Tradition in transition

Visualising innovation and change in past potting and present archaeological practice

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Loes Opgenhaffen

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Visualising innovation and change in past potting and present archaeological practice

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Contents

Preface

The palace of Knossos features in one of my earliest memories, which I visited with my parents in 1985 at age three, and to which I returned in the Summer of 2001. It was then and there that I decided to quit art school and switch to archaeology – and to become an archaeological illustrator instead. Several years later I became that archaeological illustrator, and increasingly adopted and adapted 3D technology into my visualisation practice, but never imagined it would get me as far as doing PhD research, and I certainly never thought that research would bring me back to Knossos! Now, 21 years later, I will defend my dissertation with the main objective to assess to what extent the technical tradition of archaeological visualisation has changed due to the adoption of digital 3D technology, using a Greek archaeological case study. All my creativity and passions are embodied in this research, and this is first and foremost thanks to my dear friend and promotor Dr Jill Hilditch who gave me the wonderful opportunity to develop my scientific and creative practice, and to contribute with it to the wider archaeological discipline. This was not, of course, a completely free endeavour, as I had a clear task, which was to explore how modern 3D technology could innovate an inherently visual and tangible specialisation such as ceramic analysis, in particular the technological analysis of forming techniques.

Fortunately, I did not do this research in isolation: I was part of a small team of the Tracing the Potter's Wheel project (TPW), with experimental archaeologist Dr Caroline Jeffra and directed by ceramics analyst Dr Jill Hilditch. Caroline taught me everything about potting and forming traces, and together we exchanged digital experience and created the TPW Knowledge Hub. I wanted to thank you both here for being such marvellous teachers, colleagues, coaches, and inspirators. And of course, thank you to Prof. Robin Boast, for accepting the role as principal promotor. In the first couple of years, I frequently thought – just as any PhD probably – of just giving up and quitting because the research went in every direction (everything is so exciting and interesting! But is it really necessary to learn three computer languages?). Robin acted as an incredibly inspiring and motivating coach, and put all this confidence in me without even having read a single letter. Our conversations about reflexivity, the workings, uses and non-uses of algorithms, the historicity of images, and so much more, were most inspiring, and his comments on my later writings extremely valuable. I'm very grateful for this.

Extended gratitude goes to Caroline and also Maarten Sepers. Really, I could not have done this project without you two. I first met Caroline in January 2017, at her very first day in the Netherlands, when I was working with Maarten in the Dom in Utrecht, where we were 3D scanning a funerary monument. On that cold day a warm friendship was born. With Maarten I could try all kinds of 3D scan technologies and scanner brands, and discuss both methodological and technical issues. Caroline became my unofficial daily supervisor and invaluable sparring partner in discussing any subject, ranging from digital topics, newly discovered forming techniques in ethnological videos, database solutions to gardening and Lego. Last but not least, she tirelessly proofread most of my articles and chapters, so I am at many points greatly indebted to her.

Another important pivotal role in my career goes to my friend and colleague Martina Revello Lami. By joining forces between ceramics analysis and 3D technology, we started the "Pottery goes Digital" and "Pottery goes Public" projects in late 2014. These projects laid the foundations for the present PhD research, for which my sincere gratitude. But this was not the only collaboration (that is, related to this particular PhD project, because our professional collaboration reaches beyond this particular field), we also organised, together with Dr Hayley Mickleburgh, the Archon Winter School "Sharing Practices: Archaeological Visualisation in the Netherlands", hosted by the RCE in Amersfoort and the University of Amsterdam in February 2020 – perhaps the very last physical conference before the COVID-19 outbreak. I would also like to thank Dr Chiara Piccoli and Dr Costas Papadopoulos for their important input and contribution to this conference as well. The roundtable held at this Winter School, focussing on the usefulness and applicability of existing guidelines and charters in current digital archaeological visualisation, proved to be vital input for my research – I am indebted to all the discussants. I want to especially thank Dr Paul Reilly for sharing with me his thoughts on the London Charter during this roundtable, and motivating me to contribute to the field by presenting a solution to the unsuccessful implementation of this charter in current archaeological visualisation. Many thanks to Dr Jitte Waagen and Tijm Lanjouw of the 4D Research Lab, for contributing to the Winter School but also for your substantive support and advice on my research.

Thank you so much Dr Nicolò dell'Unto for the rousing brainstorming sessions via Zoom about the planned stay in Lund and the session for the Web3D 2021 conference. Unfortunately, I wasn't able to stay in Lund to work on my PhD research, but I'm thankful I had the paper presented at the CDH meeting in Lund in 2018, and it is still my intention to return! Nicolò was a great teacher and organiser at the Dialogues with the Past-course "Critical Archiving", together with Dr Sara Perry, Dr James Taylor and Dr Åsa Berggren, to whom my gratitude also goes too, as well as all the course participants. Everyone really pushed me forward in knowing how to finally position and finish my article "Archives in Action", one of the chapters of this dissertation. Extended gratitude goes Dr Åsa Berggren, who invited me to contribute to the Special Issue of Open Archaeology on "Archaeological Practice on Shifting Grounds". This invitation came exactly at the time when I was writing the article "Tradition in Transition", included as a chapter in the dissertation. Thank you for this wonderful publishing opportunity.

The accomplishment of the promotion could not have succeeded without the support of my family. We basically run a joint family venture. Due to the chronic physical condition HSD, I am unable to work fulltime and as a result it is near impossible for me to financially maintain myself, that is, as a PhD student at a certain age. In the Netherlands, you only receive support once "afgekeurd" (medically disqualified for work), which I refuse to be, because what I envision in life is not found at home. So, despite their own limited financial sources, they helped me to keep up appearances nonetheless. First of all, I want to thank my father John Opgenhaffen, who supported me most, also on a practical level by realising the "holobox" for the "Tracing the Conical Cup" exhibition of TPW. Secondly, all praise to my ex-husband and best friend Juan Carlos Pantoja Dorado, who helped me tremendously with preparing the 3D printed "Cup Art" installation for that same exhibition, and for your moral support and insane amount of patience. Without my sister Kendra Melgarejo Palomo house and cat sitting, I wouldn't have been able to spend so much time in Greece, so you were quite crucial to the success of this whole academic endeavour, same as Mieke Beks, who arranged the best writing retreat in Belgium as one could possibly imagine. I am most thankful to my mother Annemieke Buijs, for proofreading some texts for structure and redundant descriptions and repetitions, and for being there day and night. Even my grandfather Johan Buijs contributed to the family cause with close reading and correcting the Dutch summary. Anyone who manages to still find a mistake will receive a price. Thank you Paul Opgenhaffen, for your critical feedback on the database and the UI, and for getting TPW in touch with Karissa Bell and Alex Post of Kbell+Postman, who built our TPW Knowledge Hub, and for finding social media experts such as Bela Rinderu ready to reflect on my user persona and public outreach models. Also thank you Nina of Kbell+Postman, for shining your light on these models.

This physical condition I mentioned forced me to find creative solutions in the digital realm, to seek balance between work and health, and investigate the affordances of my body, my hand orthotics and the digital devices, which are, in a way, orthotics as well; as extensions of the body and replacements of previous technology such as the pencil, the 3D scanner and the computer software are enhancing practice. Coincidentally, when I was just there for maintenance of my hand orthotics (which are based on plaster casts of my hands), I could advise the medical instrument makers of the AMC hospital how to best direct the handheld 3D scanner to record existing orthotics. But most of all, I wish to express my gratitude to Dr Mirjam de Haart and drs. Tanja Oud, for not only your medical advice and treatments, but also for your support, for reminding me that I am doing an incredible job, despite all the pain.

What helped making the writing process not a lonely exercise, was because all PhDs were working together in the same room: 3.14. Despite the different research topics, from classics and archaeology to media studies, being in the same stage of the career or writing phase enabled us to exchange interesting ideas, share deep frustrations, and utter joy when someone delivered the manuscript. Thank you, roomies of 3.14! Special thanks go to my dear friend, colleague, paranymph and desk neighbour, Marijn Stolk, not only for the moral support as we both went through some serious life events, but also for sparring and exchanging writing solutions.

My other passion lies in the ancient site of Satricum and Archaic building practice in Central-Italy, where I have participated in the excavation project as all-round visualiser for 17 years. The project provided me with an experimental space in which to test my digital 3D techniques. I am inexpressibly grateful to Prof. Marijke Gnade, director of the Satricum Research Project, for all your support in every possible way, and for letting me explore how to best scan large objects in 3D in the *Museo Nazionale etrusco di Villa Giulia*. Related to large objects, many thanks to former neighbour and micro-biologist Dr Nils Meiresonne too, who invited me to try my scanning skills on micromillimeter tall bacteria colonies. We succeeded in producing 3D models of these bacteria in an unprecedented resolution and level of detail! All this experience helped me in developing the scanning workflows.

I would like to express my gratitude to Ivan Kisjes for helping TPW with all the digital technicalities for the website and database, but also for listening to all my ideas and plans to create together algorithms to automate the recognition of so-called forming traces. Thank you Jeltsje Stobbe for your constructive comments on my paper on archiving practice, and Nina Magdelijns, Kelly Paparstergiou and Vasiliki Lagari for trying out and providing feedback on my scanning and processing workflows, and for your assistance in 3D scanning the experimental ceramics. Many thanks to Vasiliki, for inviting me to Chalkidiki, and making me feel so much at home with your family, and also to the other lovely people in Athens and Neméa. Much gratitude goes to Dr Irene Nikolakopoulou, the people in the conservation lab and the museums of ancient Neméa and Heraklion in Greece, and to Prof. Carl Knappett for allowing me to test the 3D scanning workflow on archaeological material.

I have stayed several times in the Netherlands Institute at Athens (NIA) to work on my thesis, for language courses and for the project exhibition. I am very grateful for their hospitality and the wonderful conversations with Emmy and the librarians.

Last but certainly not least, inexpressible gratitude goes to my dear friends and paranymphs Kim Pollmann and Nina Gerritsen, and my sister Zenzi Melgarejo de Paz. Thank you, girls, for being a sort of diligent sounding board for my ideas, frustrations, and for the occasional much-needed pep talk. You are amazing.

Chapter 1

Introduction

An archaeological case and the perpetual question

Archaeologists specialised in ceramics analysis have identified traces the earliest use of the potter's wheel in mainland Greece in the Early Bronze Age II (*c.* 2550-2200 BC). The wheel was not an indigenous invention but found its origins most probably in the Near East as early as the fourth millennium BC (Roux and de Miroschedji 2009). The new technology then arrived through trade and travelling artisans, via Anatolia and the northern Aegean islands, eventually mainland Greece. What the archaeologists also discovered is that local potting communities adapted the wheel to their tradition of applying a coiling-building technique to produce ceramic vessels (Choleva 2012). This resulted in a mixed techniques called wheel-coiling: partly hand-building with coils, and partly finishing the vessel with the rotational force of the wheel. Pottery manufactured with a hand-building technique, however, remained dominant (Choleva 2020; Jeffra 2013; Pullen 2008). The wheel did not seem to be a popular technological innovation and disappeared from the archaeological record, to then reappear in Minoan Crete in the course of the second millennium (1800-1700 BC). Technological and experimental studies suggest that the wheel was probably an internal development in Crete, and as such a Minoan invention (Day et al. 1997; Evely 1988; Jeffra 2011; Knappett 1999). As Minoan power expanded and interregional contact increased, the wheel became diffused as a Minoan technological innovation across the south and central Aegean islands and the mainland, and the western Anatolian coast. Here, the potting communities started to imitate not only the Minoan shapes and motifs from imported Minoan vessels in local pottery repertoires (Younger and Rehak 2008, p. 154), but also a wheel-fashioning technique. The latter indicates that the new technology was spread by travelling potters from whom the technique was learned, as such a new technique, with inherent technical know-how, skills and gestures, cannot be read from a pot alone, but needs to be learned through close observation.

The adoption of the new technique was a slow process – if adopted at all –, and potters seem to have used the wheel only for smaller vessels and particular shapes at first, alongside shapes that were still hand-built (Knappett 2008). It took until well into the Late Bronze Age (*c.* 1600-1100 BC) that also larger shapes were

Figure **1.1**. Different pot-making techniques: left, the wheel-coiling technique, and right, the wheel-throwing technique. Photos: Anneke Dekker.

wheel-fashioned, although the hand-building technique continued to be applied as well, albeit on a smaller scale. With “wheel-fashioned”, pottery specialists mean all pottery in which rotatic kinetic energy (RKE – sustained energy due to rotational motion of a wheel device) was involved during the manufacturing process (Roux and Courty 1998) (Fig. **1.1**). These technological approaches in ceramics analysis suggest furthermore that the common assumption that Mycenaean pottery of the Late Bronze Age was predominantly wheel-thrown (in which the shape is drawn from a centred lump of clay while the wheel is rotating), can no longer hold (Jeffra 2011), as new evidence suggests that several forming techniques co-existed by the end of the Late Bronze Age. The transition from wheel-coiling to wheel-throwing remains an underexplored issue, whereas it has huge implications for the transmission of technical knowledge, as wheel-throwing requires completely different set of skills, posture and gestures, and technical know-how (Hilditch et al. 2021).

By scrutinising how the potter’s wheel was introduced and adapted, it can be investigated how potting communities were connected and configured through time, in order to ultimately reconstruct how the transmission of craft knowledge was entangled in interaction networks in the Bronze Age Aegean (Hilditch et al. 2021). This is the core topic of the Tracing the Potter’s Wheel Project (TPW), which investigates the potter’s wheel as technological innovation within this exciting chronological period and region. The multi-year project is directed by Dr J. Hilditch and hosted by the University of Amsterdam within the Centre for Ancient Studies and Archaeology (ACASA), and is funded with an NWO-Vidi grant. The project uniquely combines theoretical perspectives on social interactions, technological processes and innovation, with experimental, digital 3D visualisation and analytical methods. The presented PhD research is part of this project, and is assigned with the principal task to assess to what extent digital high-resolution 3D scanning and resulting 3D models can enhance the study of forming traces, and to develop a tailored 3D scanning method that could be adopted and reproduced by other ceramics specialists. This proved to be a challenge, not only because 3D technology had never been deployed before in such an integrated manner and on a large scale in this particular field of archaeological expertise, but also because of the inherently visual and tactile aspect of analysing ceramics. How to apply a technology with such intangible data outputs?

What stands out is, however, that for a discipline particularly concerned with how technology had an effect on past societies, archaeologists seem to have little awareness of how current (digital) technological innovations have an impact on their own practice. For reference, it made me, as former archaeological illustrator and 3D visualiser of ancient architecture, particularly aware of how I adopted 3D technology and adapted it to my existing practice, and how I thought I could transfer these skills and technical know-how unproblematically to the field of ceramics analysis, with its own visualisation tradition. Scientific visualisation practice and the analysis of the resulting visual evidence, is enmeshed in shared epistemological goals. To reach these goals archaeologists use a wide range of digital visualisation methods to record, organise, analyse, interpret, and reconstruct these complex interactions in the past into a narrative and to communicate these to present-day peers and public. As such, visualisation methods form an intrinsic part of the representation of empirical and intellectual findings which are crucial to knowledge production in archaeology. In order to gain a deeper understanding in these processes, the main theoretically-oriented objective of this PhD project is to investigate how the archaeological visualisation tradition in general and object-based visualisation in particular, has responded to the introduction innovative digital 3D technology, and to what extent this has impacted current practice.

A methodology is required in order to interrogate visualisation practice and investigate to what extent digital 3D technology has impacted intellectual reasoning and interpretation processes. With this methodology, dubbed "Tradition in Transition", the PhD project aims to contribute to the current archaeological debate on visualisation practice and recent calls for a critical theoretical framework for a transparent and reflexive (digital) archaeology (Caraher 2016; Huggett 2015; Perry and Taylor 2018). Together with the standardised methods that will be developed for object-based 3D visualisation, the conceptual framework aims to provide a tailored solution to the ineffective implementation of the London Charter and similar guidelines. Especially the London Charter – as being formulated in a time that digital visualisation was in its infancy – has been surpassed by an archaeology with a firmly embedded digital 3D apparatus (Opgenhaffen et al. 2021). Moreover, the London Charter fails short in providing guidelines for public participation and co-production of digital archaeological objects, due to the one-way directed dissemination expert knowledge to public audiences (as one mass of people) (Jones et al. 2017). Other related issues which are intended to be addressed to foster the current debate, are claims for paradigms shifts or even the prosthetisation of archaeological practice due to the application of computational tools in archaeological research (Chrysanthi et al. 2012; Roosevelt et al. 2015). The conceptual framework should enable to evaluate whether (digital) tools really possess such epistemological power, or if this rather should be attributed to the archaeologist deploying and operating the machine.

The integrated research framework of TPW applied to investigate ancient innovation and practice, provides an ideal starting point to assess current visualisation practice as well as TPW's collaborative practice. The project will serve as a case study on both practical and theoretical level, in order to address the research objectives and questions raised in the present PhD project. The theoretical example of TPW is

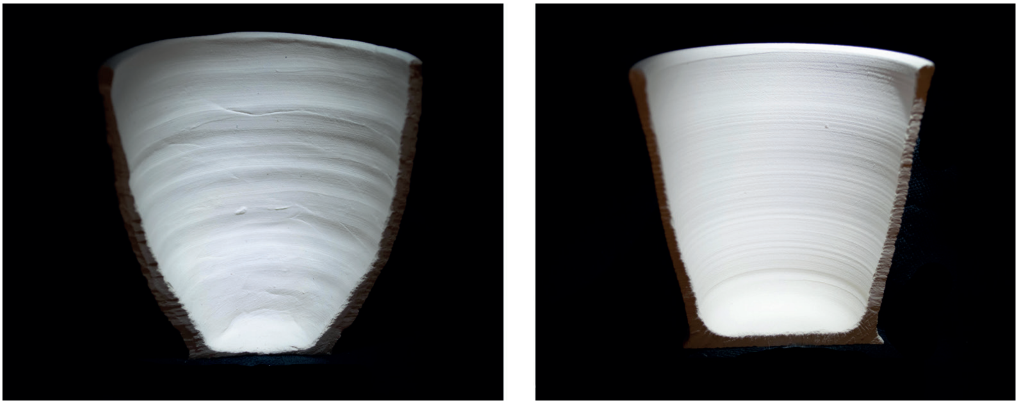


Figure. **1.2**. Two experimental cups made with the wheel-coiling technique (left), with traces of incompletely joined coils, and the wheel-thrown technique (right), which looks tidier and more symmetrical than the clumsier wheel-coiled cup, and the traces of fine, horizontal parallel running ribbed striations clearly visible. Photos: C.D. Jeffra.

the *chaîne opératoire* approach, a praxis-oriented approach with origins in sociology (Hilditch 2020; Jeffra 2015). It allows to combine practice and social theory with a reflexive approach, which enables to examine the incremental creative steps within technological processes occurring within a social environment, and places emphasis on the reciprocal relationship between archaeologists and digital devices. Communities of practice are is another concept applied by TPW to study how technical knowledge is transmitted. Central in this transmission is learning, which entails the processes of how know-how and skills are transferred to and reproduced by a next generation of archaeologists or potters. These subsequent shared practices, or communities of practice, enable a sense of belonging, of identity. The analysis of such processes and practices may help to establish what exactly is "digital archaeology" - or any archaeology using digital tools. Or are archaeologists just practicing archaeology digitally (Costopoulos 2016; Morgan and Eve 2012; Perry and Taylor 2018)?

The investigated pottery of TPW provides the practical casus for the PhD project. The experimental component of TPW works from the hypothesis that comparative material derived from modern produced, "experimental", material, make it possible to identify forming traces in the surface of the archaeological vessel (called macrotraces). A certain combination of such traces represents the forming technique, in the present case a wheel-coiling method or the wheel-throwing technique (Fig. **1.2**). The experimental typeset is part of the case study for this dissertation. All material will be scanned in 3D in order to develop a standardised method for recording ceramic forming technology in 3D. A major goal of the experimental typeset is to translate this material into an online reference collection of wheel-fashioned pottery with 3D content. This reference collection will be designed as an educational environment where students, archaeologists and lay people can learn to recognise forming techniques.

Finally, the developed method is tested on archaeological ceramics during fieldwork in Greece. Based on the experience with the heterogeneous character of archaeological material, the method can be adapted and refined. Although TPW-team

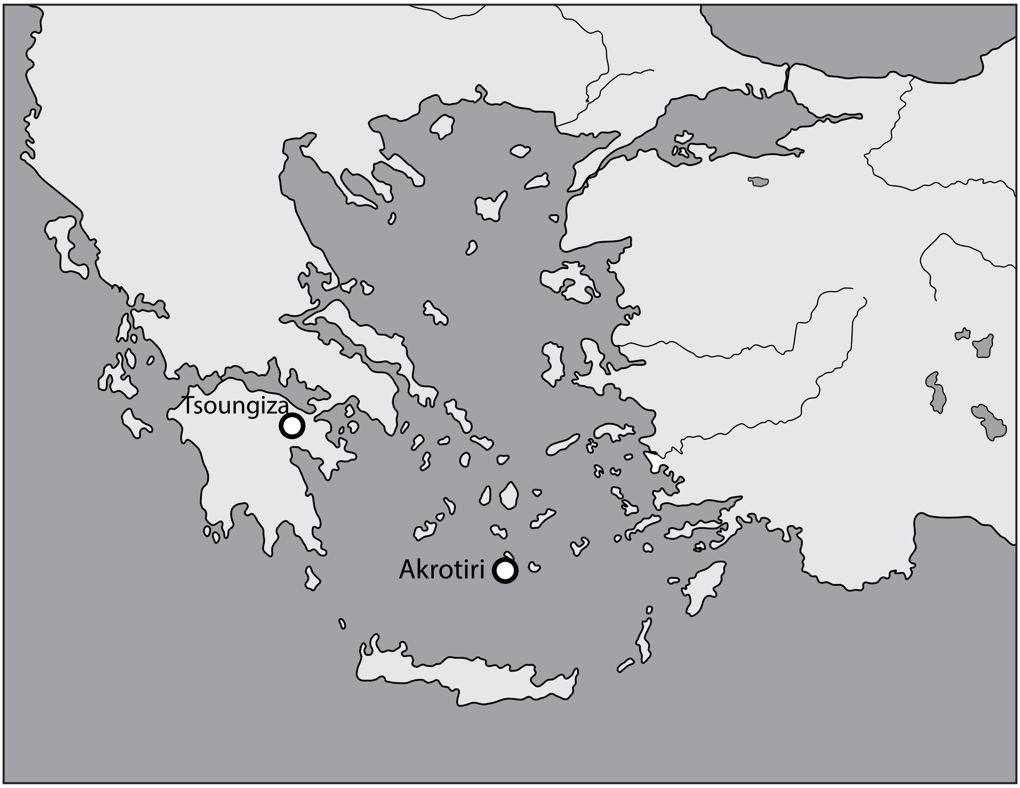


Figure **1.3**. Map of the Aegean with the two sites. Image: Loes Opgenhaffen.

has carried out research in several sites throughout the Aegean, it was not possible to make 3D scans on every site, due to permit issues. Nevertheless, two sites can be referenced in this dissertation. Tsoungiza is a Mycenaean site in the Argolid in mainland Greece, continually inhabited throughout the Middle and Late Bronze Age, and Akrotiri is an urban settlement of the Cycladic culture with Minoan influences on Santorini that flourished in the Middle Bronze Age, which abruptly ended with the massive eruption of the Thera volcano in *c.* 1600 BC. The two sites represent together a rich diachronic ceramic assemblage that covers the period from the introduction of the wheel in both cultural regions, and can deliver valuable insights on the nature of Cycladic, Minoan and Mycenaean communities of practice (Fig. **1.3**).

