Digitizing Material Culture

A study on the interaction of 3D methodology, typology and material studies in archaeological practice

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Abstract

Archaeology has always centred on material studies and has a long tradition of establishing methods for addressing the vast source material at hand. Typology is one of the most prominent of these methods, where the material is categorised into types according to morphology and geometry. There is an ongoing debate regarding the subjectivity of the typological approach and the problems that follow this issue. In recent years, there has also been an increase in the use of digital methods in archaeology to tackle many of the problems present in previous archaeological work, but this has mostly focused on field and buildings archaeology. This thesis therefore aimed at testing and discussing the application of digital methods of documentation and analysis within the field of material studies. It was investigated how a digital approach could aid and solve some of the current issues of the field of study, but also how it can further improve the science. This was done by establishing a digital work-flow, conducting analyses and discussing the theoretical and methodological aspects of the digital approach. It was concluded that there are several advantages to be gained from using the digital method, especially in detail-oriented studies and surface analyses, and that it can also be employed to greatly improve the typological method in regards to the debate of subjectivity, but that the method must be used in a proper way for this to be achieved. It can also aid in the spread of knowledge and documentation within the archaeological discipline, as well as providing the tools for deeper analysis and understanding into the material culture.

Key words:

3D mentality, typology, progressive database, digital archaeology, digital methodology, material studies, laser scanning

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1. Introduction

Archaeology has since its earliest forms centred on the study of the material culture of past societies, and as a science it has searched for structure in order to handle the vast material at hand. Typology and categorization are central approaches, recurring throughout all archaeological research, and in cases of material study they are the very foundations (Hodder 1995:164ff; Sørensen 2015: 85). While it holds a central position in the discipline, typology as a method has also been criticized for its inherent subjective nature, illustrious descriptions and often vague definitions. In response to this there have been multiple attempts within the profession to restructure the typological approaches to meet the standards of modern scientific praxis, which is primarily based on that of the 'objective' natural scientific methods (e.g. Malmer 1962: 32f; Solberg 1984: 2f; Ilkjaer 1990: 29ff). This has been discussed at great lengths throughout the history of archaeology, and still there is no coherent way of conducting typological or material studies. Some researchers choose the objective methods while others do not. Even though there are several approaches to tackle the core problems of subjectivity in archaeology, many of the solutions still regard the issues from the traditional point-of-view, with little regard for the possibilities of implementing new techniques rather than re-structuring old ones.

Even though some areas, such as material studies, might cling to the more traditional methods, other branches of archaeology have come to adapt to the technological innovations and scientific expectations of our time. Field archaeology and landscape analysis often deal with a macro-scale and a wider perspective of archaeology, and have always been quick to make use of new technology to update the quality of the archaeological material and its documentation. It is now common practice in field archaeology to use digital documentation tools – GPS, GPR or Total Stations – to document the sites/features. The acquired data is then managed with the use of digital visualisation and analytical software packages such as GIS-programmes (Chapman 2006: 9ff; Conolly & Lake 2006: 11ff, 33ff; Kimball 2014: 2ff). There has also been an increased use of 3D modelling techniques in field archaeology, to properly document the full extent of the sites (e.g. Dell'Unto 2014; Forte et al 2015). With a more thorough examination of a site comes a more detailed understanding of its position and importance in prehistory, as well as accessible data for future studies. The same could be applied on a micro-scale in material studies, something this thesis seeks to evaluate. By employing the technological solutions presented by other sciences and new technologies, as has been done in other archaeological branches, it should be possible to deepen and widen our understanding of archaeological material culture, and perhaps more efficiently tackle the problems presented by traditional material studies.

Thus this thesis aims to shed some light on the possibilities of a digital methodology and to open up for a new approach within material studies. The goal is to investigate how the practice of utilizing digital methods can enhance, affect and further the archaeological discipline and our understanding of prehistory. This discussion calls attention to the advantages and disadvantages of these techniques, as well as add to the on-going debate regarding material culture and typology. Thus it is a mixture between a theoretical and a methodological discussion, with a focus on the middle ground.

1.1 The study and its background

The purpose of this study is twofold. It is first and foremost meant to discuss the implementations of digital documentation and analyses in material studies. As mentioned, archaeology centres on the study of material culture and on the contexts, and relations between these two components. Thus there is what I choose to define as a *macro*- and a *micro*-scale within the discipline, where *macro* aims at addressing the relations between contexts, sites and landscapes as well as these entities in themselves. The *micro*-scale aims at the material studies, typologies and chronologies established through the artefacts (Malmer 1962: 14ff). While these two levels of archaeological studies are closely intertwined, they take their starting point in very different kinds of praxis and *mentality* towards the source material.

The recent increase in digital documentation solutions and approaches in archaeology has primarily been aimed at the macro-scale, lending tools and understanding to larger surveys of landscapes, inter-site and intra-site relations. This adoption of technology was mainly done to tackle the problems of field archaeology, caused by large-scale datasets and the need to manage and visualise vast contextual relations, such as in landscape archaeology or on intra-site levels (Conolly & Lake 2006: 33ff; Kimball 2014: 14ff). More recent adaptations to address the issues of visualising a 3D environment are in building archaeology, which has long struggled with the drawbacks of 2D documentation (Besora et al 2008). This implies that the use of technological solutions are on the forefront in field archaeology, while other parts of the discipline might be in need of an update.

Many of the possibilities for using these techniques in material studies, on a *micro*-scale, are yet to be firmly established. It is therefore the purpose of this thesis to address these issues, and to evaluate what advantages there are to gain from utilizing these digital documentation and analysis methods, but also to pin-point any disadvantages or problems that should be taken into account when utilizing the method. Focus should be kept on how the technology can achieve improved or new information concerning the artefacts.

As the discipline stands today, the practice of material study is firmly rooted in the use of typologies. Many artefacts are more often than not categorised by their geometric appearance (such as dimensions, curvatures and/or decorative elements) to construct relative chronologies for each 'typology' of artefacts. These relative chronologies are then tied to an absolute chronology, often by comparing multiple artefact typologies from the same context and by making use of absolute dating methods, such as radiocarbon dating (Malmer, 1962: 34ff).

The use of typologies is a good starting point for understanding past societies, as they provide the necessary *cultural characteristics* of a given point in time. There are however aspects of this practice that have been under some critique. Typologization is based on the independent observations by a human being (the researcher/archaeologist), meaning that there is an element of subjectivity. This problem has been discussed at lengths by Malmer (1962: 12ff; 1980: 260ff; 2002: 173ff) who, since the 1960s, has called for a more objective approach towards typology. Not only did he criticize the impressionistic and subjective elements often present in earlier typological descriptions (pre-1960s/before the introduction of New Archaeology), but also highlighted the possibilities of an objective approach by focusing on independent characteristics and traits on the artefacts (Malmer 1962: 12ff). Malmer's main point was the need for an objective framework for typological studies, with a work-flow based on independent measurements and mathematical proportions rather than the impressionistic descriptions conducted previously. The problem of how to objectively identify these traits and characteristics does, however, remain. In addition, the underlying mentality still leans on what O. Montelius (1884: 4f) meant was the *researcher's knowledge and expertise* of the material, and the conveyed understanding of its underlying type. This mentality and attitude is perhaps the very core of subjectivity, and while it has been addressed it has surely not been successfully tackled.

Discussions regarding objectivity are still very much ongoing, often relating to the lingering typologies from before the call for objectivity. Some of the early typologies have been revised entirely (Solberg, 1984), while others, such as the Norwegian Viking Age sword typology by Jan Petersen (1919) are still actively cited today (Androshouk 2014). Modern typologies are often structured after the 'objective' and geometrical criteria for types as advocated by Malmer: such as the typology of Iron Age spearheads by Ilkjaer (1990) or the late Iron Age spearhead typology by Solberg (1984), to mention some of those encountered in this study. Even these 'objective typologies' have subjective influences that might be unnecessary when put in context. The question that stands is: how then can this field be further improved upon by an implementation of digital techniques?

This connects to the second purpose of the thesis, namely the discussion regarding objectivity, documentation and typology. In his argumentation on the standards of how to properly study artefacts, more specifically Viking Age swords, Androshouk (2014: 17ff) finds the archaeological record fragmented and subjective in its documentation. This critique is mostly aimed at the written documentation of artefacts, but also towards the illustrative descriptions presented by drawings and photographs (ibid: 28). He further addresses the presence of '*mimesis*' in the archaeological science, the practice of utilizing 2D copies/photos of original artefacts as basis for interpretations and our attitude towards using these copies. The interpretations of the material itself might be affected by the notion that they are based on 'fakes' or incomplete copies rather than the original artefact. The general problem is that the archaeological source material is in fact "*three-dimensional originals and two-dimensional copies: drawings, sketches, pictures, photographs, and cross-section drawings*" (ibid: 17f). The problems of representation and lacking illustration limits the researcher's ability to make *correct* and *objective* observations on which to base the later *subjective* interpretations. With the use of digital technologies, it should be possible for archaeologists to properly tackle this dilemma. For this to be achieved, however, a change in mentality and attitude is crucial.

Another issue that has not been as thoroughly discussed in the material culture debate is that of *mentality* and how *archaeologists* regard the source material. The discussion is often centred on artefact interpretation and practical methods, not on the underlying attitude. Deeply rooted in the studies of archaeological material is the idea that three dimensions (*3D*) can be adequately documented in two dimensions (*2D*). The problem is not entirely limited to the issue of material studies, but is rather common in the discipline. With the recent rise of 3D documentation in field, landscape and buildings archaeology, however, the development and adoption of a new *3D mentality* is in progress. The problem of regarding a 3D artefact in 2D has been addressed previously but is primarily linked with the logistic difficulties of material studies. This is due to the fact that the artefacts are often located at different institutions and not always readily available for examination or documentation, meaning that material studies has come to rely on 2D 'copies'/depictions of the originals for their ease-of-access (Androshouk 2014: 17f). The optimal option is however often determined to be to examine the physical objects themselves to obtain a complete knowledge of the material (ibid 2014: 17f, 28f), a solution already advocated in the late nineteenth/early twentieth century (Montelius 1884: 1ff). This too is problematic, if access to the material is possible, as most artefacts are in a constant state of decay, meaning that each examination risks to damage the material, making the issue of mentality also one of *source material preservation*. The discussion regarding digital methodology must thus also be put into relation with the mentality of the archaeological discipline, to allow the archaeological discipline to fully take advantage of the digital method.

1.1.1 Research Questions

These problems are the focal points of this thesis, aimed to not only discuss the tools of digital archaeology, but also the implementation, theory, difficulties and effects that such an approach brings. As such, the aims of this thesis can be summarised into the following research questions:

- *How does a digital documentation and analysis method improve and affect the practice of material studies?*

- *What are the limitations of such a digital method?*
- *How does this alternative method fit into the theoretical discussion of material studies and typology?*

1.2 Material and Methods

This study seeks to test and stress the utility of 3D-modelling of archaeological artefacts and the analyses that benefit from or are available through this type of documentation. Therefore it was of great importance to use a material that would allow for a suitable basis for the analyses. In theory, this study would be possible on a wide range of artefacts types, as will be discussed later on, but as I had previously worked with weapon-finds and there was a material available for documentation, a weapon deposit from Uppåkra was chosen. The deposit contained 136 spearheads from the Late Roman Iron Age, Migration Period and early Viking Age (Helgesson 2004: 224f), and were kindly supplied by Lunds Universitets Historiska Museum. The spearheads allowed for a large spread in terms of size, wear and morphologic complexity. As this thesis will primarily focus on discussing the method and its implications, there will be a limited discussion regarding the specific artefact-group, and the material should be regarded as a case study rather than a detailed material study (for a more in-depth analysis of the material, in regards to traditional typological classification and interpretation of damage, see Helgesson 2004 and Andersson 2012 respectively).

One of the main focal points of the study is to evaluate the possible application and work-flow of 3D documentation as an archaeological method for material studies. As a detailed analysis of the material requires a good initial documentation, the material was documented in 3D using a high-precision laser scanner. The scanner used was a NextEngine 3D Laser-scanner, which in itself has a number of limits that should and will be discussed later on (see *Ch. 6.1 Limitations*). The 3D scanner focuses on capturing the physical shape and geometry of the artefact, important secondary data such as the attribute-data (*type, weight, material, etc.*) was therefore compiled as part of the documentation process. The artefacts were linked to the attribute-data through an artefact-unique database, constructed through the use of a 3D GIS software.

As part of the discussion for the use of digital methods, a series of analyses will be presented. A surface analysis of the artefact was conducted, employing some of the methods often used in landscape archaeology. In essence, the techniques used in landscape analysis are aimed to address topological issues, and the surface of artefacts presented a suitable area of investigation for material studies. An analysis into the damages and deformations of the artefacts was also conducted. This was not as much aimed at addressing the issue of how and why the artefacts were damaged or deformed, but rather at identifying the extents and characteristics of the anomalies. This was to supply a suitable basis for further interpretations at a later stage of the material study work-flow. A detailed study and 3D documentation of the finds might yield important information regarding the state of the weapons, both current and at time of deposit, lending additional understanding. Other digital analyses, such as artefact manipulation and reconstruction will also be discussed later on (see Ch. *4. Digital Analyses*).

This methodological approach will also be connected to and discussed in regard to usefulness in cultural heritage work concerning artefacts as well as the general mentality surrounding material culture and the archaeological source material. As is the case with the Iron Age spearheads used in this study, large quantities of the archaeological source material are in a constant state of deterioration, meaning that there are needs to establish *sustainable methods* to ensure the continued accessibility to the material for further and future analyses.

In order to properly put these new methods into the current scientific context, it is central to put it into relation with the current state and praxis of material studies. The sources for this will be the extensive literature on the subject. There is a large quantity of material studies to be consulted, being as they are the very foundations of archaeology. It was, however, important to approach this quantity from the right angle, to keep a coherent discussion. Thus the main portion of the material cited will deal with similar categories of finds as those used in the thesis itself, i.e. weapon studies, as many of the find characteristics are recurring and the methodological work-flows are much more easily compared with similar starting points. Still, it is also important to include other, more general typological and theoretical discussions dealing with these problems, such as those of O. Montelius (1884), M.P. Malmer (1962; 1980; 2002) and L.S. Klejn (1982). Therefore this study will aim at drawing on the discussions of material-bound investigations as well as more generally theoretic discussions on typology.

1.2.1 Definitions of Digitization

Before proceeding, there might be need for a small clarification on some of the terms used throughout this thesis. The most commonly mentioned, but not self-explanatory term is that of a *3D Model*. While there are several types and variations of 3D models, all can be described as a virtual medium which allows for the display of all three physical dimensions, as they are presented in the 'real world'. The medium is thus a *virtual* representation of a physical artefact, and allows for access to the morphology of the object (Szelski 2010: 3f, 594ff). Most models also allow for access to the geometrical properties, but this requires that the virtual model contains the correct measurements of the real object. The scientific applications of these models are one of the primary aims of the thesis, and as such they will be discussed further later on (*see Ch. 7.3. Digitizing the Material Culture*).

Morphology is another term of frequent use that should be defined properly. When discussing the outward appearance and characteristics of an object, the term morphology is meant to represent these attributes. It should be regarded as a term conveying the overall shape and form of the object, and can in some respects be likened to *geometry*. Geometry is, however, less inclined towards the shape and appearance of the object and aimed at its metrical properties, such as measurements and absolute extent of features/anomalies. The morphology is the visual aspect of an object, while geometry is the absolute metric data that makes up the object.

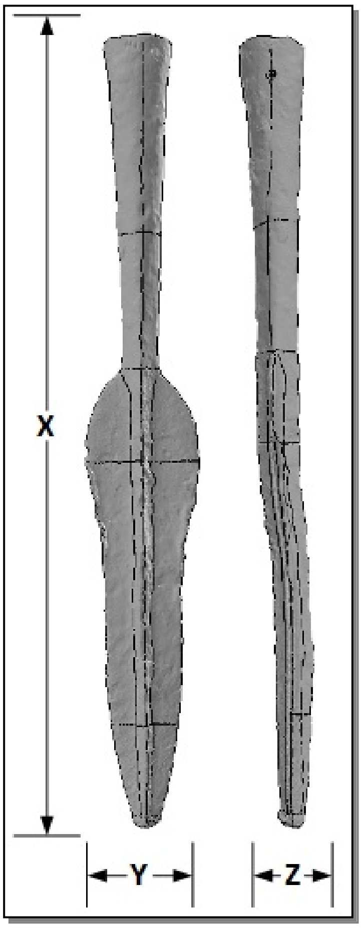

Fig. 1. Dimensions of a spearhead.

Dimensionality is always a problematic subject. As such, it might be warranted to clarify the terms and definitions of *bi-dimensional (2D)* and *three-dimensional (3D)* used in the thesis, to avoid confusion. As the selected material consists of Iron Age spearheads, it is only suitable to illustrate this on said material. The three physical dimensions are here labelled as *height (X), width (Y)* and *depth (Z)* (fig. 1). The *height* of the spearheads are considered from the base of the socket to the tip of the spear point. The *width* denotes the distance between the side-edges of the blade at its widest point, or in the case of a circular spearhead it denotes the distance between the rivets/rivet-holes on either side of the socket. Thus, the *depth* is regarded as the 'thicknesses' of the spearheads, being co-axial from the *width*. A 2D representation only incorporates two of these dimensions at a time, while a 3D visualisation allows for the display of all the mentioned dimensions. As seen in fig. 1 where multiple angles are required for the display of multiple dimensions in 2D. The picture properly illustrates the selected angles, but does not allow any information regarding other angles to be accessed, such as the opposite side of the spearhead.

While *typology* is quite commonly used in archaeology and might be considered one of the more 'basic terms' of the discipline, there might some need of clarification. Typology is both a methodology and a theoretical framework, and these together are termed as the *typological approach*. As a method, which typology is commonly referred to as, it is the act of categorising artefacts or material culture into distinctive types, based on their physical properties. These types can then be put into relation with each other, constructing typological series, which serves as relative chronologies of the specific artefact-type. Most common is the sorting depending on geometrically recurring patterns or specific shapes. The theoretical aspect of typology is much more complicated, as it contains all the discussions regarding *how a type is determined*, the *subjectivity* or *reliability* of the method and the underlying *mentality* that accompanies the approach (see *Ch. 7.1. Typology - Objectivity vs.*

Subjectivity). In this thesis, the term *typology* is used as a concept of the typological approach as a whole, as the method and theory are co-dependant, and should be regarded as such.

1.3 Limitations of the study

The study is primarily aiming at testing and evaluating the use of 3D techniques in material studies. As such, the focus of the investigation will centre on the problems related to the topic, and regards the chosen material from this perspective. Other interpretations, such as the ritual aspect of weapon deposits, contextual interpretations and the symbolism of the spear will not be the main issues of this thesis. Due to time-constraints it was not possible to include all of the 136 spears found in the weapon deposit: instead a selection was made from the available material. The choice of spearheads was based on geometrical complexity, damages/deformations, size and 'type' to provide a challenging basis for the method. Artefacts that were too deteriorated to handle properly were not selected due to preservation purposes, relating to the question of methodological limitations that should be addressed later on (see *Ch. 6.1 Limitations*). It should be noted that the material of this analysis will hold a secondary position, being primarily used for illustration purposes and to test the technique, and the focal point will instead be directed towards the digital method. A total of 19 spearheads were documented and included into the study, meaning that a selection of some 14% of the material is taken into account, which might be interesting to note for future discussions or studies.

Regarding the multiple options of equipment and software for the digital documentation, this thesis aimed at addressing its problems in the highest possible detail, leading to the use of 3D scanning as the chosen documentation method. This is to ensure a comprehensive capture of the surfaces of the artefacts to be able to illustrate some of the more detail-oriented analyses available. Thus there will be no direct tests or evaluations of different technologies, instead a brief discussion regarding the alternative technologies will be presented (see Ch. *5. Alternative Methods of Documentation*). The use of 3D scanning could be regarded as the higher end of the spectrum of available equipment, in regards to overall quality, the use of which allows for a discussion towards the possibilities of the 'lower quality' options.

