding texture transference into a .ply format were encountered. Although the texture was successfully exported in .obj format provided the 'Write Materials' checkbox was enabled, with the UV map written as a .mtl file, there is no similar analogue for the .ply format, with the texture struggling to be read and rendered as a result. One possible workaround for this is to transfer the texture into vertex color format within blender using Filters -> Texture -> Transfer: Texture to Vertex Color with the resulting mesh exported as a .ply format with 'Vertex Color' enabled and the Face Color and Texture Coordinates disabled. However upon importing this .ply into Meshlab to test the texture transference, the sketch had been poorly rendered as an incredibly low resolution (See Figure 40).



**FIGURE 40: SKETCH TEXTURE RECORDED AS VERTEX COLOURS ON THE .PLY MESH IN MESHLAB**

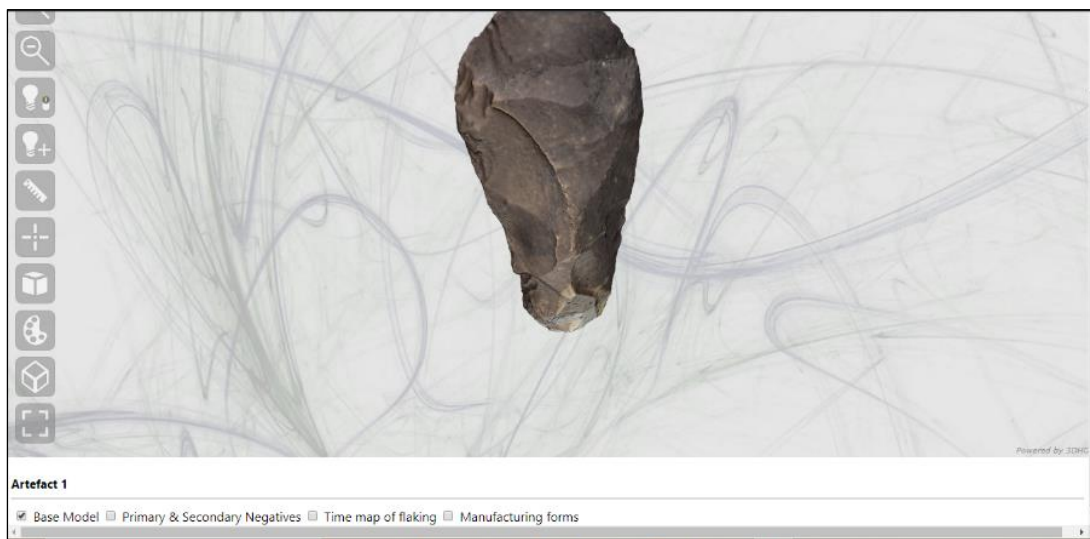
Looking at the mesh data above this lack of texture resolution is perhaps due to the low vertex count - 5800 considering the mesh used was the decimated version of the base model. One possible means of addressing this would be to map the texture onto the undecimated model, given that this comprises some 184, 503 vertices, however given the functionality of marking each of the required edge seams this is not feasible at present. The features digitised using the native paint tool in MeshLab being painted directly onto the vertex and face surface themselves, did not display this same issue. This limited the other available models for display to the two flake-negative Z-paint digitised models, and the manufacturing forms model, with the sketch-mapped model being relegated to supplementary information.

### HTML and CSS coding

The HTML file used as a starting point for this thesis' output was the "index\_all\_tools" file in the 'minimal' folder of the 3DHOP 4.2 package. Having successfully converted the required models into a 3DHOP readable .nxs format, the next stage in the 3DHOP implementation was to explore the framework's capacity for loading and toggling multiple models. To do this the models were coded as separate instances which could be toggled on and off using checkboxes via the CSS string:

```
<input type="checkbox" style="cursor:hand;"  
onclick="presenter.toggleInstanceVisibilityByName('Base Model', true);"> Base Model  
</input>
```

For the model to render successfully when the checkbox is checked the visibility of the associated mesh is changed to "false" by default so the scene is empty upon first load up. This was checked by loading the file in the Google Chrome shortcut created earlier and using the web console option (F12 shortcut) to check on coding syntax errors resulting in the basic output below (Figure 41).



**FIGURE 41: BASIC CHECKBOX FUNCTIONALITY**

The models list was moved to the top righthand corner before the 'Canonical Views' section was begun to systematically display the model from standard obverse, reverse and lateral views corresponding to illustration convention. In order to implement this, the position of the

trackball corresponding to the above views needed to be recorded. This was accessed by opening the 3DHOP output in the Google Chrome shortcut, orientating the model to the desired views, pressing F12 to open the console, and typing in the code line:

```
(presenter.getTrackballPosition())
```

Which returned the necessary coordinates to display the model effectively from the desired viewpoints. These were then input into button function brackets in the “canonical views” pane like so:

```
</td><td align="center"><button style="cursor:hand;"  
onclick="presenter.animateToTrackballPosition([42.33385977767452, -8.227603785028728,  
0, 0, 0, 2.5]);">Obverse</button>
```

With the same process carried out for the Reverse, First and Second Lateral views respectively. Following this the information pane was inserted in the bottom right, with a brief descriptive overview of the artefact and links to the digitised sketch and metadata tables using the same layout parameters for the models toggling and canonical views plane. Additional data was added as an unordered list of links below the main body of descriptive text via the code string:

```
<ul style="padding-left:25px">  
<li><a href="data/Artefact_1_Inked.jpg" target="blank">Manual Illustration</a></li>  
<li><a href="data/metadata.jpg" target="blank">Metadata Tables</a></li>  
</ul>
```

Reference coda images (Figures 16 and 45) for the information displayed by the colour-coded models (Primary & Secondary Negatives and Time-map of flaking) were also linked to via the same code string framework above resulting in a final information rich 3DHOP output below (Figure 42).

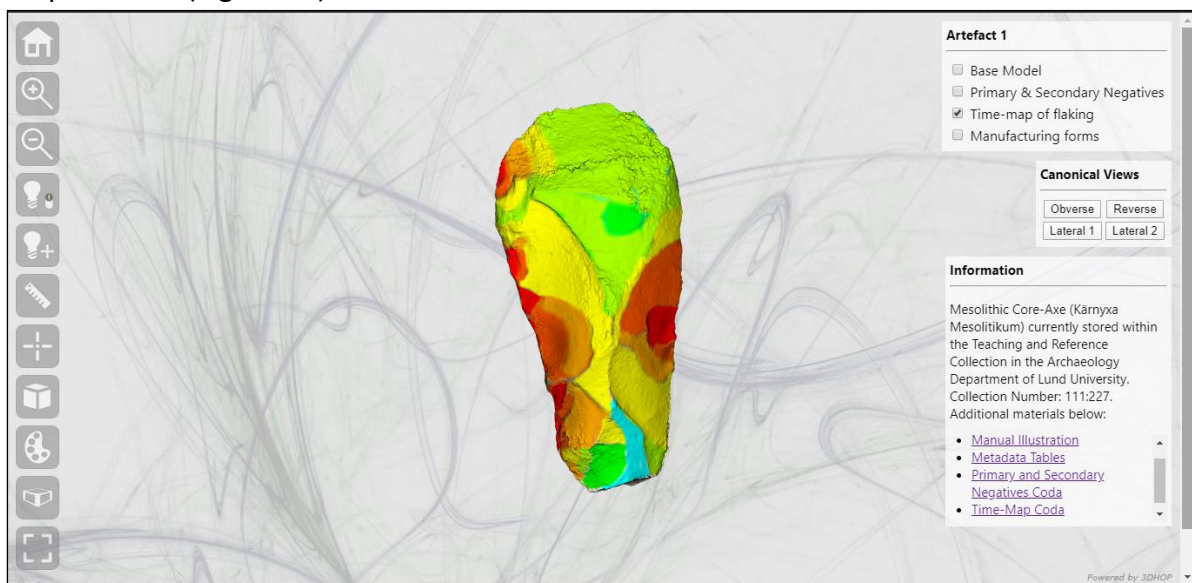


FIGURE 42: FINAL 3DHOP OUTPUT



## Chapter Four: Discussion and Analysis

The following chapter sets out to explore the findings encountered during the various strands of research summarised above, with reference to the different theoretical concerns mentioned in the introductory chapter. To reiterate, the purpose of this thesis was to delve into the praxis of 3D modelling as a means for displaying information and enriching datasets with an intersectional understanding of digitisation as a process incorporating illustration, reflexive archaeology, digital affordances, chaine-operatoire and object life-histories.