Structure of the thesis

The main objective of the presented PhD research is to explore how modern 3D technology could be enhance this inherently visual and tangible specialisation of ceramic analysis, in particular the technological analysis of forming techniques. The expansion of the theoretical approaches and methods of the TPW project on modern archaeological practice, raises the question of what kind of data and knowledge is produced with the application of new technology. This epistemological insight informed the main theme of the dissertation, which is to assess to what extent the technical tradition of archaeological visualisation in general and object-based visualisation in particular, has changed due to the adoption of digital 3D technology. This practical task of developing 3D scanning methods for and the digital presentation of ceramics analysis, the assessment of the impact of technology on the discipline in the past and present, and the formulation of a methodology to bridge the conceptual and practical issues, were investigated in published articles which are included in this manuscript. These core articles are expanded with additional chapters to clarify and elaborate on matters which were not or insufficiently touched upon in the articles. Chapters 2, 5, 7 are accepted and published journal articles and chapter 8 is a book chapter in press. Chapter 6 presents the 3D scanning and related methods such as ensuring scientific transparency and the dissemination of data. These have been successively published and continuously updated as open-access manuals on TPW's Knowledge Hub since 2019. The following section describes the structure, questions and issues in more detail.

Similar to the way ceramic specialists track developments in technical traditions by analysing potting strategies over a long period of time, a deeper understanding of the long tradition of archaeological visualisation practice, from the Renaissance to the present, may provide insights in how first antiquarians and later archaeologists, reacted to artistic, technical, scientific, and, ultimately, digital innovations. The published journal article "Visualizing Archaeologists: A Reflexive History of Visualization Practice" presents an historical synopsis of two usually separated research areas (Opgenhaffen 2021a), digital archaeology and archaeological visualisation, and forms chapter 2 in this dissertation. In this way, digital 3D visualisation is positioned in a longer archaeological visualisation tradition, which allows to assess the shared creative visual practice and its epistemic role in current archaeological knowledge production.

Chapter 3 expands the historical approach by describing the development of digital 3D visualisation technology and how this became an embedded tool in archaeological object visualisation, and more specifically how this technology was deployed to automate artefact illustration and classification practice. It is investigated to what extent 3D techniques have been deployed in ceramics analysis, and ends with examples of 3D applied in research to ancient forming technology. The state of the art of digital applications in this particular archaeological field of expertise, illustrates the urgent need to innovate a traditional specialism such as pottery studies, for this exciting technology can contribute so much more than just automating and accelerating existing recording processes. This chapter and the following two chapters aim to answer the question on what the roles are of digital 3D visualisation and how archaeologists use and perceive the subsequent visual outputs, understood in the present research as 3D artefacts, in archaeological knowledge production.

The innumerable names to describe virtual and immaterial things are explored in chapter 4. Through the inventory of current uses and abuses of terminology, such as replica, 3D model, and authenticity, the chapter intends to create awareness among archaeologists of the meaning of such terms, and that these cannot be applied interchangeably and uncritically. For example, due to the ephemerality of technological potential, the understandings of words such as high-resolution and accuracy depend on the available technology available at the time. This makes their significance highly volatile, and necessitates specific addressing of what is understood under that particular precision at the time the 3D artefact was produced. The overview also explores firm beliefs in the alleged objectivity that enshroud digital devices and their visual outputs. Finally, it is identified and defined what term is best suited to describe the visual outputs created in the present PhD project. This should encourage the community of practice of visualising archaeologists to clarify in each project what is understood under the applied terminology, and to ultimately reach consensus on a standardised terminology.

The theoretical framework for this dissertation, published as the journal paper "Tradition in Transition" (Opgenhaffen 2021b), forms chapter 5. Unlike other research which generally builds on postmodern theory and models derived from information science, the proposed methodology builds on fundamental archaeological theory and applies this to the digital. The *chaîne opératoire* approach has been employed by TPW to interrogate ancient technological processes by breaking them down into stages while preserving the social context in which things were created. The PhD project has expanded this approach with the current reflexive movement towards practice in archaeology, and applied it to assess present digital 3D visualisation and archiving practices. Tradition in Transition presents a novel framework for the community of practice of archaeological visualisers, which enables specialists to critically document their practice of creating a 3D visualisation of an object. This allows not only full transparency of the creative process, but also helps to acquire more insights in current visualisation practices, which ultimately builds up to a standardisation of the numerous existing best practices. As an example, I apply the methodology to map and analyse the development of my own visualisation practice with respect to the adoption and adaption of 3D technology, and show how I subsequently transferred my skills and technical know-how to apprentices. In addition, I observe and record the collaborative practice of the TPW team according the Tradition in Transition framework in chapter 8.

Chapter 6 is dedicated to the principal task of the PhD project: the development of a standardised method for the 3D scanning of archaeological ceramics, which have been published as open-access manuals on the TPW Knowledge Hub. It answers to the question what the best and affordable scanning technology and procedure is to scan pottery in a sufficiently high resolution to discern forming traces. It includes a method to document meta- and paradata as well, in order to safeguard transparency of technical and intellectual processes. This reflexive approach "to the documentation of the documentation process" to warrant scientific transparency (Hodder 2003, p. 61, emphasis original), contributes to calls such as those of Ian Hodder and to the broad guidelines of the London Charter (Beacham et al. 2006; Denard 2012). Most of all, these shared publicly accessible and shared methods, successively published as open-access manuals since 2019 and frequently updated according the latest developments and insights (Opgenhaffen 2020a-d), contribute to the overall goals of the TPW project, which is to make our collaborative research practice and resulting data an open resource for anyone interested in pottery forming technology and archaeological practice.

The method is further developed and discussed in the book chapter "Balancing data storage and user functionality", accepted to be published in "The 3 Dimensions of Digitalised Archaeology" (Opgenhaffen et al. in press), and forms chapter 7 of this thesis. The chapter presents the online open-access project database with 3D content, dubbed the TPW Knowledge Hub, where the metadata and paradata is connected to the contextual and principal data. An archive, however, is not an isolated entity, but enmeshed in a network of things and people. For instance, by treating 3D models as an integrated part of the archive rather as a distinctly presented class – which is often the case – this multivocal knowledge base explicitly entangles the multiple perspectives from the different specialisations – which usually operate separately too – on archaeological datasets. To reach these divergent yet intricate objectives, I introduce the approach of designerly thinking into digital archaeological practice to support the design of a user-friendly interface to share information and knowledge with a wide range of users – specialist, archaeologists, students and lay audiences alike.

The creative stages of archiving, be it data collection or the reproduction of an archiving practice, are affected and changing due to the implementation of digital technology too. These physical and intellectual processes of differentiation and classification, with its methods and gestures, are then translated into the design of the project database structure and metadata categories, to accommodate the research. This raises the question how this collection and recording practice is exactly reflected in the resulting project archive. Chapter 8, which is accepted to be published as journal article "investigates this issue by applying an expanded version of the Tradition of Transition methodology to perform a kind of reversed analysis to the uses of the research archive. As such, the impact of digital technology on existing collaborative collection and recording practice of pottery for technological analysis, may be traced and identified. Another question that this approach may answer is whether a dynamic database and interface design is reflecting a shift in how archaeologists treat the traditional written scholarly argument. The approach further allows to assess if such interactive use of the data and navigation through the Knowledge Hub, could serve as a new form of academic inquiry.

In addition, the chapter explores how a project archive with 3D content can be promoted and valorised to a diverse audience. But how to reach that audience, who exactly is this "audience", and how do we know what they want to know? A new approach is required that enables to define these user groups and their needs, as well as to analyse user experience of archaeological research archives. Research to user experience is rare in archaeology, and the definition of target audiences are, as far as could be established, a novelty. Such an approach should implicitly cover topics as re-use of data, participation and the inclusion of academic and lay stakeholders in archaeological knowledge production as well. Topics which are increasingly addressed in archaeology, archive and museum studies, yet often overlooked in the creative stages of archiving, be it data collection or the reproduction of an archiving practice. Chapter 8 explores these matters and presents an innovative model unique to archaeology, based on approaches derived from User Centred Design, to reach and include audiences for research archives. These approaches expand the Tradition in Transition methodology and as such contribute in a more democratic way to the London Charter, by involving other parties in archaeological projects, instead of unilineal presenting expert knowledge to "the public".

Lastly, the outcomes and insights of the diverse chapters are discussed and reflected upon in chapter 9, in order to address the principal question to what extent the archaeological visualisation tradition has been impacted, or even changed, due to the adoption and adaptation of digital 3D technology.

Visualisation forward

This doctorate research delivers a complete theoretically informed, digital pipeline from artefact selection to the presentation of it in an open archive, in which a micron-level forming trace in an artefact in a Greek storeroom receives a global audience, and where specialists discuss the trace which can be tracked to its creators – the experimental and visualising archaeologists. The proposed methodology and practical methods are – compared to more established reflexive research to excavation and museum practices – novel for object-based visualisation, and they explicitly promote a more standardised and transparent visualisation practice for object documentation in 3D. The reproduction of these methods will ultimately lead to more similarly produced datasets, which will improve comparative research to ceramic technology. But most of all, the methods paint – while documenting the creative process – a clearer and more critical picture of the current visualisation tradition.

Chapter 2[1]

Visualising Archaeologists.

A reflexive history of visualisation practice in archaeology

Archaeology as a visual discipline

The very first thing an archaeologist does when a sherd is found is perform a visual inspection. Visual observations on shape, style, size, and even forming technology, permit preliminary classifications that lead to the most fundamental of archaeological processes – seriation. After the initial inspection, certain technology enters the picture to enhance the observations and analysis. Archaeologists use a wide range of visualisation methods to record, organise, interpret, and reconstruct complex narratives of the past and to communicate them to present-day peers and public. Simply put, this act of visual translation, moving from the things that archaeologists find to reconstructing a narrative of past human behaviour, is as much a creative act as a scientific one. Archaeology's very foundations are built upon visual elements.

Visualisation methods form an intrinsic part of the representation of practical *and* intellectual findings, being crucial to knowledge production in archaeology (Morgan and Wright 2018; Moser 2012; Wickstead 2013). Visuals do not merely serve as a means of "scaffolding" text or guiding interpretative processes, on the contrary, they are instrumental in the transformation and mobilisation of archaeological material itself (Latour 1990; Witmore 2006, p. 268). Visualisations represent material remains transferred to a representational medium and therefore its interpretation, and the knowledge generated from this, is built from both the transferred material and translated representation. Once transformed and translated to standardised modes of documentation, they can be mobilised from its locale to anywhere in the world where they will be further studied, analysed and interpreted.

1 A version of this chapter has been published in *Open Archaeology*, 7/1, in the Special Issue on Art, Creativity and Automation: Sharing 3D Visualization Practices in Archaeology, pp. 353-377. https://doi.org/10.1515/opar-2020-0138

However, the term "visualisation" is differentiated here from the more commonly used noun "representation". Representation is rather static and implies a certain objectivity as the visual output should represent some actual state at a particular moment in time. A visualisation is an active definition because it functions both as a product and as a practice, resembling Latour's (1990) idea of inscriptions. As such, a visualisation, for example a 3D scan, of an original artefact is *different* from the original when it is translated by a digital recording procedure and a heuristic, creative practice of the archaeologist/operator, and subsequently becomes an original virtual artefact in itself (after Huvila 2017). In this way, archaeological visualisation is a *method*, a way of understanding rather than merely representing material remains, and could therefore function as a methodology to bridge theory and practice. As a knowledge-making instrument, archaeological visualisation is an integrated part of archaeology rather than a (sub-) discipline, for tools (the equipment, including software, pencils and PCs) and methods do not constitute a discipline but are an invaluable part of its creation, that could potentially be, partly at least, responsible for paradigmatic shifts.

Recent focus on the "digital turn" has addressed the impact of digital technologies on archaeological practice and how they have altered archaeological knowledge production (Beale and Reilly 2017a; Boast and Biehl 2011; Caraher 2016, 2019; Garstki 2017; Huvila 2014, 2018a; Huvila et al. 2017), but potentially this has come at the expense of visualisation practice in general. After all, visualisation in archaeology is still often performed in analogue, and has not been turned to the digital entirely. Visualisation techniques may have changed over the years, but have the ways archaeologists visualise their interpretation processes and reconstructions, and present research data and outcomes, fundamentally changed? Or do new tools merely disguise conventional practices? The answer may reside in an understanding of what a 2D image is and what an analogue 3D model does, in order to determine if the digital third dimension provides something truly different. Without understanding how archaeologists do what they do, and how it came into being as such, it will be difficult to understand how digital visualisation practices, and the technology that enables this visualisation, are part of the wider archaeological discourse. This chapter aims to raise awareness about the long tradition of visualisation practice where visualising archaeologists are taking part in, by carrying out a historical survey spanning from creative practice of antiquarians, 19th century archaeologists and plaster casts, to processual archaeologists and early computer applications, and the advent of the microchip to Autodesk. This historical awareness should contribute to the current practice of archaeological knowledge production.

To continue on the idea of turning processes in archaeological epistemologies by disruptive technologies and creative practices, Gareth Beale and Paul Reilly recently dubbed a "creative turn" in archaeology. Here, archaeological "praxis [revolves] around ideas of creativity", instead of being reserved exclusively to art (Beale and Reilly 2017a). A praxis-oriented approach may indeed enhance understanding in the mechanisms behind adoption and adaptation of new technologies into existing visualisation traditions, and the impact of the interplay between archaeologists, new tools and visual material on practice and knowledge production that has become almost completely digital. Yet, for a predominantly visual discipline about things and the so-called "material turn" (Olsen 2010; Olsen et al. 2012; Witmore 2006), that heavily relies on the visualisation of these things, it is appalling to learn how little visualisations actually appear in more theoretically oriented archaeological publications (Bradley 1997; Gamble 1992). Archaeologists tend not to depict the things they talk about (Molloy and Milić 2018, pp. 98, 110) while depriving them of "their thingly content" and "matter" by domesticating and humanizing the things (Olsen 2013, p. 290; Stobiecka 2019), or, at the other end of the spectrum, they reduce material to integers, as things are translated to immaterial data stored in databases, in order to be quantified and queried to produce daunting visualised statistics. A similar absence of images can be identified in extensive studies into the history of archaeological thought and interpretation in archaeology, such as the work of Bruce Trigger (2006) and Ian Hodder (1992, 2003, 2012), where hardly any serious attention has been given to visualisation methods and their role in the formation of the archaeological discipline. This is illustrated by the fact that the one chapter on visualisation by Stephanie Moser in *Archaeological Theory Today* (Hodder 2012) is placed at the end of the edited volume.[2] A last case in point is the Renfrew and Bahn archaeology textbook, which is abundantly rich in illustrations, not a single word is dedicated to the role of visualisation practice in archaeology. Terms such as "visualisation", "drawing" and "illustration" do not appear in the substantial Index.

In the broader humanities and social sciences already a rich tradition of explicitly exploring related issues of vision and visuality is centred around the concept of the "visual turn". Originally coined the "pictorial turn", W.J.T. Mitchell wanted to acknowledge the turn to the visual or image as something shared and mundane through time (Mitchell 2002, p. 173). Mitchell suggests that when the concept is used from an historical point of view, it can be applied as a tool to analyse the specific moments in time when new technology or media is introduced that disrupts certain cultural practice, such as the printing press, photography or the 3D scanner. This concept of the visual turn could prove to be a valuable reflexive tool for investigating past visualisation practices and to gain better understanding of current advances in archaeological visualisation. Indeed, distinctive archaeological visualisation studies, with a focus on reconstructive illustration, artist impressions, photography and artefact drawing, have been established over the past thirty years (*inter alia* Bradley 1997; Earl 2006; Frischer 2008, 2011; Moser 1996, 2009, 2012, 2014; Perry 2009, 2015; Piccoli 2017; Shanks 1997; Smiles and Moser 2005; Svabo and Shanks 2013). However, this scholarship has remained a small niche focused on specific case studies or excursions into fine arts (Renfrew 2003; Wickstead 2013) and the creative industries (Llobera 2011), which reinforces its isolation from other (digital) archaeological visual languages. This can be at least partly explained by the fact that archaeologists often seem to take digital 3D visualisations and its tools and techniques for granted (Huggett 2015b, p. 80; Molloy and Milić 2018, p. 98; Westin 2014), overlooking the role and the agency of the visualiser in the archaeological production chain, and the digital tendency to remove the human element to claim objectivity (Perry 2018).[3]

2 As noticed by Perry (2013, p. 283).

3 Fortunately, an increasing awareness of this issue can be discerned. Isto Huvila (2018b, p. 101), for example, recognised that a human actor is continuously engaged in the digital 3D

The above-mentioned issues shall be tackled by a reflexive survey of illustrations of antiquities and scientific representation from the Renaissance to the present. The survey aims to create an awareness of a long tradition of visualisation practice, of which the basis lies in the activities of antiquarians and artists, as well as artistic, technical and scientific innovations. This approach provides a critical understanding of what archaeological visualisation practice including its underlying technologies means today.

A brief history of archaeology from a visual perspective

Framing the picture

This historical overview explicitly seeks to assess visualisations from a technological perspective, which allows the materiality of visualisations to be interrogated and considers material relations within a social context, as well as the mechanical properties of the construction. A combination of reflexive and praxis-oriented approaches towards the history and development of visualisation techniques and practices in art, archaeology and science could help to understand the current workings of 3D visualisation as a creative practice, and how archaeology responds and acts upon innovations and the adoption of new visualisation technology. This approach aims to complement previous research to archaeological representation, and goes beyond the consumption of archaeological images, addressing instead the inherent practices and methods of image making and how these contributed to archaeological knowledge construction and ideas about the past. This brief overview draws from previous work on archaeological practice (Perry 2011, 2015; Perry and Johnson 2014) and reflexive studies on visualisation practices (Berggren 2014; Berggren et al. 2015; Berggren and Hodder 2003; Londoño 2014; Morgan 2016; Morgan and Wright 2018). Lastly, by taking a somewhat Dutch perspective I will introduce a few visualising with Dutch roots who have left substantial traces in our collective visual memory, with the ultimate goal of contributing to a more inclusive historical narrative on archaeological visualisation that relies heavily on North-Western examples – with a few excursions into Italy. The historical overview ends with an integrated discussion on two usually separated but complementary research areas: digital archaeology and archaeological visualisation.

Early modern visualisation techniques and images of the past, c. 1500-1750

An age of artistic exploration and narrations of the past

Although Roman architectural remains were always visibly present in Medieval cityscapes, (papal) building activities and agricultural work within and outside the Aurelian walls of 15th and 16th century Rome, lead to many discoveries of antiquities (Furlotti 2019; Piccoli 2017). These discoveries sparked the interest of Humanists and artists alike, who began to collect the antiquities, "followed by

visualisation of an artefact, and any type of visualisation relies on the technical skill and vision of the operator.