The upper limit of the artefacts that fit into the NextEngine 3D scanner is roughly 30 centimetres, or 12 inches. The effect by this limitation is that larger objects must be scanned in several chunks, drastically lengthening the documentation time. To maximize the time-use of the scanner, this study focused on artefacts that 'fit into' the scanner i.e. smaller than 30 centimetres, meaning that some spearheads were not selected due to size. This is a limitation of equipment that will be addressed later on (see *Ch. 6.1.1. The Equipment*) and that directly relates to the discussion regarding time-consumption and efficiency (see Ch. *7.3.2 Time-Consumption and Technical Expertise*).

As this study is somewhat limited in terms of time and mainly serves as a basis for discussion and illustration only a selection of the spearheads will be subjected to each type of analysis.

1.4 Previous research and scientific background

Typology is, as previously mentioned, perceived as the foundation upon which material study, and by extension archaeology, has come to stand (Sørensen 2015: 85f). Every particular type of artefact has long been subjected to typological research, the practice of comparing and structuring artefacts into relative chronologies based on their morphology and geometrically distinctive elements. This practice dates back to the earliest days of scientific archaeology, when the artefacts were the primary concern of excavators and archaeologists, with little attention paid to the larger context of the sites. This point-of-view and the establishment of typology has long been credited to O. Montelius, H. Hildebrand and P. Rivers, thus dating it back to the late 19th and early 20th centuries (Caple 2006:48f; Sørensen 2015:86f). It was a firm belief that the material culture was a direct representation of the ideology, mentality and technology of a given society. This still rings true in most archaeological approaches a century later, even if contexts and spatiality have been given more focus as the discipline has progressed.

As typology is very much alive and used in modern archaeology, there has been a rising discussion regarding its applications and implications on the discipline. Malmer (1962; 1980; 2002) began criticising the practice in the 1960s, probably closely linked to the processual attitudes of the time, meaning that there was a need to look into how material studies were performed. His attitude towards typology has come to be the foundation of the objective typological discussion. Malmer (1962: 32f) is quite obvious in his adoration of natural sciences and the need for archaeology to move away from the purely interpretative practice of traditional archaeology. He also tried and quite successfully managed to influence the discipline towards a more strict approach dependant on *objective* observations that could be measured and reproduced. Still, Malmer clung to several aspects of the original subjective notions in typology. His argumentation primarily addressed the need for a new methodology and did not address the need for a change in mentality.

Following this there has been a steady flow of greater or lesser contributions to the debate, often in the form of discussions connected to the establishment of a new typology (e.g. Solberg 1984: 1ff; Jakobsson 1992: 12f; Androshuchuk 2014: 13ff, 29ff). Several such new typological investigations have been conducted since the time of Malmer, often following his strictly 'objective' point-of-view (e.g. Solberg 1984; Thålin-Bergman 2005; Androshouk, 2013). Another prominent, though somewhat neglected, author that has addressed the problems of typology is Klejn (1982: 17ff), who quite interestingly points out that some of the fundamentals of typology are not necessarily discussed, thus expanding upon the discussion started by Malmer. Klejn, in contrast to Malmer, moved the discussion beyond the purely methodological aspect and addresses issues regarding terminology (ibid: 35ff), how types are 'verified' (ibid: 31f; 51ff) and the need for a coherent theoretical point-of-view behind the practice of typology (ibid: 10ff; 51ff; 106ff).

While there have been many practical and some theoretical discussions regarding the typological approach, the underlying structure of object evaluation has often been the same. Few researchers have taken up the possibilities of implementing new technologies and solutions to the field of material studies, even though many of the experiments have presented interesting results. M. Neiß (2013) has conducted several analytical studies regarding the use of 3D scanning on Viking Age materials, with a special focus towards artefact reconstruction and interpretation. A similar study was undertaken by C. Hedenstierna-Jonson (2006: 81ff) in her doctoral work, though the resulting discussion regarding 3D applications was not overly positive. P. Cignoni and R. Scopigno (2008) discussed the use of 3D technology in cultural heritage studies and illustrate its use with a good overview of the general application of the method. Another publication worth of note is the 3D pipeline presented by the Idaho Virtualization Laboratory (Holmer et al 2014), which presents an overview of the possible ways to employ digitization in cultural heritage works and how to manage the subsequent need for transparency through meta-data. The discussions, however, are primarily aimed towards the practical possibilities of the digital method and not necessarily the implications and theoretical issues it presents.

With regards to the material studies at hand, it might be worth mentioning the works conducted by A. Bevan et al. (2014) and X.J. Li et al. (2011) on the terracotta warriors of China. Both studies used digital technologies to tackle a specific set of research questions that would otherwise be problematic. Bevan, et al. (2014) made photo-documentations and image-based models of the facial features and ears of the terracotta warriors and conducted a comparative study of the resulting data, focusing on shape analyses. The study (ibid: 252f) raised the issue of using digital methods for conducting large scale detail-oriented analysis of archaeological features, both in the form of visualisation and surface analysis. Li, et al. (2011) on the other hand focused on the bronze weapons of the warrior-statues, searching for signs of standardisation by 'type-determining' the weapons through markings and inscriptions. The methodology focused on visualising microscopic markings and damages on the surfaces of the material, to determine previous use and/or crafting techniques and thus providing more detailed data regarding the case study. While both studies make extensive and innovative use of the available digital methods, there is a limited discussion regarding the implications of the methods. Focus is aimed at the possibilities in the particular case study and not necessarily the broader archaeological implications.

There have also been methodological debates and discussions regarding the use of virtual methods and representations in cultural heritage work (e.g. Goodrick and Gillings 1996).

These discussions were instigated in the mid-1990's with the steady increase of digital applications and technologies, and have come to be summarised in the 'London Charter' – a framework and on-going discussion regarding how to establish *guidelines* in relation to the implementation of a digital method. (London Charter, 2006). This discussion is strongly connected to the call for intellectual transparency and the establishment of new methods of sustainable documentation, focused on the accessibility and credibility of produced research data. There are, however, limited specifics in the charter, which focuses on the pre-praxis of digital establishment and not on a specific method or field of study.

2. Typological theory – subjectivity and archaeology

When dealing with material studies, it seems quite natural to structure artefacts into groups. It is human nature to structure our surroundings to better understand them. How then, does one structure a set of artefacts without any predetermined indication of their relation to one another? The answer was found quite early on in the history of material studies and archaeology: H. Hildebrand and O. Montelius (1884: 1ff) both identified their idea of the underlying structures that were termed typology. These structures, or types, were thought to easily be identifiable by a *sufficiently skilled scientist* (ibid: 4f; Klejn 1982: 39ff). The material was perceived as being ordered, by its very nature, by underlying typological structures, as they sprung from different ideas in their creation (Karlin & Julien 1994: 154ff; Schlanger 1994: 144ff). It was instead the task of the scientist to properly identify these underlying structures and ideologies and to order the material through them.

The simple logic of early archaeology was based on the statement that morphologically similar artefacts found under similar circumstances are inherently part of the same 'type'. Malmer (1962: 14f) illustrates this by the expressions: $A = A$, and $A \neq B$. This is a rather simple mathematical illustration that captures the core of typology. But how then, do we define A and B respectively? What problems arise when we take into account smaller *variations* within the same type, and when do these *variations* give rise to a new type? How do we determine if $A = a$, or if $A \neq a$? The identification of types are built upon the observation of the geometrical and morphological elements that make up the artefact. The definition of a *skilled scientist* by Montelius (1884) is deemed by one's ability to identify these elements as indicators of types. Following the establishment of these types, it is possible to determine the order of the types themselves (e.g. Caple 2006:48ff). But as the question was posed earlier, how does one differentiate one artefact from another on a scientific basis?

With the establishment of several types, there is a need to structure these types into relative chronologies. One artefact-type evolves into another, and this evolution can be used to establish the direction and order of the chronological series (Malmer 1962: 35ff). But how does one determine which artefacts should be included in such a series? And is it possible, or even relevant, to do so objectively? This links to the idea of artefact-purpose. The first subjective interpretation made by archaeologists is made very well before the type is determined. An artefact can be objectively observed as an artefact or an object, but it is not until the artefact is identified as having a specific purpose or usage that the artefact gains a subjective idea inflicted upon it. A piece of flint or iron can be regarded as such, an independent object, but it is not until someone determines its use as a flint axe or a spearhead that it is subjectively observed and labelled. This is a quite fundamental problem that has largely been omitted in the typological discussion, and that should be approached (see Ch. *7.1 Typology – Objectivity vs. Subjectivity*).

As has been noted here, there are several central problems present in the typological approach, as a method, a theory and in the underlying mentality. One was the argument put forward by Malmer (1962; 1980; 2002), which has been continued by multiple researchers after him (e.g. Ilkjaer 1990; Solberg 1984; Thålin-Bergman 2005), namely the subjectively descriptive nature of the act of type-determination. While Montelius has been criticised time and time again for his artistic and vague descriptions, Malmer (1962: 28ff) puts emphasis on the need for researchers to accurately pin-point a large quantity of, as he puts it, *independent typological elements* (my own translation). His arguments are anchored in the need for methods to identify these *elements*, which leads to the adaptation of a standardised, measurement-based technique, akin to those found in natural sciences. His main focus was reproducibility and transparency, which is typical for the processual school of archaeology, but the key drawback is found in the definition of these *independent typological elements*. How is the identification of these elements any less subjective from the identifications conducted by Montelius, and how do they imply a 'better' scientific practice?

Hurcombe (2007: 55f) pin-points the essence of typology and what, by extension, the problems with the practice are. Typology is a method of categorising material culture according to a set of predetermined criteria, imposed upon the material by the *observer*. The criteria set upon the material are interchangeable in accordance to the needs and desires of the observer. There are therefore innumerable ways to categorise a series of artefacts, both by the same observer and by any number of other observers (Caple 2006:48f). By extension, this implies that the ways to conduct typological evaluations are dependent on the choices or *sampling* of the observer/researcher/archaeologist (Drennan 2009: 79ff). Typology, however, is quite well established in archaeology, and the reason for this is the shared questions regarding time and order that are recurring in the archaeological work, the chronology and context. The method, simply put, was and is a good tool for achieving the knowledge archaeologists need. Still, typology is meant to be the basis for further interpretations, therefore it should be desirable that this basis is built on *objective* observations, rather than subjective. We must still acknowledge that archaeology, in its most fundamental form, is a science based on interpretations. As such it is not possible to fully move away from the subjective nature of the discipline. Instead we should seek to establish where the limits between subjective and objective observations should be drawn. And the tools for establishing these limits might be found in the application of a digital method and mind-set.

Keeping these theoretical point-of-views in mind, there is also a need for a balanced approach between objective observations and subjective interpretations, in order to make sure the practice of material studies does not stagnate into pure theoretical issues. Focus should be kept on the source material at hand and the research questions posed, with a mind-set towards conducting sustainable and credible research, thus returning us to the need for theoretical discussions. And thus, this thesis will do much the same in now turning to the source material.

3. Modus Operandi

The following work-flows are presented to illustrate the current and potential praxis of material studies, to provide a point of reference and a basis for further discussion. For the sake of clarity it should be noted that the part concerning 'traditional' material studies has been constructed through literary studies of how a series of authors have described their work-flows, which has been combined with a more general outline of the process (Malmer 1962; Solberg 1984; Ilkjaer 1990; Jakobsson 1992; Peirce 2004; Jensen 2008; Androshouk 2014). As such, there will be limited references to specific authors in the following sub-chapter. The digital method, however, is the product of the documentation campaign conducted within the extent of this thesis, and has primarily been structured to provide a good overview of the work-process.

3.1 Traditional Material Studies

In order to properly assess the usefulness of a new method, it is necessary to look back at what is already in use. Here follows a general work-flow (fig. 2), which stands as an outline to be put in relation with the later digital method.

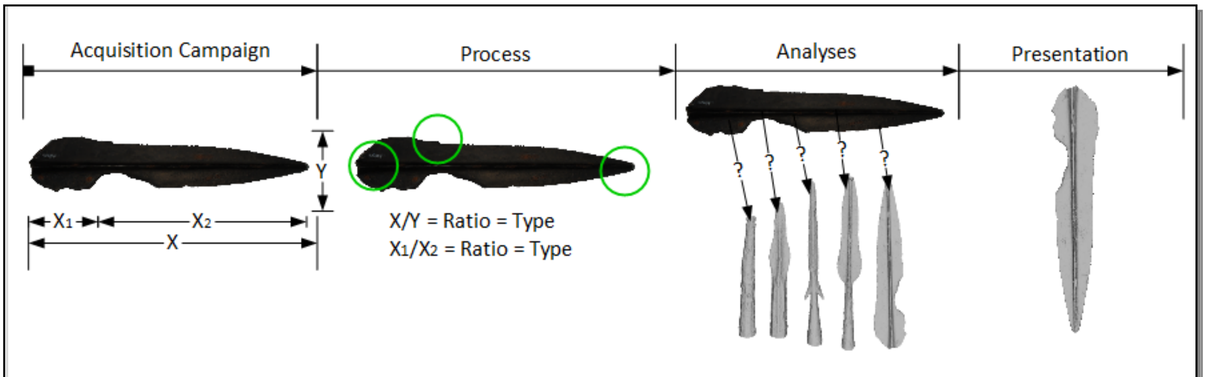

Fig. 2. A 'traditional' typological work-flow, where the artefact is documented with regards to different predetermined ratios, followed by feature identification and classification. The artefact is matched into its typological context and presented.

3.1.1 Acquisition campaign

The traditional method has its starting point in the observation and examination, not of the single object, but of the entire chosen material. The first problem that needs addressing is the identification of comparable traits and features. The researcher must establish which parts of the objects that are of interest to the posed research questions and what aspects that should be included in the documentation campaign (Solberg 1984: 2f). Depending on the research questions posed, the mode, method and extent of the campaign might differ (e.g. Androshouk 2014; compared with Thålin-Bergman 2005).

Following this the focus turns to the single object. Most often the emphasis is put on the capturing of morphological and geometric data, such as contours and dimensions. This is one of the aspects that have been subject to change. During the Montelius era, up until the processual 1960s, the practice focused on describing the artefact in great detail with illustrations and written testaments, with more focus put on the morphology of the material. After the shift towards the processual approach the descriptions were substituted with measurements and ratios, which seek to objectively capture the properties of the artefact. This instead inclined towards a favouring of geometric documentation. This more structured approach is the most commonly used in current examinations and typologies, and might be considered the current 'standard' mode of investigation. The goals of collecting these data are to compile and compare them through mathematical and logical examinations and interpretations (Malmer 1962).

Common practice is that the object of study is copied to a scaled drawing, with several of the most important measurements/features depicted. In the case of weapon studies, great effort is put on capturing the overall length, width and height of the object, as well as these dimensions for individual components, such as blade, hilt or socket (e.g. Ilkjaer, 1990). Other studies also put emphasis on the type or composition of materials and/or the existence of decorative elements (e.g. Bevan et al 2014: 250ff).

When it comes to the documentation and accessibility of the source material, it is necessary to address the mediation of the material to the researcher. Many archaeologists agree that the most desirable way is through 'hands-on' documentation. Sometimes, however, difficulties arise and the documentation must be done through other sources, such as photographs or textual descriptions made by previous studies. This adds another layer of complexity to the documentation campaign, as the material might be more or less accessible. This also relates to the value of *truth* that can be claimed by the 'copies' and the credibility of a documentation and analysis conducted on second-hand sources.

3.1.2 Processing

The following acts of type-determination are often based upon the data collected, by establishing a morphological norm for each 'type'. The standards for the deviation within each type are also established through similar comparative studies. There is also a need for construction of a relative chronology and to establish its direction (which artefact that is oldest or youngest). To guide this, archaeologists often turn to contextual studies, to see what other, possibly dated, artefacts were found in the same context (Malmer 1962: 26f, 30f; Peirce, 2004). It is quite common that the construction of such typological series are based on other typological series. To further anchor the relative chronology it is often related to an absolute chronology, which are based on (natural) scientific methods, such as dendrochronology or carbon dating (Malmer 1962: 34).

Consequently, many material studies are conducted based on already established typologies, where the documentation is often structured to follow the 'guidelines' established by the previous typology to allow for type-determinations. In addition to this, the documentation also requires the collection of data relevant to the specific research questions at hand.

3.1.3 Analysing the material

Following the typological classification of the objects of study, further analysis can be performed. This might range from geographical spread and ideological influences across regions to the detailed studies of craftsmanship and raw material usage. The common denominator is that there is a requirement to have the object put in its proper context as well as their time in order to conduct these analyses, which is supplied through the typological praxis. In addition to this, each type of analysis demands a specific dataset of additional information of the object. Weight, material and deterioration are crucial for some investigations, while entirely redundant to others. One example is the conduction of X-ray investigations as part of the documentation campaign. In the few cases where this has been performed, it was meant to answer specific research questions (Solberg 1984: 2ff; Thålin-Bergman 2005: 2ff). Therefore it is a constant balance between documenting for the sole purpose of a single investigation or to do a complete documentation.

3.1.4 Representation and Publication

When presenting the study of artefacts, be it a complete typology or a case study, there is always a need for graphical representation, which has to be adapted to the target audience. The level of detail might vary depending on if the aim is to present the material to the general public or to the scientific community. A public audience generally requires less detail and not necessarily all the data, while this might be required by the scientific community in order to present a degree of credibility and intellectual transparency to the study. For subsequent scientific studies to be able to build further upon the initial study, there might also be the need for publications regarding the raw data, catalogues or other appendices, which might not be relevant to non-specialists. Additional information about the information, so-called *meta-data*, might also be relevant to explain not only the object of study but also the circumstances surrounding the object and the initial study (Wise & Miller, 2007; Holmer 2014:29f).

The old saying: 'A picture says more than a thousand words', is quite accurate in archaeology, as it allows for a more direct representation than written descriptions. By allowing the audience to visually perceive the object, more complex inter-relations between features can be illustrated than if one was to put them in words. The perhaps most popular way of depicting an artefact is through photography, as this is seen as a more direct representation. Another method still in use is hand-made drawings, plans and cross-sections. The use of such representations are often closely connected with the requirement to present measurements and ratios, which can be illustrated 'directly on' the object. The use of subjective drawings also allows for the conveyance of selected features or traits that are relevant to the study, as only the desired features are included.

The most crucial part of proper visual representation, in terms of inclusion, is that the drawings, plans and illustrations are depicting a high degree of credible information relevant to the study, since a manual documentation means that any feature that is not included in the documentation is essentially made invisible in the subsequent visualisation. The use of graphical representation in traditional material studies is almost entirely in 2D, some illustrations include shadowing effects to illustrate the third dimension of the artefact. This lack of a complete representation is often tackled by the use of multiple illustrations from multiple angles, or simply by the addition of smaller sections from another perspective. In weapon studies, which often encompass quite thin objects, this is commonly handled by adding a cross-section of the artefact. It should be mentioned that there have been solutions to capture the 3D features of an object in the 'traditional' method as well. The use of plaster casts or wooden copies have long been used as a substitute to investigating the original object, but the precision of such methods and their scientific value might be questioned. The practice is also quite widespread for illustrative purposes (Montelius 1884: 5f; Dell'Unto 2014: 55).

The work-flow usually ends with the publication of the undertaken study, with the inclusion of the data and illustrations necessary for the argumentation. Any surplus data collected, which is not related to the research questions, is often omitted in order to keep to the topic at hand which effectively means that there is a loss of the data that is not published. Thus there is a subsequent reduction of available knowledge for subsequent studies, which by extension has to re-document the same material.

3.2 Digital Material Studies

To properly illustrate the established work-flow of the present study, the following description will encompass the entire digital work process, from acquisition to presentation. Since it is in the interest of the study, the work-flow (fig. 3) will be quite detailed. While this is an example of a work-flow, the general outline of the process could be graphically summarised as in the following chart.