### Digitisation: Affordances and Considerations

The inherent limitations involved in established digital methods for digital capture and visualisation became visible from the outset of the thesis research. Although often touted as a great levelling of the playing field by nature of the affordability and availability of equipment such as digital cameras, and a thriving open source market for 3D alignment and visualisation programs, there is a high level of prior knowledge and experience required to generate a model acceptable at a basic level of research. This became apparent during the macro and subsequent standard photogrammetry processes. However, this is the same for any true level of scientific research, with techniques and technologies used being intrinsically specialist in nature with digital approaches still relatively nascent in their development and application.

Beyond this there is a level of user constraint present in software UI and design itself. These became identifiable during the different strands of illustration explored, with the findings summarised in Table 12 below. Major concurrent issues identified were the reductive characteristics of digital modelling, with curved features displayed as lines and vertices. Following this logic, the quality of feature digitisation is depended upon polygon count, with curves easier to represent in higher quality meshes. However, the caveat here is the sheer effort and time it would take to identify seams in a model of hundreds of thousands of polygons, often unreasonable. Furthermore the level of processing power required to both generate, visualise and store models of such a calibre, in addition to the sort of supplementary data explored in this thesis is wildly unattainable for most not to mention the environmental costs of dedicated storage and constant hardware updates needed to ensure the survivability of the datasets produced. For example, Lucivero (2020) has explored the impact of computing infrastructures related to big data, the auspices of which large public collections of artefacts and site data would fall into, highlighting concerns as diverse as the carbon footprint of running data centres, “the fastest growing carbon footprint across from across the whole ICT sector” (Lucivero, 2020, 1015), the polluting factor of obsolete hardware and the ethical issues of social inequality and ease-of-access to data. Such issues are important to consider, especially given the value placed upon the potentialities for large scale digital collection programmes to operate in consort with each other, such as seminal work at L’institut national d’histoire de l’art in Paris. Through its AGORHA and AGORHA 2 projects it collects documents published across many collections and disciplines within the sphere of the institute, aiming to create “a mutualised meta-base of digital heritage data that is continually enriched, dynamically cross-referenced and interconnected”(Nurra, 2020, Seminar). Whilst this is invariably incredibly valuable to research practice, with greater inter-collection connection



and access offering unprecedented opportunities for future studies, the carbon costs of such efforts should be responsibly considered.

**TABLE 12: PROS AND CONS OF DIFFERENT ILLUSTRATIVE APPROACHES USED**

Program/Method:	Pros:	Cons:
Agisoft Metashape	<ul style="list-style-type: none"> <li>• High definition of surface information recorded.</li> <li>• Algorithm very effective at aligning photographs and modelling processes.</li> <li>• Comprehensive data quality measurement and filtering tools.</li> <li>• Features can be digitised as a separate shape file allowing for greater flexibility of data management/categorisation.</li> </ul>	<ul style="list-style-type: none"> <li>• Dependent on specific and highly controlled equipment, lighting, and focus values.</li> <li>• Polyline tool lacks undo function, and problematic manoeuvrability in conjunction with zooming/orientating the model.</li> <li>• No attribute tables available for the data beyond labels.</li> <li>• No feature to feature snapping or feature to surface snapping resulting in floating lines.</li> <li>• No user control of polyline characteristics beyond colour value.</li> <li>• Operates via vertex and line interaction – no fluid curves, simplification of true shape of features.</li> </ul>
Meshlab	<ul style="list-style-type: none"> <li>• Large suite of shaders to visually engage with datasets in new and interactive ways.</li> <li>• Z-Paint tool allows illustration of surface features and paints directly on surface – no floating digitised features.</li> <li>• Default features such as light manipulation and turning surface textures on and off</li> </ul>	<ul style="list-style-type: none"> <li>• Features digitised onto the actual model itself, no new features file produced – limiting for data management.</li> <li>• Lack of feature attribute date/categorisation -purely visual.</li> </ul>

	offer easy means of assessing surface morphology.	<ul style="list-style-type: none"> <li>• Paint tool produces simplistic schema although this is dependent on the issues being asked of the data and features being illustrated.</li> </ul>
Manual Drawing	<ul style="list-style-type: none"> <li>• More nuance in terms of reading surface morphology and displaying it visually.</li> <li>• Requires real deliberation of each mark and its meaning.</li> </ul>	<ul style="list-style-type: none"> <li>• Limited to marks and morphology, colour information and dimensional information beyond width and length lost.</li> <li>• Visual language requires prior knowledge of established systems of hatching symbology and representation.</li> <li>• Reductive – simplistic orthographic projection.</li> </ul>
Blender Projection	<ul style="list-style-type: none"> <li>• Allows new means of engaging with 2D drawings.</li> <li>• Democratizes the legibility of 2D representation – how marks relate to morphology easily visible.</li> </ul>	<ul style="list-style-type: none"> <li>• Quality of projection based upon model polygon count and drawing.</li> <li>• Triangular nature of mesh results in linear representations of curved features.</li> <li>• Basing seams on model morphology becomes exercise in making a ‘sketch’ of features on a version of the artefact as opposed to the object itself.</li> </ul>

Another more metaphysical aspect to digitisation which was revealed when attempting to project the sketch onto the modelled mesh, was the complex nature of authenticity in the digital realm. This was realised when attempting to map out seams to unfold the model so that the texture could be correctly mapped onto its constituent parts in Blender. Whilst using the lighting and rendering settings in the software to help read the surface morphology and map the seams accordingly, with reference to the drawing previously made, an awareness that the process involved taking a sketch made of an actual artefact and attempting to 'resketch' it onto a reduced version of it, with the sketch itself arguably being another version of the object itself. Therefore, it becomes a version of a version of a version of the original artefact, the production process of each in some sense reductive and operating within different interpretative 'spheres' in that the functions and tools available in the chain-line of different software used limit and constrain the interactions and questions we can ask of the artefact. At what point does this thread of authenticity break and the information embodied become worthless? Despite this, it is wrong to completely write off the value of digital heritage on a basis of authenticity. No researcher worth their salt actually considers their model to be the equivalent of the material object it represents, despite the worries of Nikonova and Biryukova (2017) that "digital simulations of life-size monuments will be perceived by society not only as an adequate substitute for the original (in itself a dangerous thing), but as the only possibility to its perception" (Nikonova and Biryukova, 2017, 172, my parentheses).