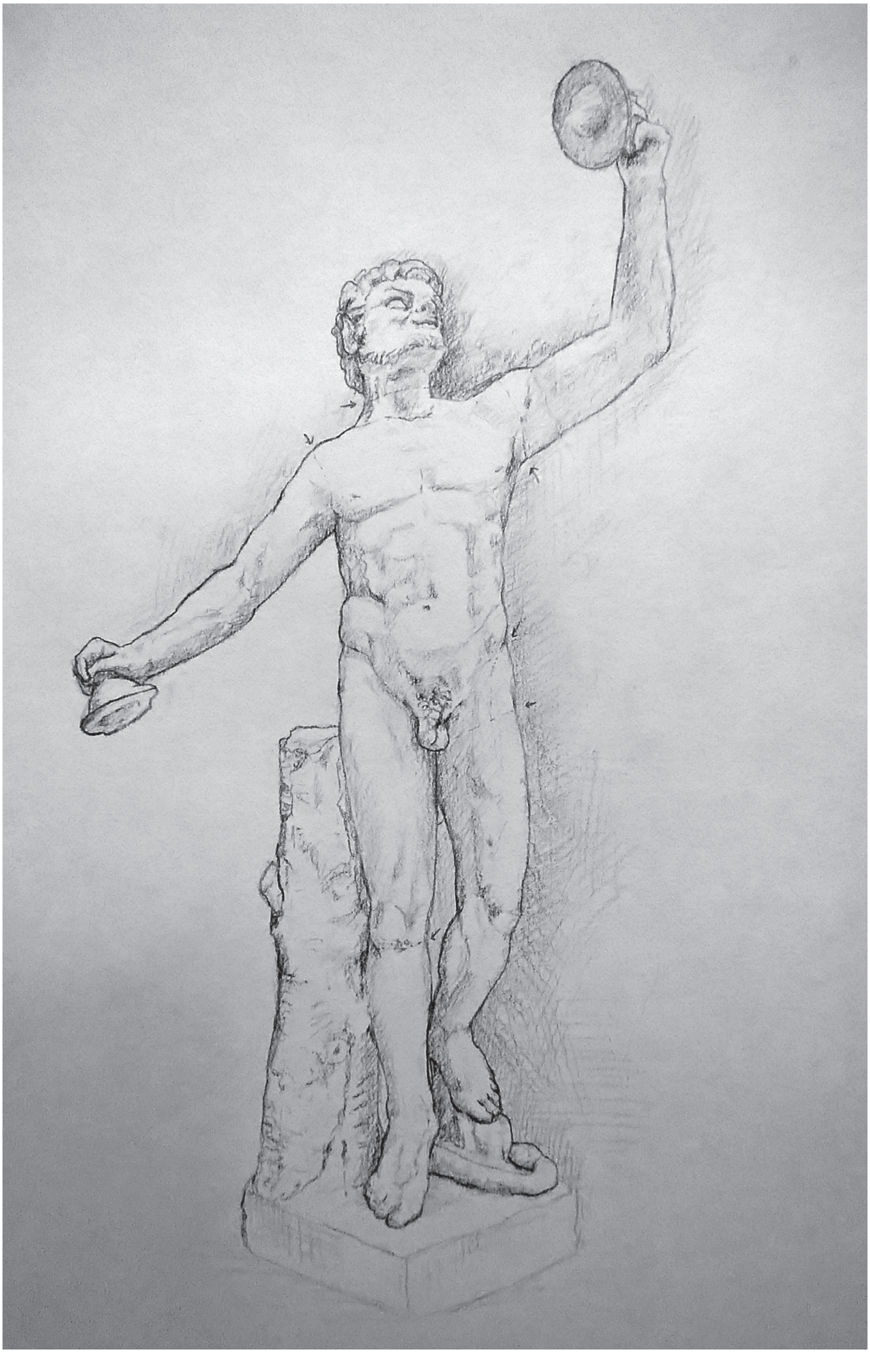


Figure **2.1**. An example of a "restored" or completed archaeological object, a dancing Roman faun from the 2nd century. Only the torso and the right thigh are antique (arrows indicating the breaks). The Rondanini Faun was completed by François Duquesnoy somewhere between 1630-1635 (British Museum, museum no. 1988,1208.1; drawing by Loes Opgenhaffen when it was on display in the exhibition "Caravaggio-Bernini. Baroque in Rome", Rijksmuseum in Amsterdam, 14 February – 13 September 2020).

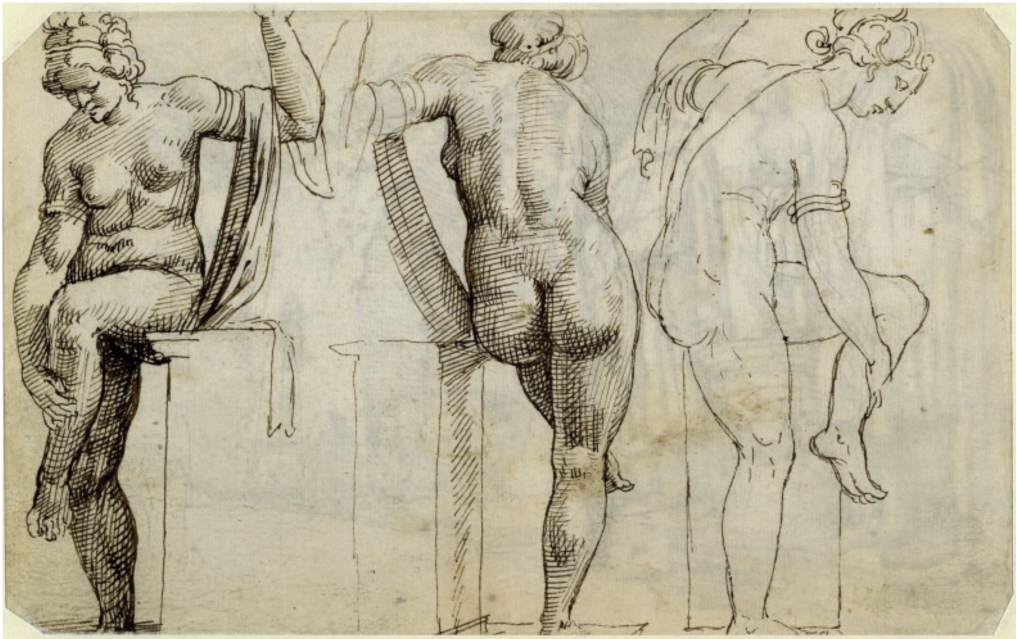


Figure **2.2**. Multiple views of the Bathing Venus by Maarten van Heemskerk, ca. 1532-1536, ink on paper. Courtesy of the Kupferstichkabinett, Staatliche Museen zu Berlin / Jörg P. Anders [CC BY-NC-SA].

the decoding, the restoring, the imitating, the reimagining, the weaving together of a grand narrative of history of these material remains and their textual traces" (Barkan 1999, p. xxi). Such a discovery, and the subsequent process of knowledge making, is illustrated in a letter of Francesco da Sangallo, who witnessed the discovery of the Laocoön group in 1506, and wrote that as soon as the sculpture was completely visible "everyone started to draw, all the while discoursing on ancient things" (Da Sangallo, *Letters on Familiar Matters* 6.2, in Barkan 1999, p. 3).

Several modes of visual documentation reflecting different collecting aims resulted from the renewed interest in classical culture. Firstly, from the above-mentioned remark by Sangallo, it could be assumed that this "discourse" needed visual guidance. The drawings were in this case made by the scholar-antiquarians themselves, and used as an epistemological tool. Dealer-antiquarians, on the other hand, commissioned (average) artists to make drawings and sketches of antiquities, accompanied with details about dimensions and subjects. These antiquarians regarded this type of simple "catalogue" drawings as instruments to transfer the necessary information about material and aesthetic properties of the object on sale, and did not consider them as artworks nor as valuable documentary evidence, as became practice in the course of the 17th century (Furlotti 2019, p. 160, figs. 89–90). Another visual mode emerged from the elevation of excavated sculptures to precious pieces of art, which needed to be restored without impediment to show the full glory and splendour of classical culture. A rich practice of producing replicas and restorations, or "interventions" (Furlotti 2019, p. 4), by artists in a contemporary style on paper or sculpture, developed over the course of the 16th century (Fig. **2.1**). These copies or interventions are unreliable as precise representational sources but they do illustrate the epistemological nature of these images, as they document contemporary interpretation processes of antique objects and the desire to know the objects as they were in the past, and not as they are in the present. An interesting representational innovation in the 16th century was the recording of multiple views of one sculpture, to overcome the disadvantage of two-dimensionality of the medium (Fig. **2.2**) as to demonstrate all sides of the object. Although an artistic exploration at this point in time (Barkan 1999, p. 146), this way of representing a 3D object on a 2D surface became a standardised archaeological practice in later times.

A quite different visual mode in this period was painting. Early Renaissance artists in Italy experimented with relatively unprecedented mythological and classical scenes. Unlike the previous exclusively religious representation that was supported by a clear visual established language, early Renaissance artists who experimented with these "new" classical subjects had no visual framework to build upon (Gombrich 1972, p. 32); they had to innovate. The scenes were derived from ancient texts and Roman iconography, but the artists looked to sculptures and sarcophagi to render the characters, and in some instances influences of Etruscan or Greek visual motifs have been identified (Collins 2001). This absent visual vocabulary is best illustrated by Botticelli's *Mythologies* (late 15th century) and Pinturicchio's *Scene from the Odyssey* (1509), which is executed in an early 16th century setting, including clothes, interior, and ship (Baxandall 1988). Recent artistic innovations such as linear perspective, foreshortening and chiaroscuro (technique from the visual arts that accentuates the contrast between light and dark), enabled these pioneering artists to create a certain three-dimensionality on a flat surface, resulting in convincing, realistic images of fashionable symbolic paintings of classical historical scenes representing contemporary Humanist, Neoplatonic ideals or Christian virtues. Whereas these Italian Renaissance paintings set a stage with figures performing significant actions based on texts, 17th century Dutch painters (or northern art more generally), on the other hand, maintained a different visual culture that was rooted in a tradition of observation and describing nature (Alpers 1983). Only through sight and seeing, it was believed, new knowledge could be obtained. New technology such as the invention of the lens increased visibility enhanced observations made by the naked eye. Dutch artists not only adopted artistic innovations into their practice, but also new technology such as the lens to translate vision through this lens onto the canvas, giving Dutch paintings its distinctive descriptive character and fine-grained rendering of nature and matter, not always appreciated by their Italian contemporaries (Alpers 1983).

Illustrated artefacts as evidence

During the 17th century, progress witnessed in scientific method was stirred by empiricism and rationalism based on first-hand experience and original observations, on which deductive reasoning could then lead to new knowledge. The antiquarians regarded illustration as a way of doing research, and details in the drawing were seen as facts (Smiles 2013, p. 12), as they had experienced it themselves (so it is true) (Nordbladh 2007, p. 112), or they communicated the empirical observations

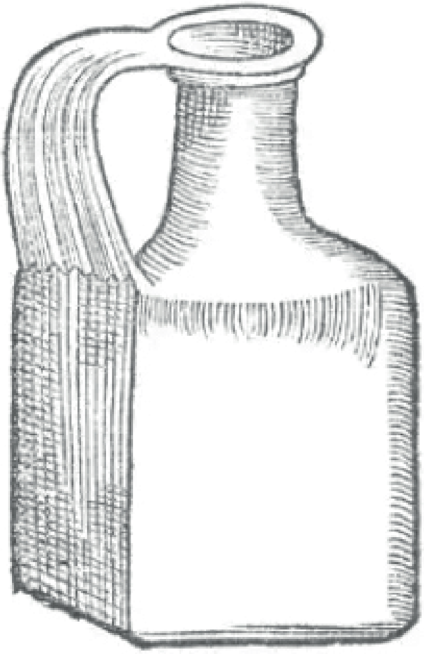


Figure **2.3**. Engraving of a Roman glass vessel from Voorburg-Arentsburg with typical, unnatural emphasis on important features such as the rim and handle, published in Inferiores Germaniae Provinciarum Unitarum antiquitates by P. Scriverius, 1611. Courtesy of Leiden University Libraries [392 B 2].

made by the artist (Smith 2004, p. 150). Similarly, a more stylised and "archetypical" depiction of reality developed in scientific representation, by ruling out deviating features and finding corresponding features, so that representative items could be placed in groups. These rudimentary classifications were made first in "museums" and private collections (or *Wunderkammer*, cabinets of curiosities). Objects, smaller antiquities - not elevated to art as sculptures were - and natural specimens alike, were grouped together by visual association (Moser 2009). Illustrators were recruited by the antiquarians to turn the antiquities into sources of data that would advance knowledge of the past. The antiquarians recognised that artefacts should be accurately depicted, yet a degree of artistic manipulation (called "scientific realism" by some) was preferred over naturalism in order to retrieve more information from them. An important innovative technique in the 17th century was the use of hard outlines and a frontal view to isolate the object from its background in order to emphasize its shape.[4] The rim of the vessel was distorted by unnaturally depicting it in perspective instead of frontally, so that the viewer would have a clear impression of the shape of the rim (Fig. **2.3**). The image was manipulated in such a way that it should be able to guide the viewer, preferably without accompanying text, because it was believed the image should speak for itself. This way of depicting allowed the attribution to a period in time and the identification of the place of origin of the object on the basis of these physical and stylistic characteristics (Schnapp 2014). The (pottery) drawings were recognised as valuable means of assessing how groups of objects were connected, enabling comparisons and establishing the first classes of artefacts (Moser 2012). Transformed into drawings, the artefacts were mobilised to transmit the evidence to other antiquarians, who could then compare their antiquities with the printed examples, contributing to the further development of classes and the construction of knowledge about the past.

Due to the absence or scarcity of Roman remains in northern Europe, antiquarians redirected historical visualisation to national and local prehistories, although these artefacts and local histories (about Britons, Celts or Germans) were for a long time explained through secondary descriptions derived from classical texts (Moser 2009;

4 Stephanie Moser has demonstrated this development in her research to the paper museum of the Comte de Caylus (Moser 2012).

Smith 2004). During the 16th and 17th centuries, England witnessed a revolution in the scale and methodology in the study of its history. An example is the English antiquarian John Aubrey (1626-1697), who, encouraged by King Charles II, carried out surveys at Stonehenge and Avebury. He documented the remains in high detail with many drawings by himself, accompanied by descriptive text to improve comparison (Trigger 2006, p. 106). These detailed recordings created a tradition of English antiquarians who then started to group types of monuments and make accurate and detailed descriptions of (special) archaeological finds. By the 18th century, drawings of ancient remains, in a style reminiscent of to the Dutch and Italian examples (distorted perspective to emphasize important features), were considered in England just as important as the remains themselves (Smiles 2013, p. 11) (Fig. **2.4**).

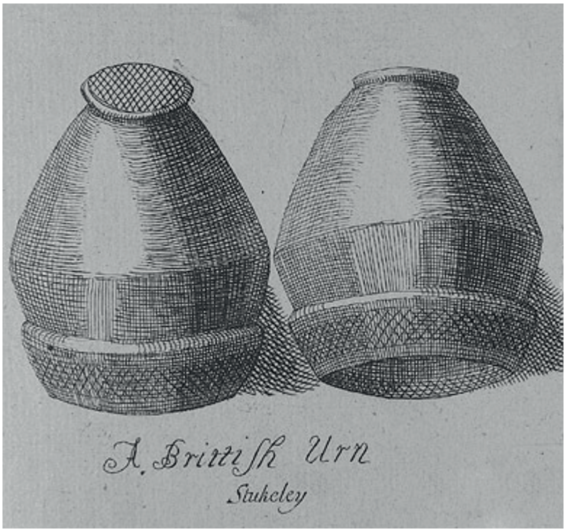


Figure **2.4.** Engraving of "a British Urn", by William Stukeley, 1717. It is depicted from two sides in order to provide information about the rim and base. Reproduced with the kind permission of the Society of Antiquaries of London.

It also became fashionable to record landscapes and ruins in often romantic settings, called *vedute* (view paintings), though in the course of the 18th century the genre received a more urban identity, due to increased travel by either artists or by elite members undertaking grand tours (and desired souvenirs) (Janson and Janson 1997; Moser 2009). The most salient examples to illustrate this genre are the etchings of the architect-antiquarian Giovanni Battista Piranesi (1720-1778), who documented, reconstructed and studied many Roman remains, which he published in several volumes. Piranesi pioneered in new methods of archaeological illustration (Wilton-Ely 2004), but also saw the remnants as creative potential to reconstruct the ruins into dramatically rendered monuments (Wilton-Ely 2007). John A. Pinto explained that this direct experience of the ancient ruins, and their incompleteness, stirred the imagination and fantasy, resulting in imagined restorations, which was a complete contrast to the accurate measurement of these same ruins by architects such as Piranesi (Pinto 2012), but typical for documenting and designing architecture in those days (Pinto 2012, p. 3). Architects of the 18th century recorded ruins visually in three dimensions: a ground plan, the elevation, cross-sections (to convey its inner structure), and perspective (reconstruction) drawings. Architectural fragments were visually documented too, increasingly in a way in which archaeologists today would recognise the "T"-section used to illustrate pottery. Up until today these *vedute* prove to be invaluable visual documents in research to Roman architecture, and reproductions still sold as souvenirs to modern tourists.

These developments in Italian and English practices of visualising and mobilising artefacts demonstrate the formalisation of a growing yet distinct practice. This development created the foundation for the emergence of artefact classification systems and the acknowledgement of artefacts as evidence of past human behaviour (Moser 2012). These detailed drawings made way gradually for conventionalized line drawings, suggesting a "scientific" mode of representation (Moser 2012, p. 293), and were the first attempts at the codification and professionalisation of artefact drawing. This shift to stylistic analysis, systematic description and comparison of artefacts, in which drawings played an increasingly central role, did not mean the interest in beauty was rejected altogether. On the contrary, (Romantic) realism continued to be preferred in reconstructions of the Graeco-Roman world and prehistory.

Over the course of the 17th century, images of artefacts became part of the "working objects" to study past human behaviour (Daston 2014, p. 321), and due to these new techniques and methods, the antiquarian tradition gradually transitioned into a new archaeological discipline with a strong visual component, yet, as will become clear in the next section, visual traditions would not be replaced altogether.

From visionary antiquaries to visualising archaeologists, c. 1750 - 1950

Unknown innovators and impactful innovations

By the 18th century, in the northern European countries, the study of artefact-oriented antiquity based on texts gradually evolved into distinct disciplines such as classical archaeology, *Altertumswissenschaft* and art history. These disciplines were taught at universities by renowned scholars such as Johann Winckelmann (1717-1768) and Christian Gottlob Heyne (1729-1812), who gave visual representation and direct observation of material culture and excavations an important role in the interpretation process. Winckelmann published in 1764 the seminal work *Geschichte der Kunst des Alterthums*, in which he treats Graeco-Roman, Egyptian and Etruscan art from a stylistic perspective by grouping the objects based on style, which he then could connect to certain periods in time. Heyne, founder of the modern *Altertumswissenschaft* and the first ever archaeological course, worried that illustrations such as those in Winkelmann's work would take the attention away from the text (Skoie 2002, p. 139), but he did use imagery next to his commentaries of ancient texts nonetheless. The images were not only visual aids in the identification of styles and dating; in this research tradition the illustrations visually scaffolded the direct observations of the scholar, as evidence for his reasoning, in addition to its primary function of displaying the grandeur of classical civilisation. Although both Winckelmann and Heyne are celebrated in archaeology for placing the study material culture on the disciplinary map, there were other achievements in archaeological practice of similar, if not greater, scale that are perhaps less well-known throughout the modern discipline.

Although hardly known in wider archaeological circles, Caspar Reuvens (1793-1835) is a prominent figure to any archaeology student within the Netherlands. Deeply inspired by Heyne and the 16th-century humanistic culture of collecting antiquities, though struggling with this "antiquarian impasse" (Eickhoff 2007, p. 107; Hoijtink

2009, p. 71), Reuvens became the first appointed professor in archaeology in the world at Leiden University in 1818, and was founding director of the Rijksmuseum van Oudheden (Dutch National Museum of Antiquities). Reuvens treated archaeology in the same way as history and philology, in which archaeology could supplement the aspects of past cultures in which the ancient authors remained silent (Halbertsma 2003, p. 43). He expanded the focus on classical and Egyptian antiquities to local Dutch material culture from the pre- and protohistory, and was particularly interested in the Roman period in the Netherlands.

Reuvens' greatest contribution to Dutch archaeology were the systematic and scientific excavations of the Roman site Voorburg-Arentsburg (ancient *Forum Hadriani*) from 1827 to 1834, the first large and systematic excavation of its kind. Reuvens took great care in detailed documentation by devising a site plan with the locations of the finds recorded. The site plan of *Forum Hadriani* (Fig. **2.5**) is not a romantically rendered drawing of the remains situated in the landscape as was customary in those days, but a scale-drawing including the limits of the excavations, plotted by a topographer, and levelling of the entire site. Other documentation comprised drawings of find contexts and architectural features, as well as stratigraphic profile drawings (perhaps one of the earliest archaeological stratigraphical drawings known), and although the archaeological remains were rendered in perspective view, they were accompanied with annotations to detailed descriptions (Besselsen 2014,

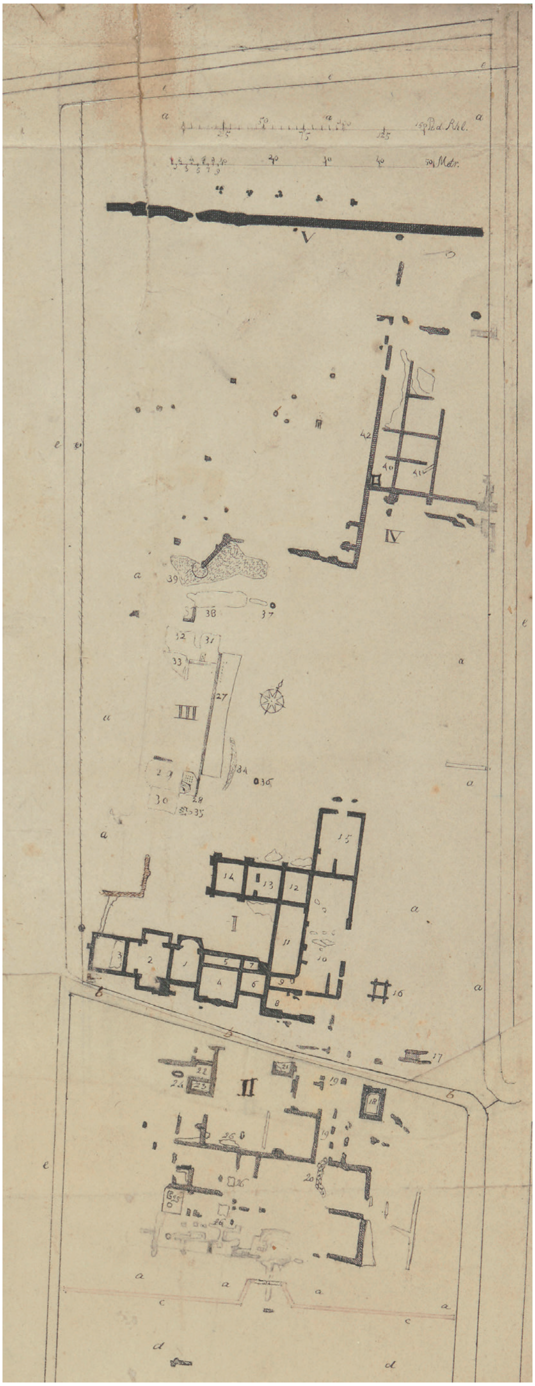


Figure **2.5**. Part of the original excavation plan, with annotations. Courtesy of the National Museum of Antiquities, Leiden [RA 30 c b].

fig. 1.4), and artefact drawings were created by professional illustrators (Fig. **2.6**). Another example of the level of detail in his documentation is illustrated by Reuvens's research on the altars dedicated to the indigenous goddess Nehalennia from the Roman period. Reuvens made study drawings of the altars accompanied with notes, collected any data he could find about the original find context of the objects and conducted a survey of local oral traditions, which was a novelty in the Netherlands (and perhaps even still today). According to J. Ayolt Brongers (2007, p. 115), it is thought that Reuvens made drawings and sketches to organise his reasoning and interpretation process.