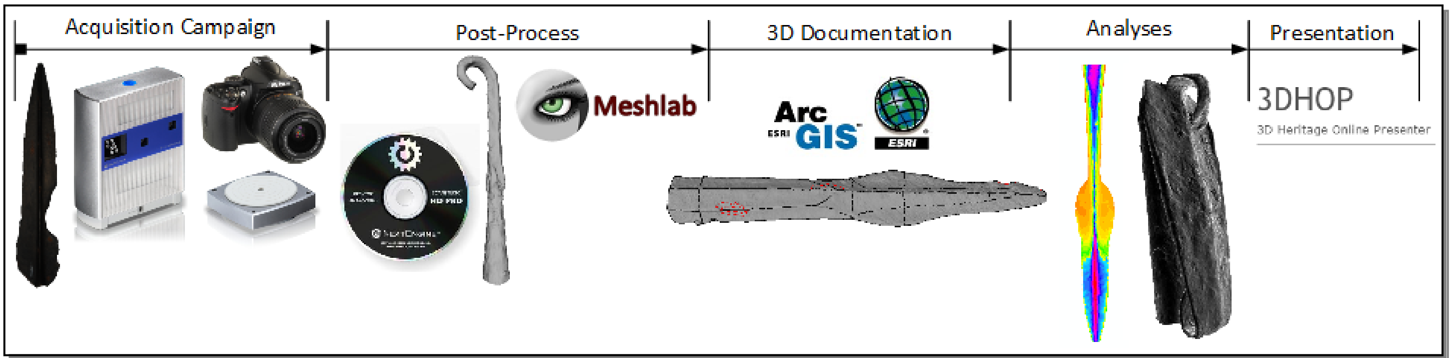

Fig. 3. Digital work-flow of the work process. The artefact is captured using a 3D scanner and a camera. The collected data is post-processed in ScanStudio HD and Meshlab to generate a 3D mesh. The mesh is exported into ArcGIS for a 3D documentation. The 3D models are also subjected to different analytical methods and can later on be published in online or offline databases. Illustration by N. Björk. *All logos and associated concepts © their respective companies.*

3.2.1 Acquisition Campaign

The documentation campaign for this study was structured to achieve a good basis to test the limitations and possibilities of 3D documentation and techniques. In order to properly achieve this goal, a suitable material was needed. The material in question, a weapon deposit unearthed during the excavations in Uppåkra, contained some 136 spearheads. These artefacts showed several geometrical characteristics that would form a suitable basis for the subsequent acquisition campaign.

The technology primarily used in this study is that of 3D laser scanning, which might be considered a wider term of a specific type of equipment. The technology is basically measurement tools which utilizes laser as a signal to determine the distance from the equipment to the object measured. A 3D laser scanner is a tool which measures and calculates several points on the surface of an object to translate these return-signals into a collection of points, which efficiently describes the outward geometry of the object. There are three types of 3D laser scanners primarily used in cultural heritage studies, due to their non-contact nature. There are the *time-of-flight* scanners (such as the Leica ScanStation C10) which calculates the time of a laser-signal to reach the object and return, thus providing the distance from the scanner to the object. The *triangulation* laser scanners (NextEngine) makes use of a sensor to acquire the position of the laser point on the object and then calculates the distance between the sensor, the point and the laser emitter. The *phase-shift*, or structured light, scanners (Faro Photon 80) calculate the distance by determining the changes in the wave-length of the emitted light (San José et al 2011:378f). All three technologies have their pros and cons, which has been discussed at length in various articles and has their specific uses in cultural heritage works (e.g. Balzani et al 2004; Baracchini et al 2004; San José et al 2011; Barsanti et al 2012; Holmer et al 2014).

A *NextEngine 3D Laser Scanner* was used as the primary piece of equipment for this study, which was provided by the Humanities Laboratory at Lund University. The scanner consists of multiple components, the main component being the scanner itself, which makes use of MultiStripe Laser Triangulation as a medium for capturing the geometry of the scanned object, i.e. there are several laser rays simultaneously measuring the surface of the object. The scanner is essentially a laser-measurement tool that captures the position of the object in its relation to the scanner itself, with the added benefit of providing the real-world measurements of the target artefact. The scanner also includes a camera-function for colour information capture, but since it is of medium quality a Nikon D3000 with a DX 18-55mm lens was used for additional photo-documentations to complement the colour information where the NextEngine was found lacking. The computer used to process the scanned data was a Lenovo W520 laptop with Intel Core I7 Processor, 16 GB RAM and an NVidia Quadro 2000M graphics card and a desktop of similar hardware capabilities.

The scanner has three dimension settings, two of which were used during this campaign. The 'Macro' lens, which is suitable up to 5.1" x 3.8" (13 x 9.5 cm) with a DPI of 400 and the 'Wide', which handles objects up to 13.5" x 10.1" (34 x 25.5 cm) at 150 DPI. The scanner also incorporates a rotating platform (*AutoDrive*) with a gripping arm, which allows for fastening of the scanned object to ensure a proper exposure of the surface (fig. 4). The scanner can only document what is visible to the sensors, which is why the platform is an important component in order to gain a coherent documentation. The rotation of the platform is divided into segments, as the scanner requires the object to be stationary, thus each segment corresponds to a single scan sequence. The number of segments is customizable, as is the degree of rotation. A general rule of thumb is that the more segmental scans an object is subjected to, the higher the precision of the captured data. This also directly relates to the balance between sampling and time-consumption of the scanning process, as more segments require more time (see Ch. *6.2 Sampling and Precision* and *7.3.2 Time-Consumption and Technical Expertise).*

Fig. 4. NextEngine 3D scanner with AutoDrive platform, without gripping arm attachment. © *NextEngine Inc.*

The material was, as mentioned previously, strictly limited to suit the timeframe of this project. The selected spearheads, 19 in total, were chosen based on their conservational status as well as their morphological/geometrical properties, with several different 'types' included for diversity. The spearheads were subsequently documented by fastening the artefact on the platform and performing a 'Macro' 360° scan, divided into 12 segments of its geometry (fig. 5). In the case of the spearheads, the easiest way to perform an efficient documentation was to fasten the artefact between the tip of the spear and the base of the socket, exposing the entirety of the blade and sides of the socket to the sensors. As this left the tip and parts of the socket in the 'blind zone' of the scanner, there was need to perform additional documentations of these parts (fig. 6). As such, a minimum of two additional scans were performed per object, one for the socket and one for the tip, each consisting of an approximately 90° (*bracket*) scan, divided into 3 segments. The time-consumption for this basic process is approximately one hour and twenty minutes, with circa fifty-five minutes for the 360° scan and ten minutes per additional 'bracket' scan.

Fig. 5. Fastened spearhead (6762), photographed by the NextEngine 3D scanner. Notice the 'blind zones', i.e. the base and the top areas.

As the geometry and scale of the spearheads differed greatly each spearhead required special attention in order to sufficiently capture all features and angles. As some of the artefacts were too large to fit into the 'Macro' setting (see lens settings above) of the scanner (such as spearhead 4417), these required several acquisitions with different settings. To fully capture the artefact, a coherent 360° scan was conducted in the 'Wide' setting, with complementary scans in 'Macro' on parts of the object previously in the 'blind zone'. Artefacts with greater geometric complexity (such as spearhead 6461 or 6674) also required additional scans, often in the form of additional 'brackets', to successfully capture the entire artefact.

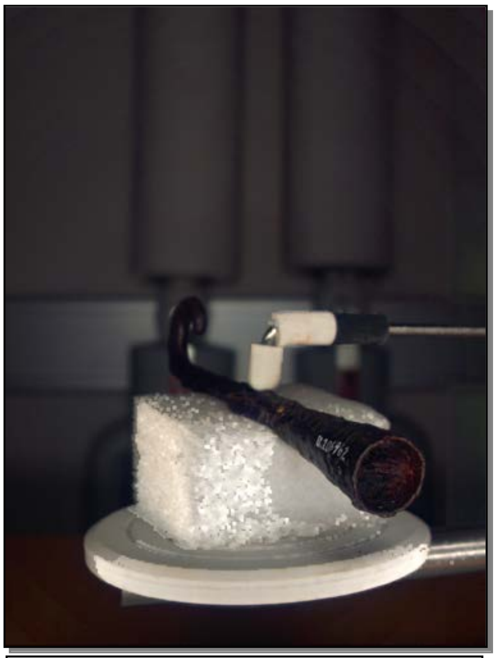

Fig. 6. Attached spearhead (6762), photographed by the NextEngine 3D scanner. Bracket scan of the base of the socket, later merged with the previous scans for a coherent 3D model.

One interest of the study is to evaluate the efficiency of the method, a rough time estimate was noted. A 360° of 12 segments took approximately fifty-four minutes to complete, with no difference between 'Macro' and 'Wide' settings. A 'bracket' of 90°, 3 segments, takes roughly ten minutes to perform. This, with some time for positioning the artefact on the platform, adds up to roughly 1 hour and 30 minutes per artefact on average. If there are needs for additional documentation, such as with spearhead 4417, the acquisition demands more time. The acquisition campaign of this project was conducted during the course of six days, with an estimated work time of six hours per day, successfully documenting 19 spearheads of varying complexity in high precision.

As the laser scanner is essentially autonomous during the scanning process, this time was used to collect additional attribute-data of the objects. This is the type of data that the scanner cannot collect, such as the weight of the object, dating or the typological definition (as determined by Helgesson 2004). There was no additional need to collect measurements of the artefacts, as the scanner captures these details by default, meaning that the model generated has the correct measurements of the original artefact. Following the completion of the acquisition campaign, there was no further need for artefact-handling, as all the necessary data had been acquired.

3.2.2 Post-Processing

The subsequent post-processing step centred on the alignment and cleaning of the generated point-clouds using *ScanStudio HD*, the software associated with the NextEngine scanner. It should here be mentioned that the laser scanner does not generate a complete model of the object, but rather a *dense cloud of points* that are the return-signals measured by the surface of the object (fig. 7). Thus the data acquired from the scanner is in the form of dense point clouds, which often exhibit some 'noise', faulty or miss-measured points that need removal for a smooth model generation. Most often, the software is able to align the separate 'segments' of the scanning without difficulty, though at times it is necessary to manually provide reference points to guide the alignment algorithm.

Fig. 7. Examples of dense point-clouds generated from different segmental scans.

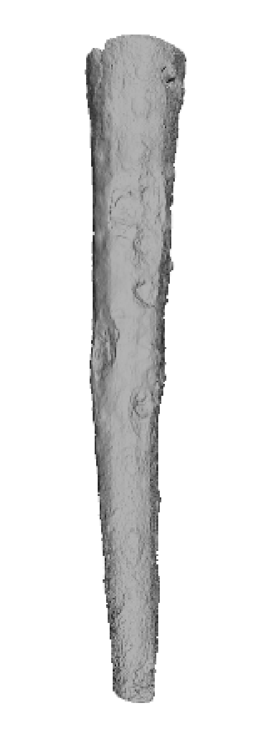

Fig. 8. Poisson-Reconstruction of spearhead 4455.

With a properly aligned and sufficiently 'clean' model, the data can then be exported from ScanStudio HD to *MeshLab* (*1.3.4 BETA*), which allows for the generation of solid 3D models through the application of a Poisson Surface Reconstruction (see Cignoni et al 2008 for a more in-depth discussion). This process runs an algorithm that creates a multitude of triangles that makes up the surface of the model (fig. 8). Simply put: the algorithm selects the three points closest to each other and creates a surface in the space in between the points, repeating the process to create a 'closed' model i.e. without any holes between points. This process implies that there is a small scale of 'simplification', as the surface between the points is completely flat. This 'simplification' is smaller with a higher density of points as there is a smaller surface between the individual points, which is achieved through higher degree of sampling (i.e. higher quality scans or a larger quantity of scans) (see also Ch. *6.2 Sampling and Precision* for further discussion).

As the overall point generation of the scanner is relatively high (see DPI count mentioned above), the model generated though the Poisson is quite heavy and demanding on system hardware. And as the scanner registers the same point on the object from several angles, there are many redundant points included in the generation of the Poisson, as these add no additional geometrical data and only serve to guide the alignment process. Thus it is necessary to limit the density of these points. This achieved through the decimation of the generated vertices of the Poisson model. The decimation process selected for this study was the Quadric Edge Collapse Decimation, as this allows for the option of preserving the edges and contours of the model and thus focusing the decimation to the larger surface areas of the model. This is crucial to the authenticity of the model, as none of the contours are compromised to change due to the simplification process of the decimation. Through classical trial-and-error testing, it was determined that the optimal vertices count of the Poisson

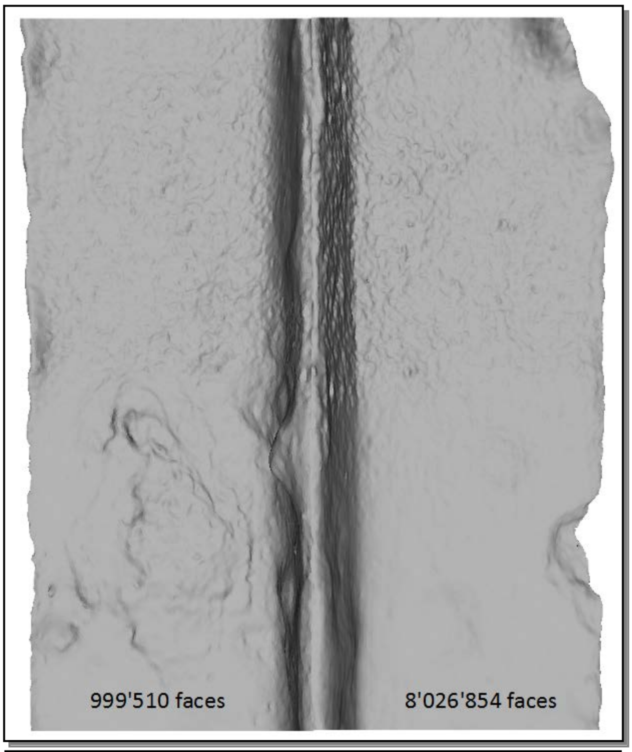

Fig. 9. Comparison between decimated mesh and non-decimated mesh. The differences are barely noticeable while the computational effects are significantly less with less faces.

models should be approximately 1’000’000. This preserved enough geometrical complexity while still being manageable by the software packages used in later analyses. The original complexity of the models ranged from 5’000’000 to 9’000’000 vertices, making the simplification between 1/5 and 1/9 of the original potential of the model. The level of decimation was done to suit the needs of this particular study, but taking into account the very minor simplifications brought on by the decimation, it might be favourable to drastically lower the number of faces to save storage space for future access. The majority of the removed points are often duplicates or so close to each-other that there is minor influence on the geometry, meaning that little-to-no data is lost in the decimation process. The level of decimation must of course be customized to each category of artefact to ensure a decent level of detail while keeping the data manageable (see fig. 9 for comparison).

Thus it could be concluded that the ‘documentation stage’ of the artefact ends with the generation of the full-scale Poisson of the artefact, which is based on the demands on the data from the research questions. Depending on the needs of the study or the desire for a *complete documentation*, it might be necessary to generate a texture containing the colour information of the artefact (see *Ch. 3.2.3. Colour Information*). Following the decimation of the model, it was sufficiently prepared to be exported to the suitable software for further analysis. As for the time-consumption of the post-processing stage: a rough estimate is a processing time of approximately 1-2 hours per model depending on artefact complexity, counting from the initial alignment to the decimation stage. It should be mentioned that most of the time required is tied to autonomous data-processing, such as alignment calculations or Surface Reconstruction. This time estimate is closely linked to the computation power of the hardware. There is however no relation between computation power and model quality, given that the hardware is capable to process the data (see Ch. *6.1.2 Software and Hardware* for additional discussion).

3.2.3 Colour Information

Depending on the research questions posed and the aims of the study, it might be necessary to include the colour information of the artefact. The analyses presented in this study have aimed at the discussion regarding objectivity, documentation and typologies and focusing on the morphology and geometry of the source material. In the case of the Uppåkra spearheads, there is limited information to collect, as the material is quite homogenous in its colour, except for areas of damage and/or deterioration. Thus, the resources of this thesis have been focused on the metrical examinations of the material, rather than on the colour information.

It is, however, often desirable and essential to include colour information for the sake of a *complete documentation*, as discussed later on (see Ch. *7.3. Digitizing the Material Culture)*. To achieve an adequate capture of this documentation, it is often required that a small photo-campaign is conducted in relation to the scanning process. This is the case of the thesis at hand, where parts of the material were photographed (with the Nikon D3000 or by the NextEngine) to generate high-quality textures. A texture is, simply put, a projection of the colour information onto the 3D model in the form of a separate raster image that is linked to the geometry. Another process is that of colour-per-vertex, which allows the surfaces of the model to hold limited colour information. The process of generating colour information (texture or colour-per-vertex) for a specific model is basically an alignment, similar to that mentioned in relation to point-clouds, where the software identifies the correct position/angle of the model in relation to the image. The software can then project the image onto the model and by connecting models from several angles, it is possible to create a coherent colour reconstruction of the object (fig. 10).

Fig. 10. Colour Information transferred as Colour-per-Vertex onto the 3D model of spearhead 4417.

3.2.4 Analysis Overview

There are numerous ways in which to analyse any archaeological material. The traditional methods mentioned earlier can also be applied to a digital documentation campaign, though with some variations to account for the digital nature of the 3D model. Investigations regarding geographical and ideological spreads can be traced through the use of GIS mappings, with the added possibility for database management and system querying, simplifying and improving the work-process. Use-wear analysis can be conducted in the form of anomaly detection. In terms of raw material analyses, this is perhaps the most problematic to join with a digital method, as it is closely tied to the physical object. With sufficient documentation, however, the destructive investigations regarding raw material analysis might be counteracted and complemented through digital means. The virtual model also allows for a close-up examination of the material without any risks of damaging the actual artefact. The added advantages of the digital method are the possibility for object manipulation and reconstruction, which is an addition to the revised analyses of the traditional approach.

A more in-depth account of the digital analytical approaches is presented chapter *4. Digital Analyses*.

3.2.5 Visualisation, Publication and Accessibility

The generated models were primarily meant as an illustration to this study and its argumentation. Therefore, its visual goals have been structured to accommodate the needs in the thesis, recurring as pictures but also as moveable 3D models. The illustrations given here were achieved primarily by screen-capture (*2D*) or generations of pdf-files (*3D*) containing the 3D models, which shows that there is a versatility to the method. The data created in 3D can thus be displayed as both a virtual 3D model or as a 2D depiction, in accordance to the needs of the study.

In terms of publication, there is a limit to publishing this type of data, as it is strictly digital. However, most of the publications of today are published digitally and are very much virtual in their nature. In order for this method to gain additional value, it is favourable to allow for the raw data and necessary meta-data to be made available, primarily to the scientific community in order to improve future research, but also to the general public to allow greater access to the cultural heritage. Thus there should be a difference between the amount of data supplied to the public and to specialists. The 3D model, however, can be reused for both purposes. This can be done in two ways: first of all through this publication, which will contain most of the documentation undertaken through the study (see *Appendix*). The second, more important way is the publication in the form of digital databases. There are limited software packages and scripts available for publishing these kind of databases but, being on the forefront, the creators of MeshLab (*the ISTI - CNR research center*) are working towards an easily accessible software for online presentation, to making 3D models and data more accessible. This software, 3DHOP (*Heritage Online Presenter*), allows for the remote access to large quantities of data (i.e. high quality 3D models) to be viewed in a user-friendly way. It should be noted that this software is still under development and as of now there are limited functionalities besides the viewing of the model. Thus it might prove difficult to properly convey all the data of this thesis at the time of publishing. Further implementations could include measurement tools, vector/raster support and the possibility to securely retrieve the data with the permission of the copyright holder.

It should also be mentioned that through the use of 3D printing technology, it is possible to reproduce a physical copy of the artefact based on the acquired 3D model. This might provide a new way for presenting the material culture to the public, but also allowing for researchers to 'print' reconstructed versions of an artefact. This will unfortunately not be conducted as a part of this study, as there was no time nor access to such equipment.

4. Digital Analyses

Following the completion of the documentation campaign, the data was subjected to several types of analyses to illustrate the possibilities of the digital method. Some other analytical methods will also be mentioned, to relate the use of digital documentation to other analytical methods.