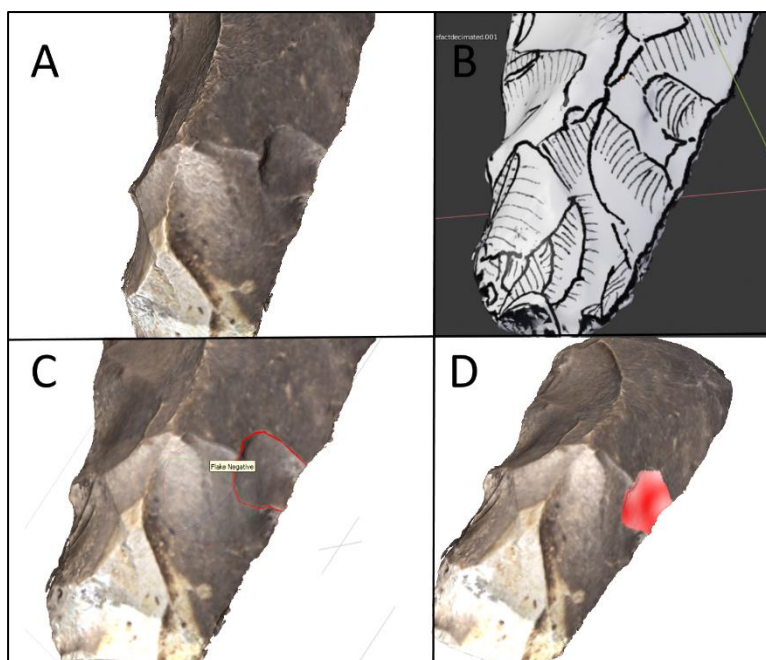
It is also important to stress the fact that both digital and manual illustrative approaches are at vastly different points in their development, and hence there is an innate tension expecting easy transference or interaction between one method or the other. Manual illustration is intimately bound with our perceptions of archaeology as a discipline and how we conceptualise artefacts given that it was the first means antiquarians had during the birth and development of archaeological praxis, to record and interpret the relict features of the past they encountered. As such it is often, however subconsciously given the benefit of the doubt, so inextricably linked with our understanding of the discipline as a whole, that recognizing limitations or having a functioning interpretative awareness of drawing as a *technique* not an end product is often difficult to access. This is effectively conveyed by its non-inclusion as an entry in either "A Dictionary of Terms and *Techniques* in Archaeology" by Sara Champion (1980), (my emphasis) or in "The Concise Oxford Dictionary of Archaeology (2. ed)" by Timothy Darvill (2009) (Online edition search for the terms "artefact illustration", "illustration" or "drawing" returned no definition results, available at: <https://www.oxfordreference.com> [accessed: 06/05/2020]). Much of the benefit of manual drawing is that it employs a long standing and comprehensive language of representation, one that has been developed critically over the last century or so. Thus, it is perhaps unrealistic to hold digital means of illustration and display to the same standards at such an early point in its evolution. These questions of representation are more deeply considered in the following part of this chapter but one of the subtle cons that belies manual drawing standards is the fact that traditional hand-drawing is a reductive technique due to its reliance on projection processes. These render the object flat and thus expecting this orthographic projected image of a sketch to map seamlessly onto a 3D captured mesh reflects poor

understanding of the deeper issues at play within both approaches. As much as the triangular nature of the mesh and limitations of the software processes constrained this combined visualisation approach, the cons of manual illustration are also as much at fault, an issue perhaps not recognised during the actual research campaign itself.

Finally, the difficulties involved in capturing the cutting edge of the axe-form and any associated use-wear damage situated on it, an incredibly thin surface with even smaller features again shows the limiting factors of photogrammetry. However, the self-reflexivity of this paper would redirect this new experiential knowledge back into the research process, ensuring a more intensive focus upon the cutting-edge during the photogrammetry campaign allowing for a better capture of the required information. As such, this criticism involves not so much the method itself, as how it is used.

### Questions of Consensus

Moving beyond the relatively high-level concerns addressed above, one of the major topics of consideration that the reflexive and practical research processes summarised above was the importance of consensus. During the exploration of illustrative approaches to data visualisation and representation it was quickly realised that all forms of data representation involve a language of symbology. For the hand-illustration phase this was self-evident, with Raczynski-Henk (2017) defining drawing surface features with reference to “a specific “grid”, consisting of different forms of hatching and other types of symbols” (Raczynski-Henk, 2017, 18) and established conventions of layout in the form of the French or American projection system. Whilst this is fine on a 2D plane, the morphological complexity of 3D data is such that it is difficult to develop a usable convention for displaying surface features and associated data. Whereas flake negatives can be digitised as either polygon or polyline features quite easily, other more subtle features such as formation processes perhaps only lend themselves to attached attribute tables in which the visual dimension, the main value of 3D data is lost. As such, all illustration processes are reductive, requiring the transformation of physical features into simplified symbols legible only by a key symbology, however the base 3D model, being more of a facsimile as opposed to a schematic representation of an object, should avoid these ontological concerns. This should be of no issue to a specialist used to reading the surface of a flint and identifying features which should be readily visible on the texture of a decent quality mesh although a standardised system of representation and visualisation would increase research efficiency. Once we consider the realm of public engagement however, speaking to an audience with little prior knowledge such concerns gather more weight. This is compounded even more when we recognise the variety of means of digitising data across 3D modelling packages whether via polyline, polygon, painted pixels, attribute tables etc (See Figure 43). One means of circumventing this, is the sketch mapping process followed above which dispenses with the need for the creation of a new representational language by adapting established hand-drawn practice although the constraints of hand-drawing have previously been mentioned.



**FIGURE 43: VARIOUS MEANS OF DISPLAYING FLAKE NEGATIVES DIGITALLY:**

*A = Meshlab Radiance Scaling*

*B= Conventional hand drawing projected as texture in Blender*

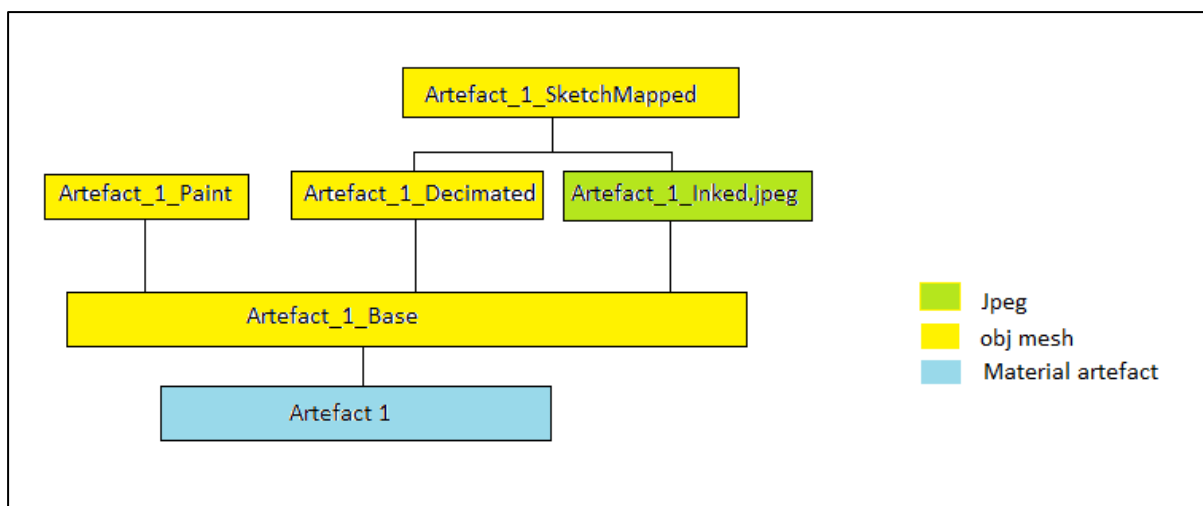
*C= Agisoft Metashape polyline tool with label attribute*

*D = Meshlab Paint tool)*

The outputs above are rather simplistic and It is important to note that visualisation techniques can be multilayered, combining digitisation tools across the spectrum of available 3D software to create multiple cosmogonies of reference.

The other more conventional instance of standardisation in digital heritage praxis is that of metadata. Here the work of the AGORHA projects again comes into play as offering an idea of possible solutions to questions of metadata coherence across different platforms and schemas. AGORHA operates under the aegis of the FAIR system, standing for Findable Accessible Interoperable and Reusable. Through utilising data systems such as Regex (Regular Expression) and Open Refine which organise and parse datasets based upon searchability they aim to standardise terminologies of reference for the collections they digitise, adopting a Dublin Core schema for compatibility between collections (Nurra, 2020, Seminar). Contrary to the linguistic and symbological concerns mentioned previously, Nurra (2020) emphasised that it is “not the vocabularies you set but the *media* you use” (Nurra, 2020, Seminar, my emphasis) that is key in making data more accessible to different audiences. Thus, highlighting the fact that digital models need to be conceptualised via new frameworks of reference given the multifaceted complexity of the information they embody.

This multifaceted nature became apparent when trying to compile metadata for the models created using the Dublin Core Schema (See Appendix 3) with the sketch-mapped model particularly difficult. In this case was the model merely a combination of two other resources (the base model and the sketch) or a model in its own right? Dublin Core was chosen as it is considered a benchmark “used or referenced in more areas and disciplines than any other metadata scheme” (Liu, 2007, 48). It is particularly useful also because it deals with networks of data which in this case suits the multitude of models per artefact quite well (See Figure 44) with the terminologies used based upon the latest schema standards outlined in the DCMI 2020 standards (DCMI, 2020).