Another novel technique that Reuvens deployed in the field was the casting of a skeleton in plaster, with all its grave gifts still in position (Buijtendorp 2007). This meticulous documentation is still useful for interpretation by modern archaeologists[5], and, moreover, the first time that this *combination* of visualisation techniques applied in archaeology was documented (Brongers 2007, p. 112). Where did Reuvens get the inspiration to visually document his excavation? Brongers suggests he must have been inspired by Vitruvius, who prescribed three ways of drawing architecture: horizontally, vertically and in (bird-eye view) perspective (Brongers 2002, 2007). Reuvens was also in close contact with Jean Emile Humbert, a military engineer who served in Tunis, where he conducted excavations of ancient Carthage (Brongers 2002, 2007). Military survey methods might have inspired Humbert to visually document his discoveries in quite some detail, and these technical skills were shared with Reuvens who subsequently developed and expanded these recording methods.

Unfortunately, Reuvens' untimely death in 1835, at the age of 42, prevented full publication of his unprecedented projects and he was not succeeded. More crucially, perhaps, was that his documentation methods were not continued, as no-one was appointed professor as successor at Leiden University. This meant that his ground-breaking methodology and results soon fell into oblivion, only to be re-invented abroad, half a century later, by influential archaeologists. Today, he forms an important chapter in Dutch archaeology (the impact of his work is still visible in the Rijksmuseum van Oudheden, and the yearly national meeting of Dutch archaeologists bears his name) and deserves more than being a footnote in the wider history of the archaeological discipline. Incredibly, the near modern standard of Reuvens's data documentation enabled Dutch archaeologists such as Tom M. Buijtendorp, more than 150 later, to virtually re-excavate the findings (Buijtendorp 2010).

The visual approach of Reuvens illustrates how the image became during these formative years of the young discipline a convincing and tangible "simulacrum" of artefacts and reconstructions (Smiles 2013, p. 18). As codified simulacrum, perhaps the most significant innovation in the history of archaeological visualisation is the development of the T method in the second half of the 19th century to standardise the visual recording of pottery. This method enabled to demonstrate different dimensional information of an object on a flat surface at once: the section and interior and exterior surfaces, the latter often with the suggestion of three-dimensionality by stippling or another cross-hatching. As such, illustrations were attributed increasingly to a role

5 Forensic archaeologist Maja d'Hollosy (Skullpting/University of Amsterdam) was able to make a facial reconstruction based on the plaster cast, as the original skeleton has since been lost.

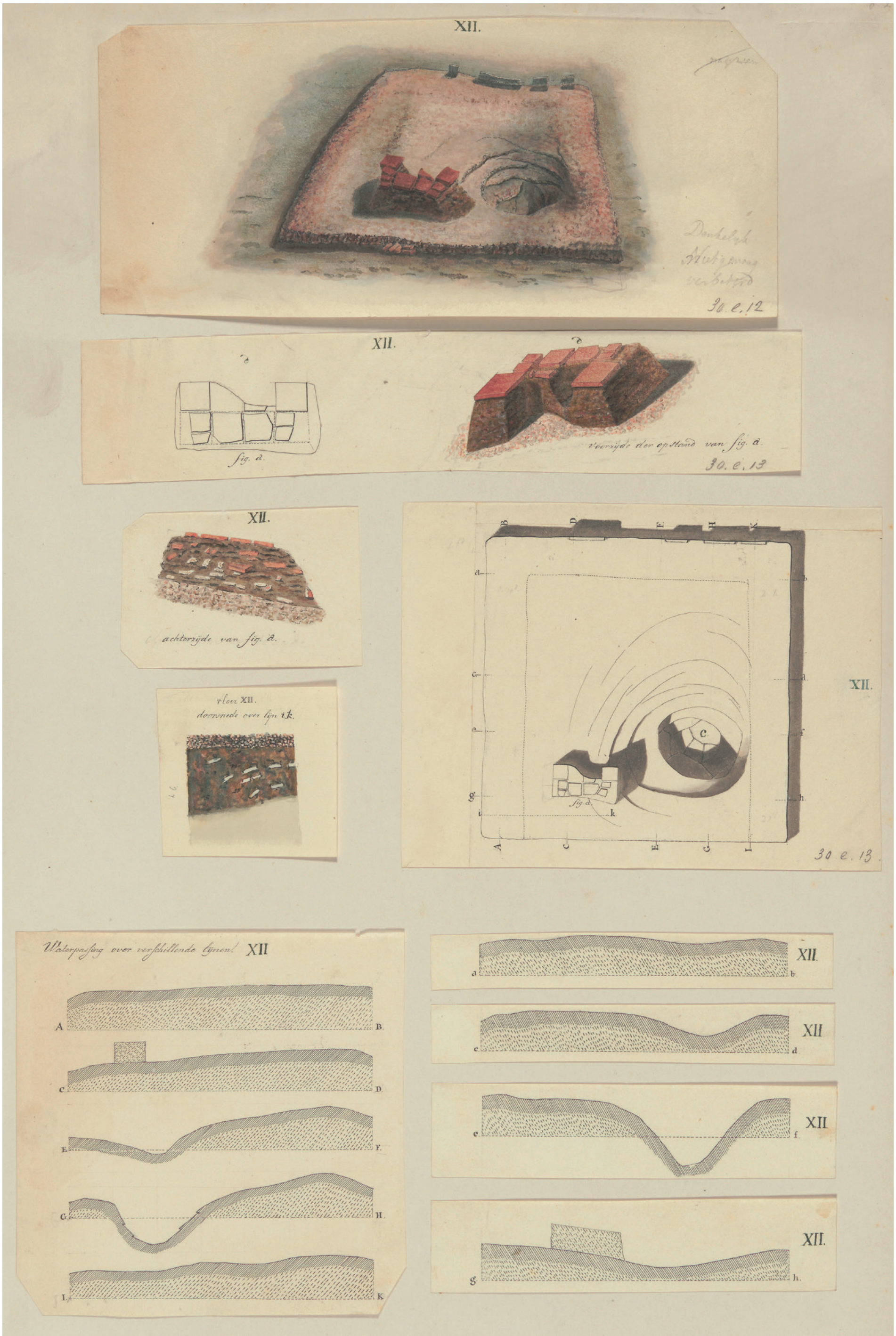


Figure **2.6**. Detailed documentation of a find context consisting of both watercolours and line drawings, in perspective, plan and section. Courtesy of the National Museum of Antiquities, Leiden [RA 30 e.12].

as a research method to guide and to structure archaeological interpretation and easy comparison between shapes, opening possibilities to the further refinement of classification practices. The conventionalized methods were meant to represent the evidence as accurate as possible, and standards were developed to visualise the distinction between documentation and interpretation. The symbolical conventions enabled a shared and standardised communication between scholars (Piggot 1965).

Besides 2D documentation and reconstructions, from the mid-19th century physical 3D models became popular modes of visualising archaeological processes and results. This particular mode of archaeological visualisation is still largely unexplored territory[6], and its impact on archaeological visualisation practices and knowledge production is unclear, yet the epistemological similarities between these physical models and current 3D visualisations are striking. This will be demonstrated through the remarkable wooden excavation models of Augustus Pitt-Rivers and models made of plaster and cork.

Augustus Lane Fox Pitt-Rivers (1827-1900) purportedly deemed important artistic and surveying skills, as well as drawing objects in detail and terrain mapping, to support observation and study of material culture (Bowden 1991; Evans 2014; Piggott 1978).[7] An innovative effort of Pitt-Rivers was the documentation of artefacts, including sherds, in their original context within the site, whereas contemporary antiquarians simply thought it enough to know from which site the artefact came from. Less well-known, though of crucial significance in understanding current digital 3D visualisations, are the physical 3D topographical models of excavations produced by Pitt-Rivers in the late 19th century, of which over 50 have been preserved (Fig. **2.7**a-b). He remarked that he only needed to give scaled contoured plans to his estate carpenters to carve to models out of wood (only a few were fashioned in plaster). The surface was painted in high detail, with annotations to the recorded finds (Bowden 1991), indicated either

Figure **2.7**. a) The Cissbury model, from the Farnham Collection, now in The Salisbury Museum (with permission of The Salisbury Museum), b) The model of Woodyates [CC BY-SA 4.0 license, downloaded from https://www.dayofarchaeology.com/the-pitt-rivers-archaeological-models/].

6 For examples of these studies (not plaster casts), see de Chadarevian and Hopwood 2004; Evans 2004; Perry 2013).

7 Rethinking Pitt-Rivers project: http://web.prm.ox.ac.uk/rpr/index.php/article-index/12-articles/216-pitt-rivers-on-art.html (accessed 26 May 2022)

by pencil or with pins in the large-scale models. Some of the models are extremely elaborate, with different parts held together by hinges, so that different layers, features and finds within the landscape, could be explored and interrogated simultaneously on different panes. Christopher Evans has found a photograph of an excavation in which such a model is clearly visible (2004, fig. 5.6), suggesting that "modelling was part of the process of excavation and not just a museum display tool" (Evans 2004, p. 123). Pitt-Rivers himself mentioned that it was of "utmost importance" to have carefully rendered models of excavations in museums (Bowden 1991, p. 143). Yet, for an untrained eye the excavation models of Pitt-Rivers are hard to read, because of the codified way of depicting topographical information and stratigraphy. In most models, annotations to accompanying texts helped to convey meaningful information, without such aids they were far from self-explanatory. It is clear that the models fulfilled a dual role: to record and situate contextual archaeological data and interpretations, and the communication of the data and resulting insights to peers and public. So far, the models of Pitt-Rivers appear to be unique, no other annotated excavation models, complete with find locations and stratigraphy are known.

Closely related to Pitt-Rivers's models are the archaeological site models rendered in cork. These are unannotated 3D site plans with as primary aim presenting new discoveries, such as excavated architectural remains in Pompeii, or monuments, such as Stonehenge. The light weight of these models meant that they were easy to transport and could communicate quickly to the scholarly world newly unearthed buildings and other spectacular features (Evans 2004). Another method of visualising three-dimensional data and multiple data sources, yet of a more fragile nature than cork, was through the replication of objects and monuments by plaster casting and by reconstruction executed in plaster. Both cork and plaster models were used to translate immobile large monuments and excavations on a smaller scale. They were collected and put on display in British salons and other social settings; this, together with his military background where he got acquainted with military survey methods such as landscape modelling (Evans 2004), were the places where Pitt-Rivers became acquainted with the idea of mapping excavations in 3D, which he expanded to its full potential.

Pitt-Rivers and Reuvens had in common their excellent recording methods that were well ahead of their time (Adkins and Adkins 1989), reaching modern standards. They both used their distinct recording methods and adoption of visualisation tools to organise not only the documentation, but also to guide the archaeological reasoning process, in which the visualisation of the material evidence played a crucial role in the creation of knowledge about social life in the past. Through these visual methods, modern archaeologists were able to trace these processes through the visual, and worked out and re-interpreted the site documentation[8], something that would be missed if only print and text was preferred over the visual. Reuvens's methodology of recording in three dimensions was not continued and eventually fell into oblivion, and, according to Mark Bowden, contemporaries of Pitt-Rivers were not very keen on this

8 Pitt-Rivers's excavation of Woodcuts was re-interpreted some 50 years later by professor Christopher Hawkes, source https://salisburymuseum.org.uk/collections/pitt-rivers-collection/woodcuts-model (accessed 26 May 2022)

innovative way of documenting he introduced (Bowden 1991), perhaps explaining why this particular 3D recording method was not more widely adopted, and archaeologists continued to document three-dimensional data onto 2D surfaces. However, the third dimension was not abandoned altogether, as from the late 19th century onwards, plaster models were increasingly employed as a non-invasive technique to test hypotheses for, for example, (colour) reconstructions[9], completion or re-assembly of fragmented objects, or as proposals to restore ruins. These models enabled not only to transfer new discoveries and knowledge in three dimensions, but functioned as an epistemological tool to assist the archaeological reasoning process as well, similar to the mathematical and naturalistic models deployed in the sciences (de Chadarevian and Hopwood 2004).

Reconstructing ancient life: from objects to people

Besides static representations of artefacts on paper and sterile reconstructions of ancient cities and reconstructed statues and monuments, artists had the power to reconstruct the dynamics of ancient life. A famous example of representing classical Roman every-day scenes are the paintings of the "archaeologist of artists", the Anglo-Dutch painter Sir Lawrence Alma Tadema (1836-1912) (Swanson 1977, p. 44). Alma Tadema gained his knowledge of the ancient world by reading the classics and academic treatises, and through direct observations during his numerous travels to Italy, especially Rome and Pompeii. This knowledge resulted in very detailed and historically accurate paintings, which were either hailed or reviled. Some critics sneered that Alma Tadema included so many items in his paintings that they resembled a catalogue (Prettejohn 2016), which actually demonstrates how well-informed Alma Tadema was. Essential in his painting was the interaction between people and the three-dimensional space, as he sought to revive classical everyday life (Stoter 2016), but the carefully rendered objects (archaeological finds such as drinking vessels) also had a practical purpose. All vessels and other objects were carefully chosen and placed, not as mere aesthetic decoration, but to inform about their function and use too (Moser 2016; Sijnesael 2016). The accuracy of Alma Tadema's painting derived from his personal study of the archaeology and architecture, even though it was common at this time for artists to use a professional draughtsman to sketch the building first; Swanson comments that extent of the architectural detail in his paintings allows their practical construction (Swanson 1977), as can be seen in the use of Alma Tadema's works in the epic films of Hollywood.[10]

Reconstructions of classical scenes were not reserved to Romantic and realistic art alone. Although Alma Tadema claimed to be historically and archaeologically accurate,

9 Already much discussed are two famous reconstruction plaster models of Rome by the hand of Paul Bigot and Italo Gismondi. Based on archaeological and historical evidence, the models were continuously updated according to new discoveries. Bigot even explored the possibilities of lighting by placing projectors with different colours on diverse locations, whereas Gismondi was more interested in building materials and construction methods.

10 On the set of *The Ten Commandments* (1956) the director, Cecil B. DeMille, showed works of Alma Tadema to the decor builders (Swanson 1977). More recently, his painting formed the central point of inspiration for the sets of *Gladiator* (2000) and *Exodus: Gods and Kings* (2014) (Blom 2016).

archaeologists wished to distinguish their visual outputs from art with scientifically informed depictions. In the 19th and 20th century drawings and reconstructions were increasingly made by either archaeologists themselves or by illustrators and architects or topographers who directly participated on excavations or were involved in the archaeological debate. The architect and archaeological illustrator Piet de Jong (1887-1967), another Brit with Dutch roots, spent the first decades of the 20th century working as an illustrator in several ground-breaking excavations. His many beautiful watercolours of artefacts and architecture from Knossos, Pylos, Mycenae and the Athenian Agora heavily influenced the image of Aegean prehistory and Classical archaeology (Papadopoulos 2006, p. 2), which continues to this day. In 1922, de Jong became the first appointed architect for the British School at Athens, and between 1922 and 1930 he collaborated on the reconstructions of the ruins of the Palace of Knossos with Sir Arthur Evans, including the design that was subsequently materialised in concrete and painted almost as bright as his watercolours. De Jong was also a proponent of peopling his reconstructions of the past, but these figures seem to have been placed as passive extras, merely serving a role as indicators of scale for the massive architectural protagonists. These reconstructions were as much an expression of Art Nouveau and Art Deco as well as an exploration of contemporaneous ideas about modernity (Papadopoulos 2005), and, in John K. Papadopoulos words, "the building today represents one of the finest examples of 1920s architecture" (Papadopoulos 2005, p. 101).

Over time it is possible to see that reconstructions of the past were always constructed through a contemporary framework. In the Renaissance the images reflected Christian or Neoplatonic and Humanist ideals, as well as contemporary symbols, weaponry, dress and architecture, which changed in 17th century historical genre painting more towards classical interiors, dress and weaponry. In the 18th century the *vedute* of Piranesi represented Neoclassical ideals, the 19th century paintings of Alma Tadema contemporary Victorian life, and Piet de Jong reconstructed Minoan palaces according to modern 20th century architectural styles. The power of these images is strong, for it is hard to visualise the Minoan palaces differently from the reconstructions of Evans and de Jong[11], or to re-imagine the extravagant Roman costumes and lavish interiors of Egypt and imperial Rome contrarily to the movies and series which imprinted those images on us.[12] Nevertheless, these reconstructions were artistic attempts to provide a visual insight into the life of the people of the past, corollary to presenting objects as evidence of past life and textual reconstructions written by antiquarians, philologists and archaeologists. Piet de Jong's archaeological visualisations, however, are more than pretty pictures of a peopled past, for they have structured the interpretation process of archaeologists, providing insights on construction details and architecture that otherwise might have remained invisible. The fact that his vivid imagination had to be restrained sometimes suggests that the illustrator took part in this process.

11 See for example about the impact on modern architecture in Papadopoulos 2005 and Philippides and Sgouros 2017, and for the influence of the Minoans as constructed culture in the first decades of the 1900s on modern cultural expressions, see Farnoux 2017.

12 The power of the image on modern perceptions has been thoroughly studied by Moser, for example Moser 1992, 1996; Moser and Gamble 1997.

Modern archaeological visualisation, 1950 – 2000

By the middle of the 20th century the first digital computers entered the world stage, causing a fundamental change in society over the next 50 years. Archaeological visualisation practice was not immune to these changes, eventually moving, though not entirely, away from the drawing board to the computer screen. The earliest accounts of the use of computers in archaeology date from the 1960s (Lock 2003)[13], and do not include archaeological illustrators or visualisation. In fact, computational technologies and the concept and applications of models and modelling[14], are closely associated with the development of New Archaeology. As processual archaeologists focused on creating comparative datasets to explain archaeological processes, the possibility to explore computational analysis to assist in the processing of large numbers of datasets was welcomed by some archaeologists (Gordon et al. 2016, p. 5). About the same time of the advent of the first desktop computers, in 1973, the first conference on *Computer Applications and Quantitative Methods in Archaeology* (CAA) was organised, which aimed to bring together archaeologists, mathematicians and computer scientists, and is still held annually.[15] In the following decade, a continued focus on the digitisation of data and the implementation of database systems became standardised practice in archaeology, leading to a (paper-based) systemisation in survey and excavation recording methods (McKeague et al. 2019; Reilly and Rahtz 1992). It was not until well into the 1980s, however, that digital visualisation technologies enabled archaeologists to visualise, analyse and interpret all this digitally recorded data, with applications such as GIS[16], AutoCAD and Adobe Illustrator.

Computer-Aided Design (CAD) software was developed for accurate drafting and prototyping, and after the launch of Autodesk AutoCAD in 1983, was rapidly adopted and deployed into visualisation practice by archaeologists. Early adopter Harrison Eiteljorg II explored the potentials of AutoCAD as early as 1988. He did not only promote a more accurate and time-efficient way of drawing, but also recognised the opportunity to update the drawings in concordance to new data and insights in the same document, which has been previously impossible. An even more significant technological advancement was the possibility to connect the drawings to its underlying data in the database (Eiteljorg 1996). Finally, archaeology could measure and reconstruct excavations and architecture in "high precision" along the z-axis, enabling Eiteljorg to generate a 3D reconstruction of the 6th century BC entrance to the Athenian Acropolis. All these possibilities were integrated in a single program that could be operated and controlled by the archaeologist. For the digitisation of artefacts and pottery drawings, archaeologists adopted and deployed Adobe Illustrator soon after its launch in the 1980s.

Eiteljorg explored the third dimension in AutoCAD, but before the first commercial desktop CG packages appeared on the digital stage in the 1990s,

13 For example, Chenhall 1968).

14 For example, Clarke 1972

15 https://proceedings.caaconference.org/year/1973/ (accessed 26 May 2022)

16 Not treated in this overview due to the limited scope of the chapter and the theme of the dissertation, not to mention the vast body already existing literature.

computer engineers and archaeologists were experimenting with solid modelling as early as 1983. In that year, John Woodwark and his colleagues from the University of Bath were looking for a project to test their new solid modelling system DORA. Archaeologist Barry Cunliffe, who was preparing a BBC television program on Roman Bath at the time, provided Woodwark and his team with the data to model the temple precinct of Roman Bath in 3D (Woodwark 1991). Due to the limits of the computing facilities, it was not possible to render an animation, and a sequence of images was generated instead. Although this enterprise had a strong technological focus, the 3D model was beneficial to archaeology nonetheless; abstract concepts such as power and space could be explored by the archaeologist Cunliffe, who determined the viewpoints for the images (Reilly 1992, p. 150). Inspired and impressed by this first 3D reconstruction, computer engineers and an occasional tech savvy archaeologist would produce several 3D models of archaeological subjects in the following years, giving rise to the archaeological sub-discipline *Virtual Archaeology* that developed over the course of the 1990s. The term Virtual Archaeology was introduced by Paul Reilly in 1991, who proposed to develop new recording strategies and research practices in which digital technology would support the documentation, interpretation and annotation of archaeological data (Beale and Reilly 2017a). In the seminal book *Virtual archaeology: re-creating ancient worlds* edited by Maurizio Forte and Alberto Siliotti (1997) which presented famous archaeological sites digitally reconstructed in 3D, Reilly's approach was expanded with the addition of digital 3D modelling. The book expressed the future potential impact of 3D modelling on archaeological theory and interpretation methods, and had an unprecedented focus on the archaeology instead of the technology used to generate the images.

Though literature suggests archaeologists were not in complete control of the reconstruction process (Miller and Richards 1995), other archaeologists attest that they actually were deeply involved in the reconstruction processes of for example sites in London, York and Cunliffe's experiments in Wiltshire.[17] Nevertheless, by the turn of the century, due to increasing computing power, commercially available hardware such as 3D scanners, and the development of graphic interfaces of 3D modelling software, archaeologists gradually began to operate these instruments themselves. As a result, Virtual Archaeology transformed from a showcase of technological prowess to an independent specialism employing these technologies, fully operated by themselves, as embedded tools in archaeological research.[18]

The digital advances in archaeological practice in the 1980s and 1990s eventually lead to a growing divide between a distinct "digital archaeology" and mainstream or "conventional" archaeology in the 2000s. Visualisation practices obviously play a role in both archaeologies, yet it is difficult to assign a place to these practices in this divide. The next section will explore the differences and similarities between current

17 Robin Boast, personal communication.

18 This is reflected in the explosion of research papers dedicated to 3D (modelling) technology as a research tool, for example, Barceló et al. 2002; Forte 2003; Frischer and Dakouri-Hild 2008; Goodrick and Gillings 2000; Hermon 2008; Hermon and Nikodem 2007; Llobera 2011; Niccolucci 2012; Ryan 2001; Wittur 2013.

archaeologies that both use visualisation technology in research, in order to assess what archaeological visualisation means in contemporary archaeological knowledge production.