4.1 Contour Analysis and 3D drawings

Perhaps the simplest but most efficient type of artefact analysis is that of contour and feature drawings. The use of such a method relates to the current praxis of 'traditional' (*or bi-dimensional*) material analysis, where an examination of the material is often aimed at capturing individual features and the general shape and outline of the artefact. In this thesis this was conducted using a 3D-based Geographic Information System (GIS).

Fig. 11. 3D drawing conducted on the surface of the 3D model of spearhead 6762. Red areas are designated as deformations/damages and black lines delimit the contours.

GIS is a type of data processing software that aims at the handling of geographical data and at general database management (Conolly & Lake 2006: 11ff). These systems have quickly gained popularity in archaeology, primarily in field archaeology, and have earned the status of a credible and necessary archaeological tool. The power of GIS lies in its ability to compile, combine, store and handle large amounts of data. These data, often in the form of larger database systems, can then be put into relation to each other with visual representations such as maps, drawings or plans (ibid: 33ff). While the software is based on the manipulation and handling geographical data in the form of raster or vector files, there is no limit in the use of GIS software packages in other areas than geographical. One such area is the drawing of artefacts, which in essence is nothing more than creating geometrical shapes of a surface in the form of vector files (fig. 11). The surfaces of a scanned object are considered no different to the software than those of a terrain model or trench wall.

The software used in this study is ESRI's *ArcGIS*, specifically the *3D Analyst extension* of the software known as *ArcScene* (ESRI 2013). ArcGIS is a widely used software package specifically aimed at handling archaeological geographic data. The software allows the user to import 3D models of high quality (*i.e. high resolution geometry and textures*) into the GIS, and for the use of all the basic functionalities of GIS systems mentioned above, primarily those of displaying and handling 3D vector and raster data as well as database management. With the availability of a visualised a 3D model in the software, it is possible to document the features of said model/artefact in high precision (see Ch. *6.2 Sampling and Precision*). The GIS allows for drawings to be done directly on the surface of the 3D model. Given that the 3D model in itself is a quite accurate virtual replica of the 'real', physical object, the drawing generated reflects the reality of the artefact in high precision. This, by extension, allows for more precise analyses and interpretations to be made from the drawings. The technique of establishing 3D-drawings has recently been adopted as support for excavation and survey documentation, using virtual models as a basis for interpretation (see Kovács 2011; Kimball 2014; Forte et al 2015, for similar discussions).

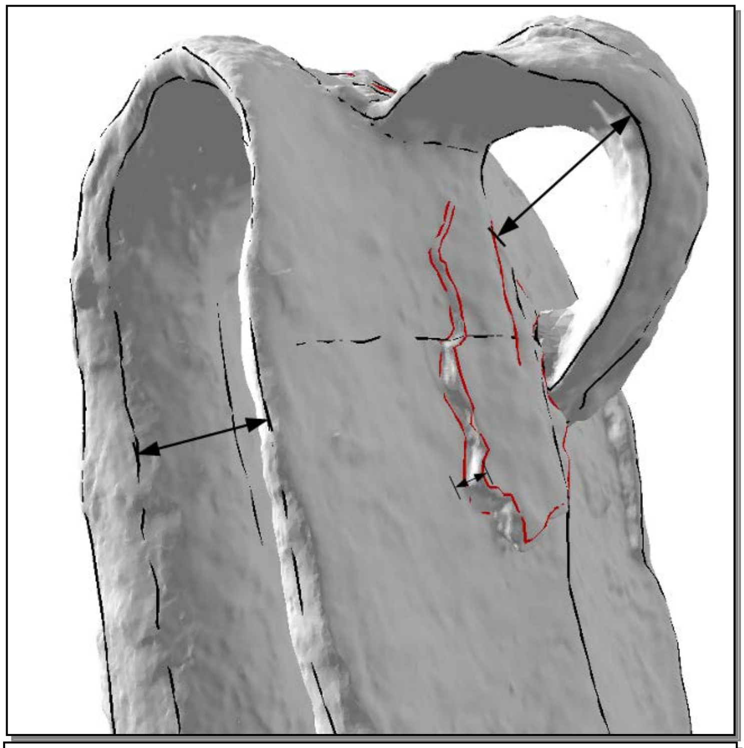

Fig. 12. The 3D model allows for measurements between different elevations at any angle, it also provides a good basis for capturing the differences in elevation between features/contours. (Spearhead 6461).

The features of the artefacts were captured in the form of multi-line vectors and stored in the form of shape-files. The process is almost identical to bi-dimensional GIS documentation, where a feature is identified by the user and documented by circling the outlines and extents with a single vector line. This is a subjective process, and stands as a part of the later interpretation stages of the work-process, it is, however, based on an objective foundation. This lends more credibility to the drawings, as their detail is potentially higher and more accurate compared to a manual 2D documentation and the accessibility to the 3D model allows for corrections and re-evaluations to be easily conducted. Sometimes it was necessary to make use of several lines to properly show the extent and complexity of a contour and to make sure all geometrical aspects were properly illustrated. A single point is not sufficient for documenting geometry, but can easily be used to pin-point areas of interest or to save interesting attribute-date linked to a specific area. Polygons were deemed problematic and not used at all, as the surface area generated in between the outlines of the polygon tend to oversimplify the geometry of the artefact. Through this trial-and-error investigation of the available expressions, it was deemed that multi-lines appeared as best suited for this kind of documentation. It can be added that the vectorisation of a spearhead took somewhere between forty-five minutes and one hour to complete.

As the GIS software allows for points to be placed on the surface of the model itself, it can easily capture small deviations and anomalies by sufficiently precise documentation. Other deformations and features were also documented, divided into categories and sorted into a database. Some of the features, such as the mid-ridge of spearhead 4417 or the deformity of 6461, were given special attention to illustrate the elevation and inter-relation of the surface (fig. 12).

4.2 Surface Analysis

The next type of analysis relates to the high precision of the laser scanner. As the scanner captures/measures the surface of the artefact with sub-millimetre precision, there is enough elevation variety in the data to treat the surface as a landscape. Landscape analysis is quite established within archaeology and is structured to identify the variations, or *anomalies*, in the typology of a landscape (Chapman 2009: 9ff). This is often aimed at reconstructing ancient landscapes and the conditions for a site, settlement, or region. While most of the techniques and technologies available are primarily aimed at a macro-scale landscape perspective, there is no inherent difference between the topography of a piece of land and the geometry of a spearhead, given that the documentation of the spearhead is precise enough. The proposed methodology is aimed at testing landscape-scale-based techniques on a micro-scale level of analysis.

Following is a short overview of the analytic work-flow. The Digital Elevation Model (DEM) analysis is structured to visualise data in 2D but takes into account the third dimension of the dataset, i.e. the 'height' of the object. A DEM is a medium for displaying heights. It can be constructed using either raster data in the form of a pixel-grid or vector data in the form of a TIN, akin to the mesh of a 3D model. The method used in this surface analysis is a raster-based version, which is bi-dimensional and thus calculates the height-grid from a 0-plane. Therefore, the dataset of the spearhead was oriented so that the surface to be examined was directed from a top-down perspective. In order to achieve this the model was re-orienting in MeshLab to a suitable angle, displaying the surface to be analysed 'upwards'.

Subsequently, the dataset was imported into ArcGIS, in the same way as during the contour analysis. The 3D model was then converted into a raster dataset (with a pixel-size of roughly 0.0002 cm^2), using the *Multipatch to Raster* process.

A Multipatch feature is a type of GIS feature, based on rings or triangles that represents the outer layer of a 3D surface, much like the vertices that make up a Poisson mesh (ESRI 2008). The strength and utility of this analytical method lies in the transference to a raster image: as the GIS interpolates the height values and relation of the 3D models vertices, the relative variations between points/features are highlighted. Essentially, the process is based on the distance between the 0-value of the map and every point on the surface of the 3D models. The surface-points of the 3D model are converted into pixels, preserving a relative height-value in the form of a separate colour value per height-level. Anomalies in the otherwise homogenous surface become more apparent as they are divergent in these relative height-values and are thus more easily identifiable. This is also true for the contours of the model, which are highlighted as a sudden variation between the end-limits of the model and the underlying 0-value that the algorithms are calculated against. Through this process, it is possible to generate a measurable and arguably objective contour outline of the model as well as a quantitative assessment of the surface anomalies (see fig. 13). By extensive manipulation of the colour information of the pixels, it is possible to over-emphasise the inclination and height-relation of the model, efficiently producing a 2D model of the 3D

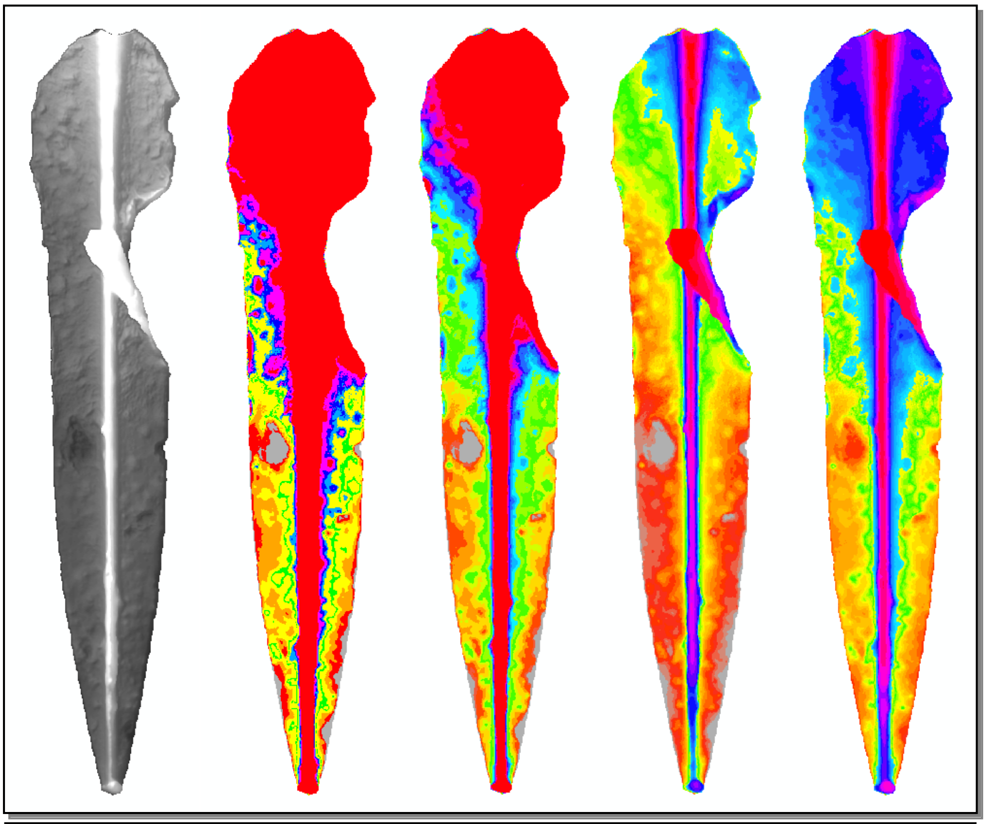

Fig. 13. Surface analysis of spearhead 4417. The areas of deviating colour mark anomalies in the surface of the artefact. Note the patch recurring on the mid-left of the artefact, a patch of rust, and the deformations along the edges of the blade.

height-surface, which is displayed through variations in colour (Bevan et al 2014: 253ff). While this is abstract in terms of visualisation, it is a method of representing an additional dimension in a bi-dimensional plane and allows for observations of strictly three dimensional characteristics and inter-relations. However, the key implementation of the method is still its ability to highlight anomalies in the surface. This must then be subjectively interpreted, as to identify what every anomaly represents. The objective parts can in this way be enhanced and the basis on which to state interpretations has become more scientifically stable.

4.3 Object Manipulation

One of the most convenient possibilities presented by the use of digital models is that of object manipulation. As the model is not bound by the laws of physics, it is possible to subject it to several types of otherwise impossible operations. MeshLab allows for the appliance of functions commonly known as *Shader*, these functions alter the properties of the 3D model in various ways. The functionality of the shaders range from making the model transparent (‘*X-ray*’), allowing for see-through visual observations, to highlighting of surface anomalies (‘*electronic microscope*’), similar to the above mentioned surface analysis. The transparency shader allows the researcher to visualise the relations between multiple surfaces at once. It should be noted though, that while the shader is called ‘*X-ray*’, it is in no way a real representation of the interior of the model, as produced by an X-ray examination, which penetrates the surface of the artefact. Instead it visualises the outer surface of the artefact, but allows for a deeper understanding of its morphological properties and relations. It is always important to remember that a 3D model is only a representation of the data captured by the equipment. Other shaders given as examples here are the ‘*Cook-Torrance*’, ‘*Radiance Scaling*’ and ‘*Toon*’ functions available in MeshLab. These shaders generally

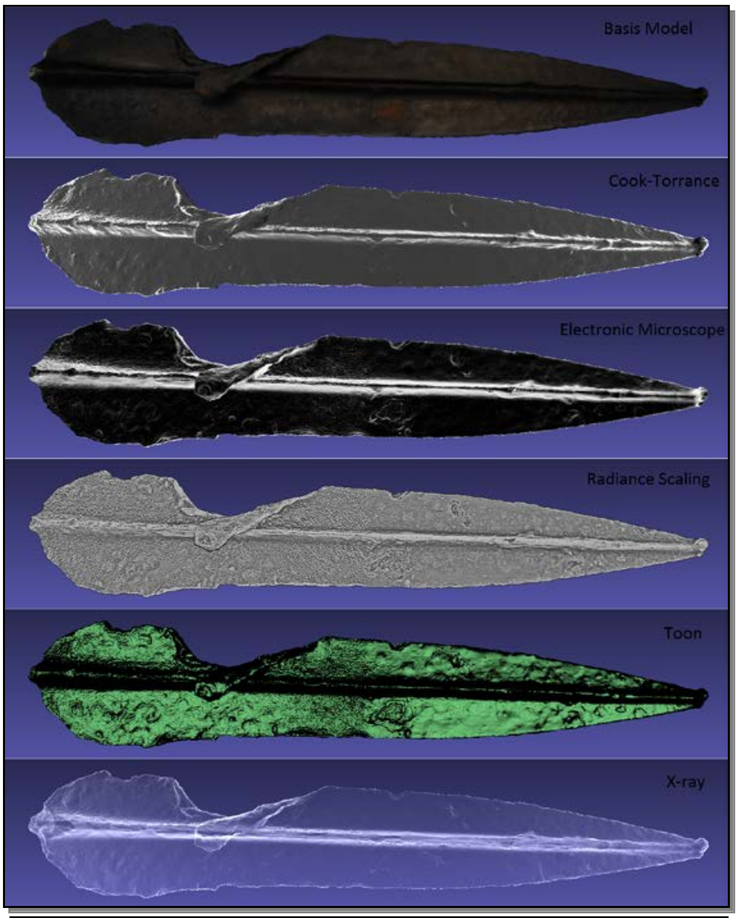

Fig. 14. A selection of shaders available in MeshLab, highlighting different aspects or characteristics of the model.

changes the lighting conditions and reflectance of the model to better illustrate or highlight different aspects of the surface (fig. 14).

This connects to another possible manipulation: that of cross-sections. As the model has no real mass, there are no limits to how it can be sectioned. By positioning the model in the appropriate angle, it can be subjected to a rendition that allows the view of the contours of a given cross-section (see fig. 15). This process can be repeated at any part of the model, allowing for full access to the contours of the model, which would otherwise be difficult to reproduce accurately in 2D.

The last, but perhaps most powerful function of object manipulation has not been given specific emphasis in this study: the use of virtual reconstructions. Through the use of 3D modelling software packages, it is possible to conduct 'repairs' to damaged or deteriorated artefacts, efficiently restoring them. The strength of this method is that while each 'repair' is essentially an interpretation, the use of a virtual medium allows for unlimited variations to be produced at a low-cost. While it should be kept in mind that such reconstructions are interpretative, they also unlock the possibilities of regarding objects as they *were*, not as they *are*, making way for new types of interpretations. This ease-of-access to the models and knowledge reproducibility also allows for the repeated testing of different hypotheses at a reasonable research cost (see *Ch. 7.3. Digitizing the material culture*). This practice can be of great aid in conservatory or cultural heritage presentations, but also to increase the knowledge and deepen the understanding of the artefacts.

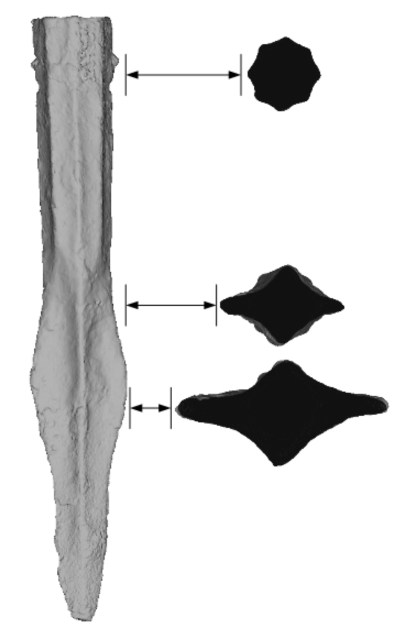

Fig. 15. Cross-sections of spearhead 5842, generated through Meshlab.

4.4 Destructive Methods and Artefact Preservation

As has been stated above, the 3D model of an artefact is a virtual representation of the artefact. There are many other methods of documentation that are destructive in their nature, while the digital documentation is non-destructive. As there are some methods that have to be employed in order to gain specific data, such as material composition analyses (Thålin-Bergman 2005) which destroy parts of the object, there is a decline in quality and an increased active deterioration of the source material. This means that every additional destructive method employed will negatively affect the potential for further analysis on the same material. While a virtual representation of the material cannot give this kind of information, as there is no physical object to sample, it could be used as a 'backup' of the object for future studies (e.g. Dell'Unto 2014: 55f; Pospíšil 2012: 2f). Through sufficient digital documentation, it would be possible to employ destructive analyses with less risk of losing data for future reference and studies. While such preservative documentation does not represent an '*analysis'* in itself, it connects to the discussion regarding digital artefact preservation for future studies and the use of digital methods to aid *other* analytical methods.

4.5 Contextual and Spatial Analysis

One of the primary aids for the typological methods mentioned by Malmer (1962: 30ff) is that of contextual similarities and combinations (*fyndassociation*, in the words of Malmer). As GIS is a geographical data management tool it allows for the positioning of 3D models in their find context. Many excavations make use of Total Stations or GPS equipment to document the positions of individual finds in their find context (*in situ*). These data are often used to construct artefact-spreads, to allow for an overview of spatial correlations. The method of spatial analysis can be applied to the 3D documentation in the same manner, as long as the initial documentation campaign of the site took into account the need for a third-dimension, which is height-relations (fig. 16) This issue will be addressed further in the discussion regarding 3D mentalities (see Ch. *7.2 Multi-Dimsensional Mentality*).

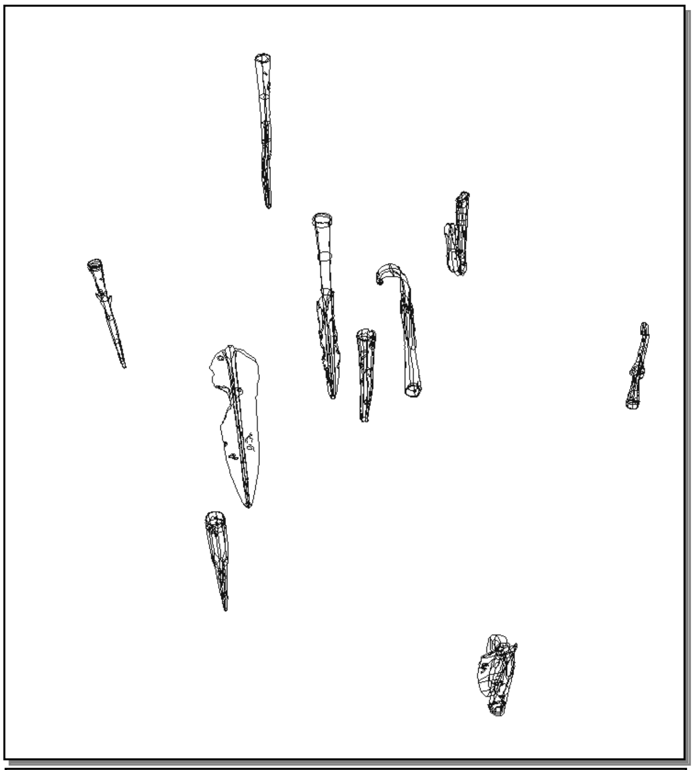

Fig. 16. Positional spread of ten spearheads in ArcScene.