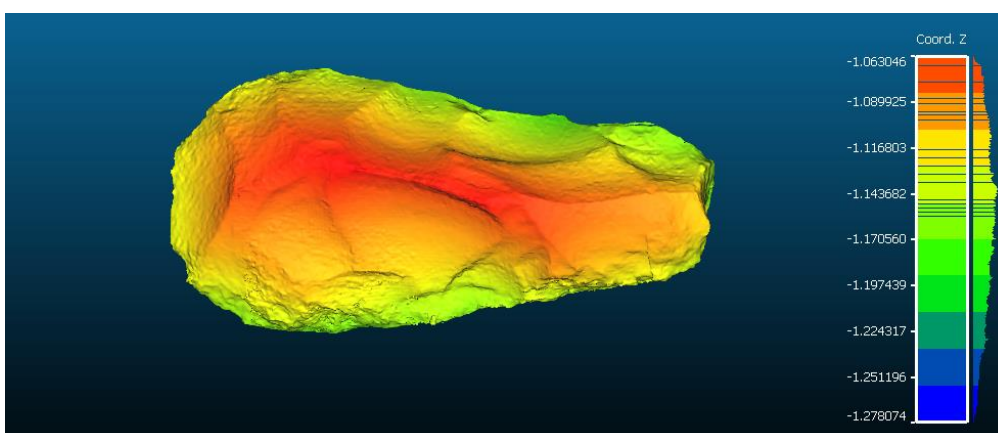


**FIGURE 44: RELATIONAL NETWORK OF ASSOCIATED FILES FOR ARTEFACT 1, EACH WITH THEIR OWN ASSOCIATED METADATA SHOWING HOW THE CONNECTIONS TRAVERSE MEDIA TYPES**

Another more obscure issue of standardisation that became apparent during the various digitisation processes was the difference of model coordinate systems and mouse controls across the different programs used. Transferring models from one 3D editor to another involved a change in viewer orientation and the mouse controls for simple commands like pan, zoom and camera view. A shared logic across the board could improve the efficiency and ease of the more reflexive engagement with models discussed here, although understandably coordinate systems are dependent upon the type of data imported - e.g. objects versus landscape data, and could perhaps be allayed through remapping of controls if available.

### Approaching Temporality

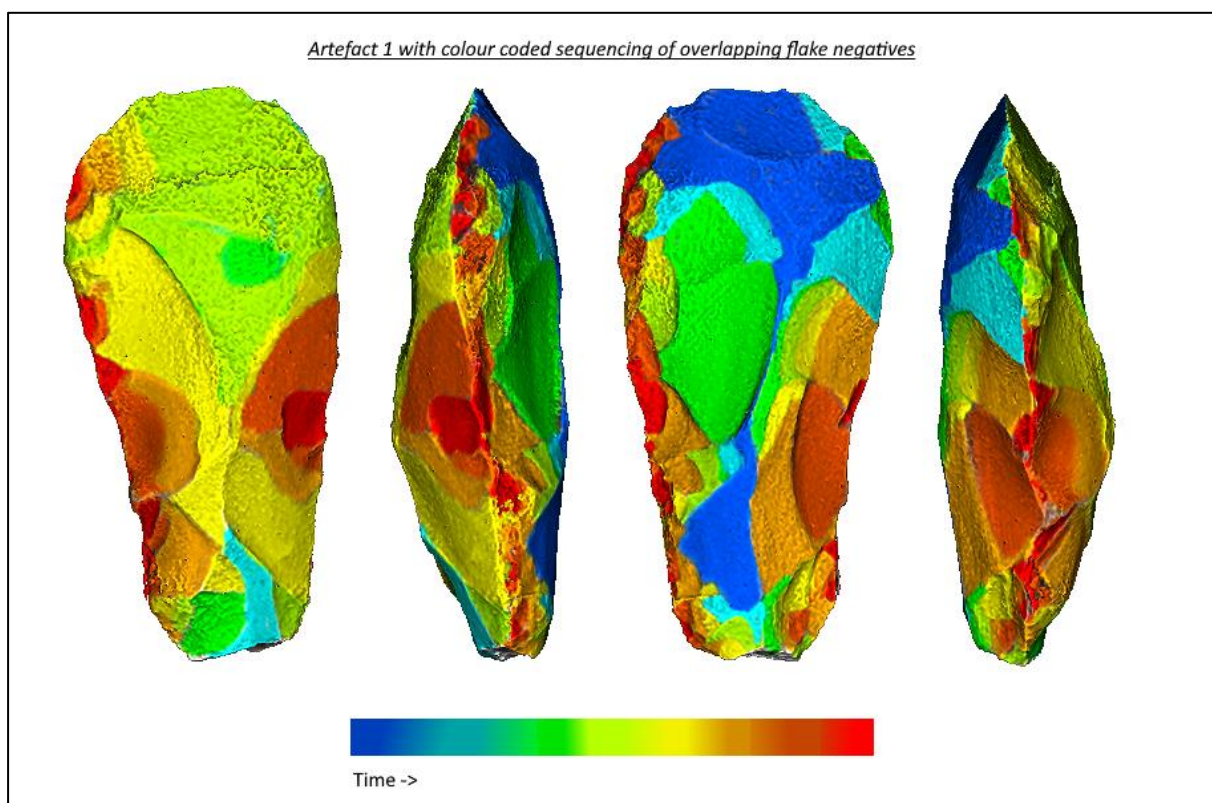
Until now, all of the examples listed have explored the dynamic aspects of space to digital display of archaeological data, but what about the temporal dynamism that the digital sphere allows? Assuming that time has a reductive action upon the surface of a flint artefact, a simple means of illustrating this would be to generate a height map of the surface of the flint, with higher z – axis approximating ‘untouched’ raw flint surface and lower values representing flake negatives and human/weathering action upon the stone (Figure 45).



**FIGURE 45: HEIGHT MAP GENERATED IN CLOUDCOMPARE BASED UPON ARBITRARY CATEGORIZATION OF Z VALUE 'SURFACE' CO-ORDINATES**

The example above is obviously incredibly reductive but represents an attempt to visualise time in a quantitative way. Perhaps flattening the surface and exporting as a greyscale jpeg would give a better read of surface topology that could be used to visualise key features.

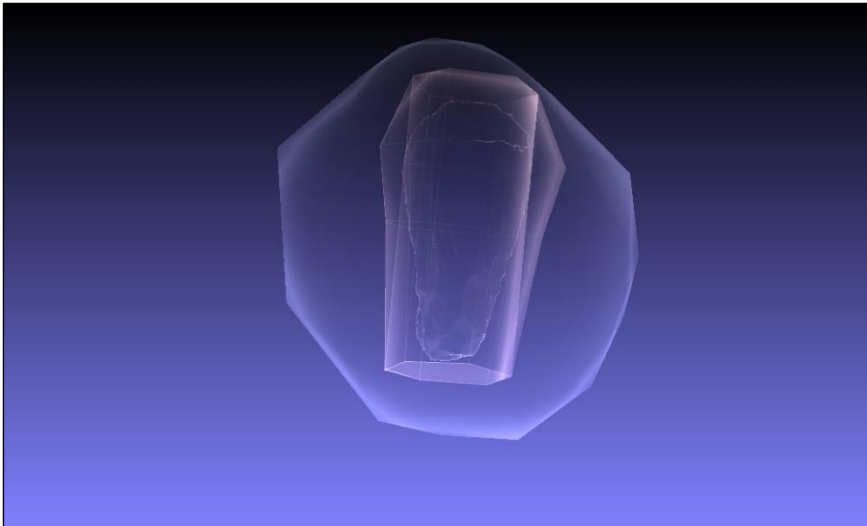
The 'primary and secondary' marks digitised in figure 16 above is an incredibly reductive model of time as manufacture process. This colour sequencing of marks was refined again using the same paint methods in MeshLab with an added default radiance scaling shader to emphasise surface features. In this forensic attempt at the digitising process, the pattern of overlapping marks was 'read', from the most recent 'red' marks through all of the underlying marks to 'dark blue' (Figure 46 below). Whilst the front of the artefact appears 'younger' than the reverse side, this is due to the fact that the colour scheme is based upon the total number of associated overlaps not overall age, a reductive process that little reflects a much more temporally complex actuality of contemporaneous marks.