Contemporary use of digital visualisation technology in archaeology

Today, archaeological research takes place within a digital society, involving principally screen work and digital applications. Yet, in the over 50 years that archaeology has adopted a rich array of digital methods to record, manage, analyse and visualise archaeological data, the discipline has managed to shatter into various sub-disciplines that distinguish themselves purely by digital applications. Digital Archaeology is the most prominent of these. Davide Tanasi recently explored the multiple uses and definitions of the term and pinpointed the start of a common use of the term with the launch of the 2006 book *Digital Archaeology: bridging method and theory* edited by Evans and Daly (Tanasi 2020, p. 24). Digital Archaeology is not restricted to the use and application of digital tools, but rather an approach that explores the relation between archaeology and spatial information and communication technologies (Daly & Evans, 2006; Grosman, 2016), supplemented with the application of a wide range of digital (3D) technologies and computer graphics. It claims to offer an alternative to the destructive nature of excavation and related field practices, and is believed to be more efficient in both cost and labour, and more accurate than traditional field practices (for example, Nobles and Roosevelt 2021; Roosevelt et al. 2015).

Virtual Archaeology used, and indeed still uses, a wide range of cutting-edge digital 3D technology and computer graphics to visualise and reconstruct archaeological remains. Although frequently associated with 3D reconstructions and 3D recording, it has become an embedded tool in archaeological research to simulate processes and present and assess data in a dynamic, visual way. Virtual Archaeology has not been received exclusively positively; the uncritical adoption of 3D technology and technologically focused presentations of 3D reconstructions have been accused of being "wonderful imaginative illustrations" (Barceló 2000, p. 9) or "pretty but meaningless" images (Miller and Richards 1995, p. 21), as these images were detached from its underlying archaeological data, and data uncertainties not being displayed caused serious methodological gaps. As a result, these photorealistic renderings of the past were called deceiving or misguiding (Eiteljorg 2000; Wheatley 1993, 2000), and even considered dangerous by some (Earl 2006, p. 193). These accusations have overshadowed the projects that indeed challenged these technically difficult issues by producing scientifically informed and research-based 3D reconstructions (some early examples: Eiteljorg 2000; Fletcher and Spicer 1992; Reilly 1992; Roussou and Drettakis 2003). More recently, solutions to record the process of 3D reconstruction and the element of choice (or paradata) have been successfully developed, for example by Emanuel Demetrescu, who developed the *Extended Matrix* (Demetrescu 2015, 2018).[19] The *Extended Matrix* is a stratigraphic approach that safeguards the scientific transparency of the 3D model, in which the role of the visualiser is acknowledged

19 http://osiris.itabc.cnr.it/extendedmatrix/ (last accessed 26 May 2022)

in the process of knowledge production since the onset. The issue of displaying the level of certainty within 3D reconstructions has also been effectively tackled by several scholars in the last decade (for example, Apollonio and Giovannini 2015; Ferdani et al. 2019; Ferdani et al. 2020; Hermon and Nikodem 2007; Noordegraaf et al. 2016).

A decline in the use of the terms *Virtual Archaeology* and *Cyber-Archaeology*, a fully digital approach[20], can be observed today, yet the technology, methods and practices associated with these subdisciplines remain in use. The above-mentioned approaches seem therefore mainly to differ on a semantic level, as by now archaeologists are "doing archaeology digitally" (Costopoulos 2016; Dallas 2015; Morgan and Eve 2012; Perry and Taylor 2018), using a wide range of digital tools and visualisation methods. A growing number of digital archaeologists acknowledge these digital practices are at the core of archaeology, in tandem with direct observational and interpretative practices (Caraher 2019; Ellis 2016; Morgan and Wright 2018; Perry 2015; Perry and Taylor 2018), which are situated within the wider societal trends in relation to digitality (Huvila 2018b). The current debate revolves around issues such as the difference is between "knowledge and 3D knowledge" (Huvila 2017), how digital (3D) visualisations become meaningful conveyors of knowledge (Dell'Unto 2018), and what kind of potential new archaeological insights they may generate. Others have investigated the meaning of digital palimpsests (Reilly 2015) and the shifting perceptions towards physicality and digitality, which has resulted in a new phenomenon that has been recently dubbed *phygitality* (Dawson and Reilly 2019; Reilly and Dawson 2021). However, these pioneering archaeologists and their adoption and application of digital visualisation technologies has not yet caused a fundamental shift in general archaeological thought, as these tools and methods tend to overshadow the underlying theoretical underpinnings (for a recent discussion of this phenomenon, see Perry and Taylor 2018).

Notwithstanding the apparent superficial subdisciplines, a shared approach towards changing digital practices can be observed: a reflexive one, in which the visualising archaeologist plays an important, creative role in the process of knowledge making. This blend of computational thinking, technology and existing practices could result in a creative visualisation practice that produces completely new and different knowledge about the past.

Looking back and moving forward towards an introspective visualisation practice

This survey has built upon established research into archaeological visualisation practices, and confirms the idea that although the archaeological record may be fully digital, its visual traditions have not been replaced altogether, and are often

20 This term was coined by Maurizio Forte, who pursued to integrate the latest developments in computer science, engineering and the exact sciences in order to answer anthropological, historical, and archaeological queries (Forte 2003). The generated "digital ecosystems" or 3D models were in this respect important carriers of information and active devices in the process of knowledge production and transfer, in which the model-maker played a central role.

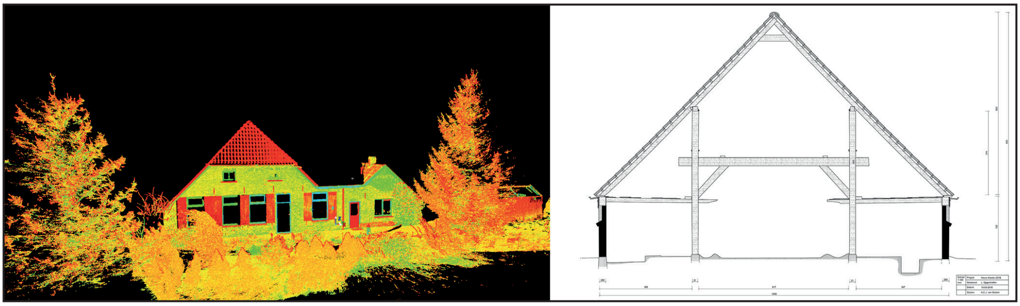


Figure **2.8**a. Pointcloud of a farmstead (scanned with a Leica P30 by M.H. Sepers) and a CAD drawing based on a section of that pointcloud (image by Loes Opgenhaffen). Same visual outputs, yet completely digital workflows.

not simply more than "facsimiles of the analogue technologies that preceded them" (Beale et al. 2017; Beale and Reilly 2017a) (Fig. **2.8**a-b). The images of the past as produced by Renaissance artists and antiquarians, the visual recordings of ancient architecture by Rococo and Neoclassical architects such as Piranesi, the visual encoding as established by pioneering early modern archaeologists, Alma Tadema's reconstructions of classical daily life and Piet de Jong's renderings of Minoan palaces, all have influenced not only our image of the past, but also how we render them today. Going further still, the reconstructions of Alma Tadema and de Jong can be seen to have engaged the perceptions of spectators in an unprecedented way, in which the past came alive, finding clear parallels to the aims of modern virtual 3D reconstructions.

From its nascent beginnings archaeology has always used 3D techniques to translate archaeological remains into another representational format. This process started in the 15th century with the acceptance of the Euclidean plane as a window in which to place three-dimensional objects, i.e., pictorial perspective. The antiquarians commissioned artisans and made use of artistic techniques to render naturalistic images of classical remains to support the written narratives of the past. Different modes of unstandardised visual documentation were applied in early modern research to the past to either guide scholarly discourse revolving around the reconstruction of the past, organise collections and price artefacts on the market, disclose new discoveries and knowledge, or create artful restorations to visualise the envisioned splendour of the ancients. Artistic explorations and subjective standards were used in artefact illustration to reach a visual effectiveness that allowed the conveying of information that was deemed to be important. Concomitant to wider developments in scientific representation, direct visual observations on shape, style, size, and even forming technology permitted classifications, a process set in motion when

Figure **2.8**b. 3D scanned pot and an automatically generated section drawing (scanning and image by Loes Opgenhaffen). Same visual outputs, yet completely digital workflows.

antiquarians and scholars alike began to organise and catalogue their collections, a visually based practice that would become fundamental to archaeology. In order to translate and mobilise the observed findings, the image of the artefact was increasingly manipulated to highlight those features and presented as evidence of this reasoning about features. Once identified, these features allowed comparison between artefacts, and the first grouping were made. Visualisation methods were progressively deployed in different ways by diverse national research traditions, whether to record a discovery, to sell an antiquity and price its aesthetic qualities, to catalogue British monuments, manifest Thomsen's Three Age system, define Winckelmann's stylistic attributions, or to develop Reuvens's systematic recordings, all of which eventually resulted in a shared visually encoded vocabulary. In all these archaeological and scientific enterprises, the illustrator was a key member in the discovery of new information and insights.

When the emergent discipline of archaeology advanced over the course of the 19th century, and conventionalised drawing became the standard, dimensionality was achieved by shading and stippling, as well as multiple views. Prints, casts and physical 3D models enabled the mobilisation of archaeological data and the transfer of knowledge. All images, whether 2D or 3D, analogue or digital, were and still are to an extent manipulated by cross-hatching, tags or algorithms, in order to "enhance" the visibility of details deemed significant by the specialist, and to create directionality for the observer to recognise these important features.

A shifting archaeological creative practice

This chapter aimed to apply a praxis-oriented, technological approach towards artisans, artists and antiquarians. However, the scarcity and fragmented nature of the evidence complicated the reconstruction of the agency and role of the visualiser in knowledge production and the formation of an archaeological visualisation practice. Yet, two previously separate worlds of visualisation practices have been brought together in one overview, demonstrating that the two share the same legacy once the techniques that enabled the visualisations are removed, and focus is shifted to the creative practice of the visualising archaeologist and the role that both the image and the maker play in the archaeological process of knowledge production.

This overview aims to create an awareness of the long tradition of visualisation practice in which visualising archaeologists are taking part in, and what this awareness contributes to the current practice of archaeological knowledge production. The epistemic power does not reside in the image itself; it is the visualiser that imbues the image with meaning by the choices they make in "pointing" to a particularity that might contribute to new knowledge (Goodwin 2003). Bringing these choices, the agency of the visualising archaeologist, and the data that was used to reconstruct fragmented archaeological remains, to the foreground, increases scientific transparency. This process of meaning-making follows a drawn-out practice of "enhancement" or "pointing" in visual evidence, a practice that shows that a visualisation does not speak for itself. The convincing, realistic physical annotated 3D models of Pitt-River's excavations were not self-explanatory, as some kind of familiarisation with the visual conventions and the annotations to archaeological features was required. Just as a digital 3D visualisation of a scanned artefact does not convey information on its own; that role is attributed to the contextual data and the visualising archaeologist.

The epistemological similarities between these early illustrations, the physical models and current 3D visualisations are striking, yet archaeologists using digital technology have only recently started to change the way they reason and create archaeological knowledge. Ultimately, a balanced combination of computational thinking, technology and existing practices will indeed result in a more creative visualisation practice that produces completely new and different knowledge about the past. For now, however, the survey has shown that the visualising tradition is currently at a transitional stage towards this blended creative practice. The methods, ideas and knowledge at the core of archaeological visualisation have not changed but are in a process of digitisation and automation. Although modern visualisation technology enables the "accurate" and "precise" recording of artefacts, terms heard repeatedly throughout history with every new innovation, archaeologists should be aware that these terms are thus momentary and reliant on technological change. Digital technology is celebrated for its capacity to integrate multiple data sources and the ability to update models with new information, which result in multiple interpretations and ensuing visualisations. These digital wonders share the same motives as the physical 3D models of Pitt-Rivers and the plaster casts of Rome, which allow us to return to the question what a digital 3D model is and what it does: a 3D model is a visualisation and a visualisation is a dynamic process of integrating data and emerging ideas, a method that enables the visualising archaeologist to think creatively in order to (re)create and (re)construct multiple narratives of the past.

Chapter 3

Brief history and state of the art of digital 3D recording in archaeology

Introduction

The previous chapter has demonstrated that archaeology has always used 3D techniques to translate archaeological remains into a representational format in order to transfer knowledge. Antiquarians used artisans and artistic techniques, such as perspective and chiaroscuro, to render naturalistic images of classical remains. When the emergent discipline advanced, and conventionalised drawing became the standard, dimensionality was achieved by shading and stippling, and plaster casts and physical 3D models enabled the mobilisation of archaeological data. At present, these analogue 3D visualisation practices are gradually being replaced by digital counterparts. The production practice of the visualisations with these digital tools have only become more complex. It is often unknown what the technology does and how it exactly works. Some routine archaeological work has been automated with these tools, and as a consequence visualisation practice and the visual outputs have become a black box. The discussion on the archaeological illustrations as black boxes – with a focus on the invisibility of preceding reasoning processes, the multiple actors involved and the tools and methods used in the creation – is an old one but still relevant as these issues are still pressing (Caraher 2016; Demetrescu 2018; Huggett 2012, 2017; Ribes 2014; Shanks and Webmoor 2013; Westin 2014; see also Ryan 2001 and Mudge 2012, although term black box is not used, but indeed the opacity of 3D visualisations is discussed. On the absence of the creator see, for example, Perry 2018; Sapirstein 2020). While this dissertation overall provides a methodology to prevent blackboxing of visualisation practice, this chapter in particular does that by explaining the techniques and methods developed and applied to create 3D artefacts of mobile objects.

Because the applied 3D techniques have not been developed for archaeology specifically, but in another discipline (with often a different purpose and consequently different understanding), an overview of the recent history of digital 3D visualisation technology provides context and understanding of the multidisciplinary aspect of the digital tools used by archaeologists. Once the technology is transferred into another scientific tradition, such as the field of archaeological ceramics analysis, both archaeological research trajectory as well as the digital innovation will be adapted. Therefore, the "multidisciplinary" aspect of the technology, as David Ribes (2014) described the distribution of visualisation, does not take place in a physical space, as the practitioners stay within the boundaries of their discipline, but occurs in the performed practice. Archaeologists use a 3D scanner developed for film industry, and scripts such as the Gouraud shader, which was developed in a mathematics department 50 years ago, but hides the wireframe of the scanned artefact behind the surface in today's modelling software. The archaeologist never met the movie director nor the mathematician, yet they are linked while practising. This multidisciplinarity is considered here in a similar fashion as a boundary object, as the technology maintains its mechanics in both traditions, but is understood differently as it is deployed in divergent practice and research objects, with dissimilar resulting outputs. Therefore, to understand the performative role of the equipment in archaeological practice, an understanding of its original appearance should be pursued. In this line of reasoning, no analogy with ancient potting practice can be forged here, as the potter's wheel was most probably not invented in relation to ancient locomotion, but had developed within a tradition of potting.

These "shaders" which make the models look realistic via their algorithms, are more important than often realised, because they have an effect on how we perceive the 3D artefact; they make the digital object feel familiar. Such algorithms are applied as invisible background processes when pointclouds are produced by 3D scanning and when they are processed into 3D meshes. This act of visualisation comprises an entire history of a compilation of thousands of algorithms which define what we finally see on a computer screen. These historic algorithms became enshrouded in 3D software packages and presented as something new, in a similar vein as Adobe Photoshop (or MS Access), which received many superficial make-overs but in essence and functionality, remained largely the same over the past 20 years. It is necessary to create an awareness among archaeologists using 3D technology that the machine presented as bleeding-edge is largely based on old tech and, similar to an artwork, is an elaboration or culmination of previous work performed by a multitude of actants.

This following section may perhaps seem anecdotal, but it shows examples of where (part of) the archaeologists' 3D visualisation software and recording equipment originated and how it was "distributed", or transferred, to archaeology. It shows how socially and technically networked these inventions and innovations are, and how they build forth on previous innovations. This should create an awareness of the intricacy of the black box of the technology as part of the increased complexity of current archaeological visualisation practice. The earliest accounts of the use of computers in archaeology to process "large quantities of data" (Chenhall 1968, p. 15) go back as far as the 1960s. Processual archaeologists began to put focus on creating comparative datasets, some of which were analysed by computers (Gordon et al. 2016, p. 5), and until well into the 1990s innovative digital tools were used by post-processual archaeologists to process increasing amounts of data, until digital technology became fully integrated in the archaeological toolkit (Tanasi 2020, p. 22). It took, however, until well into the 2000s before digital 3D visualisation technology, specifically computer graphics imaging (CG) and 3D scanning, became accessible and more widely adopted into archaeology's creative practice beyond mere data visualisation. The first steps in CG, however, and specifically digital 3D representation of real-world data, were taken in roughly the same period as the first statistical computing.

Historical development of (digital) 3D modelling and "scanning"

As early as the 1950s, the US army started experimenting with optical scanning devices using cameras with fast shutters, light and projectors. The technique was dubbed "LiDAR" before laser light was invented in the early 1960s. Airborne LiDAR was used by the military, NASA and aerospace industry from the 1970s onwards. Processing the captured data into an image proved to be more difficult than recording it, due to still-limited computing power. The technology was not employed in its full potential until well into the 1980s, despite some experimentation with it in the late 1970s in military applications (United States Air Force School). These trials consisted of digital range scanning and simple binary structured light sequences (with computer controlled and space encoded laser projection, and digital camera systems (Posdamer and Altschuler 1982). Each of these projected beams are assigned to camera pixel correspondence. These binary patterns still form the basis of current light patterns (Taubin et al. 2014, p. 41).

Curiously, complex archaeological strata and artefact relations, however, were not the first choice by these engineers to be spatially visualised. Instead, the object of interest to test new digital hardware and software such as Sketchpad[21], were molecular structures. The first digital 3D, vector-based wireframe, was a visualisation of a molecular structure created in 1963 by Ivan Sutherland under the auspices of the University of Utah.[22] The 3D effect was reached by having the structure rotated with a device known as "the globe", a plastic dome on which the user placed his hand, the predecessor of the virtual trackball (Francoeur and Segal 2004, p. 41) (Fig. **3.1**). "A Computer Animated Hand" made by Ed Catmull in 1972, a PhD student under the guidance

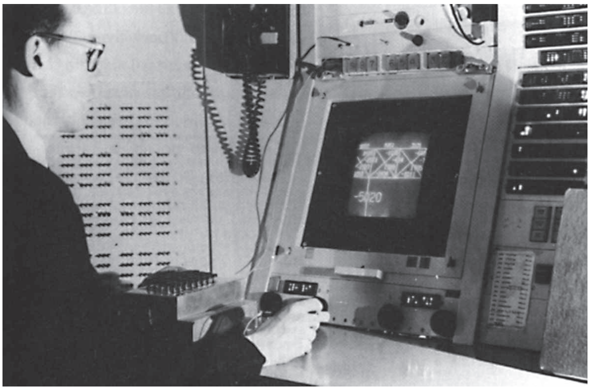


Figure **3.1**. Ivan Sutherland on the MIT TX-2 computer. https://www.vintag.es/2018/09/sketchpad-ivan-sutherland.html (accessed 26 May 2022)

21 "Sketchpad: A Man-Machine Graphical Communications System" was developed by Ivan Sutherland in 1963. It described a system that computerised drawing. It is regarded as the first step into the multibillion-dollar industry of computer graphics (CG). Sketchpad consisted of a monitor, a physical interface of a light pen and a push-button console (Sutherland 1963).

22 Produced under the Project MAC at MIT, headed by biophysicist Cyrus Levinthal (cf. Francoeur and Segal 2004).

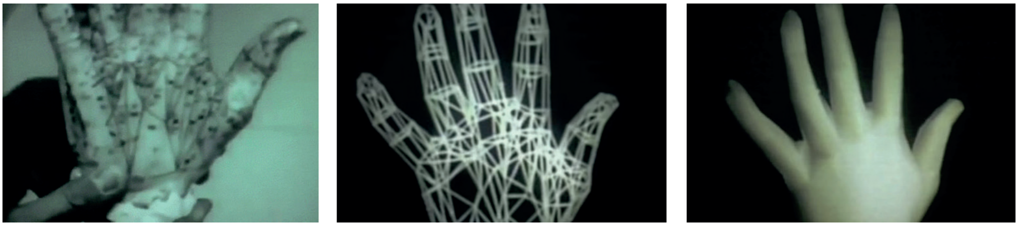


Figure **3.2**. Screenshots from Catmull's "A Computer Animated Hand". Left, the actual hand with drawn triangles and coordinates; middle, computerised wireframe of the hand; right, the hand rendered smoothly. https://www.youtube.com/watch?v=fAhyBfLFyNA (accessed 26 May 2022)

of Sutherland, and future co-founder of Pixar, is probably one of the first 3D rendered images ever seen on film. It was created by drawing manually polygons on the plaster cast of a hand, which were then digitised by typing the coordinates of the connecting points of the wireframes into the machine. This resulted in vectorised wireframes, on which Catmull projected a solid surface, for which he wrote texture mapping and shading codes (Sito 2013, p. 64). He also designed an algorithm to hide the wireframe behind the surface (Fig. **3.2**), something that was never done before and that is still being used today in CG – blockbuster movies and archaeological visualisations alike.

Another early "scanning" experiment, that is the translation of real-world coordinates into a digital three-dimensional reference system, was performed by, again, Sutherland starting in 1972. Sutherland and his students aimed to realistically render a Volkswagen Beetle. They were the scanners themselves: they obtained the coordinates by drawing points and polygons on the surface of the car, of which the x, y, and z coordinates were then measured with yardsticks and listed as text data files (McDermott 2015), a similar process as the recording of Catmull's hand. Several shaded images were directly imprinted on a film recorder which took days to record. To automatically reconstruct surfaces from the measured points through triangulation (a procedure that creates a polygonal surface from the collection of points in 3D space (Turk and Levoy 1994, p. 312)), algorithms have been written since the early 1980s. However, the key code to merge digitally captured separate scans into a single polygonal mesh, by "zipper" (connecting) the corresponding vertices (triangles) ordered and cleanly, was developed in 1994. It resulted in the legendary "Standford Bunny", which became a digital test bunny for many algorithms to follow.[23] Many of these algorithms are still used in for example the open-source 3D software Meshlab, which also provides references and descriptions of these "filters" (Cignoni et al. 2008).