In practice, the utilization of 3D models as spatial markers is not that advanced. The model is moved to the correct position in the GIS using the extracted coordinates of the find position. This allows for the use of 3D models as an addition to the digital documentation of the excavation, using GPS or Total Stations. By repeating the process with multiple models, this allows for a direct visual representation and virtual reconstruction of the context of the finds. By adding additional information, such as maps of the site or positions of dated samples, this makes use of the strength of the GIS, which is combining multiple datasets. Another strength of the GIS is its ability to manage data, primarily in the way of system queries. Following the 3D drawing process, the 3D models are not only visual representations of the artefacts due to the database linked to the drawing. Each database contains a set of attribute-data, i.e. data that cannot be visualised in a 3D model, such as weight or material properties. By linking the databases of each artefact, it is possible to query the system to select and highlight specific types of data. This method is widely known and used in archaeology in general, but the addition of a 3D model also allows for the highlighting of specific, individual features on each artefact, which might be recurring in multiple artefacts and thus showing correlations.

Malmer (1962: 33f) mentions the advantage of being able to evaluate the stratigraphic relation between finds, as this gives hints towards the inter-relationship between different 'types' and artefact groups. The ability to visualise these relations, in 3D, with the additional possibilities of system queries brings a new level to the already established use of contextual and spatial analysis. While it should be used with caution, the utility of being able to reconstruct the conditions of an excavation allows for re-evaluations of the initial interpretations made on-site, which in the end improves documentation quality, allows for scientific transparency and opens for a more objective approach.

5. Alternative Methods of Documentation

It has previously been mentioned, in passing, that the documentation method made use of in this study is not the only way to perform digital documentation campaigns. New techniques are being explored continuously, both in general and for the specific application in the archaeological discipline.

5.1 Image-Based Modelling techniques

One of the perhaps more widely known methods that should be mentioned is that known as Photogrammetry, Structure-from-Motion (*also known as SfM*) or Image-Based Modelling (*IBM*). This particular technique is, simply put, based on a set of images of a target object/context/area, and there is a range of available software packages that are able to reconstruct the geometry of objects through algorithms, which calculate camera positons and image depth (Bevan et al 2014: 249ff). Often used as a cheaper and more flexible alternative to 3D scanning, the technique is used in excavation documentation and building archaeology as it requires only an adequate camera and the necessary software to generate the 3D model (Kimball 2014: 17ff; Forte et al 2015: 5f). While it was not in the primary interest of the study to conduct a comparative analysis between 3D techniques, a smaller campaign was conducted using the photogrammetry method, to illustrate the difficulties it presents in artefact documentation (for a deeper discussion regarding Image-Based Modelling, see Hess & Robson 2010; Szelinski, 2010:303ff).

The primary problem of the IBM technique is that it relies more on the active choices of the photographer/researcher. A 3D laser scanner with a rotational platform, such as the NextEngine used for this study, relies on an automated process to capture the artefact of interest, after the artefact has been attached to the equipment by the researcher. The active choices in laser scanning are thus the positioning of the artefact and the number of scans. IBM on the other hand is dependent on the choices of the researcher as each photograph is taken, from which angle and distance from the object (fig. 17). The added complexity is that the number of pictures taken affect the output quality of the model, the more pictures taken in an area, the higher the potential quality on the model. For an objective documentation to be achieved, the researcher has to document the artefact from every angle and every part of the object in equal measure, something the 3D scanner obtains per automation, given that all areas are visible to the sensors (Bevan et al 2014: 253ff). Thus there is a difference in the reliance on the researcher/user and the reliance on the equipment between the two techniques. The IBM relies more on the researcher's knowledge of the technique and understanding of the artefact, such as which areas are important to capture in detail and the estimated number of pictures to achieve a good result. The detail and quality of an IBM campaign is therefore the result of active choices by the researcher. The laser scanning option instead relies on the researcher's knowledge on positioning the artefact so that the entire artefact is exposed to the sensors at least once. The scanner then documents every part of the artefact in its field-of-view in high detail. Thus it relies more on the understanding of the technique and equipment, rather than the artefact. If the aim is to achieve an objective documentation technique, then it could be argued that the IBM is of a more subjectively dependent nature, due to the higher number of active choices from the researcher, which also adds the human element of error. Laser scanning, on the other hand, has a lower degree of subjective elements present. I would thus argue that while both techniques allow for the capture of artefacts in high detail, there are less subjective choices

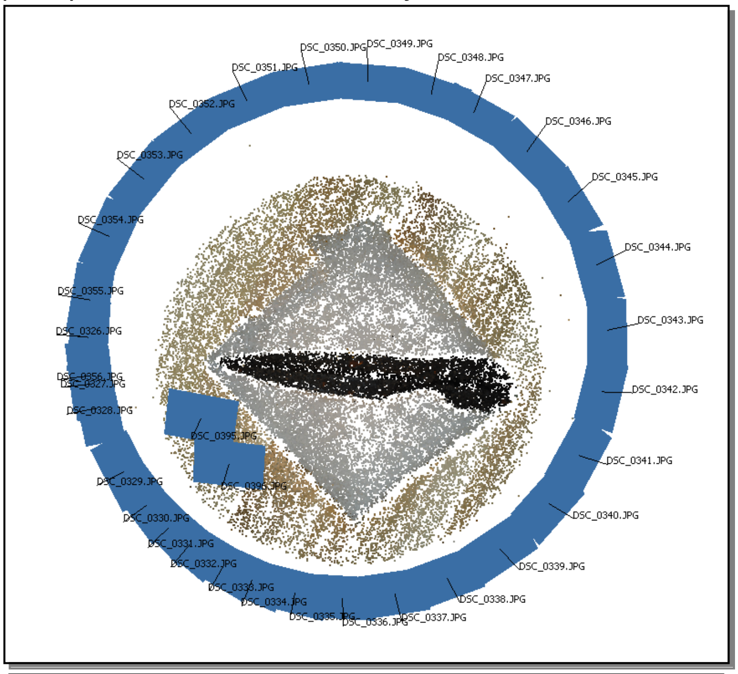

Fig. 17. Photo-documentation using IBM techniques, conducted as a smaller side-acquisition for comparison. Blue squares indicate pictures taken, and the resulting point-cloud is seen in the middle. (Spearhead 4417).

made by the researcher when using a more automated technique, such as laser scanning, which by extension would make the technique more inclined towards more objective results. It is therefore arguably easier to obtain an objective model of an artefact when using laser scanning, but it is also quite possible to do so with IBM as well.

While the algorithms reconstructing the geometry generates an adequate standard, there is also a difference in the subsequent precision of the two methods. In terms of representation and illustration, the IBM technique is a preferable choice, as it automatically contains the colour information of the artefact and can be conducted on a smaller budget. On the downside, the geometry is more simplified (fig. 18). This is due to the fact that there are no 'real' measurements taking place, instead the algorithms reconstruct the *shape* of the object readable from the information given by the photos. In contrast, the 3D scanner actually measures the surface of the artefact. Thus, in terms of geometric capture, the scanning method offers a better basis for further analyses, as many of these analyses depend on the smaller anomalies of the surface of the object. Thus it could be argued that 3D scanning is a preferable technique to employ when aiming at a coherent and high-quality documentation. It should however be noted that a IBM documentation might be more time and cost efficient in its nature, as it requires less documentation time, and the post-processing is largely automatic in many software packages. There have been comparisons made between IBM and laser scanning with regard to their usability in Cultural Heritage work and the comparisons were mainly aimed towards the technical characteristics of the methods as a criteria for the most versatile method (e.g. Aguilera & Lahoz 2006; Barsanti et al 2012; Porter 2015). It would, however, in light of the present discussion be interesting to conduct a thorough comparison between the methods in order to test their applicability in terms of objective documentation and the number of active choices made by the user that might influence the result. This is, however, a topic for a discussion not included in this thesis.

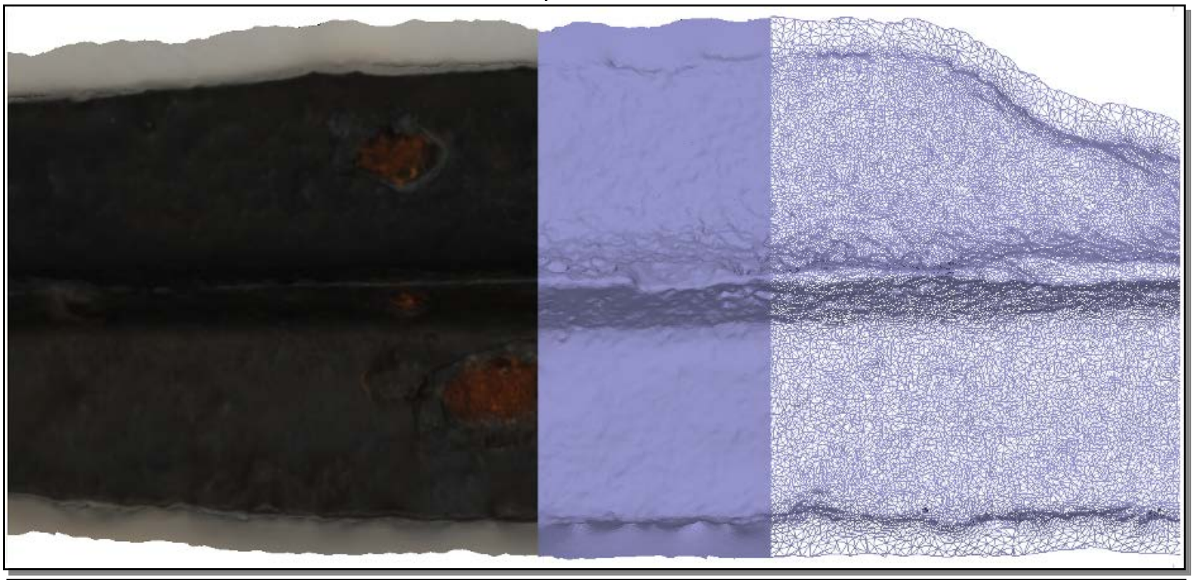

Fig. 18. IBM allows for the generation of high-quality textures and good visualisations, but the surface generated is of a lower mesh density and relies heavily on the number of pictures acquired to portray complex geometry. (Spearhead 4417).

This connects to the discussion regarding why a digital documentation method and mentality should be pursued the means of recycling, re-evaluating and reproducing data (see Ch. *7.3 Digital Utility*). There are multiple ways to conduct digital documentation and analyses, which is why it is important to construct a coherent practice and mind-set to how these methods are employed, to make sure that they live up to their potential as a way of joining large quantities of data and allowing for greater access to said data, thus generating more knowledge and opening for a more transparent discipline.

5.2 Reflectance Transformation Imaging

It should also be mentioned that all digital techniques do not make use of a three-dimensional approach, but instead seek to encompass the effects of this *extra dimension* onto the more traditional two-dimensional approach. While this stands in stark contrast to the aims of this thesis and the issues of 3D mentality it might be warranted to mention alternatives. One such method, which will be discussed only briefly, is the Reflectance Transformation Imaging (also known as *RTI*) technique.

RTI is a technique focused on the viewing of a 2D surface with the lighting conditions of a 3D perspective. Instead of capturing different angles of the object itself, the technique focuses on capturing different angles of light, i.e. the direction of the light source. By having a stationary object of capture and a stationary camera angle, thus fixing the parameters of the acquisition, the effect is achieved by having the light source moved for each new photograph taken. As such, it is in many respects a polar opposite of the IBM technique. The strengths of the RTI technique lie in its ability to highlight anomalies in the material, features that would otherwise be difficult to pin-point accurately. Much akin to the surface analysis presented above is the fact that the 3D perspective is not always necessary in order to conduct these kinds of surface analyses. The down-side however lies in the recurring 2D limitations. The analysis only allows for the visualisation of the shadow-effects created by the lightning, thus there is no information regarding the topographical relations between the features. Subsequently, there are limits to the usability of the method if the research questions of the study require more in-depth knowledge regarding the surface.

While not allowing for a 3D visualisation per se, the technique is worth mentioning for the sake of discussion, as there have been multiple uses for this technique in material studies (e.g Mudge et al 2005; Mudge et al 2006; Cultural Heritage Imaging 2015). The studies have primarily been aimed at surface analysis, identification of anomalies and overall documentation. While the method in question does not answer for a coherent 3D documentation, it might still provide a stepping-stone towards a new digital mentality in the discipline. Perhaps the first step is adopting 2D digital techniques and a later extension would be towards the adaptation of a 3D method and a 3D mentality.

6. Limitations, precision and visualization

With the work-flow and analytical aspects presented in full, there are a few other aspects in the use of this method that should be addressed, if it is to be utilized and implemented properly.

6.1 Limitations

Each methodological approach contains various numbers of possibilities and limitations. In order to properly apply a method, it is therefore necessary to be aware of the limitations of what a given method can and cannot accomplish. The previous chapter has, in short, discussed the alternative methods of digital documentation in relation to material studies and thus this section will primarily consider the actual limitations of the 3D scanning technique.

6.1.1 The Equipment

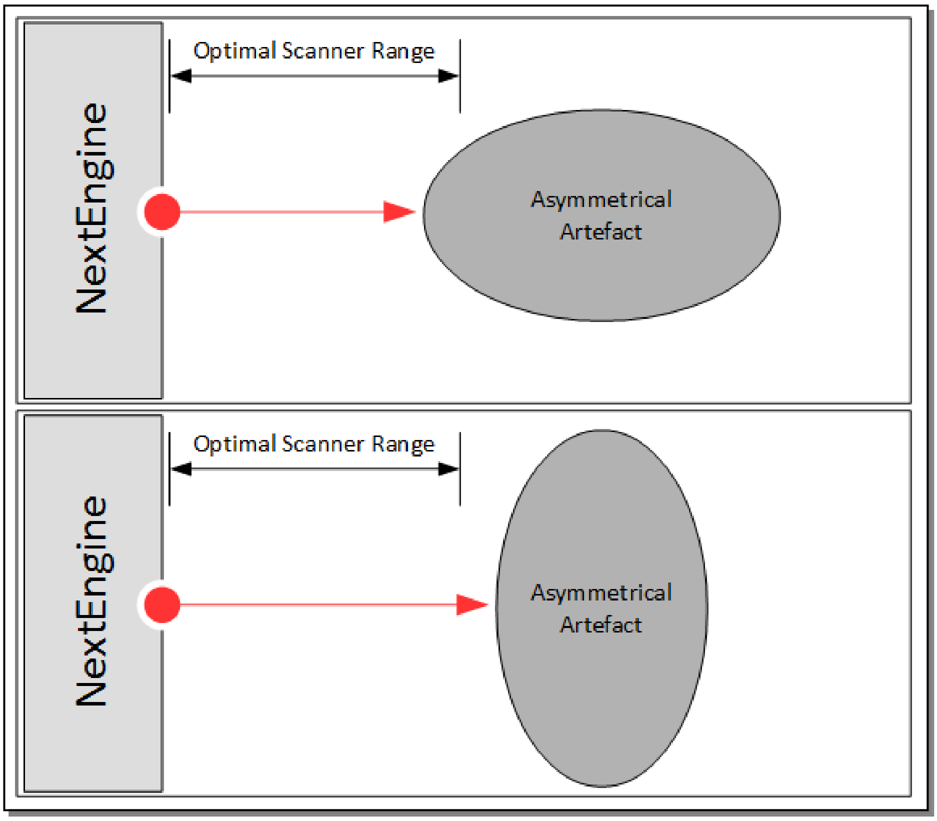

Fig. 19. The problems of asymmetrical artefacts and optimal scanning conditions, as the distance between object and lens differs depending on angle.

While the work-flow presented might seem quite forward, there are several aspects that should be considered. First and foremost, it is crucial to be aware of the physical limitations of the equipment used. In order to undertake a coherent scanning process, the object to be scanned need to fit the scanner. The upper limits of NextEngine 3D scanner used in this study is approx. 12 inches, or 30 centimetres (i.e. max. height of an object). While the spearheads investigated by this thesis are quite small and therefore rather unproblematic, the scanner also has a practical limit in as for the radius (i.e. width and depth) of an object. The settings of the scanner, ‘Macro’ and ‘Wide’, were discussed previously. There is an optimal range for each setting, meaning that depending on the radius of the object, there might be implications in regards to lens focus. However, this problem is most recurrent when the morphology of the object documented is asymmetrical: when the distance between object and scanner lens will differ as the object rotates (see fig. 19).

With sufficient knowledge of the software packages and the technique, it is fully possible to work around this limitation. By partitioning the artefacts it is possible to make several segmental scans. The parts can then be aligned and merged, similar to how the sockets and points of the spearheads were documented in this study. However, this work-around is much more time-consuming and requires a very structured partitioning of the artefacts, to make sure that all segments are documented. While this limitation does not mean impossibilities, it is a problematic aspect to handle properly and that requires attention.

6.1.2 The Software and Hardware

The post-processing step makes use of several modelling software packages, as mentioned previously. While MeshLab, ScanStudio HD and ArcGIS, which were used in this study, are quite extensive in their data management, the limits are often connected to the hardware used. The computational power required for a sufficient documentation might be relatively high depending on precision and resolution, and the processing stages (cleaning, aligning, Poisson reconstruction, etc.) can be demanding on a system. This hardware limitation is also closely linked to the time-consumption of the method, as the potential of the hardware determines the processing time (see Ch. *7.3.2 Time-Consumption and Technical Expertise*). There are, however, several limitations to the software packages themselves, though these are mainly functionalities that are not commonly used, and as such they are not given priority by the software developers. Examples of such functionalities, are the inability to fully rotate an object or add a 3D scaling unit in ArcScene. While these are minor limitations, they are causing inefficiency in the work-flow and are quite frustrating to deal with. Another limitation, which has been addressed previously, is that of virtual representations but as this is a vital part of another discussion, it will be developed further on (see Ch. *6.3 Digital Visualization*).

6.1.3 Materials

When working with any digital technique, it is good to have a sufficient knowledge of how the technique works. This is not only to properly make use of it, but also to know how the technique interacts with different materials. In the case of laser scanners, the medium of capture is basically a laser measurement tool and as such it is restricted by the physics of light. This greatly affects what type of materials can be subjected to a laser scanning approach. Generally, the scanner functions poorly with transparent or highly reflective materials, such as glass or precious metals. As the laser scanner sends an output-signal onto the object, there is need for a return-signal to the equipment so that the measurement and positional data can be registered. With a transparent material, the signal might pass through the surface of the object, meaning that the return-signal can be distorted or non-existent. The same is true with reflective materials, as the signal might bounce and scatter, resulting in poor data-collection (see fig. 20). It should, however, be noted that there are different levels of reflectance, and that some 'reflective' items might be possible to scan properly. The optimal circumstances are however opaque materials, such as bone, ceramics or stone. The spearheads of this study were mainly corroded iron, which provided a surprisingly good surface for scanning, as the reflective properties of the metal are effectively reduced by corrosion and rust. There are substances that can be applied to very reflective surfaces to reduce these problems and allow for the capture of materials such as gold or silver, though they should be used with care when it comes to archaeological artefacts as the substances might interfere with other substances used for preservation. It would, however, be interesting to conduct further studies on how conservational work-flows could adapt to the use of anti-reflective substances. For now, it is important to know that these limitations are perhaps the most problematic ones to solve and they need to be considered at quite an early stage when choosing a documentation method.