**FIGURE 46: 'TIME-MAP' OF ARTEFACT 1 WITH COLOUR CODE PLOTTING SEQUENTIAL OVERLAPPING OF FLAKE REMOVAL ACTION**

However, the main benefits for discussing the visualisation of temporal development of artefacts is in the representation of information to the general public. To this end, a simplistic development of artefact from raw node, through core to core axe was attempted. This involved creation of simple approximations of a flint node and core using reference images in blender, with simple textures added. These were imported into Meshlab and along with the decimated mesh of artefact 1 arranged in nesting doll fashion to show the relationship and chaine-operatoire between raw material and final product. An x-ray shader was used to visualise this (See Figure 47).





**FIGURE 47: THREE MODELS COMBINED IN MESHLAB TO GIVE AN APPROXIMATION OF THE ARRANGEMENT OF AXE, CORE AND RAW MATERIAL NODE FOR THE CORE-AXE [ARTEFACT 1]**

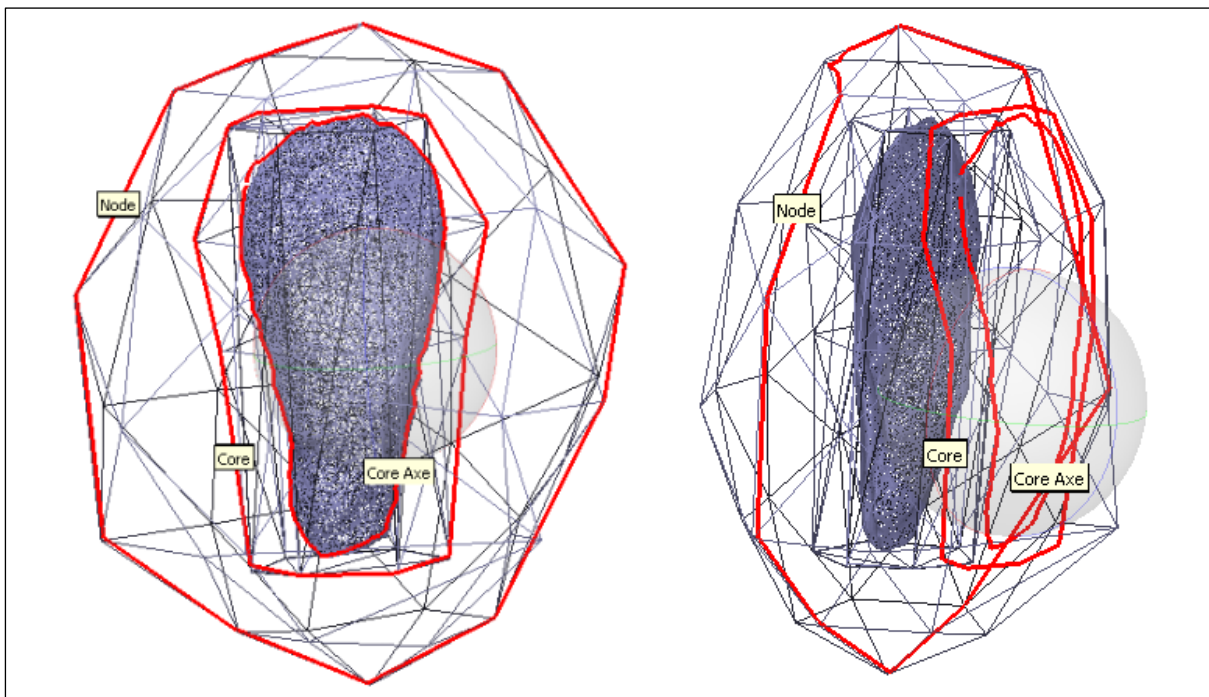
An alternative could be to export the composite model above into Metashape, bisect it with a cross section view so that the outlines of the constituent parts of the model are visible, and outline these with the polyline tool, labelling them accordingly. As such there are two issues with this plan. Firstly, Meshlab is unable to align models which have no corresponding or overlapping meshes, thus unsuitable for nested meshes like this. Secondly, the chunk alignment tool in Metashape is much the same, reliant on concurrent markers. Perhaps Cloud Compare could be used but due to lack of experience with the software this was not feasible.

The simplest option would be to switch between each manufacturing stage sequentially by toggling the visibility of each model, something supported by a framework like 3DHOP. Initial experimentation with the Compute Planar Section Tool provided a flat cross-section as opposed to the sliced view we required, and the slicing tool filter proved too much for the computer system to handle. Attempts to circumvent this by manually deleting 'frontal' faces to reveal the internal meshes was workable but messy in its results. Instead, the models were 'stacked' through each-other in steps, via a decrease of their corresponding Y-values in Normals, Curvature and Orientation -> Transform:Translate. This resulted in a visual representation of the relationship between each mesh and the next offering a composite model of the changing forms the artefact assumed in its life-history (See Figure 47). It also served to preserve the textures unlike the X-ray shader but was only effective when viewed from a frontal orthographic view, with the true spatial relationships between the different stages of manufacture lost on the viewer as a result.



**FIGURE 48: STACKED VIEW OF THE THREE MESHES WITH TEXTURES PRESERVED CORRESPONDING TO FLINT NODE, CORE AND AXE RESPECTIVELY**

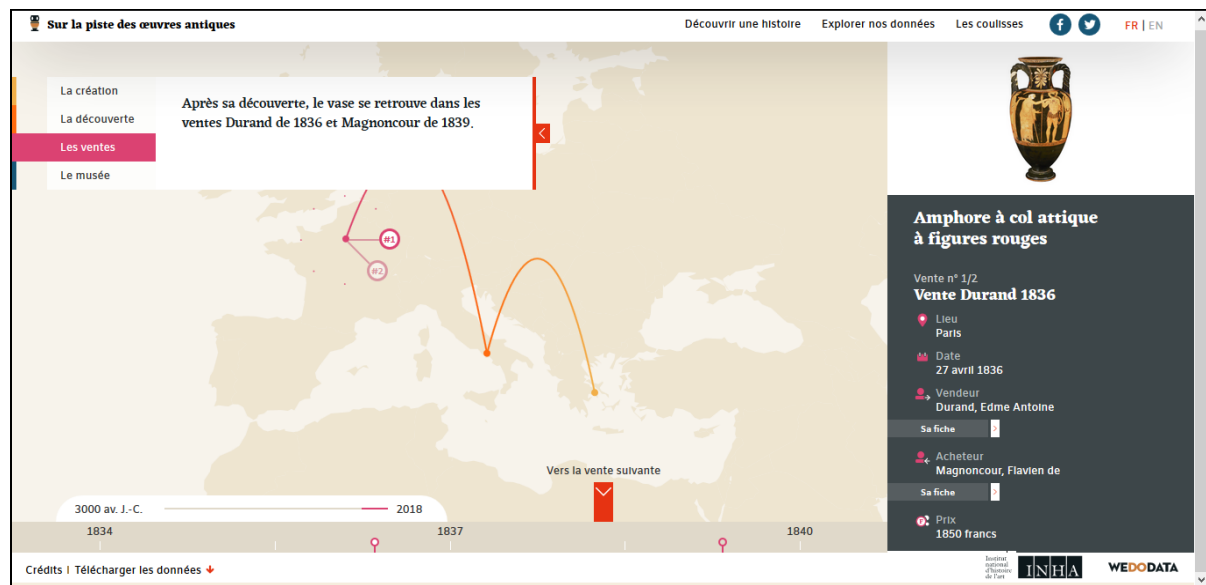
Transferring the models into blender and merging them using the Join function circumvented this issue and allowed the resulting composite model to be imported into Agisoft Metashape, allowing for the more thorough visualisation of data through the polyline tool. However, whilst this superficially appears quite good, this schematic neatness is quickly dispelled upon rotation of the artefact (Figure 49) rendering the schema useful only in orthographic view, ironically undercutting the unique functionalities three dimensionality has to offer and producing what is effectively a flat two dimensional representation.