3D laser scanning of humans for the animation industry developed at about roughly the same time: the *Head Scanner* was developed in the 1980s by Cyberware Technologies (Edl et al. 2018, p. 2), specifically to scan human heads to enhance realistic features in the animation industry (such as Arnold Schwarzenegger's for *Terminator 2*). By 1993, Cyberware introduced the full body 3D scanner. By the mid-1990s, 3D scanners appeared on the consumer market, which could automatically combine the scans and produce

23 For a few examples of different research papers, see https://faculty.cc.gatech.edu/~turk/bunny/bunny.html

colour textured models in minutes – if budget allowed it. Computer-Aided Design (CAD) software could produce 3D renderings of architecture from the late 1980s and in 1990 Autodesk released their first CG package 3-D Studio DOS, which was later renamed 3D Studio Max (Johnson 2015). These 3D modelling applications did not become widely adopted at the time because they were expensive and required specialists to operate them; 3D modelling was still based on entering code, rather than through a more intuitive graphic interface as is the case today. However, the development of the technologies described above are still at the core of today's archaeological apparatus.

3D scanning and modelling of objects in archaeology

The Utah Teapot is probably the most iconic image (of a pot) in computer graphics and the first photogenic, "high-quality" virtual object (Fig. **3.3**). It was inspired by a Melitta teapot that its creator had bought at a department store in 1975 (Carlson, 2017, p. 91).[24] A decade later, some archaeologists were able to experiment with digital 3D visualisation technology in million-dollar projects predominantly to visualise lost architecture and other exciting archaeological remains (cf. chapter 2; Forte and Siliotti 1997). Vast ancient landscapes, monumental architecture, entire cityscapes and iconic artefacts were being recorded and reconstructed, and illustration processes automated. But what about smaller objects such as pottery, and the application in a specialisation such as ceramic analysis? When and how did digital 3D visualisation enter the ceramics scene, and how does this technology support specialist research into pottery forming techniques? This section provides a brief overview of the first applications of digital technology in the documentation and analysis of objects and pottery, followed by a state of the art of 3D technology in ceramics analysis specifically. One of the earliest accounts of 3D digital recording of archaeological objects comes from the Swedish Archaeological Research Laboratory (AFL) in 1989. At a time when off-the-shelf 3D (laser) scanners were not yet available on the market and had to be assembled from several parts, the AFL purchased a laser scanner specifically constructed by the engineer Henry Freij for archaeological research (Kitzler Åhfeldt 2010). Its enormous size (200x200 mm), heavy weight, limited depth of view (DOF) (which was only 12 mm deep) and "poor software" made it ideal for recording small areas and microstructures, but impossible to use for large-scale or large object scanning. However, they applied the method in combination with statistical analysis to grooves in rune stones to distinguish individual carvers (Kitzler Åhfeldt 2010, p. 5), which is impossible with more traditional,

Figure **3.3**. Utah teapot. Courtesy of the Computer History Museum. Cat. no. 102710359. Image credit: Gwen Bell.

24 For the original drawing of the teapot, the base of the 3D model, see https://graphics.cs.utah.edu/teapot/ (last accessed 26 May 2022). It demonstrates the very physical practice of early 3D modelling. Also, the drawing on graph paper will be a recognisable practice for archaeologists.

analogue techniques. The researchers of the AFL were exploring the true potential of 3D scanning beyond mere automation of existing research practice, which, as will be shown in the next section, would become the core application of 3D scanning of pottery.

Another early application of 3D scanning to objects to enhance both research methods and communication was performed by Jiang Zu Zheng and Zhong Li Zhang in 1999 to complement "traditional recovery and presentation techniques", to carry out "a different kind of examination" and create a virtual exhibition (Zheng and Zhang 1999, p. 6). They used a portable laser range scanner along with a camera to obtain texture information to reconstruct some of the warriors of the Terracotta Army.

As mentioned in the previous chapter, archaeological illustrators had to retrain to adapt to rapidly changing technologies (Lock 2003, p. 136), especially after the turn of the century with the rise of affordable and easy digital 3D modelling software and increasingly accessible and inexpensive computing power. As early as the 1990s, archaeologists and illustrators were experimenting with the creation of textured 3D models based on vectorised profile drawings produced first in CAD (Lock 2003, p. 156), where wireframes were "spun" around the profiles (in CAD) or lathe algorithms were applied by rotating vectors around a central axis to generate a solid model. This vector-based application became an integrated function in the first Adobe Creative Suite in 2003 (with Illustrator 11). This way of creating 3D models based on vector drawings, in Adobe Illustrator and Blender for example, is still a popular visualisation method in archaeology today.[25]

A combination of profile drawings and photographs were, and often still are, the usual method to study pottery, but practices started changing roughly a decade ago. In the 2000s, only in extremely rare occasions was digital 3D recording technology used to document ceramic vessels (for example, (Razdan et al. 2001; Rowe et al. 2002; Salvadori 2003; Schurmans et al. 2002), but it was impossible to visualise or view the resulting 3D models directly and interactively in a database. Even today, digital 3D recording technology is hardly used to study ceramic forming technology in particular, rather, it is mostly applied to automate traditional drawing (Banterle et al. 2017; "GigaMesh: Home" n.d.; Gilboa et al. 2013; Karasik 2010; Karasik and Smilansky 2008; Melero Rus et al. 2004; Pobelome et al. 1997; Wilczek et al. 2018) and classification procedures (Banterle et al. 2017; Gilboa et al. 2004; Koutsoudis et al. 2010; Mansouri and Ebrahimnezhad 2015), in order to be more time-efficient, accurate and to document an process ceramic finds on a large scale (Göttlich et al. 2021). The algorithms to automatically generate profile drawings from 3D models depict them in the traditional, conventional style. However, the images are based on "perfect" profiles, meaning an ideal section based on a measured mean average of the entire vessel or sherd, except in the drawing solutions provided by DACORD (Wilczek et al. 2018) and *GigaMesh*. These earlier solutions, unfortunately, were not shared with the open-access computing community of archaeologists,

25 The added value to knowledge production is disputable, unless such 3D models are, for example, deployed to train machine learning algorithms to automatically reconstruct and identify pottery shapes. A project such as ArchAIDE has developed VASESKETCH to do exactly that (Banterle et al. 2017).

except for the more recent ones of DACORD[26] and the GigaMesh[27] software.[28]

Although there are still projects dedicated to improving the pipeline of automated illustration, one may wonder if 3D data is actually necessary to produce 2D images. Valentine Roux and Avshalom Karasik (2018), for example, developed a classification system to identify "inter-individual variability" that could correspond to individual potters by applying contour analysis based on the silhouettes of ceramic vessels on photographs (Roux and Karasik 2018, p. 36). Other recent projects successfully adopted profile (vectorised) drawing and photography-based approaches as well, such as Arch-I-Scan (Núñez Jareño et al. 2021; Tyukin et al. 2018; van Helden et al. 2018) and ArchAIDE (Gualandi et al. 2021; Wright and Gattiglia 2018), with machine learning approaches drawing from synthetic (expert knowledge from profile drawings) and original datasets (photographs of profiles) to train the classifiers. Ultimately, these projects aim to automatically identify pottery shapes and types[29], and Arch-I-Scan aims to move further than ArchAIDE by only needing a photograph, whereas ArchAIDE requires additional input from the user by manually tracing the fragment on the digital photograph.[30] These latter projects are building vast online accessible databases where archaeologists can compare and automatically classify pottery on a large scale. These are ongoing projects, and the ArchAIDE mobile and desktop apps are still available.[31]

Lastly, several projects have been and still are concerned with automating the re-assembly and completion of fragmented material (Chandrakar et al. 2017; Rasheed and Nordin 2018, 2020; Stamatopoulos and Anagnostopoulos 2016; Tsiafaki et al. 2016; Willis 2011; Zvietcovich et al. 2016)[32], often operating from the assumption that complete

26 DACORD: https://dl.acm.org/doi/10.1145/3230672

27 GigaMesh: https://gigamesh.eu/?page=home

28 The Pottery3-D program developed by Karasik (2010) is available on request. For the other software, SIDRAC (Melero et al. 2010) and VASESKETCH, it is unknown where this can be found. See also the proprietary software TroveSketch, together with open-source (?) Vessel Reconstructor here: http://www.museo-on.com/go/museoon/home/news/_page_id_787/_page_id_82/_page_id_602.xhtml

29 Another project worth mentioning, though not using 3D, is ROCOPOT (Parisotto et al. 2020). It aims to ease the archaeologist's analytical and interpretative processes by digitally enhancing organisation and classification of a typically difficult pottery class such as Roman common ware, in order to support comparative analysis. The project performs hierarchical clustering algorithms to recognise features in 2000 conventional profile drawings derived from traditional catalogues.

30 http://www.archaide.eu/. Last accessed 18 October 2021.

31 There were and are many other projects focussing on automating archaeological classification practices and creating online databases with 3D content, for example the ProDesLab Pottery Management System (Di Angelo et al. 2021) and the Pottery Information Query Database (PIQD) (Smith et al. 2014). The first is inaccessible and the second should be revived soon. Another promising project that aimed to develop an online accessible platform with 3D toolkit was the Horizon 2020-funded project GRAVITATE. It focussed on automating the reconstruction and refitting of fragmented heritage objects through an integration of semantic and geometric descriptors. It seems not to exist anymore, as its website is not functioning any more (http://gravitate-project.eu). For an excellent recent overview of automatic feature recognition and 3D databases to support automated classification of pottery, see Di Angelo et al. 2021.

32 For an overview of reconstruction applications, see Rasheed and Nordin 2015, and predictive digitisation, (virtual) restoration and degradation assessment tools, visit http://www.

objects lead to a more comprehensive reconstruction of the past. This assumption notwithstanding, 3D models of fragments do provide a solid and non-invasive technique for virtual restoration of delicate objects, they can demonstrate the level of restoration in a transparent way, they may show several working hypotheses, and they can function as powerful tools to communicate and disseminate information to peers and the public.

So far, archaeological objects and pottery fragments can be digitally re-assembled, reconstructed, virtually restored, automatically classified and their shapes and types identified by machine learning algorithms, and traditional practices such as drawing can be replaced by digital processes based on 3D models. The mentioned cutting-edge 3D technology has not, however, addressed manufacturing techniques beyond wheel-thrown pottery, which was furthermore mostly applied to orient the pottery to produce the drawings and to support the identification (Fig. **3.4**). Interestingly, lithic and metal specialists seem keener to deploy 3D technology to analyse ancient manufacturing techniques and methods, or use-wear (e.g. de Almeida et al. 2013; Grosman et al. 2011; Magnani 2014; Molloy and Milić 2018). The next section explores the current 3D applications to investigate specifically production procedures of ancient pottery.

Modern 3D recording techniques to analyse ancient ceramic forming technology

Little research has specifically addressed 3D technology to investigate manufacturing techniques of pottery, and most of it deployed it to identify the use of a potter's wheel ("rotational plates") in Peru, for example (Mara and Sablatnig 2008). The aim of that project was to determine the technological advancement of a community, which is whether they applied a fast or a slow wheel. Similar to the computational methods developed to automate archaeological illustration based on 3D scanned pottery, this was done by analysing the symmetry of the profile derived from 3D models. This symmetry is calculated on undulations in the profiles of Nasca vessels and on the section of the horizontal axis (Mara and Sablatnig 2008), under the assumption that the discontinuous wall thicknesses were caused exclusively by wheel-throwing. Another pioneering project approached the symmetry of a vessel by applying curvature colourisation of the surface of the vessel. The deviation in the symmetry was then used to determine the level of standardisation within the vessel class, "reflecting the skill level of the vessel maker" (Schurmans et al. 2002, pp. 194, 200).

More recently, several research projects combined Computed Tomography (CT) and 3D scanning or photography. Konstantinos Bouzakis and colleagues may have been the first to deploy CT scanning and laser scanning with a handheld scanner on two oinochoe, in order to analyse and reconstruct the forming techniques of the two jugs (Bouzakis et al. 2011). Through the accurate scanning techniques, they could compare the jugs and determine that they were made from the same mould, and also identify gestures of the potter's hands based on the asymmetrical deformations

presious.eu/resources/software (last accessed 14 April 2022) for open-source software.

OPERATIONAL SEQUENCE OF ARCHAEOLOGICAL RESEARCH TO POTTERY				
	TECHNOLOGY	ACTIONS	RESEARCH AIMS	FINAL OUTPUT
SELECTION		selection of material	Documentation of vessels	ANCIENT ARTEFACT
DOCUMENTATION	laser scanner SLS scanner micro CT	semantic description 3D scanning 3D processing data entry	Automation of traditional illustration practice Automation of traditional classification practice Automated restoration practice (re-construction, re-assembly)	2D IMAGE 3D ARTEFACT
ANALYSIS	micro CT 3D analytical software	visual inspection machine algorithms 3D modelling enhanced digital inspection	Support identification of ceramic technology	3D ARTEFACT
IDENTIFICATION	3D analytical software	analogue identification 3D modelling machine algorithms enhanced digital identifaction	Indentification of gestures of potters Finding individual makers Reconstruction of social organisation of pottery production	3D ARTEFACT
PRESENTATION	online database online 3D viewer	data entry 3D publication	Public outreach Dissemination of expert knowledge Transparent practices Sharing data Collaborative research 3D reference collections of technological ceramic data	3D ARTEFACT 3D REFERENCE COLLECTIONS

Figure **3.4**. Summary of the various applications of 3D technology, which depends on both research stage and research aims. The operational sequence of archaeologists will be further explained and investigated in chapter 5. Image: Loes Opgenhaffen.

in the surface of the vessel, indicating the successive operations in the sequence of assembling and producing the pot. Théophane Nicolas et al. combined two 3D scanning techniques, laser scanning for an accurate recording of the geometry of the vessel's surface, and photogrammetry to obtain a photorealistic texture layer, with CT scanning. It provided detailed data and visualisation possibilities to identify and analyse different forming traces and the reconstruction of *chaîne opératoires* of pottery production (Nicolas et al. 2017). They acknowledge, however, that CT scanning is a relatively expensive technology and difficult to operate, and therefore inaccessible to most researchers. Moreover, due to the costs, this technology is usually reserved for investigating distinct artefacts, although in these two cases it was applied to analyse common pottery, albeit only with two vessels in each study.

Research of Corina Ionescu et al. (Ionescu et al. 2019) and Sara Díaz Bonilla and colleagues (Bonilla et al. 2020) went beyond such individual cases, by building reference material of surface treatments of pottery, corresponding to different finishing techniques. Ionescu et al. used modern, but traditionally produced pottery as reference data to compare with Neolithic material. They applied vertical scanning interferometry (VSI) for the analysis of surface roughness. To prepare their samples, however, they had to apply a sputter-coated gold layer. The resulting topographic maps are in 3D, on which quantitative surface analysis could clearly discriminate the difference between smoothing and burnishing techniques. A VSI device is needed if other projects wish to compare their dataset to these results. Similar to the approach of TPW and expanding on the previous project, Bonilla combined experimental archaeology with digital binocular photography and 3D laser scanning confocal microscopy (LSCM), in order to create a catalogue of traces to identify a range of tools used for surface treatment of hand-built pottery. More comparative data could improve "understanding of pottery production processes, the organisation of the labour and the social characteristic of the pottery makers" (Bonilla et al. 2020, p. 147).

In 2015, I started the small project Pottery goes Digital with pottery specialists and a programmer, to explore the possibilities of 3D scanning for ceramics analysis. The aim was to automate the identification process of macrotraces, in order to support archaeologists in determining the forming technique and to recognise traces hard to detect with the naked eye. A NextEngine laser scanner was used to scan experimentally produced pottery, and the Visualisation Toolkit (VTK) software was used to train the algorithm to successfully identify the trace (Revello Lami et al. 2016) (Fig. **3.5**). Pottery goes Public, a project by the same researchers, expanded on the prior project and aimed to gain a deeper understanding in workshop organisation, now with a focus on finishing techniques. Potter stamps were scanned with the NextEngine laser scanner, recreated with 3D modelling software and printed in 3D. Preliminary curvature analysis between the models of the stamps already showed deviations in at least the moulds. The public was then invited to use the stamp and imprint in slabs of modern clay. Demographic characteristics and stamping gestures were recorded together with the imprint, which were intended for comparison with the ancient stamps in order to detect individual potters (Opgenhaffen et al. 2018). The project ended prematurely and could not provide a 3D reference collection, unfortunately, but provided a useful model for participatory research and promising future directions for the application of 3D technology in ceramics analysis nonetheless.

Another example of research to the potter's personal style has recently been provided by Ortal Harush, who creatively combined experimental archaeology with 3D technology as well. Subsequent cluster analysis was applied on flattened data to analyse the vessels produced by the individual potters, ultimately to elaborate "understanding in ceramic variability" in ancient pottery (Harush et al. 2019). Most projects described here have an experimental archaeological approach, yet not as structured or as large scale as the TPW project, and with limited and inaccessible results. Based on this review of current research, it can be concluded that there are no dedicated projects deploying 3D scanning techniques to enhance the visibility and analysis of wheel-forming traces. This particular archaeological tradition is at the eve of a transition.

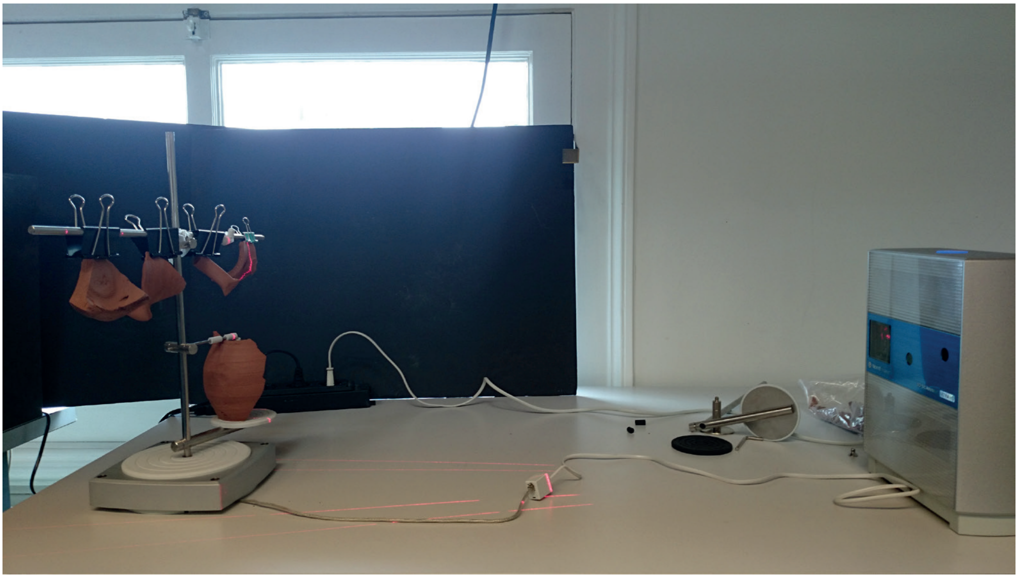


Figure **3.5**. the NextEngine scanning experimental ceramic fragments in 3D for the Pottery goes Digital project. Photo: Loes Opgenhaffen.

What's in a name? Critical considerations on current terminology

Introduction

This chapter aims to create awareness of the concepts of transparency and authenticity, in their current uses. At the same time, it must be acknowledged that these concepts cannot be applied interchangeably, and that the volatile aspect of "high-resolution" and related terminology, such as "accuracy", is dependent on the available technology available at present. This results in an ephemerality of technological potential, and for this reason digital 3D recording should never be an end-goal on itself, but instead an integrated and reasoned method within a research framework. Words describe the essential character of a thing; therefore, it should be carefully weighed which words are to be applied when proposing a methodology. Is the 3D artefact merely a mute and senseless digital replica of a meaningful physical artefact? Or, instead, is it an active model that guides research queries to the most approximate solution (such as the identification of traces of the use of a potter's wheel in the Bronze Age Aegean)? It is crucial to consider the names and terms we call things (Clark 2010, p. 63), for they are signifiers and sense-makers, which can be misleading if not applied properly or uncritically.

Although technology-oriented archaeologies such as Digital Archaeology and Virtual Archaeology, as well as what is understood with visualisation, have been explored in chapter 2, a plethora of terminology remains unaddressed. For example, archaeologists have used digital 3D visualisations to denote the process of recording, visualising, representation and reconstruction, but also as a way of registration and recreation of archaeological data which could then provide "graphic and metric information of high accuracy and quality" (Tsiafaki and Michailidou 2015, p. 38). So, in some occasions, visualisation is used to denote both process and product. How does this work? What is the measured quality, and does accuracy not imply quality as well? What is a model? Is it distinct from a 3D model? And is a 3D model a copy or a facsimile of an "original" artefact? Or rather a schematic description of all properties or representational models, as to model a situation?

The chapter provides an overview of current understandings and uncritical uses of a deluge of digital jargon, as well as firm beliefs in the alleged objectivity that enshroud digital devices and their visual outputs. The overview is primarily aimed to identify and define what term is best suited to describe the visual outputs created in the present PhD project, but it also contributes to the community of visualising archaeologists, who should reach consensus on definitions and a standard use of terminology, as they now seem to be used interchangeably (Champion 2019, p. 340). Lastly, this section responds to Alice E. Watterson's plea for what digital 3D visualisations "*can* and *should* do" for archaeologists (Watterson 2015, p. 121, original emphasis).