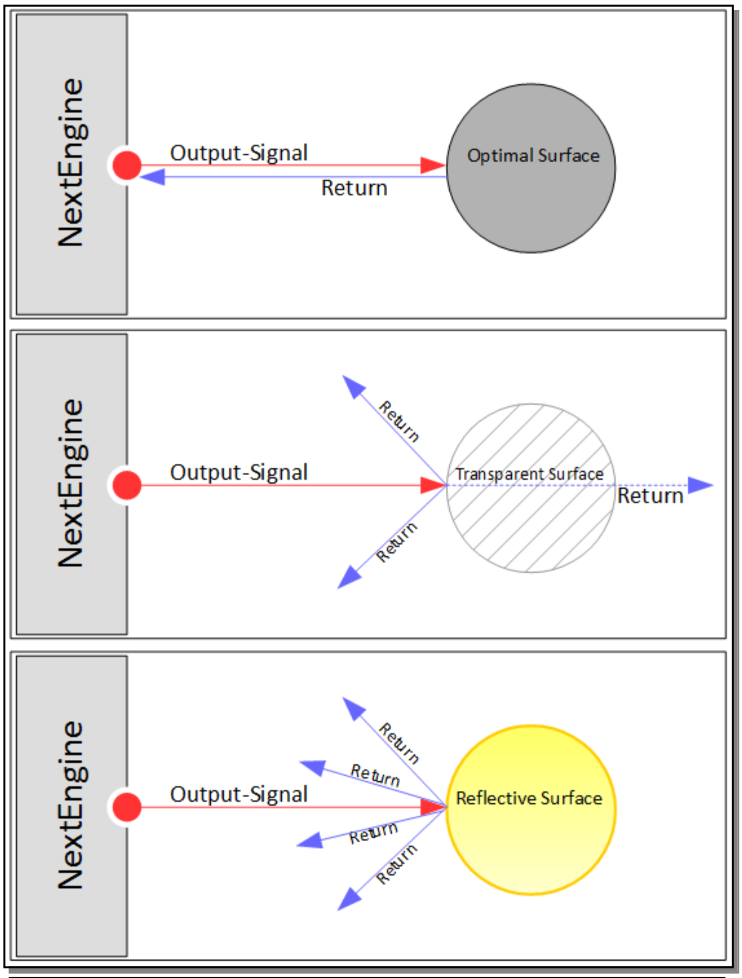

Fig. 20. Illustration regarding material limitations and surface reflectance.

Preservation status and deterioration is another aspect that has to be taken into account when regarding the source material. While some characteristics of artefact deterioration might be favourable, the artefact itself must be capable of handling. Artefacts that prove too badly damaged might risk breaking during the documentation process. This is, however, also true during conventional artefact handling, though it is crucial to take into account the frailty of the source material to minimize loss of data.

6.1.4 Technical Expertise

Another primary limitation of the method is the need for sufficient knowledge regarding the used software packages and equipment. Without proper knowledge of how to utilize a technique there is a risk for improper use of the equipment, poor research results and inadequate documentation. If the primary goals of using digital methods are to improve the archaeological discipline, then there is a need for adequate knowledge of the methods.

A 3D scanner is a quite potent measurement tool and like a total station or GPS, there are aspects to the usage of such a device that need to be considered before employing it. As such, there is a clear limitation as for who can conduct these types of documentation campaigns and analyses. But with the proper training, the digital method might be a valuable addition to the practical knowledge of archaeologists. It is always difficult to precise an estimated time to learn new methods and technology, depending on the aptitude and previous knowledge of the student. But for the sake of the argument, it might be added that I learned these technologies and techniques during the course of a few weeks as part of a university course, and as with most things, practice is essential to properly grasp the entirety of any method. The basic knowledge of how to operate a laser scanner can, however, be taught quite easily as the majority of the work is repositioning the artefact. The main bulk of the necessary knowledge is instead the post-processing steps, where the learning curve might be a bit steeper. It should, however, be mentioned that the techniques are not as advanced as they might seem, rather there is a need for a basic knowledge to understand the implications of using the methods which, again depending on the student, might be learnt via a short introduction to the method and technology.

The adoption of 3D modelling tools can be likened to the general adoption of GIS software packages. GIS might be considered the 'standard' in archaeological database and geographical management tools, with wide-spread usage not only amongst GIS-specialists, but also in other parts of the discipline. While the software has several basic functions that can quite easily be mastered, there are multiple other tools that are to be employed only by an experienced user for a useable and adequate result. Therefore it might be argued that there are levels of limitations in terms of technical expertise, where there are parts of the available methods that require deep knowledge and are other parts that are quite easy to grasp, and thus are more user-friendly.

6.2 Sampling and Precision

When regarding a method of documentation, the first thing that should be addressed is how reliable it is. And how then, do we determine if a method is reliable? In archaeology, when it comes to the micro-scale documentation of material studies, everything is in the details. A sword or a spear can be simplified into a pointed and/or sharp object whose primary function is to cause harm. Or a pot can be described to be an object whose function is to contain something. The more details we have regarding an object, the deeper is our understanding of it.

When in the realm of manual documentation, in the form of drawings and plans, the precision and detail of the documentation is directly connected to the researcher's ability to transfer the metrical measurements and features expressed by the object onto a sheet of paper. In the digital counterpart, the same situation is true, but of a slightly different character. The use of a 3D representation of the object allows for a 'direct' documentation on the surface of the model (Forte et al 2015). This effectively removes the *subjective transference* part present in the manual documentation. Another component that needs to be addressed to ensure the quality is the ability to sufficiently capture the complexity of an object. In manual documentation this is, again, related to the artistic skills and precision of the researcher. Digital documentation has little to do with artistic skills, but is more dependent on the precision of the equipment and the technical expertise of the user. As the GIS software packages make use of simple geometric shapes, such as points, lines and polygons to express the geometry, there is a need for discussion regarding the *sampling* of the documentation.

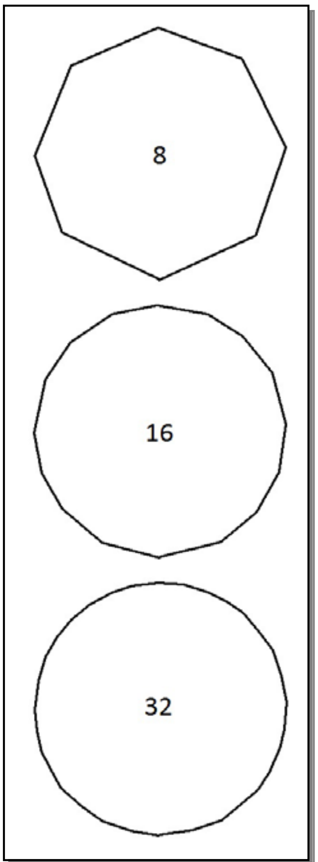

Fig. 21. Examples of sampling precision.

Sampling is the active choice of interval between documented points. In the case of this study, this is the number of points used to capture and describe the surface of the artefacts. The easiest way of expressing the complex geometry of artefacts is by using multiple lines to describe the outlines or contours of features. Thus the precision of a documented feature is directly linked to the amount of sampling in capturing the morphology/geometry. As an example: To capture a curved feature, the contour could theoretically be expressed through 8, 16 or 32 points that connect to a single line (see fig. 21). As the amount of sampled points increase, so does the precision expressed by the line (Drennan 2009: 80ff). By extension this implies that to successfully capture a complex feature (e.g. circle), there is a need for a high number of samples taken, while a simple geometry (e.g. square) requires a low number of samples. Not only is this important for the researcher to be aware of, it is also something that should be included in terms of transparency. The exact count of points might not be necessary, but like the practice of defining the scale of a map, it is of interest to declare to what precision a feature or object has been documented. A declaration in terms with 'ten points every centimetre (or millimetre)' or 'a ratio of 10-1' might be enough to give the reader an understanding of the degree of detail in the documentation. This is of course also dependant on the scale of the object representation upon which the sampling is based, as a high degree of sampling can only be done on a high resolution representation, which lends to the need for high-precision equipment and techniques to ensure a high-quality result. This declaration and transparency is also warranted in order to allow for future studies to evaluate the necessity of additional documentation.

The drawback of a large quantity of sampling is that it stands in direct relation to the time-consumption of the method. Digitizing the features of an object is one of the parts of the work-flow that takes the most amount of active work-time. Thus it is necessary, as always, to find a balance between the degree of necessary documentation and the time available (Drennan 2009: 126ff). But as noted above, as long as the model itself is readily available, there is the possibility to re-evaluate the captured data and re-acquire any missing portions with a higher degree of sampling i.e. precision.

While addressing sampling, it should also be mentioned that the degree of sampling is also important in the acquisition campaign. Returning to fig. 21, it could be imagined that the artefact captured is represented by the numbers in the middle of the 'circles'. A higher degree of documented samples (points) results in more details of the object being captured. The NextEngine 3D scanner handle this through the use of the *AutoDrive* platform, which rotates the artefact to capture multiple angles automatically. As the scanner uses laser sensors to capture the surface of the object, all visible parts are documented equally. The degree of sampling could instead be argued to be the numbers of scanned segments conducted. The alternative methods mentioned previously, IBM and RTI, are highly dependent on the sampling degree. An IBM campaign relies heavily on that enough pictures of the object are produced for the surface reconstruction, as is RTI for a coherent light-display. The sampling of the IBM and RTI is a direct action of the user taking the pictures, meaning that angles neglected are under-represented in the result, they have a generally lower resolution. The scanning process on the other hand encompasses a lesser degree of active sampling choices, as the equipment in itself documents angles set-up before it. This relates to the objectivity discussion as fewer active/subjective choices by the user implies a higher degree of objectivity (see Ch. *7.1 Typology – Objectivity vs. Subjectivity*).

Sampling is not only applicable in terms of documentation, but also representation. A higher degree of sampling also reflects a higher resolution of the final result. A 3D model is a surface described by several vertices, and the detail described stands in direct relation to the number of vertices displayed. A large quantity of vertices allows for a more detailed geometry and morphology to be conveyed, while a small quantity results in simplification

(Szelinski 2010: 594ff). And, again, as this is highly dependent on hardware resources, there is a need for balance between the need for sufficient representative sampling and the possibility to display such detail. As for the models presented in this thesis, the objects are displayed using approximately 1’000’000 vertices, which in the case of the spearheads equal an adequate level of resolution. It is, however, important to remember that the number of vertices that convey a sufficiently ‘good’ quality differs in relation to the complexity of the artefact or site in question, as well as to the demands of the research conducted.

6.3 Digital Interpretation

As stated in previous paragraphs, the 3D drawings created were not the maximum level documentation of the artefacts, as there is always room to further increase the details of the sampling applied. Instead the focus should, in this case, be turned to the visualisation of the artefact. The 3D model allows for high precision documentation to be performed on the surface of the object, and instead of providing a separate illustration of the geometry, this method provide both documented data and the basis model in one. The visual implication of this is the possibility to re-evaluate the documentation performed, if need be. It is thus possible to back-track the methodological process of previous studies conducted in this way by accessing the visual representation (i.e. basis model) on which the analysis was conducted. If there are flaws or gaps in the 3D drawings, this can be seen in the visualisation of the data, as the drawing and the model can (and perhaps should) be presented together.

In terms of visualisation, the use of 3D models presents a unique opportunity to express the complexity of the artefacts. As the model allows for the display of the artefact from any angle of the captured surfaces this simplifies the presentation of the material, as there is only need for one model of sufficient resolution to convey the data. Common practice in weapon studies is to supply the general contours of the artefact as well as some cross-sections of important areas. A 3D model instead shows the entirety of the artefact, meaning that no complexity is lost in logistic simplification and the choice of what aspects to illustrate.

There are however some disadvantages to this type of visualisation. As the 3D model containing all the data of the object is strictly a virtual construct, there are limited possibilities to produce a non-virtual representation of the model. This dependency on virtual workspaces is perhaps one of the most limiting aspects of digital methods. The presentation of the material is thus based mainly on a digital publication of the material, if the goal is to make use of the full utility of the advantages of the method. This might seem unproblematic in our digital world, but nonetheless it is a hindrance that must be mentioned. There are however no limitations, as presented in this thesis, to generate 2D illustrations from the original 3D versions. It is also possible to use these 3D methods to produce 2D representations of the third dimension, and thus achieve a non-virtual medium for the data (see *Ch. 4.2 Surface Analysis*). This compromise includes the above argued precision of 3D documentation with the 'easy-to-use' aspect of analogue presentations.

7. Discussion

In the presentation of work-flows, materials, methods and analyses above there has been a continuous approach towards the usage of digital methods and their application to material studies. The following discussion has sought to encompass the problems, attitudes and solutions surrounding digital methodologies and their relation to the archaeological discipline.

7.1 Typology - Objectivity vs. Subjectivity

There are several problems presented by the subjectivity in archaeology. The only way to achieve new archaeological knowledge is by forming interpretations based on the available source material. By extension, the way archaeology generates new knowledge is either interpreting newly acquired data or by re-interpreting a set of data from a new perspective, research question and/or methodology. This practice in itself should not pose a problem to the discipline, except that the data that these interpretations are based upon are subjectively generated, through the interpretations of the function, meaning and type of the material culture. At first glance, this might not seem overly problematic, but it becomes cumbersome when the practice is the basis for a scientific discipline. There are many methods in use in archaeology, but the one focused on primarily in this discussion is typology, as it is one of the most fundamental methods in modern praxis and one heavily influenced by subjectivity.

Keeping in mind that subjectivity is a core subject of discussion, it is worth posing the question whether it is sustainable that all parts of the archaeological work-process are allowed to be subjective and interpretative. As has been thoroughly discussed, there are subjective elements in the present typological material as they were based on a method that is inherently subjective. How, then, can the problems of subjectivity in typology be countered? The approaches previously undertaken, by Malmer (1962; 1980; 2002) and others (e.g. Keljn 1980; Sørensen 1997; Hurcombe 2007; Sørensen 2015) have been a step in the right direction, though not necessarily all the way, and the search for more efficient ways to tackle this dilemma has moved slowly. With the introduction of new tools for documentation, it is warranted that the discussion be addressed again. The question that this discussion builds upon is simple: can and should archaeology try to achieve objectivity? And the follow-up question is then: how?

Malmer (1962: 25f), which I refer to quite often, claims that to achieve objectivity the feature on which a typological examination is conducted must be objectively discernible. The problem thus returns to the core issue in typology, as it is questionable which features that can be objectively observed and how we identify them. And how can we be certain that the features and traits of the object are representative for the entirety of the object-type, if the documentation in itself was based on subjective observations? I would argue that the solution to these problems can be found in the digital work-flow established in this thesis, alongside the theoretical mind-set and mentality presented.

A solution might be the use of digital 3D documentation, preferably utilizing laser scanning or other automated techniques. Techniques that rely on a low degree of active choices from the user limit the possible subjective influences on the documentation process. It is thus possible to conduct an arguably objective documentation of the material, using digital methods, on which to base further investigations and interpretations. There is, however, the above argued reliance on the choice of *sampling*. The sampling-choices are closely tied to the later steps of documentation, but it is also important to be aware that the technology relies on the researcher to conduct scans of the object so that the entire object is captured. While the technology used in the acquisition campaign collects the data objectively, it is up to the researcher to make sure that all parts of the model are equally documented to the same quality, in terms of making sure the scanner can capture the entire artefact in a coherent way.

Consequently this method is by no means an autonomous method of documentation, but relies on the researcher's knowledge of the *technology* rather than on the knowledge of the *objects*. In this way, a focus on a digital approach allows for a broader attitude towards documentation, as the knowledge of the digital method can be reused, in contrast to the knowledge of specific artefacts. A digital approach arguably also eliminates *active choices* used in more 'traditional' methods, i.e. the subjective elements, as the researcher cannot actively or inactively choose *not* to document a specific element. This is due to the fact that the documentation is not actively conducted by the user, but rather by the equipment. The subjective influences are instead strongly connected to the *3D mentality* and *technological competence* of the researcher, to properly conduct the acquisition campaign and the underlying attitude towards the documentation (see *Ch. 7.2. Multi-Dimensional Mentality* and *Ch. 6.1.4. Technical Expertise* respectively).

The uses of digital datasets also allows for multiple other analytical, objective or subjective, methods to be applied. Most interesting is the application of surface analysis, as this allows for an additional objective stage of identification, primarily regarding of anomalies. With the features and traits of the object properly highlighted and 'identified', we are left with a solid foundation upon which we can base further, subjective interpretations of what the identified features represent (fig. 22). These objective bases can also be further used to re-evaluate the interpretations, meaning that the documentation would be reusable in multiple studies.

Another interesting feature with the method is the ability to safeguard the objects (through virtual copies) from outer influences that can hinder or problematize interpretations, such as destructive analytical methods or further deterioration.

As such, the use of digital methods are not meant to inflict a strictly objective work-method on the archaeological discipline, but rather opens up for a discussion regarding what stages of the work-flow that should be objective and which should be subjective. This is particularly interesting for the typological method. As an object presents numerous combinations of characteristics and traits, it might prove difficult to discern what elements that should be considered for type-determination. By providing a more solid basis, in terms of visualisation and identification, the types determined through a digital approach might be more cemented in their taking into account more tangible elements. By prolonging the objective segments of the work-flow, we can thus achieve a more credible typological practice that cannot be so easily undermined by subjective actions and interpretations.

Fig. 22. Objectively identified surface anomalies, readily available for interpretation.

To put this into perspective, we could turn to the typology of early Iron Age spearheads, as done by Ilkjaer (1990). When reading Ilkjaer's typological work, it is clearly stated that the spearheads were divided into two categories, *Speer* and *Lanze*, defined by the notion that *Speer* is a lighter throwing weapon while *Lanze* is a larger close-combat weapon. This could be argued to be a strictly subjective interpretation of the *function* of the source material, which subsequently follows through to the typological examination, and further into the studies that use the typology as a reference. While I do not claim that this definition is wrong, it is not necessarily the right one. To question this we might turn to Oakeshotte (1996: 119), who references the Sagas (written down in the Medieval Period) and counts up to six different types of spears mentioned, of which two are described as throwing-spears. It could thus be questioned why Ilkjaer has chosen to define the spears of Illerup-Ådal in only two categories. Turning to the study of Solberg (1985) concerning Merovingian and Viking Age spearheads, there is no distinction made in regards to the function of the artefacts, instead all types are regarded as *spears* in the general terminology. This demonstrates the subjective actions present in typologies that follow the 'objectivity' advocated by Malmer.

The problem of subjectivity becomes more central when a typological documentation is structured according to these initial interpretations, i.e. if Ilkjaer documents his *Speer* differently from his *Lanze* (fig. 23). Instead, I would argue that the interpretations of an artefact should be conducted at a later stage, to ensure an arguably objective and reusable documentation. This would have implications of course, meaning that the documentation campaigns must either encompass all the available material (e.g. all the artefact-finds from the Uppåkra deposit) or be structured so that the omitted material can easily be supplemented later on. As for this master's thesis, it encompasses 19 spearheads out of a total of 136 found in the deposit, which is 14% of the entire source material. This study is aimed at an *objective* documentation process as an initial priority, the aims of the study come at a later stage and are not directly involved in the documentation process. As the different focus of the study is compartmentalized in this way, the subjective and objective elements can be kept separate. The established work-flow would also allow these 19 spearheads to be reused in a subsequent study along with a complementary documentation of the remaining 117 spearheads, resulting in a successive coherent database of the material (see Ch. *7.3.3 Compartmentalization and progressive databases*).