**FIGURE 49: BREAKING THE ILLUSION OF THE MANUFACTURING FORM SCHEMA IN METASHAPE**

This is arguably again the restrictive nature of adopting 2D illustration technique and conventions to 3D forms and software ill-suited to them coming into play rather than any deep limitation with the digital methods and frameworks themselves.

To broaden the scope of attention a bit further, the Ventes d'antiques project by the Institut national d'histoire de l'art in Paris, again under the AGORHA initiative serves to showcase the sort of interactive depth of visualisation that a hyper connected digital artefact collection can enable with regards to object life-histories, in this case post functional life (See Figure 49).



**FIGURE 50: VIEW OF INHA'S TIMELINE APPROACH TO OBJECT LIFE-HISTORIES, TRACING THE JOURNEY OF A 5TH CENTURY B.C. GREEK AMPHORA FROM ITS SOURCE THROUGH VARIOUS ANTIQUITIES SALES TO A 19TH CENTURY FRENCH COLLECTION**

(Available at: <https://ventesdantiques.inha.fr/story.php#fr/80461/ventes> [accessed: 04/05/2020])

Although digitisation of the object in question is limited to high resolution photography, there is no reason why 3D scans could not replace this within the current framework.

## Reflexive Approaches

One strand of this thesis was to explore how the 'sandbox' milieu of many 3D processing programmes actually engenders a more reflexive archaeology as opposed to the lack of depth of which it has been accused. 3DHOP perhaps embodies this 'sandbox' approach best, with a host of tools available to interactively engage with 3D data and display information in a visually relevant way. In processing and modelling the different aspects of modelled data discussed above, the large array of tools and interactive filters available offered a real critical engagement with the artefact and its connections to space, time and the visual nature of the data it embodies. As such what became apparent during these processes was the key importance of this period of experimentative interplay with the artefact as a dataset, the 'dialogue' itself, not the final models produced. The ways digital interfaces can impede and limit our interaction with our data has been much discussed, and rightly so. And yet we tend to forget the allowances that such interfaces can provide. For example the ability to switch between different view modes, solid to wireframe etc, and selectively highlight certain

structures or aspects thereof (Figure 34) *during* the period of modelling and questioning is immensely invigorating, expanding the potential for research questions and allowing us to explore stale data in fresh ways. The ability to spatially visualise and question datasets digitally dispenses with concerns about time, access and visibility as would be the case in the field. Greater recognition of data as data, and the processes involved in interacting with and creating 3D data outputs offer a much more nuanced understanding of the discipline as a whole, and this can only be a good thing.

### Best Practices

One of the original aims of this thesis, was to attempt to identify an efficiency of approach, a means of maximizing the potentialities of 3D archaeological methods and digital data. The first step to achieving this is arguably implementing a coherent metadata schema in which each digital media produced is comprehensively described to a standard vocabulary and the links between them clearly delineated. Such efforts enable a greater adherence to aims of data transparency and replication, offering strong bases for future research that may be based upon the data thus digitised. This goes some way to addressing the ideas of digital data as 'living resources' previously discussed, enabling models to be effectively studied beyond the instance of a single study.

Issues of standardisation in terms of model quality is difficult to assess, given the multiplicity of artefact forms and research needs in the discipline as a whole, however it is good practice to have a high quality base model which you can generate simplified copies from as and when required. This ensures that the degree of fidelity of representation in terms of the original artefact is retained, whilst permitting workable model qualities for display and dissemination. With the litany of digital illustrative options available, identifying the tools which offer the best visual display of the surface and feature information required and then sticking to that visual vocabulary ensures clarity and coherence of approach.

Whilst the opportunities for reflexive engagement with digitised data have been stressed within this thesis with digital archaeology used as an analytical tool during the research approach, issues of data publication are also important to consider. For example, a common criticism, indeed one which this thesis effectively succumbs to, is the inherently undisplayable nature of 3D dimensionality, with 3D models being reduced to 2D images on the page. As such, a seemingly valid conclusion would be to completely disregard the usefulness of creating 3D models given they are unpublishable within the context of the academic journals and research papers that are the bread and butter of our discourse, with traditional illustration techniques displaying the same information at a fraction of the labour cost. However, the key benefit of digital data, is its ease of access and shareability. Thus, in implementing a 3DHOP output, and linking this output as an HTML page within the associated research paper, real and substantial engagement with the data discussed in text is enabled, undermining these former criticisms.

### Conclusions

This thesis has sought to explore the rich and uniquely complex nature of data representation and visualisation of digital heritage within the 3D realm. Although initially planned as a process of identification of suitable datasets within an ultimate 3D hop output, it instead

developed into a mediation on the nature of digital illustration, with a focus on investigating digital heritage from a dynamically situated spatial and temporal context. As such much consideration was given to questions of data symbology and consensus, digital affordances and the nature of the data we input versus that we produce as result of these digital processes. This depth of focus upon rather esoteric issues of digitisation engendered the use of one artefact at expense of scanning the other two artefacts chosen. By expanding the depth of research upon issues of illustration and visualisation we were unable to follow the formation process approach elucidated in the opening chapter beyond a consideration of how to conceptualise them in a metadata format; perhaps this is an area for future research into data enrichment. Furthermore, given the outcomes of some of the issues of visualisation, a lot of the data associated with formation processes is very context specific, not lending itself well to visual display and interpretation of the sample artefact chosen. Throughout this thesis, digital data was explored from the actual praxis of identifying, creating, and visualising data outputs themselves, whilst also attempting to situate them within the frameworks of reference and connections that are associated with them. It is hoped this two strand approach has endeavoured to produce a more nuanced understanding of the involved issues, and whilst the outputs generated tend towards a simplistic quality, the complexities of the considerations around them have attempted to imbue them with the depth of theoretical discourse that surround them.

Finally, it would be remiss not to mention the carbon cost of such reliance upon computing power and the accumulation of large heritage datasets that would be so conducive to our line of research. This is an issue not previously considered by the researcher, and it therefore begs the question of weighing the benefits of such large-scale modelling efforts, or at least a more considered approach to the application of such methodologies.

Regardless of these issues, it is hoped that a more nuanced understanding of the intricate complexities of visibility and representation such as the thread of this thesis can lead to better digital conveyance and awareness of the multifaceted nature of historic artefacts, not as static tools or objects d'art, but as nodes of "authenticity founded on the networks of relationships between [the] people, places and things that they embody" (Foster and Jones, 2020, 1). This is an idea perhaps best conveyed ironically not by the digital media through which we visualise and represent past artefacts, but in the ephemeral networks of metadata and paradata around them, an interconnective array only conceivable within a digital workspace.

Word Count Excluding Figure Captions, Tables and Table Headings = 15,606

## Figures Sourcing

Figure 1: Harris, M. (author), 2020

Figure 2: Harris M. (author), 2020

Figure 3: After (Högberg and Olausson, 2017, 31 ,Figure 22)

Figure 4: Harris, M. (author), 2020

Figure 5: Harris, M. (author), 2019 in (Clarke et al., 2019, 3, Figure 2, unpublished)

Figure 6: Harris, M. (author), Helicon Soft Ltd, 2020

Figure 7: Harris, M. (author), Helicon Soft Ltd, 2020

Figure 8: Harris, M. (author), Agisoft LLC, 2020

Figure 9: Harris, M. (author), Agisoft LLC, 2020

Figure 10: Harris, M. (author), Agisoft LLC, 2020

Figure 11: Harris, M. (author) after Brøgger's (1906) standard axe views, Agisoft LLC 2020