Picturing visualisation

Although computers can facilitate visualisation, it still remains an activity that occurs in the mind, whether this activity was sparked by an observation of a material entity or a brilliant idea of something that has no material existence yet. To better understand what is actually meant with the term visualisation, it might be useful to have a look at how information scientists picture it. Visualisation is the cognitive process that is structured and externalised with the aid of visualisation tools into visual representations, that is, images. Data scientist Colin Ware argued that visualisation is an "important part of cognitive systems" (Ware 2013, p. 2), because more information is acquired through vision than all the other senses. Information design or information visualisation aims to reveal patterns and relationships that are impossible or difficult to perceive and deduce without the aid of visual representations (Meirelles 2013, p. 11). Furthermore, visualisations of data can be considered as "cognitive artefacts" (Ware 2013) or "mental models" (Morgan et al. 2021), due to the cognitive relationships underlying them, such as the recording of data, conveying information and meaning, facilitating feature detection and recognition, manipulating data, perceiving unanticipated emergent properties, or laying bare immediate problems in data. Information visualisations are multi-scalar, and ultimately serve as models of both physical and conceptual realms in that they facilitate hypothesis forming and scientific reasoning (Meirelles 2013, p. 13; Ware 2013, p. 4).

In order to retrieve meaningful information from abstract data, experience and creativity is essential to produce a well-designed presentation of relevant data (Tufte 1990). A good visualisation of different kinds of data and their relations is reached by visually layering and separating various aspects of the data, reducing noise and increasing the visibility of the content, without distorting the data (Tufte 1990, p. 53). The main difference between information visualisation and scientific visualisation is that information visualisation is concerned with the visualisation abstract data which does not necessarily have a spatial location (Mazza 2009, p. 11), such as hypotheses and interpretations, as opposed to scientific visualisation, where data always has a physical origin.

Archaeological visualisation, however, which is the scientific visualisation of archaeological data, largely concurs with the definition of information visualisation, except that the archaeological visualisation can be data itself. Through this "graphical externalisation" of the data the archaeological visualisation becomes a source, or "a trace" on itself (Cameron 2007, p. 61; Earl 2013, p. 194; Ireland and Bell 2021, p. 153). As such, no direct engagement can occur between material data and digitally visualised output. These two extremes could be united by acknowledging visualisation as an embodied practice, and as such as "an encounter between human and non-human" participants (Ireland and Bell 2021, p. 153), equally shaping archaeological knowledge. Therefore, archaeological visualisation is a powerful methodology, because it bridging the divide between the material and the immaterial, theory and practice.

The term "visualisation" was differentiated from the more commonly used noun representation in chapter 2. Representation is indeed rather inert and implies a certain objectivity as the visual output should represent some actual state at a particular moment in time. A visualisation on the other hand, is an active definition because it functions both as a product and as a practice, resembling Latour's idea of inscriptions and the performativity of images, or "images at work" (Daston and Galison 2007, p. 19). This performativity of archaeological visualisation is a recurring theme throughout the presented research, and the term will be used as such.

High-resolution and accuracy

In the 3D scanning industry, accuracy measures how closely the recorded digital output matches the real-world object. Resolution, on the other hand, is the distance between two points in the 3D model. More fine details are captured and visualised if the resolution is high, i.e., the closer the points or higher the resolution, the closer – or "accurate" – to the original. A higher resolution requires more computing power to process and depends also on the skills of the operator. Consequently, accuracy and resolution are volatile terms, as older 3D models obtained with then cutting-edge 3D scanners are now – as technology advanced – antiquated. A similar desuetude of once innovative technology is the production of plaster casts of artefacts, now valuable historical objects of study themselves and often scanned in 3D (Joy and Elliott 2018). Yet, it is believed that the digital "registration and recreation" in 3D of archaeological excavations and artefacts provide "graphic and metric information of high accuracy and quality" nonetheless (Tsiafaki and Michailidou 2015, p. 38). Accuracy is difficult to measure, and it is increasingly accepted that the accuracy of a digital 3D model depends on the recording and communication of the metadata and paradata of the process of its creation to safeguard scientific accountability and rigour. This understanding of accuracy of data formalises and tends to objectify the 3D visualisation, because the digitally created data is machine readable and quantifiable (Hermon and Niccolucci 2018)). Such a perception undervalues the sociality of the process of image creation, the impact of the skills of the visualiser on the model, whether it is a 3D scan or a virtual 3D, and therefore denies its creative practice and inherent subjectivity (Beale 2018, p. 93). It has already been demonstrated how the socially situated practice of creating a 3D artefact impacts the resolution of both the model and the accuracy of the data. To accommodate this impact and present it transparently, the recording of the technical metadata and paradata is displayed together with the 3D artefact in the TPW Knowledge Hub, of which the archiving practice is described in a subsequent chapter. Taken together, they show how technological choice, skills, machine agency and other circumstances affect the final resolution of the model. The data model of the Knowledge Hub therefore accommodates that the degree of accuracy of the data is as high as technologically possible but never complete, as certain intangible aspects of visualisation practice cannot be captured in any form of data.

Objecting objectivity

The idea of mechanical objectivity emerged in the mid-19th century. It intended to minimise the intervention of human influence to maintain an objective process of research and visualisation, as to form a working object, devoid of interpretations. It led to standardisation of visualisation practice, with conventionalised methods such as profile drawing and cross-hatching, with preferably no sign of its maker. The profile drawing was presented as objective data, as a source of information. With the recent shift to scientific practice as creative and performative endeavour, this "perception of objectivity" of data visualisation became gradually reversed to the process of creating images as inextricably subjective, as are the visual products (Cameron 2007; Morgan et al. 2021, p. 624). With this emphasis on how knowledge is constructed and by stipulating the transparency of the fabrication process, traces of the maker are now deliberately left in the visual artefact, for example by providing paradata.

The discussion above delved into the continuing focus on automating the identification and classification of pottery typologies with digital 3D technology, and how that might reduce human subjective influence and inaccuracies, e.g. acknowledging that it cannot be entirely eliminated by some (Smith et al. 2014; Tsiafaki and Michailidou 2015), generating 3D models with a "greater objectivity" (Molloy and Milić 2018, p. 111). Although the subject/object debate as static and divided entities has long been battled (Daston and Galison 2007; Latour 1987, 1993), a persistent conviction in mechanical objectivity remains in certain specialisations in archaeology, as if the visualisations are produced by machines operating by themselves. The possibility of quantifying the number of points and pixels of a digital 3D artefact does not dehumanise and mathematise the very production of those points, despite being inferred as precise mathematical representations of a concrete or abstract entity (Barceló 2000, p. 9; Piccoli 2018, p. 49). As chapters 2 has demonstrated, this creation is a collaboration between people, things and tools, with each their agency and taking place in a social environment (Cameron 2007; Ireland and Bell 2021). The 3D scanner is operated by an archaeologist or technician, and complex scans are often manually processed. Indeed, it is recognised increasingly that archaeological data is not a matter of fact, and is instead performative and highly contextual, and even the act of entering records is a subjective one (Labrador 2012), created by preconceived research objectives and knowledge, and with both cultural and social influences (following Srinivasan 2017; but also Huggett 2019, 2020, section 2; Sørensen 2017). Precisely this particular associative and contextual data, such as the remarks and description of the 3D scanning process or the videos of experimental potting, is the direct visualisation of the project's collaborative practice. The process of creating and the integration of associated data with the 3D model makes it a meaningful but subjective object. As such, the digital 3D artefact draws together the narrative of the thing it represents.

This performative, social and subjective aspect of making a model connect to the issue of transparency. It is crucial to inform and check documentation and interpretation processes because of the inherent human factor in the mechanical process of 3D recording archaeological artefacts, as the operator has a considerable influence in the final appearance of the 3D artefact (Garstki 2018; Jensen 2018). This documentation also helps to "avoid the assumptions of objectivity that often accompany the attribution of technological authority" (Garstki 2018, p. 80). Similarly, Sorin Hermon and Franco Niccolucci have defined authenticity as providing enough information with the 3D model so that future researchers can elaborate on the research and visualised outcomes, and check the "facts", to safeguard intellectual transparency and accountability, and to quantitatively measure the quality of the visualisation (Hermon and Niccolucci 2018). But when does archaeological data become a fact? According to Bruno Latour and Steve Woolgar, something becomes a fact when assemblages or constructions become embedded in a body of knowledge drawn upon by others, and when the transformative process of social negotiations and uncertainties which created them has been forgotten (Latour and Woolgar 1986). In other words, facts are constructed, and archaeological knowledge production is a process of conveying information by applying agreed and shared rhetorical or digital devices to convince a targeted audience (Jones 2002, p. 170). The challenge is then to demonstrate how this creative process of producing something authentic based on an authentic original has produced data, which is not necessarily a fact but is instead an assemblage of social negotiation, natural circumstances, personal choices and traceable computer settings; i.e., a subjective series of actions to produce a 3D artefact.

Copies, surrogates and representations

If regarded as an active participant, the visual outputs in this dissertation cannot serve as mere copies. Copies usually have negative connotations, as not being the real thing, even as fakes. Yet without copies, the original does not exist (Latour and Lowe 2011). Copies can be qualitatively good or bad, depending on the technology used to translate the original artefact into a digital medium, the aim of the visualisation, and the skills of the creator. A copy is, however, too static to grasp the movement of the digital visualisation, of the socially and technologically embedded practice of visualising and its subsequent multiple and multiplied uses. Copies do not replace or substitute originals, as do surrogates, a term applied by for example digital archaeologists Sorin Hermon and Franco Niccolucci (Hermon and Niccolucci 2018). A digital 3D model of a Mycenaean jug does not replace nor substitute the real jug, instead it is complementary, an extension of the original, as its physical appearance is further investigated through the mediation of the digital 3D model.

If it is not a copy or surrogate, is the visualised 3D recording on the computer then a representation of the recorded artefact? The online Cambridge Dictionary[33] defines "representation" as "the way something is shown or described", or as a "picture, model, etc., of something", and "image" as being a "mental picture" of something. Elsewhere, representation could be defined as "an image or likeness of something", of which the image is a "reproduction" of something.[34] It seems that it depicts the state in which it occurred in a rather static way – as is – instead of something to inform, to push further, and to guide scholarly argumentation. The definition furthermore suggests that the 3D visualisation technology used to transform the original artefact into a 3D representation, has produced something not exactly the same, despite the description of the original artefact in Cartesian x, y, and z coordinates and provided colour information. Furthermore, it cannot be a reproduction in the strict sense, as it is translated into another medium. These definitions and terms do not fulfil the expectations for the visual products produced for the presented research, as they are not static images but entities that can be queried and interacted with. Other terms need to be investigated.

(3D) Reconstruction, re-creation or construction?

The American heritage dictionary of the English language states that "reconstruction" means "to construct again; rebuild", and to re-create "to create anew" or "*reconstructed the sequence of events from the evidence*" (Pritchard 2000, p. 1461, emphasis original). Similarly, Jeffrey Clark (2010) states that a reconstruction of a past is technically not possible, for it is not only fragmented and unknown. Moreover, it is generally accepted that the past is a construction of the present, which changes according paradigms, society, new data and insights, agency and multivocality - all producing multiple pasts. A reconstruction re-creates things that exist. So, a 3D reconstruction of an artefact, be it a building or a ceramic vessel, is a construction of how the artefact may have looked, and simulates one or more possible pasts. However, the term reconstruction has become embedded in archaeology, especially in the specialisation of virtual "reconstruction" of architecture and fragmented artefacts. Here, the term has become synonymous with the term "restoration", which is to construct a structure (parts of a pot, statue or building) that is no longer there. Because of the object-oriented perspective of the present thesis, reconstruction will not be a word often used. Indeed, the 3D scanning process and subsequent processing of the scans into a 3D model, technically reconstructs or re-creates the artefacts in its *current state*. Yet it feels like the visual products created for this research project can act as something more. Perhaps exploring the definitions of models and modelling may deliver the answer.

Modelling 3D artefacts

Chapter 2 of this thesis, on the history of archaeological visualisation, ended with a definition of what a digital 3D model is and what it does: a 3D model is a visualisation and visualisation is a dynamic process of integrating data and emerging ideas, a

33 https://dictionary.cambridge.org/dictionary/english/representation (accessed 9 February 2022)

34 The American heritage dictionary of the English language (Pritchard 2000, p. 1480).

method that enables the visualising archaeologist to think creatively in order to (re) create and (re)construct multiple narratives of the past. But as research progressed, is this conclusion still sustainable? A 3D model as the outcome of a process of data modelling seems logical, yet as a product rather fixed and immutable. Mats Dahlström, however, sees the translation process of the physical artefact into a flat digital medium as a sense of movement (Dahlström 2019). This movement is further strengthened when the 3D visualisation is embedded with contextual data and media. The movement between these media, visualisations, texts and data within a connected digital world, makes it no longer linear, but recursive instead (Dahlström 2019, p. 196), meaning the potentiality of continuous enrichment with new data. Sven Havemann on the other hand, pointed out that 3D modelling is often used to denote "the process of creating a digital replica" of a real object (Havemann 2012, p. 145), and that the product of this process is a 3D artefact. This process of 3D modelling of a 3D artefact can be subdivided into two different approaches: one of acquiring a 3D artefact based on 3D scanning technology or image-based modelling of real-world objects, or the creation of a "synthetic" 3D artefact based on scant archaeological evidence, elsewhere called virtual reconstruction or 3D modelling (Havemann 2012, p. 145). Isto Huvila adds that in the act of 3D modelling a "digital object", human engagement is a fundamental factor, whose skills and expertise on the object in question has a profound impact on the resulting 3D artefact (Huvila 2017, p. 101). What remains unclear in these three studies is the distinction between a digital replica, digital object and a 3D artefact, or if these are interchangeable. Indeed, an artefact implicates more than just being a replica, a mere copy. In earlier chapters it was explained how a 3D artefact is the result of human crafting, consisting of inherent features that normally would have been invisible if some actions or tools weren't involved, and, moreover, are produced within a social context. Similar to their physical counterparts, the 3D artefact gains further meaning through continued interactions with people, data and devices in a digitally connected environment as Dahlström described.

Computational models could be understood as "t*emporary states in a process of coming to know* rather than fixed structures of knowledge" (Bentkowska-Kafel 2012, p. 248; McCarty 2004). A model without its context, without proper definition, can mean anything ranging from a mathematical model to an architectural model (McCarty, 2004). Thus, the model's situatedness and context demarcate its value. Huvila understands a model and the act of modelling as ideological collaborative constructions and communication and considers them as active participants, explaining what is done and which knowledge exists while simultaneously acting and contributing in the construction of knowledge (Huvila 2017). Modelling may then be defined as "a heuristic process of constructing" (McCarty 2004). So, despite the actual use of the 3D models in the present research as "convenient vehicle to conduct 'experimentation'" (Barceló 2000, p. 9) – by simulating analogue, sensory practices in a virtual environment and running analytical software on its geometrical properties to retrieve additional data – it is the archaeologist who interprets the observed data and translates this into meaningful information. The model is then used to communicate the observations and knowledge about the ancient potting practice to the outside world. How the information is then received and the model perceived, depends on the context of the observing user, of expectations, training and experience to look at (virtual) objects. This situated and dynamic interaction between users/observers and the 3D models can be considered as *performative* because it is part of the activities as persons get around in and in a networked and social environment, leading to different experiences of the same model (Goodwin 1994; Molyneaux 1997).

The present research follows Clark's conclusion that 3D models are "not the end point of the research" (Clark 2010, p. 67, emphasis original), they are part of ongoing research and future uses, be it academic or non-scholarly practice. The 3D visual outputs of TPW are embedded in the Knowledge Hub with its contextual data, technical metadata, intellectual, creative and circumstantial paradata, human observations, i.e., the entire research practice so far, and continuously updated by future uses. 3D models are not a *research tool* but a research object instead, for they cannot act upon themselves, they do not create (following Champion 2019, p. 340). The process of creating (scanning and processing), however, is a technique and its use of the 3D model in analytical software is a method, but it is not a tool: tools are the DAVID-SLS3 and the computer. These techniques, methods and tools are part of the operational sequence of visualisation practice in the production of archaeological knowledge, and the 3D model is an active participant in this. In fact, as being carefully crafted by an archaeologist (or operator or visualiser/illustrator) and subsequently used by a wide array of people, 3D models are 3D artefacts. Therefore, this dissertation uses the term "3D artefact" to denote the product of the creative practice of 3D archaeological visualisation.

Authentic digital artefacts

Since Walter Benjamin's seminal essay about mechanical reproductions of artworks, in which he argued that these reproductions could not be authentic because they are disconnected from the historicity of the original object, due to the ability to be reproduced infinitely (Benjamin 1935), many studies have proved otherwise. Both the experimentally produced vessels and digital artefacts are crafted with great care, and their operational sequence has been recorded in detail to provide full transparency of practice and data - a trajectory that imparts authenticity to a digital 3D artefact. But is the digital 3D artefact just as valuable as the original artefact, and could the object still retain its original "aura"? This is a topic which has already been investigated excellently, and perhaps a little provocatively, by Stuart Jeffrey, and more recently by Thiago Minete Cardozo and Sarah Kenderdine, as well as the edited volume on aura and authenticity by Paola Di Giuseppantonio Di Franco et al. (Di Giuseppantonio Di Franco et al. 2018; but also Cameron 2007; Jeffrey 2015; Jones et al. 2017; Kenderdine and Yip 2019; Minete Cardozo and Papadopoulos 2021).

Elsewhere, it has been acknowledged that authenticity is a cultural construct and not inherent to the materiality of the object. Gareth Beale remarks that authenticity does not reside in the image of the object itself, but instead is generated by the interaction between the visualiser or maker, the user, and its audience (Beale 2018), similar to Siân Jones' contention that it is the relationships between people, place and things that allow authenticity, and not the object itself (Jones 2010). Cornelius Holtorf (2013), not particularly talking about digitised objects, responds to Jones that because of the age-value or pastness of a thing, a materialistic approach is also necessary, as this is actually carried in the object itself by the wear and tear and manufacturing processes. In that case, or in the case of the 3D artefact, the concept of "trajectory" of the artefact should be considered, as these material clues from the past do reside in the material, as well as in their immaterial representation. Does that make the 3D artefact authentic, has part of its authenticity been migrated? According to Bruno Latour and Adam Lowe (2011) as well as Sarah Kenderdine and Andrew Yip (2019), the authenticity does indeed migrate and "proliferate" in their digital materialities through association with the original object. Therefore, the question should rather be: do archaeologists allow 3D artefacts to have its own authenticity, and can they let go of the prevailing materialist groundings of that authenticity and their assumed deception (Edgeworth 2014; Garstki 2018; Jensen 2018; Sapirstein 2020)?

Latour and Lowe's concept of the trajectory of an artefact (or work of art), concurs with the Tradition in Transition framework that combines *chaîne opératoire* and reflexivity, albeit with a focus on production (*contra* the biography of objects approach). The 3D artefacts of ancient ceramic vessels, being diligently fabricated and continuing to be objects of analysis, and subsequently manipulated to extract data about the original artefacts, together with the associated data, are part of the trajectory of that "original" artefact. The delocalised interrogation of physical properties of the artefact through the digital object, this looking for clues about that same artefact located in a dusty storage room, allows elaborating multiple interpretations and enriches the artefact with information. The original becomes *enhanced* (Latour and Lowe 2011, p. 278).

Towards a shared and standardised practice

The presented doctoral research aims to enhance ceramics analysis by providing a standardised method for digital 3D visualisation. However, 3D recording should never be a means to an end, but an integrated and well-informed method within any research framework. This starts with an agreed and shared terminology as well. The chapter has demonstrated that such an informed method depends on the awareness of the ephemerality of technological potential, such as "high" precision and resolution. Also, the resolution of a 3D artefact is subject to human choice and research aims — some projects do not require a micro-millimetre resolution and need a fine-grained photorealistic texture instead. This notion of the inextricable human factor in the crafting of a 3D model makes it an inherent subjective endeavour, which makes it an authentic and meaningful object in its own right.

A 3D model is a visualisation and a visualisation is the dynamic process of integrating data and ideas about the ancient artefact, enhancing the original and elevating the 3D model to a 3D artefact. The performativity of images is a recurring theme throughout the dissertation, and related to that notion the terms

3D model (as working object), 3D artefact (as enriched and enhanced artefact), and 3D visualisation as the creative and cognitive process of generating 3D models through a series of generative actions with the support of digital tools.

The next two chapters present a methodology and standardised method as well, to integrate digital 3D visualisation as a reasoned method within a research framework. However, actual standardisation in terminology and practice can only be reached if all members of the community would adopt and use the same terms and methods. Chapters 4, 5 and 6 together form an example, a starting point, towards a shared and standardised practice for digital 3D visualisation in order to enhance research to ceramic forming technology.

Chapter 5[35]

Tradition in Transition.

Technology and Change in Archaeological Visualisation Practice

Introduction

Archaeology is predominantly a visual discipline about things (Olsen 2010; Olsen 2012; Witmore 2006) that heavily relies on the visualisation of these things. In order to record, organise, interpret, and reconstruct complex narratives of the past and to communicate them to present-day peers and the public, archaeologists use a wide range of visualisation techniques. Yet, for a discipline equipped with theoretical approaches and methods to assess how technology had an effect on past societies, for example the impact of the potter's wheel on ceramic production in the Aegean Bronze Age, archaeologists have surprisingly little awareness of how current (digital) technology has an impact on their own visualisation practice and subsequent knowledge production. Even today, after the "material turn" that has placed an ontological emphasis on the material, productive aspects of things and their interdependence with people, visualisations of things are nevertheless deprived of their human origin. Daunting, scientific-looking visualised statistics are produced as if no human was involved in processing the data, as if no potter made the pots which the digits represent.