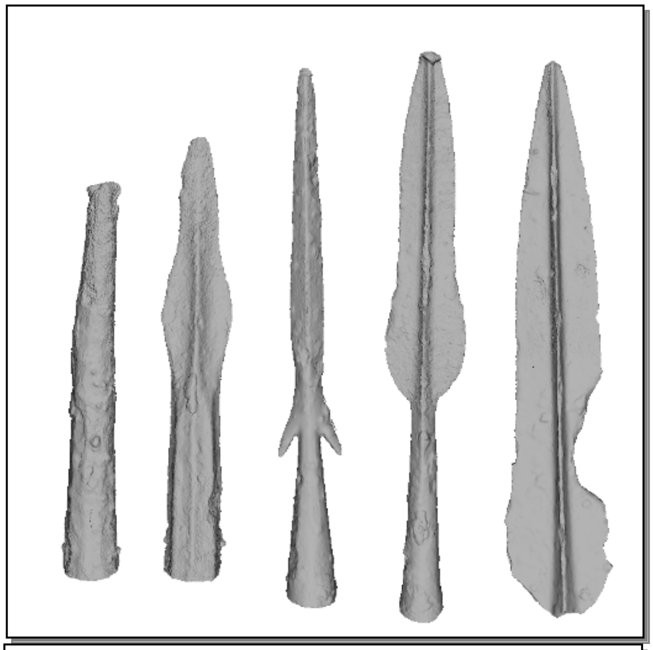

Fig. 23. Illustration of the vast diversity in spear-types, which raises the question of how types are defined. Spearheads are roughly to scale.

It is also interesting that Solberg (1985: 150f) mentions that her study has yielded an addition of ten new types and eleven new variations of spearheads previously not described. In Solberg's words: "*Accordingly, our classification has demonstrated a greater variation in the Norwegian spear-heads … than formerly recognized*" (ibid: 151). This notion might be rooted in the problem that the variation within types, the *sampling* of the number of types, is subjectively chosen in accordance to the identification of features deemed relevant to the typological study at hand. Thus it is not surprising that Solberg has identified multiple new types and variations, since the study was based on a new set of features and criteria previously not used. Androshouk illustrates yet another aspect of this dilemma through an example regarding two sword-drawings of great similarity. The depictions of the artefacts had been conducted previously and the type-determination was subsequently conducted through the use of said illustrations. The depictions looked alike, while the original artefacts were, in fact, very dissimilar (Androshouk, 2014: 20f). This lead to a misinterpretation of the investigated artefacts, which were depicted as being part of one type while the reality of the objects displayed something much different, witnessing to the issues of representation and interpretations.

Thus it is possible to argue and conclude that there is still work to be done in the ways of restructuring typology to accommodate for an increased objectivity within the archaeological practice. I would however argue that the means to achieve this type of objectivity is possible through the application of a digital methodology. Such an application is not without its own constraints, as it also requires a change in the underlying mentality of how archaeological work is conducted. But for the sake of striving towards a more transparent and viable discipline, there are tools readily available if they are applied correctly.

7.2 Multi-Dimensional Mentality

Throughout the course of this thesis, there have been three major areas of interest: method, theory and mentality. Thus it should perhaps be put in relation as to why mentality is associated with methodological and theoretical issues. In modern science, methodology is regarded as a concept encompassing the framework of how research and data collection is to be undertaken, and how selected methods are to be applied (Herrman 2009:3ff). Theory on the other hand is the framework associated with how to perceive and understand the data collected, which might differ depending on the theoretical perspective applied (Hodder 1991:6ff; 1995:164ff). Any problem can thus be addressed from a number of different angles, therefore it is necessary to clarify not only how a problem is to be addressed but also from which angle. If the *methodology* is the 'how' then the *theoretical perspective* is the 'from which angle'. The *mentality*, however, is a separate aspect in relation to this, as it encompasses the researcher's initial attitude towards how to apply and project both method and theory onto the source material. Therefore it lies on the borderline between method and theory, as it requires and is required by both. Mentality, as defined in a wider scientific context, is the characteristic way of thinking of a specific group or individual (Hume 2003:41ff). Thus it could be argued that a mentality is the perception of the problem itself by the researcher, and how the problem relates to the large picture of the discipline. Depending on the mentality and attitude of the researcher, the subsequent research might differ, even if the same theory and method are applied. In short, the method and theory of a scientific study might be actively chosen, while the mentality is the subconscious attitude of the scientist. How then, does this affect archaeology, and the practices of material studies and typology?

Before the introduction of 3D visualisation techniques, displaying an object in three dimensions proved problematic. Within archaeology, the inability to display the entire complexity and inter-relations in an artefact, a building, a site or a landscape, led to other approaches being adopted. To convey the interpretations of the 3D source material, 2D methods were employed, since this was the only available and possible mode of documentation (Museum of London 1994:7ff). New 2D methods were based on old ones, all built to work around the limitations of technology. This has proved somewhat problematic. The 'incomplete' documentation causes a simplification of features or relations leads to information loss, which by extension means that the interpretations are not addressing all aspects of the source material. There have been, as previously mentioned, solutions constructed to counter this problem, often in the form of several descriptions/illustrations from different angles. The effect of this is large quantities of data, which can be cumbersome to handle and interpret. This too proves somewhat problematic, as we come back to the essence of the problem at hand, that the material we are investigating is indeed three-dimensional while the 'traditional' methods and techniques employed are unable to fully capture all dimensions at once. With the normalisation of the attitude towards this 'unavoidable' data loss came the adoption of what I claim to be a *2D mentality*: the notion that a 3D object can be adequately documented in 2D.

With the introduction of 3D techniques able to capture and display the entirety of an artefact, a building, a site or a landscape, comes the solution and additional problems. The methods currently employed are constructed to work around a dimension that is now possible to include. How then, are we meant to adopt a new dimension? The answer might seem straight forward, but it might also be complicated. By implementing new methods, such as the ones described in this thesis, the inclusion of the third dimension and the entire complexity of the study object is made available for study. This was true even with 2D methods, however only through direct contact with the source material, which in itself might be problematic. The main difference however is the ability to access and visualise inter-dimensional relations in their true form, which is non-simplified. The added functionality of the digital part of the 3D mentality allows researchers to 'think-outside-the-box' so to speak, in that the physical limits of the material can be transcended. This should be used cautiously however, as to not impress characteristics to the model that the physical artefact does not encompass.

In the light of a discussion regarding mentality, there should be a distinction made between *mentality* and *perspective*. A *3D mentality* implies that the structure and aims of a documentation campaign or study acknowledge and encompass several dimensional aspects of the source material. This effectively means that the use of the datasets acquired does not end after the completion of the study at hand. Thus, the documentation should seek to capture the object in a coherent way, striving towards minimizing the simplification and exclusion of data. A *3D perspective* on the other hand focuses on using the necessary techniques to document a multi-dimensional set of data to answer only a set of specific research questions. The data-collection stops after the desired data is acquired, leaving other 'unwanted' or 'unnecessary' data invisible and non-existent for future studies. The primary difference between the two lies in the underlying *attitude* towards the documentation and reusability of the dataset. A *perspective* is a temporary theoretical or methodological approach to a problem while a *mentality* is the mind-set of the researcher to how to handle and convey a material, from documentation to publication.

I would argue that it is necessary for archaeology to adopt a more multi-dimensional mentality, as the discipline is multi-dimensional in its nature. Archaeology works not only in spatial dimensions, but also in a chronological perspective, as we continuously deal with issues regarding time. As our focus lies in the bridging of the temporal dimension and the spatial dimension, it therefore seems natural to assume that we should seek to encompass all aspects of prehistory, which also includes the third-dimension of artefacts. While the adoption of 3D models for material studies might seem far from the overall mentality of the discipline, there is an underlying need for a shift in thought to properly encompass the addition of a further dimension. I would also argue that this shift is quite different to the shifts in paradigm that have been recurring in archaeology, such as processual or post-processual archaeology. Instead of demanding a new way of thinking, a 3D mentality would require attention to be turned towards the entire object of study and away from simplifications. Focus should thus be aimed at incorporating a 3D mentality, regardless of the approach, ideology or perspective of the researcher, instead of trying to overhaul already established ways of thinking. It should thus be regarded as a complementary approach that improves upon what is already established, but calls for a more balanced and fundamentally stable way of perceiving the source material.

7.3 Digitizing Material Culture

One of the primary questions posed by this thesis is that regarding the usability of digital methods. How does one determine if a method can improve the established discipline? In order to discuss this, several aspects must be taken into consideration, ranging from economic/logistic aspects to the demands put on researchers to the actual knowledge increase.

This thesis has presented the more 'traditional' work-flow of material studies, as they are most commonly conducted, and put it alongside the digital work-flow established as part of the study itself. This was done in order to establish the current state of material studies and to provide an alternative approach to documentation and analysis of material culture. In order to further evaluate the usability of the digital method there was also the need to look into what new angles and knowledge that were made available by the digital approach. The digital work-flow established in this thesis has been structured to provide a starting point for the discussion of the utility of digital methods. As such, it should not necessarily be regarded as the only way to perform this type of documentation. Instead, it should be regarded as a framework, and example or perhaps a guide to how these types of material studies could be performed.

To evaluate and discuss a new methodology, it must be regarded in terms of practical application and how it would function as a tool for future studies. It must thus be put into the larger picture of how material studies can be performed and how they will improve archaeology as a discipline, not in specific case studies, as has been the case so far.

7.3.1 Impact on Material Studies

Modern society is very influenced by digital functionality. Digitization has characterized the last decades, with more information being shared and connected through digital platforms. This has also lead to an adaptation within different sciences, since it is now possible to share large quantities of data over large distance. To conduct an archaeological investigation, the researcher had to either go to the museum or base the study on images or illustrations of the source material. This connects to the discussion regarding 'mimesis' by Androshouk (2014: 17ff), that a photograph or an illustration might be regarded as a representation of the original object, but it does not have the same *value of truth* as the real object itself. This, by extension, affects how archaeologists conduct their scientific investigations and the quality of the results, as interpretations might be based on angled or already interpreted data in the form of simplified illustrations, which was aimed towards documenting an entirely different aspect of the object of study. Even if this type of scientific work is viable, as it has been used for over a century in scientific archaeology, there is always a need for pursuing a higher quality of results. This is especially true in the archaeological and cultural heritage sphere, as many artefacts are in a state of deterioration.

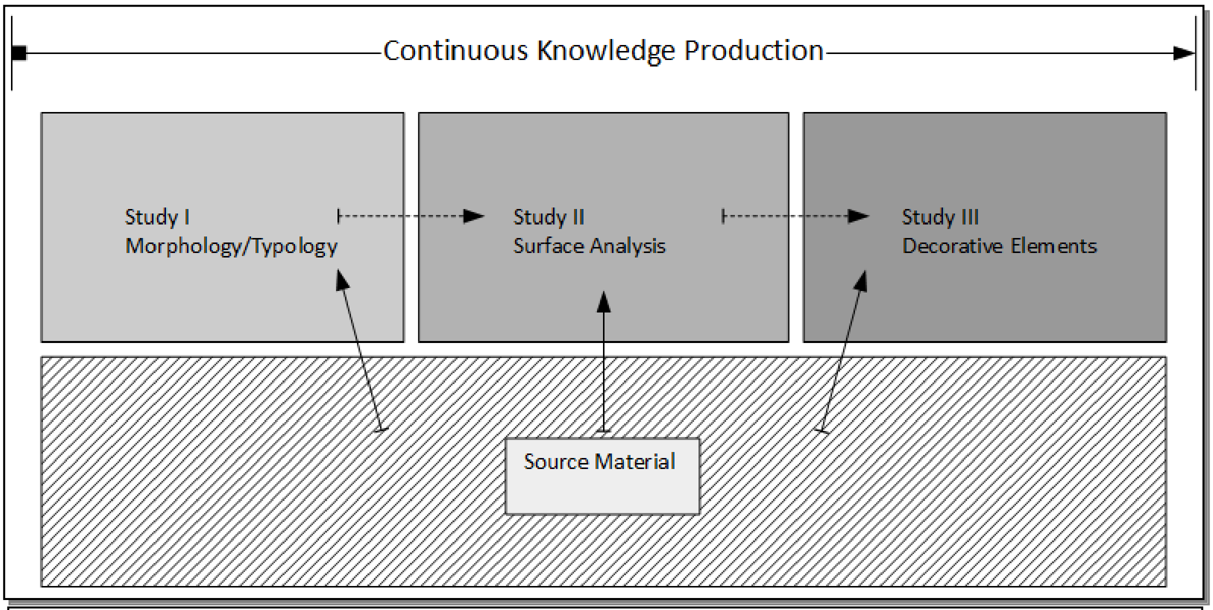

Fig. 24. Traditional knowledge production, illustrating the two options of re-using data or re-documenting the source material.

By utilizing digital methods, many of these problems present in the traditional approach might be averted. As an example, we might compare the work-flows presented in this thesis.

The traditional investigation of an artefact is conducted from the point-of-view of the research questions posed at the start of *example study I* (fig. 24). The artefact, if available for first-hand documentation, is documented from the perspective of the problem at hand, may it be for the act of type-determination or surface analysis, but the study rarely includes more data than is required to answer the questions posed. The subsequent result is that *example study I* answers the question posed and the work is completed and published. Any other studies that regard the same artefact now have two options. The first is to base the new study on the data collected from the previous one, which might be problematic if the research questions are different or the theoretical/methodological perspective are not the same. The second option is to conduct a second documentation campaign of the same artefact, but from a new perspective, methodology or research question. This has several negative implications on both studies. First of all, there is a limited reusability for the knowledge produced during the first study, making it less valuable and credible from a scientific point-of-view. The main reason of generating new research and knowledge is for it to be used in subsequent generations of yet newer knowledge, thus causing an exponential increase. I would like to argue that this process is somewhat hampered due to the fact of limited aspects of previous documented data can be re-used. The second aspect is that knowledge that cannot be confirmed or properly authenticated is less credible and less prone to be used as a basis. The goal of a scientific study should thus be aimed at providing continuity, with a basis in previous works conducted and allowing for future ones to be performed. A surface analysis study, for example, can thus only be used by another study which addresses the same elements of the object of study, i.e. the surface. Otherwise, the second study has to rely on data that was intended for a different purpose, and might be considered 'incomplete' for a study that aims to investigate decorative elements. This might prove especially true and increasingly difficult as archaeology in recent years has grown to encompass several new theoretical approaches that requires datasets previously unknown. Regarding the preservation of the source material and its accessibility, there is also the aspect of multiple documentation campaigns. Multiple campaigns imply greater stress on the material, which might suffer damage or increased deterioration due to extensive handling, meaning data-loss for future potential studies.

How then, can a digital method tackle these dilemmas? The answer, as has been argued in this thesis, lies in the documentation approach and structure of a digital work-flow. By utilizing digital solutions, such as 3D scanning or IBM, for the first documentation session, it is possible to provide the current and future studies with a coherent dataset, and make sure that the knowledge and all data generated is compatible and usable regardless of theoretical approach or research questions. To return to the example above, if *example study I* aims at conducting a typological study of the entire artefact and uses a 3D documentation, the morphology/geometry is captured. If the researcher also regards the artefact with a *3D mentality*, as argued previously, the documentation campaign is structured not to be limited to the elements relevant to the typological examination, but to capture the entirety of the artefact, regardless of study aim. The dataset generated can then be used by the study at hand, providing a good documentation on which to build further interpretations of the artefact 'type'. With *example study I* completed, the subsequent results are made available, along with the dataset of the original documentation. This allows any later study to make use of the first documentation, but in accordance to the research questions posed in the new study (see also Ch. *7.3.3 Compartmentalization and Progressive Databases* for further discussion). By using a 3D methodology and documentation, the dataset does not represent a portion or specific set of elements of the artefact, but is instead a virtual 'copy' of said artefact. This reconnects to the discussion to the problems mentioned by Androshouk (2014). If 'mimesis' implies the use of copies and the lack of *truth* in these copies, then how do we regard a virtual 3D model? The model in itself is a close-to-perfect representation of all aspects and dimensions of the artefact, and thus it could be argued to contain a higher degree of *truth* than a bi-dimensional representation.

Another issue is that of *intellectual transparency*, where the knowledge generated should be reproducible or at least transparent to the degree that the interpretations made can be followed, thus lending credibility to the study. It has been argued previously (see *Ch. 7.1 Typology – Objectivity vs Subjectivity*) that the use of digital establishes a foundation of objective data upon which to base interpretations. This would provide archaeology with an aspect that has been difficult to implement, namely that of *reproducibility*, which is a vital component in the objectivity discussion. As of today, it might prove difficult to properly anchor an interpretation, as it is a subjective statement regarding the source material, more or less based on scientific data. By not only providing the interpretation, but also the source dataset upon which the interpretation is made, with a coherent work-flow to illustrate how an interpretation was made, is it possible to lend more credibility to the archaeological discipline.

To continue the previous discussion, the use of a 3D digital methodology can summarily provide archaeologists with the means to conduct largely objective documentation of the source material, generating data that can later be reused indefinitely by any number of diverse studies. At least, this is the general ideology behind this argumentation. The implementation of such a digitized methodology requires several changes in the archaeological discipline regarding mentality and praxis, primarily within material studies. It would also put more emphasis on the initial documentation of material culture. To be able to utilize such a work-flow in archaeological practice, there is an increased pressure put on the 'first' digital study, as it needs to be conducted with high precision to enable future studies to take advantage of the digital material. This is somewhat paralleled by the documentation practice within field archaeology, which seeks to document and interpret the contexts as thoroughly as possible before their destruction. Perhaps a similar mind-set could be applied to the documentation of material culture. The subsequent change brought on by a digital method would shift the focus from a single-study oriented documentation towards a focus on capturing the entire material. If conducted correctly, this would effectively remove the need for any additional documentation to be undertaken and later studies can become more efficient in their time-use, having more time to spend on interpreting the data supplied. Thus it is also possible to evaluate different studies, strategies and theoretical perspectives, as they would all be based upon the same dataset, only from different angles.

7.3.2 Time-Consumption and Technical Expertise

With the discussion regarding more coherent initial documentations, there is always the temporal aspect of a study to take into account. A digital method would potentially save time for subsequent studies, with a proper initial documentation. It must be kept in mind, however, that the initial documentation of an artefact will potentially demand additional time.

Time is always a resource to take into account when evaluating a method and a specific work-flow. In terms of efficiency, time can be put in relation to costs of materials, equipment and personnel use as well as the time vs. quality of the method employed. Therefore, this study chose to encompass a time-estimate of the established documentation process, from acquisition to presentation. The initial part of the work-flow was the acquisition campaign, which was estimated to about 90 minutes per artefact (one 360° scan à 60 minutes and two 90° brackets à 10 minutes). Depending on the morphological complexity of the object scanned, additional scans would be required, extending the capture by approximately 10 minutes per additional scan. No artefact captured within the limits of this study required a longer acquisition than 120 minutes, giving a general span of between 90 and 120 minutes. It should be noted that these scans were conducted with the NextEngine 3D scanner, and the potential efficiency of different equipment might vary. It should also be mentioned that while this scanning process is quite time-consuming, it is also semi-automatic. This means that the equipment is mostly autonomous during the scanning and requires the user only to re-position/replace the artefact in-between scanning sessions. By extension, this means that the scanner can operate with only minor supervision during the extensive time-of-capture, and it is thus possible for the researcher to conduct other work simultaneously, or even operate several scanners at a time.

The post-processing step is mostly consisting of model generation, alignment and cleaning processes, which depends heavily on computational hardware. As such, the time-consumption is also linked to the hardware available for the project. The estimated time required for the post-processing was between 60 and 120 minutes per model. However, the post-processing is much like the scanning process as it is semi-automatic. Large time-segments are computation time to reprocess the data, after selections made by the researcher. Thus, this step also allows for other work to be conducted alongside the post-processing.

The 3D-drawing documentation on the other hand, is a human-based or manual process. The drawing and database compilation of each spearhead took approximately 45-60 minutes to complete. This, however, is linked to the precision/sampling of the documentation as a higher degree of sampling requires more time (see *Ch. 6.2 Sampling and Precision*). The documentation of this study was conducted at roughly four points per centimetre (4-1).

Depending on the researcher's familiarity with GIS software packages, the time-consumption might vary, but keeping in mind that the process is the much the same as *vectorising* a 2D terrain map, many archaeologists already possess the necessary skillset for a time-efficient documentation. This is also one of the reasons why ArcGIS was chosen over other software packages, as to illustrate the usability of already established knowledge, which many archaeologist's already possess. The other reasons were of course the use of database management, which in itself aids the time efficiency of the method.