Figure 12: Harris, M. (author), Agisoft LLC, 2020

Figure 13; Harris, M. (author), Agisoft LLC, 2020

Figure 14: Harris, M. (author), ISTI-CNR, 2020

Figure 15: Harris, M. (author), ISTI-CNR, 2020

Figure 16: Harris, M. (author), ISTI-CNR, 2020

Figure 17: Harris, M. (author), 2020

Figure 18: Harris, M. (author), 2020

Figure 19: Harris, M. (author), 2020

Figure 20: Harris, M. (author), 2020

Figure 21: Harris, M. (author), 2020

Figure 22: Harris, M. (author), 2020

Figure 23: Harris, M. (author), 2020

Figure 24: Harris, M. (author), 2020

Figure 25: Harris, M. (author), Blender Foundation, 2020

Figure 26: Harris, M. (author), Blender Foundation, 2020

Figure 27: Harris, M. (author), 2020

Figure 28: Harris, M. (author), Blender Foundation, 2020



Figure 29: Harris, M. (author), Blender Foundation, 2020

Figure 30: Harris, M. (author), Blender Foundation, 2020

Figure 31: Harris, M. (author), Blender Foundation, 2020

Figure 32: Harris, M. (author), ISTI-CNR, 2020

Figure 33: Harris, M. (author), Blender Foundation, 2020

Figure 34: Harris, M. (author), Agisoft LLC, 2020

Figure 35: Harris, M. (author), Agisoft LLC, 2020

Figure 36: Harris, M. (author) after Brøgger's (1906) standard axe views, 2020

Figure 37: After (Glørstad, 2011, 32, Fig. 12)

Figure 38: Harris, M. (author), 2020

Figure 39: Harris, M. (author), ISTI-CNR, 2020

Figure 40: Harris, M. (author), ISTI-CNR, 2020

Figure 41: Harris, M. (author), ISTI-CNR, 2020

Figure 42: Harris, M. (author), ISTI-CNR, 2020

Figure 43: Harris, M. (author), Agisoft LLC, Blender Foundation, ISTI-CNR, 2020

Figure 44: Harris, M. (author), 2020

Figure 45: Harris, M. (author), CloudCompare, 2020

Figure 46: Harris, M. (author), ISTI-CNR, 2020

Figure 47: Harris, M. (author), ISTI-CNR, 2020

Figure 48: Harris, M. (author), ISTI-CNR, 2020

Figure 49: Harris, M. (author), Agisoft LLC, 2020

Figure 50: (Available at: <https://ventesdantiques.inha.fr/story.php#fr/80461/ventes> [accessed: 04/05/2020])

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## Appendix 1: Macro-photography Paradata

Camera Parameters:	Photo Number:	Stack Number:	Artefact Projection:
50mm lens, ISO 120, F8 +/-2 2/3	100 3307 - 100 3321	1	"Core-Axe" Side 1
50mm lens, ISO 120, F8 +/-2 2/3	100 3322 - 100 3334	2	"Core-Axe" Side 1
50mm lens, ISO 120, F8 +/-2 2/3	100 3335 - 100 3346	3	"Core-Axe" Side 1
50mm lens, ISO 120, F8 +/-2 2/3	100 3347 - 100 3353	4	"Core-Axe" Side 1
50mm lens, ISO 120, F8 +/-2 2/3	100 3354 - 100 3366	5	"Core-Axe" Side 1
50mm lens, ISO 120, F8 +/-2 2/3	100 3367 - 100 3381	6	"Core-Axe" Side 1
50mm lens, ISO 120, F8 +/-2 2/3	100 3383 - 100 3397	7	"Core-Axe" Side 1
50mm lens, ISO 120, F8 +/-2 2/3	100 3398 - 100 3406	8	"Core-Axe" Side 1
50mm lens, ISO 120, F8 +/-2 2/3	100 3407 - 100 3416	9	"Core-Axe" Side 1
50mm lens, ISO 120, F8 +/-2 2/3	100 3417 - 100 3431	10	"Core-Axe" Side 1
50mm lens, ISO 120, F8 +/-2 2/3	100 3432 - 100 3445	11	"Core-Axe" Side 1
50mm lens, ISO 120, F8 +/-2 2/3	100 3446 - 100 3458	12	"Core-Axe" Side 1
50mm lens, ISO 120, F8 +/-2 2/3	100 3459 - 100 3467	13	"Core-Axe" Side 1
50mm lens, ISO 120, F8 +/-2 2/3	100 3468 - 100 3480	14	"Core-Axe" Side 1
50mm lens, ISO 120, F8 +/-2 2/3	100 3481 - 100 3490	15	"Core-Axe" Side 1
50mm lens, ISO 120, F8 +/-2 2/3	100 3491 - 100 3502	1B	"Core-Axe" Side 2
50mm lens, ISO 120, F8 +/-2 2/3	100 3503 - 100 3520	2B	"Core-Axe" Side 2
50mm lens, ISO 120, F8 +/-2 2/3	100 3521 - 100 3534	3B	"Core-Axe" Side 2
50mm lens, ISO 120, F8 +/-2 2/3	100 3535 - 100 3542	4B	"Core-Axe" Side 2
50mm lens, ISO 120, F8 +/-2 2/3	100 3543 - 100 3553	5B	"Core-Axe" Side 2
50mm lens, ISO 120, F8 +/-2 2/3	100 3554 - 100 3568	6B	"Core-Axe" Side 2
50mm lens, ISO 120, F8 +/-2 2/3	100 3569 - 100 3576	7B	"Core-Axe" Side 2

50mm lens, ISO 120, F8 +/-2 2/3	100 3577 - 100 3592	8B	"Core-Axe" Side 2
50mm lens, ISO 120, F8 +/-2 2/3	100 3593 - 100 3611	9B	"Core-Axe" Side 2
50mm lens, ISO 120, F8 +/-2 2/3	100 3612 - 100 3632	10B	"Core-Axe" Side 2
50mm lens, ISO 120, F8 +/-2 2/3	100 3633 - 100 3647	11B	"Core-Axe" Side 2
50mm lens, ISO 120, F8 +/-2 2/3	100 3648 - 100 3658	12B	"Core-Axe" Side 2
50mm lens, ISO 120, F8 +/-2 2/3	100 3659 - 100 3662	13B	"Core-Axe" Side 2
50mm lens, ISO 120, F8 +/-2 2/3	100 3663 - 100 3674	14B	"Core-Axe" Side 2
50mm lens, ISO 120, F8 +/-2 2/3	100 3765 - 100 3684	15B	"Core-Axe" Side 2
50mm lens, ISO 120, F8 +/-2 2/3	100 3685 - 100 3695	16B	"Core-Axe" Side 2
50mm lens, ISO 120, F8 +/-2 2/3	100 3696 - 100 3703	17B	"Core-Axe" Side 2
50mm lens, ISO 120, F8 +/-2 2/3	100 3704 - 100 3715	18B	"Core-Axe" Side 2
50mm lens, ISO 120, F8 +/-2 2/3	100 3716 - 100 3726	1C	"Core-Axe" Profile
50mm lens, ISO 120, F8 +/-2 2/3	100 3727 - 100 3734	2C	"Core-Axe" Profile
50mm lens, ISO 120, F8 +/-2 2/3	100 3735 - 100 3748	3C	"Core-Axe" Profile
50mm lens, ISO 120, F8 +/-2 2/3	100 3749 - 100 3765	4C	"Core-Axe" Profile
50mm lens, ISO 120, F8 +/-2 2/3	100 3766 - 100 3778	5C	"Core-Axe" Profile
50mm lens, ISO 120, F8 +/-2 2/3	100 3779 - 100 3788	6C	"Core-Axe" Profile
50mm lens, ISO 120, F8 +/-2 2/3	100 3789 - 100 3801	7C	"Core-Axe" Profile
50mm lens, ISO 120, F8 +/-2 2/3	100 3802 - 100 3809	8C	"Core-Axe" Profile
50mm lens, ISO 120, F8 +/-2 2/3	100 3810 - 100 3816	9C	"Core-Axe" Profile
50mm lens, ISO 120, F8 +/-2 2/3	100 3817 - 100 3822	10C	"Core-Axe" Profile
50mm lens, ISO 120, F8 +/-2 2/3	100 3823 - 100 3836	11C	"Core-Axe" Profile
50mm lens, ISO 120, F8 +/-2 2/3	100 3837 - 100 3854	12C	"Core-Axe" Profile
50mm lens, ISO 120, F8 +/-2 2/3	100 3855 - 100 3861	13C	"Core-Axe" Profile
50mm lens, ISO 120, F8 +/-2 2/3	100 3862 - 100 3868	14C	"Core-Axe" Profile