The subsequent analytical steps and their time-consumption also vary depending on knowledge in the different software packages and on the purpose of the analysis. Reconstructing artefacts might demand a great amount of time depending on the intended quality of the reconstruction while object manipulation in the form of MeshLab shaders take close to no time at all to render. Thus, the representative analytic approach in this timeline is the surface analysis. It requires repositioning of the artefact and processing in the form of vector to raster transformation, and thus has a few mandatory actions which take time. The process is strictly manual and requires roughly 20 minutes to conduct. For an efficient time-use, the same artefact might be repositioned several times before moving to the next software, to provide several surfaces/angles for raster transformation. As the surface analysis is based on software packages previously used in the post-processing and 3D-documentation steps, any researcher utilizing a digital method should also have the necessary skillset to conduct an efficient analysis.

The last step in the work-flow is the presentation of the material and results. This too, is quite diverse depending on the mode of presentation chosen and on the target audience. This thesis aimed at addressing the use of web-based modes of visualisation, in the form of

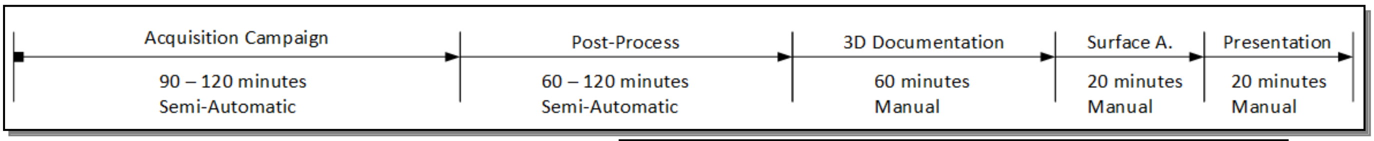

Fig. 25. Timeline of the digital work-flow, per artefact.

3DHOP. While the software is in its early stages, there are several customization options available to properly display the model and data as desired. Other visualisations undertaken is the generation of 3D-PDFs, images/screenshots and illustrations. When it comes to data and model presentation, there is no generic time-consumption per artefact, as one research project might have a different presentation than another. As for this thesis, the process of generating models in 3DHOP and 3D-PDFs takes roughly 20 minutes per model, which might be considered guidelines to the general time-consumption of the presentation stage.

It should also be put forward that technology is steadily increasing in quality and capacity, always addressing issues and problems. With more powerful hardware, software and equipment, the time-consumption of this methodology should improve substantially in the future, making it even more efficient and advantageous to use.

Taking into account the entirety of the time required to fully document a single artefact, as done in this thesis, 4 – 6 hours are required per object of study (fig. 25). This might be regarded as a long processing time, but it must be put into relation that the data acquired by this type of acquisition is aimed at a long-term perspective. This does not necessarily mean that the initial study would have to be exceedingly longer/larger, as it already requires a digital documentation. The general ideology behind this method is, as argued above, that a study that seeks to utilize the advantages of a digital methodology should also aim at performing a coherent documentation, thus creating a solid foundation for the study at hand and for future studies on the same material.

7.3.3 Compartmentalization and Progressive Databases

The previous discussion has centred on a linear and complete documentation-flow, regarding the continuous reuse of the same material from one initial study. This is however seldom the case, as not all studies are taking into account the entirety of the source material. Instead it is usual to make samples of the material. This has been done in this study, which only includes some 14% of the spearheads of the weapon deposit of Uppåkra, and but a small fraction of the total Iron Age spearheads world-wide. This is another, quite central, aspect of digital documentation methods. As has been argued previously, the methodology employed are largely objective and if used correctly it can provide a coherent and relatively complete documentation of the object of study. This aspect can be combined with the use of *compartmentalization* of the documentation, to capture the entirety of a source material, such as the spearheads. As it this study provides a detailed, objective documentation of the 19 spearheads covered, it could theoretically be combined with other documentation of the same type. A second study, of for example *Illerup Ådal* (Ilkjaer, 1990), would thus be compatible, as the documentation process was equivalent. This is only possible with a non-subjective and/or non-angled documentation however, as it has to be free from the initial assumptions and expectations of the researcher, to make sure that no aspect is over- or under-emphasised. By structuring the material studies in accordance to this model, it is possible to construct large-scale databases from several small-scale documentations from individual studies. I would term these as *progressive databases* as they can be added to continuously, given that the documentation standard is the same.

The essence of the *progressive database* model is that small-scale studies that investigate a sample of the material can be compiled into databases. Three independent studies, with different perspectives but the same digital method, with samples of the same material can be made fully compatible by using the same documentation method and a 3D mentality. Through the use of compartmentalization, the entire material can be documented in segments over time. Each subsequent study would re-use the material required from previous documentations and adding only that which has not yet been documented (fig. 26). Thus there would be a constant addition made until all of the source material was documented. This would connect to the previous discussion of time-consumption, as each new documentation would only have to be on material previously undocumented, and the time could be spent on providing high-quality representations of these parts of the material rather than conducting a whole new documentation.

This database practice and compilation of digital material culture would allow archaeologists to have greater access to the datasets of different types of material studies. A small-scale study with limited resources could put focus on analysing and interpreting the material. It also allows for the undertaking of large-scale investigations, which would otherwise be limited as the material would be spread over a large geographical area and many institutions. This would result in a more efficient archaeological discipline in terms of knowledge-production, as the resources can be more focused instead of spent on re-documentation.

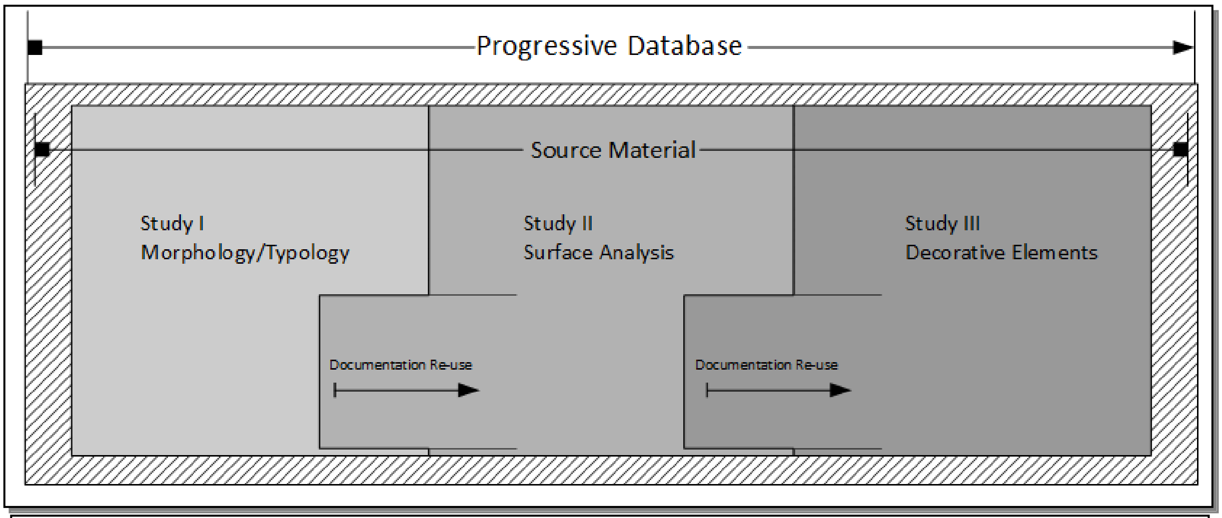

Fig. 26. Progressive Database model, an illustration of how to structure the re-use and complementing documentation of a source material by multiple studies.

To put this in perspective, there have been three studies undertaken on the spearheads of this thesis. One by Helgesson (2004), one by Andersson (2012) and now the study you are currently reading. While the material is the same, the studies differ greatly. Helgesson aimed at a typological examination while Andersson did a damage analysis of the crooked spearheads. Each subsequent study required a detailed documentation aimed at capturing the traits of interest to the research questions posed. Thus, there were limited ways to make use of the data collected in between the studies, as it was incomplete when put into relation of the complexity of the artefacts. If instead Helgesson had conducted a coherent digital documentation campaign and based his typological documentation on the dataset, he could have achieved a more objective type-determination. He would also have been able to create a database which included the entirety of the artefact-complexity, due to the nature of the digital techniques. His study could thus have formed the basis upon which Andersson conducted his study, with the added possibilities for Andersson to use the dataset for additional analyses in relation to his damage-oriented study. This would efficiently remove the need for a documentation campaign by Andersson and the time-resources could be better distributed towards further analysis and interpretation. The knowledge generated by Andersson would be added to the database of the weapon deposit, granting ease-of-access to any subsequent studies that would be conducted on the same material.

This would also be favourable from a preservation point-of-view, with regards to the frailty of some of the spearheads. It might be argued that the documentation of material studies is also destructive, as repeated handling of the same material risks damaging the source material and thus a digital approach would limit the damage to the artefacts. The logistics of material studies, i.e. accessing the material, has also been central in the discussion since its beginning. With the introduction of digital methods, the focus of these logistic resources would be redistributed towards digital collections and not physical, thus allowing for a better preservation status on a majority of the artefacts, as they are less exposed. It also allows for access to collections outside the time-boundaries of the museums and institutions.

7.3.4 Potential and Quality

This discussion has centred on the 'large-scale' improvements to archaeology brought on by a digital methodology. But it is also important to remember the qualitative, study-oriented improvements. This thesis has presented numerous analytical methods that are made available through a digital documentation and there has been a discussion with regards to the objectivity aspects of these analyses. It is clear that the use of digital 3D models allows for more detailed studies to be carried out and visualised. The most basic use of a 3D model allows for visual observations of the artefact, as if observing the 'physical' artefact. More advanced uses, such as 3D-drawings or surface analyses each, aid the evaluation and interpretation of the material. But the strength of the digital method lies in its adaptability. Starting from a digital 3D model of the material, it is possible to conduct almost any series of analyses that can be conducted on the 'physical' artefact. Those analytical methods that cannot be done, such as destructive material analyses, might still benefit from a preservation point-of-view, as the digital model is unaffected. The digital approach is also not limited by the physical limitations of the artefact, as mentioned when presenting 'shaders' and object manipulation tools (see Ch. *4.3 Artefact Manipulation*), meaning that analytic methods previously impossible are made readily available when handling a virtual model.

Researchers utilizing a digital method could thus customize the data to fit the research questions posed and be able to handle larger datasets, meaning that the limitations of a study are expanded. This is similar to how GIS has revolutionised other branches of archaeology, unlocking the potential for large-scale data management and visualisation that would otherwise be cumbersome to handle. Digital method thus allows for accessibility to the source material on a new, more detailed angle in terms of analysis, visualisation and reproduction.

I would also argue that the digital approach supplies a higher degree of quality than the traditional method, both in results and in visualisation. A contour-drawing made on the surface of a 3D model follows the actual geometry of the artefact and thus it can be regarded as highly accurate. The 2D equivalent, often made manually and by studying the artefact, is more prone towards simplifying the details, as there is the human element present. As with the discussion regarding visualisation, a 2D drawing relies heavily on the artistic skills of the researcher as well as on the active sampling choices when every line is drawn. There might be a high degree of sampling, where an artefact is depicted with a high number of lines, but every line is still a subjective action. A 3D drawing is also a subjective action in much the same way, but it has the added advantage of being able to draw on the 'surface' of the artefact, i.e. on the 3D model. This allows for a more detailed capture, as it does not rely on the artistic skills of the researcher to convey the geometry and morphology, but rather on the level of detail captured by the used technology. The error margins of active sampling choices are thus reduced, meaning that the researcher only has to identify a feature and limit it, and not convey it onto another medium, i.e. a paper or such. A higher detail of capture therefore allows for a higher degree of detailed drawings done on the model, allowing a 3D approach for potentially higher quality. The same conclusion could be made regarding the surface analysis, which identifies anomalies. The extent of an anomaly might be problematic to visually determine, but the digital method employed efficiently provides a basis for further interpretation, removing the need for a subjective interpretation of the anomaly and its properties. Thus it is argued, following this study, that the digital method supplies archaeologists with the tools necessary for increasing the level of detail possible by material studies. The potential of the digital method can thus be argued to be preferable and advantageous in material studies. I would also argue that a digital methodology would greatly improve material studies, similar to how digital methods have improved field and landscape archaeology.

8. Summarising the impact

How does a digital documentation and analysis method improve and affect the practice of material studies?

This thesis has sought to illustrate the implications of utilizing a digital methodology in material studies. The primary improvement provided by a digital approach is that of data production. With the use of digital methods, it is possible to access a range of analytical tools that would otherwise be unavailable or difficult to employ. This efficiently allows researchers to expand the possible areas of study that can be undertaken, and allows for a more in-depth and detail-oriented knowledge-production in relation to the source material. The perhaps best example of 'new tools' is that of object manipulation, allowing researchers to change the properties of the artefacts studied. This proved close to impossible before the application of digital solutions, at least at the detailed level that is possible with the digital approach. Another example is that of surface analysis, which allows for the objective identification of anomalies and their extent. This identification might then serve as a basis or foundation upon which interpretations regarding the anomaly can be made. It has been argued extensively that the one of the main improvements brought on by a digital approach is that of producing large quantities of high-quality data which can be used for further interpretation of the material, thus lending additional credibility to these interpretations. This data has also been argued to be objective and reproducible, which again supports a more solid foundation for the interpretative archaeological science. The last, and perhaps most important aspect of a digital documentation, methodology and mentality is that of accessibility. With a digitalization of the source material comes the possibilities for distribution of the data to the scientific community. This allows for intellectual transparency to how conclusions and interpretations were made, as well as allowing for a more efficient use of resources, as there is limited need for documenting the same source material again. This gives more credibility to each researcher, to the archaeological discipline and allows for a focus towards producing new knowledge, instead of re-affirming and re-documenting old one.

What are the limitations of such a digital method?

It has been established in this thesis that there are several limitations to applying a digital method. The primary limitation is that of technical expertise. This implies having the required knowledge to produce, manage and analyse 3D data, as well as skills in managing digital documentation equipment. This can however be likened to the basic skillset required to operate and handle geographic data and field archaeological documentation equipment, which is steadily increasing and becoming in-demand.

Other limitations are those of the equipment, hardware and software. The equipment has practical limits to the size of the physical object that can be captured at once, causing extended time-consumption, which by extension limits the undertaken study. A greater responsibility is placed on the researcher conducting the documentation campaign, primarily that of the first digital documentation. This means that the initial documentation might demand more time to conduct for it to reach the adequate standard. The technology used is also demanding in terms of hardware capabilities and performance, which might further limit the use of the method. And since the method is not yet established in archaeology, there are limits to the functionality of the software packages available. These limitations, however, are not of an impossible character, but rather hindrances in terms of efficiency. With sufficient technical expertise, there are ways to overcome most limitations given enough time and resources.

Another limitation of the study is that of material composition. This is connected to the mode of documentation, and the properties and function of the equipment. The technology used in this thesis, laser scanning, relies on the fact that the surface of the scanned object is opaque or of minor reflectance. This implies that some materials with a high reflectance or none at all, such as precious metals or glass, might prove difficult to capture, meaning that there are certain elements in the material culture that are more problematic to document with this type of documentation campaign.

> *How does this alternative method fit into the theoretical discussion of material studies and typology?*

When regarding typology from a digital point-of-view, it could be argued that the digital methodology might revolutionise how type-determinations are conducted. One of the constant discussions regarding typology is that of subjectivity contra objectivity. It has been argued throughout this thesis that a digital method of documentation and analysis has the capacity of being objective in its nature. Thus it is possible to use a digital method to overcome the problems in typology, which are the subjective interpretations and impressionistic elements in the description of types. It was also argued that the use of 3D models as a reference for artefact documentations, such as drawings or plans, provides a higher degree of quality, making for a more accurate representation of the artefact. This also contributes to raising the quality standard of subsequent interpretations based upon the digital material. Other methods might also strongly benefit from the use of a digital method, but more indirectly. Methods of a destructive character are often unwanted and shunned in archaeology, as the source material is lost in the process. By using digital documentation, it is possible to preserve the material in a virtual form as a point-of-reference for future studies, regardless of the deterioration of the physical source material.

Another major aspect of archaeology addressed in this discussion is how the source material is regarded by archaeologists. Previous theoretical discussions regarding typology and material studies have perceived the source material from a 2D mentality, caused by the normalisation of the use of 2D depictions of the material. This limitation of technology, which archaeologists have long strived to work around, is no longer valid with the introduction of 3D modelling techniques and virtual workspaces. Thus there is a need for a change of mentality, which should seek to encompass not only the third dimension but also allow for a digitization of the source material. In order to achieve the accessibility previously mentioned, there must not only be an application of digital methods, but also the adoption of a digital mind-set, to what is possible with a virtual material. This mind-set would allow for a wider spread in knowledge and documentation, resulting in a higher overall quality within the field of material studies. There is therefore need for the discussion concerning digital methods not only to regard the application of the method in small-scale case studies, but also the theoretical implications of a large-scale change of attitude. Thus we should take the time to consider not only the direct advantages of using 3D techniques and technology on a single study, but also regard how archaeology as a whole is conducted and how we can adapt to the digital society of today.

9. Future Studies

Following the completion of this study, which meant to argue regarding the usability of digital methods in material studies, it would be warranted that the methodology and work-flow be tested to its full extent. While this thesis serves as an outline and general overview of the utility of the method, future studies with digital material studies would be to put the presented method into practice. Given that large portions of the discussion of this thesis has aimed towards the digitization of typological research, it would be interesting apply this to a full-scale typological study with a 3D mentality in mind. It would also be of especial interest to test the possibilities of improving upon already established typologies and material studies, by performing 3D documentations and compiling already established data and knowledge, thus creating coherent databases of a specific type of material culture.

The utilization and possibilities of digital documentation method for material studies is largely unmapped territory, but this thesis has hopefully shed some light on the possible implementations, limitations and expectations of using said method. Future studies should perhaps seek to employ this digital methodology, analytical methods and 3D mentality in practical archaeological work, as this is the only way to truly incorporate new methods to a discipline.

10. Conclusion

This thesis has sought to address and advocate the use of digital methods, their applicability and possibilities, but also the issues and theory that needs to be applied with them. This was done by establishing a digital work-flow based on the acquisition and analysis of 19 Iron Age spearheads from Uppåkra, Scania, and the digital method has been illustrated in its entirety, from initial documentation to publication. The equipment used was a NextEngine 3D scanner, meant to illustrate the detail-oriented possibilities of the method. To put the new method into contrast, the more 'traditional' praxis was also addressed. Following the documentation campaign the artefacts were subjected to a 3D-drawing documentation using a GIS software, with the compilation of an artefact-unique database. A selection of the spearheads were also subjected to further analysis, aimed towards surface topography, anomaly detection and artefact manipulation for acquiring new data. This connected the work-flow to the on-going theoretical discussion regarding typology and subjectivity. The thesis presented arguments regarding the use of digital methods to establish objective documentations and datasets of the source material, to counteract the issues of subjectivity. Several of the limitations of the digital method were also addressed, such as the need for technical expertise in handling the equipment and software packages.

To address the issue regarding resource investment and demands of the method, a time-estimate was established in relation to the work-flow, where it was also argued that a restructure of the attitude towards material studies might improve the discipline as a whole through a more efficient use of already produced data. It was also argued regarding the use of progressive digital databases to achieve reproducibility and re-using previous datasets as archaeological praxis, with the added advantage of increased credibility, intellectual transparency and knowledge accessibility. The overall theoretical discussion conducted through the thesis recurred to the notion that there is a need for a change of mentality in archaeology. It was argued that there is need to move away from the notion that three-dimensional objects can be adequately documented in two dimensions. This was argued to be crucial in the adaptation of material studies to a new digital methodology and a practice of addressing the entirety of the material, instead of parts.

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Appendices

Appendix 1 - Spearhead 4417 mesh

Appendix 2 - Spearhead 4417 colour

Appendix 3 - Spearhead 4417 reconstruction

Appendix 4 - Spearhead 4417 surface