50mm lens, ISO 120, F8 +/-2 2/3	100 3869 - 100 3875	15C	"Core-Axe" Profile
50mm lens, ISO 120, F8 +/-2 2/3	100 3876 - 100 3886	16C	"Core-Axe" Profile

## Appendix 2: Standard Photogrammetry Paradata: Artefact 1

Camera Parameters:	Photo Number:	Chunk:	Artefact:
50mm lens, ISO 100, F8 +/- 2 1/3	100 4517	Blade_Down_RAW merge	Artefact 1: "Core-Axe"
50mm lens, ISO 100, F8 +/- 2 1/3	100 4518	Blade_Down_RAW merge	Artefact 1: "Core-Axe"
50mm lens, ISO 100, F8 +/- 2 1/3	100 4519	Blade_Down_RAW merge	Artefact 1: "Core-Axe"
50mm lens, ISO 100, F8 +/- 2 1/3	100 4520	Blade_Down_RAW merge	Artefact 1: "Core-Axe"
50mm lens, ISO 100, F8 +/- 2 1/3	100 4521	Blade_Down_RAW merge	Artefact 1: "Core-Axe"
50mm lens, ISO 100, F8 +/- 2 1/3	100 4522	Blade_Down_RAW merge	Artefact 1: "Core-Axe"
50mm lens, ISO 100, F8 +/- 2 1/3	100 4523	Blade_Down_RAW merge	Artefact 1: "Core-Axe"
50mm lens, ISO 100, F8 +/- 2 1/3	100 4524	Blade_Down_RAW merge	Artefact 1: "Core-Axe"
50mm lens, ISO 100, F8 +/- 2 1/3	100 4525	Blade_Down_RAW merge	Artefact 1: "Core-Axe"
50mm lens, ISO 100, F8 +/- 2 1/3	100 4526	Blade_Down_RAW merge	Artefact 1: "Core-Axe"
50mm lens, ISO 100, F8 +/- 2 1/3	100 4527	Blade_Down_RAW merge	Artefact 1: "Core-Axe"
50mm lens, ISO 100, F8 +/- 2 1/3	100 4528	Blade_Down_RAW merge	Artefact 1: "Core-Axe"
50mm lens, ISO 100, F8 +/- 2 1/3	100 4529	Blade_Down_RAW merge	Artefact 1: "Core-Axe"
50mm lens, ISO 100, F8 +/- 2 1/3	100 4530	Blade_Down_RAW merge	Artefact 1: "Core-Axe"
50mm lens, ISO 100, F8 +/- 2 1/3	100 4531	Blade_Down_RAW merge	Artefact 1: "Core-Axe"
50mm lens, ISO 100, F8 +/- 2 1/3	100 4532	Blade_Down_RAW merge	Artefact 1: "Core-Axe"
50mm lens, ISO 100, F8 +/- 2 1/3	100 4533	Blade_Down_RAW merge	Artefact 1: "Core-Axe"

Camera Parameters:	Photo Number:	Chunk:	Artefact:
50mm lens, ISO 100, F8 +/- 2 1/3	100 4622	Blade_Up_RAW merge	Artefact 1: "Core-Axe"
50mm lens, ISO 100, F8 +/- 2 1/3	100 4623	Blade_Up_RAW merge	Artefact 1: "Core-Axe"

50mm lens, ISO 100, F8 +/- 2 1/3	100 4624	Blade_Up_RAW merge	Artefact 1: "Core-Axe"
50mm lens, ISO 100, F8 +/- 2 1/3	100 4625	Blade_Up_RAW merge	Artefact 1: "Core-Axe"
50mm lens, ISO 100, F8 +/- 2 1/3	100 4626	Blade_Up_RAW merge	Artefact 1: "Core-Axe"
50mm lens, ISO 100, F8 +/- 2 1/3	100 4627	Blade_Up_RAW merge	Artefact 1: "Core-Axe"
50mm lens, ISO 100, F8 +/- 2 1/3	100 4628	Blade_Up_RAW merge	Artefact 1: "Core-Axe"
50mm lens, ISO 100, F8 +/- 2 1/3	100 4629	Blade_Up_RAW merge	Artefact 1: "Core-Axe"
50mm lens, ISO 100, F8 +/- 2 1/3	100 4630	Blade_Up_RAW merge	Artefact 1: "Core-Axe"
50mm lens, ISO 100, F8 +/- 2 1/3	100 4631	Blade_Up_RAW merge	Artefact 1: "Core-Axe"
50mm lens, ISO 100, F8 +/- 2 1/3	100 4632	Blade_Up_RAW merge	Artefact 1: "Core-Axe"
50mm lens, ISO 100, F8 +/- 2 1/3	100 4633	Blade_Up_RAW merge	Artefact 1: "Core-Axe"
50mm lens, ISO 100, F8 +/- 2 1/3	100 4634	Blade_Up_RAW merge	Artefact 1: "Core-Axe"
50mm lens, ISO 100, F8 +/- 2 1/3	100 4635	Blade_Up_RAW merge	Artefact 1: "Core-Axe"
50mm lens, ISO 100, F8 +/- 2 1/3	100 4636	Blade_Up_RAW merge	Artefact 1: "Core-Axe"
50mm lens, ISO 100, F8 +/- 2 1/3	100 4637	Blade_Up_RAW merge	Artefact 1: "Core-Axe"

## Appendix 3: Artefact 1 Supplementary data Metadata

Title:	Artefact 1
Title:	111:227
Title:	Kärnyxa Mesolitikum
Alternative:	"Plutten"
Creator:	Unknown
Contributor:	Null
Type:	Flint Artefact
Medium:	Flint
Format:	Null
Extent:	Null
Description:	Mesolithic flint Core-Axe, Scandinavian
Date Created:	Null
Source:	Lunds Universitet Teaching Collection

Title:	Artefact_1_Base
Alternative:	Null
Creator:	Harris, Michael
Contributor:	DarkLab
Type:	3D Mesh
Medium:	Null
Format:	obj
Extent:	31.6 MB
Description:	A Photogrammetry model of a Scandinavian Mesolithic Axe
Date Created:	19/04/2020
Source:	Null

Title:	Artefact_1_Decimated
Alternative:	Null
Creator:	Harris, Michael
Contributor:	DarkLab
Type:	3D Mesh
Medium:	Null
Format:	obj
Extent:	909 KB
Description:	A Photogrammetry model of a Scandinavian Mesolithic Axe processed through five iterations of Quadric Edge Collapse Simplification in Meshlab
Date Created:	23/04/2020
Source:	Null

Title:	Artefact_1_Inked
Alternative:	Null
Creator:	Harris, Michael
Contributor:	DarkLab
Type:	Image
Medium:	Null
Format:	jpeg

Extent:	502 KB
Description:	Digitised image of a hand drawing of a Scandinavian Mesolithic Axe
Date Created:	23/04/2020
Source:	Null

Title:	Artefact_1_SketchMapped
Alternative:	Null
Creator:	Harris, Michael
Contributor:	DarkLab
Type:	3D Mesh
Medium:	Null
Format:	obj
Extent:	976 KB
Description:	Artefact_1_Decimated mesh retextured with Artefact_1_Inked.jpeg image
Date Created:	23/04/2020
Source:	Null

Title:	Artefact_1_Paint
Alternative:	Null
Creator:	Harris, Michael
Contributor:	DarkLab
Type:	3D Mesh
Medium:	Null
Format:	obj
Extent:	31.6 MB
Description:	A Photogrammetry model of a Scandinavian Mesolithic Axe with Primary and Secondary Flake Scars Highlighted in MeshLab
Date Created:	19/04/2020
Source:	Null

Title:	Artefact_1_Paint2
Alternative:	Null
Creator:	Harris, Michael
Contributor:	DarkLab
Type:	3D Mesh
Medium:	Null
Format:	ply
Extent:	8.79 MB
Description:	A Photogrammetry model of a Scandinavian Mesolithic Axe with colour coded sequencing of Flaking Highlighted in MeshLab
Date Created:	10/05/2020
Source:	Null