Fortunately, the epistemic role of both visualisers and visualisations in archaeological meaning-making practice is increasingly recognised by the visualising community itself, originating in Stuart Piggott's work (Piggot 1965, 1978). However, the practice of visualisation has become progressively more complex since the uptake and deployment of digital (3D) technology into existing visualisation strategies, and the resulting dynamics of this heuristic and creative process are not fully within the spectrum of the archaeologist's gaze yet. Perhaps this is due to the invisibility of the craft and scientific research skills of the archaeological visualiser in the visual outputs, and that these skills are not mentioned or explicitly connected to the visualisation either (Maxwell

35 A version of this chapter has been published in *Open Archaeology*, 7/1, in the Special Issue on Archaeological Practice on Shifting Grounds, 1685-1708. https://doi.org/10.1515/opar-2020-0218

2017; Perry 2015). Whilst it is increasingly customary within the field of scientific virtual 3D reconstructions to make the creation and decision-making progress of the visualiser transparent and accessible, this is less so for other visual formats, for example digital 3D scans of artefacts. This last category is generally regarded as a static mechanical, dehumanised production process, a digital copy of an analogue original artefact. Yet, a visualisation is much more than a technique or a "statement of reality" (Clark 2010, p. 63), it is a creative, generative and experiential research method that considers the multiple human and material/non-human digital agents in the process of translation of artefacts into visual formats. Technological choice takes a central role in this creative process, as it represents some factors behind the adoption and adaptation of new technology into existing visualisation practice. Both visual products and archaeological artefacts are the "material correlates" of this process and are, moreover, interrelated with epistemological concerns that relate to knowledge production about the past (Hilditch 2020; Svabo and Shanks 2013). However, Isto Huvila and Jeremy Huggett have signalled an insufficient understanding of how archaeological remains are recorded and how new knowledge is generated from this data, and have proposed to draw from practice theory to increase this understanding (Huvila and Huggett 2018). This chapter assesses the extent to which archaeological visualisation practice has transformed or changed in response to an increasingly digital discipline using 3D technology.

But what exactly is "traditional" archaeological visualisation? The most common recording practice for archaeological artefacts today is still manual archaeological illustration and digitisation in Adobe Illustrator or other image processing software. The automation of conventional recording practices with innovative 3D technology and software started in the mid-2000s focusing primarily on automatically generating familiar 2D technical illustrations of artefacts (Gilboa et al. 2004; Kampel and Sablatnig 2006; Karasik and Smilansky 2008; Martínez Carrillo et al. 2010; Salvadori 2003; Smith et al. 2014; Wilczek et al. 2018). This particular technique did not, however, become widely adopted by archaeologists or illustrators, whereas a decade earlier a new method for digitalising drawings with Adobe Illustrator did find its way into wider visualisation practices. Ethnoarchaeologist Valentine Roux has stated that "tradition ensures knowledge production" (Roux and Courty 2019, p. 6), yet such automation of existing visualisation traditions did not automatically lead to new knowledge, despite the production of more digital data. Is it the case that the technical reasons and social conditions responsible for adoption or rejection of such innovations in existing visualisation strategies is contingent upon generation of new knowledge?

Gareth Beale and Paul Reilly have recognised "emerging traditions" of a distinctly digital nature within the archaeological community (Beale and Reilly 2017b). Traditions, however, are processes that undergo a long development that are then maintained and reproduced over time, and hence can only be identified when techniques and methods are repeatedly employed. What can be measured, fortunately, is the extent to which 3D tools and techniques are changing the way archaeological visualisers (archaeologists and external illustrators alike) produce artefact visualisations. When archaeological practice is considered as a "craft activity" or "creative practice", as Beale and Reilly propose (Beale and Reilly 2017b), with a focus on not only the interaction between archaeologists themselves but also with their tools and material context, then change or adaptation of technical traditions may indeed be identified. In fact, the study of performative acts, being "the physical [or digital] renderings of mental schemes learned through tradition" (Lemonnier 1993, p. 3), may be the key to obtaining a greater understanding of what current archaeological "tradition" is and to what extent this visualisation tradition differs from earlier traditions – as opposed to the idea that traditions can only be understood *a posteriori*. The following discussion investigates the technical knowledge involved in the creation of a visualisation of an artefact, specifically when new (3D) technology is introduced and adopted into existing practice, and explores the underlying processes and mechanisms that shape and change this practice. To this end, the concept of 'Tradition in Transition' is presented, a methodological framework combining practice and social theory with a reflexive approach, which enables us to interrogate the incremental creative steps within technological processes that occur within a social environment.

The deliberate emphasis on artefact visualisation and not site documentation, architectural reconstruction or the automation of pottery documentation in 3D, is due to my experience and the current research project. The Tracing the Potter Wheel project (TPW) focuses on the identification and assessment of the appearance of the potter's wheel as a technological innovation, and its adoption and adaptation (or rejection) into existing local potting strategies. The shared conceptual framework of the project is built upon the *chaîne opératoire* approach, a praxis-oriented approach with roots in sociology (Hilditch 2020; Jeffra 2015a). During this project, questions arose about my own changing visualisation practice alongside a growing self-awareness of both the agency and the reciprocal role that tools and equipment play in the visualisation process. The TPW project is a useful case study to not only present analogies between past and present practices but also to explore the ways in which archaeologists can study these practices. My research in TPW also aims to connect what archaeologists actually do, why they do it (knowledge about the past, meaning in the present), and how they use digital (3D) tools and techniques to visualise and produce that knowledge.

Sorin Hermon has already introduced the *chaîne opératoire* approach as a method to structure research using digital 3D visualisation for investigating archaeological artefacts and creating 3D reconstructions (Hermon 2012; Hermon et al. 2018). The proposed "Tradition in Transition" framework takes Hermon's work as a starting point and builds on this promising approach by expanding the practical to the social, as performative methods can serve as heuristic tools for the behavioural study of knowledge-producing archaeologists. The proposed framework is also an answer to recent calls for an introspective (digital) archaeology (see Huggett 2015; Perry and Taylor 2018). It furthermore provides a methodological and tailored solution to the unsuccessful implementation of the London Charter and similar initiatives (for a recent critical assessment of the charters, see Opgenhaffen et al. 2021). The agency of the visualising archaeologist and material engagement with both tools and archaeological material take a central place in this versatile framework, rather than creating or highlighting a set of equivocal guidelines emphasising the use of digital tools. The framework also addresses the pressing need for transparency of data and workflows alike, through the reflexive recording of the decision-making process of the visualising archaeologist.

The theory: praxeological and reflexive approaches combined

Becoming digital

Before my current research, I was an independent and traditionally trained archaeological illustrator, increasingly turning my focus to digital (3D) applications to meet growing commercial and scientific demands for fast, accurate documentation and 3D reconstructions. Although I was adopting and learning to use new devices and software, and placed an emphasis on the role of 3D modelling as a research tool, I did not critically question why and how I appropriated these new technologies into my existing practices. I was carrying out research to create scientifically informed 3D images and I was using this technology to improve the results. Reflexivity was primarily reserved for a multivocal approach for involving and engaging the public (Opgenhaffen et al. 2018). Working alongside colleagues to analyse ancient pots and past potting practices within the Tracing the Potter's Wheel project inspired me to reflect on current archaeological visualisation practices as well, especially from the perspective of digital 3D technology as a technological innovation. The framework encouraged me to critically assess my active role in the visualising process, starting as an archaeological illustrator but now operating as a visualising archaeologist. I also wanted to question the new digital 3D tools I use and their mutual agency in the entangled image-making and meaning-making process. Was I still a visualiser within this project, or just a technician passively pushing the buttons? To what degree has my practice changed through the implementation of new tools? To what extent has the visualisation tradition in archaeology been transformed? Another, yet no less important, question is how these changing technologies and practices had affected the archaeological visual product, or whether it essentially remained the same. I use my personal experience as a case study throughout this chapter to show how the framework can be implemented within research. In the next sections I explain the applicability of the chosen theoretical approaches, such as the *chaîne opératoire,* communities of practice and reflexivity, and how their integration towards a coherent methodology enables the community of archaeological visualisers to further reflect, assess and document visualisation practice and the process of image-making.

Approaching technology with the *chaîne opératoire*

The *chaîne opératoire* is an analytical framework in which the technology of material culture can be compared to explain social processes. Within this multi-scalar approach, the detailed analysis of the technical process is regarded as a meaningful sequence of performances and actions on matter in order to create a thing, a process that is entrenched and occurring within a given social context. These performances and actions are associated with knowledge and technical know-how (Gosselain 2019; Lemonnier 1993; Leroi-Gourhan 1993). Whether Bronze Age potsherds are the object of study to identify technical acts left by the use of the potter's wheel by a potter in a certain locality a long time ago, or the creation of the digital reproduction in 3D of that same potsherd by an archaeologist with a 3D scanner to enhance the identification of traces left by those technical acts, the underlying mechanisms of making a thing remain the same. The *chaîne opératoire* conceptualises visualising archaeologists as making *choices*, a choice to adopt new technology and learn how to use it in order to enhance analytical practice, to retrieve more archaeological data and, ultimately, create new knowledge about past behaviour. The implementation of this approach offers huge potential for identifying, describing and assessing archaeological practice and changing traditions.

Technical knowledge is usually learnt or transferred by watching and replicating the performative acts of others, until the gestures are internalised and become habitual. New knowledge is produced once new techniques and tools are introduced into an existing practice, such as the potter's wheel or the total station, which require new types of gestures, actions and adaptations of existing ones. These actions were first discussed by Marcel Mauss (Mauss 2006), who embedded techniques in a social context by separating them from the previously exclusive natural realm (Hilditch, 2020). Mauss's student André Leroi-Gourhan elaborated on this concept by seeing artefacts as extensions of the body, "meaningfully constituted through the results of sequences of gestures applied to material" (Audouze 2002; Hilditch 2020, p. 63; Leroi-Gourhan 1993), making technical acts simultaneously social acts. He called these series of actions *chaînes opératoires*, or operational sequences, an explicit technological approach to material culture. Although predominantly applied in prehistoric archaeology, the concept has been adopted increasingly in other archaeological specialisms as well in the last couple of decades. These studies demonstrated that objects are socially produced through a dynamic relationship between the social and the practical, with specific attention for the sociality of the actions on matter and the bodily gestures involved in this process (Leeuw 1993; Lemonnier 1993). The use of tools was increasingly considered as equal participants along with the techniques and bodily gestures (Roux, 2003), as well as conscious and unconscious decisions by the producer, or "technological choice", which is fundamental in the technical process to explore the possibilities within the practice (Leeuw 1993; Lemonnier 1993; and others). Notably, Valentine Roux has successfully implemented the *chaîne opératoire* in ethnoarchaeological studies to ancient and modern pottery production to methodically identify which traces correspond to certain manufacturing methods and techniques, and through this reconstruct the inferred steps in the operational sequence. Taken together, the concept of *chaîne opératoire* "effectively links a rigorous and practical set of empirically-grounded analytical methods with a robust anthropological theory of social reproduction" (Dobres and Robb 2005, p. 163).

The importance of tools and decision-making in the operational sequence of ceramic production and the distinction between techniques and methods, is brought a step further in this chapter, as archaeological visualisation practice has become expanded with digital and machinic participants (Cameron 2021). The *chaîne opératoire* approach integrated within a reflexive, praxis-oriented framework allows more emphasis to be placed on the reciprocal relationship between archaeologists and digital devices. The introduction of new tools and technologies played a crucial role in Leroi-Gourhan's work, connecting social and evolutionary processes with technological development. Moreover, he connected the human body to prosthetic devices, as external organs in the process of making things, with the bodily gestures performing actions on matter with the tools as extension of the body. Perhaps archaeologists could perceive the tools they use for visualising material culture as a kind of prosthesis or mediator as well. If so, how do archaeologists act upon and respond to digital 3D technology, such as 3D scanners and 3D modelling software, when visualising artefacts? How do they adapt their practice and gestures and bodily movements with these intermediate machines and screens?

The idea of a prosthesis in relation to archaeological images as replacing something that has been lost or is absent has been explored briefly by Brian Olsen and co-authors (Olsen et al. 2012, pp. 81–85), albeit restricted to images. Graeme Earl expanded this to the practice of making images itself, by seeing 3D modelling as "digital prosthetics" in which the process of 3D modelling becomes a bodily experience through repeated actions (Earl 2013). These approaches tend to focus on either the digital things that replace something or digital tools being assimilated into archaeological (bodily) practice. However, they remain detached from each other, ignoring the intricate relationship between tool and archaeologist and how they shape each other. Research into the introduction to the potter's wheel draws attention to issues of both potter and tool, such as how the posture of the potter adapts to using this new tool, as well as considering how novel production practices are created and adapted in response to this new tool, through their combination with pre-existing forming methods like coiling (the application of rotary kinetic energy, or RKE, to a preformed rough-out) (for example Gandon et al. 2013; Roux and Courty 2019; Roux and de Miroschedji 2009). It is from this perspective that Stobiecka rightfully states "[p]rosthetization is a process of mediation between technology and archaeology, where both components should be balanced" (Stobiecka 2020, p. 346). The notion of digital 3D tools as prosthetics is here understood from a praxis perspective, following the work of Jean-Pierre Warnier (2001, 2009), more specifically as "the capabilities of these methods to work not only as physical, but also mental, extensions of our work" that enable "constructing strands of research, knowledge and perception" (Chrysanthi et al. 2012, p. 9). The tool, whether it is the blind (person) with their stick (Warnier 2001, p. 7, after Paul Schilder's *Körperbild*), the ballerina "merged" with her *pointe* shoes (Hoogsteyns 2013), or the archaeologist with the 3D scanner, is an integrated extension of the body. For the archaeologist, its material affordances have a direct impact on the archaeologist's practice. The instrument as praxis is therefore a "situated dialectic of activity" that works in mutual directions, to the body and the machine, including its material agency (Malafouris 2008, p. 33).

Innovation and invention take a central place in studies on technological change, and the concepts dovetail with the *chaîne opératoire* which allows to identify the underlying mechanisms to assess *how* they occur. Technological *innovation* is the intentional or unintentional uptake and adaptation of an invention in an existing tradition, but it does not replace it (Guille-Escuret 1993, p. 214; Roux and Courty 2019, p. 217). A fundamental concept for considering innovation and invention is technological choice, a process which also determines the appearance, function and the sustainability of the product, be it a Minoan bridge-spouted jar, a Late Archaic Italic temple, a Philips air fryer or a Wavefront .obj file extension. This choice for potential solutions to technical problems are usually limited by the tradition and inherent technical know-how in which the ancient potter or modern archaeologist operates (van der Leeuw, 2008). When a technology originally designed for a specific tradition is adapted and embedded into a different technical tradition, a process of social negotiation starts due to the dissociation between the technical facts and the existing social facts (Guille-Escuret 1993). New relations and associations in the community have to be made. The process of introducing new 3D technology into existing visualisation traditions and confronting other practitioners within the community, is still being negotiated and, in the process, its position within the archaeological tradition is still being determined, as Perry and Taylor have recently demonstrated for digital archaeology (Perry and Taylor 2018). An *invention* occurs on an individual level within an existing system, on the other hand, creates a new tradition (Leeuw 2008, p. 242), and requires a strong stimulus and need for technological change (Cresswell 1993, p. 207), and is often limited by external environmental factors and economically driven. An invention is "a break in the routine", a creation of something new "that was absent before" (Lemonnier 1993, p. 21). Although the potter's wheel originated as early as the second half of the 5th millennium BC in the Near East (Roux 2003; Roux and de Miroschedji 2009), the transmission and uptake of the wheel as a technological innovation in other potting communities followed a different trajectory than that of the invention, hence not replacing the existing potting tradition. Sometimes the offered technology was, despite its technological advantages, rejected wholesale due to unfounded social beliefs. Digital 3D scanners are an exciting technological innovation, but they have not replaced a whole tradition of visualising archaeological remains. The social organisation of visualising archaeologists, however, may have changed, as have some methods and gestures within the practice.

Communities of practice

Making things, be it pots or 3D visualisations, do not occur in isolation but within a social context. A technical tradition reflects the identity of a social group which is maintained and reproduced by transmitting technical knowledge and know-how to next generations of practitioners. The learning of techniques within socially embedded contexts relates to Pierre Bourdieu's concept of habitus: the mental structure that becomes internalised in individuals through time within a given social context. Habitus structures the learned capacities to think and act in fixed ways, while the agency of individuals reflects and reproduces simultaneously the social structure (Bourdieu 1977). These actions can be analysed to understand more about this learning process of individuals and the social groups they belong to. The concept especially addresses everyday material and intellectual embodied or "habitual technological routines" (Dobres 2010, p. 110) of practitioners, allowing them to enrol into dedicated communities of practice and providing a sense of belonging and identity. The routines are the prerequisite for social reproduction (Wenger 1998) and could help at least partly explain why particular traditions were successful and persistent whereas others were ineffective and inconstant (Dobres 2010).

The identification of these social groups, or communities of practice, is the next level of analysis of practices. The concept of community of practice was formulated by computer scientist Etienne Wenger (1998), who was building on earlier work of anthropologist Jean Lave on "situated learning", which can be understood as a form of socially embedded participation in the practices of these communities (Lave and Wenger 1991). In other words, a community of practice is the locus where learning takes place (Hughes 2007, p. 31). This organisation is shaped by practical and social engagement, which consists of learning by doing through a shared experience, personal participation in social life and producing (material and conceptual) artefacts (Wenger 2010). It is through this dynamic and active, entangled process of engagement that any practice receives its meaning. The creative nature of making things also informs the construction of identities related to the community (Dobres 2010). When an individual can operate outside the socially constituted system this might – but not necessarily – cause a disruption of production sequences or research strategies (Wenger 1998). This notion could shed light on how these communities have changed, and if their participation in certain activities (with new tools or technology) within those practices have transformed the social structure of the community. With this in mind, should we consider digital archaeologists as a community of practice, distinct from a community of archaeological visualisers and visualising archaeologists using digital technology? Or is it one community of archaeologists sharing the same technical tradition?

These social behaviours are not only determined by their social context; they are shaped by the material and the environmental contexts too. The first step to unravel these socially embedded practices is by studying the decision-making process as sequences of acts and gestures and reconstructing the *chaîne opératoire*, by analysing in great detail the material remains or ethno-archaeologically by digitisation process of artefacts. Each trace may reflect an act or stage in the operational sequence of a technician making a thing, and simultaneously, the analysis places the technician in a socially informed environment. When a new experience or technology is brought by a practitioner into the practice of a community, a process of negotiation starts whether to adopt or reject the new element. The new method or tool disrupts the existing *chaîne opératoire* and the social organisation that the practice reflects. As a consequence, the learning of a practice has to be realigned, and as such the social organisation redefined. A balance between preserving the tradition and abandoning it to start something new is often possible when different communities of practice interact with each other and explore the boundaries beyond familiar practices. Beyond those boundaries, other social groups do learn and transfer things in another way (Roux and Courty 2019). Artefacts, whether material or conceptual, real or virtual, receive a different meaning across that boundary, which is archaeologically interesting when the identification of networks of learning and technological transfer are the desired goals. According to Wenger (2010), learning a practice is not only restricted to learning new techniques but also about acquiring technical know-how and knowledge about the world in which this takes place. Technological boundaries are the identifiable results of that technical know-how and knowledge of a shared practice, and as such conform to social boundaries (Roux and Courty 2019, p. 5). Technical traditions, however, can be so strong that they can coincide with social boundaries, making them more resistant to change than, for example, more easily transferable features such as aesthetics and style (Roux et al. 2017, p. 320). There is a striking relationship between techniques and identity, because a technical tradition, or *chaîne opératoire*, is indicative for a tradition, an inherited way of doing things (Roux and Courty 2019, p. 6) that expresses a social group within that larger tradition.

Engaging reflexively with people, technology and material

Commonly used methods to investigate potting practice are experimental archaeology[36] and ethnography[37], of which the latter might prove useful to analyse visualisation practices. Whereas archaeologists are adept at applying ethnographic approaches to explain past and present cultures, Matt Edgeworth rightly noticed that archaeologists themselves are remarkably ignorant in explaining their own academic practices (Edgeworth 2006a). In his seminal edited volume on ethnographies of archaeological practices, Edgeworth proposed that archaeologists should instead focus reflexively on practices in both the past and present (Edgeworth 2006a). A near decade later, he explored through an ethnographic case-study how a large part of the archaeologist's research praxis and acts of discovery moved to the screen, and how these affected modes of perception. He noticed in this study that the archaeologist "is using embodied skills and multiple senses in physically engaging with the computer hardware" (Edgeworth 2014, p. 54), indicating how displaced the archaeologist has become from the physical, archaeological material or excavation. This ethnographic, introspective method combined with that of the *chaîne opératoire* could serve as a methodological device to shed more light on the murky visualisation toolkits of archaeologists and their intricate digital practices. Another ethnoarchaeological approach, as one might term it, is to reflexively map and analyse current digital visualisation practice, in effect meeting Huggett's call for more introspection to digital practice (Huggett 2015a), which is progressively becoming customary in archaeology.

The concept of reflexivity is ingrained in the work of Bourdieu and is closely associated with his concept of habitus, the fixed ways in which a person has learned

36 In the TPW project experimental archaeology is an integral part of the framework in which the experimental archaeologist reconstructs pots with different techniques and methods. The resulting traces left in the surface of the pots can then be compared with ancient traces in order to identify techniques and methods within an assemblage. Once the *chaînes opératoires* present have been reconstructed, they can be subsequently compared technologically with assemblages from other sites in order to discern connections between communities. For more information on TPW's experimental methods, see https://tracingthewheel.eu/ and Hilditch et al. (2021). On specific experimental methods relevant to TPW, see Jeffra 2015a, 2015b.

37 Anthropologists and ethno-archaeologists have carried out ethnographic studies to contemporaneous potting traditions and communities in for example India (Roux and Corbetta 1989), the Philippines (Leeuw 1983, 2020) and Niger (Gosselain 2015, 2016), which provides invaluable insights in technological processes.

to think and act, while simultaneously the agency of that person both takes place in and is inextricably bound up in that social world (Schirato and Webb 2002). Practicing archaeologists are bound up in their observations of any given object as well, within a social structure, be it on an excavation or in a lab. The resulting archaeological knowledge is consequently biased by the social and material engagement with the object under study and the practices performed under particular research conditions (after Warwick and Board 2013); in other words, there is no presupposed "distinction between subject and object" in archaeological research practices (Berggren 2014, p. 6256). A reflexive approach to current, digital archaeological practice has indeed been advocated for over 25 years (Berggren 2014; Berggren and Hodder 2003; Carver 2006; Hodder 1997, 2005; Morgan 2016; Perry and Taylor 2018; Tringham 2010; Tringham and López 2001) and could be a solution to not only overcome this bias, but to gain a more profound understanding of the mechanisms underlying the uptake and transmission of new digital technology into existing archaeological visualisation strategies.

These previous reflexive studies are, however, typically focussed on fieldwork practices, the transparency of data and workflows, defining a "computationally-informed framework" (Perry and Taylor 2018, p. 12), multivocality of interpretation processes, the democratisation of technology, the flattening of social hierarchies in the field, and to giving a voice to different participants or "stakeholders" in the production of knowledge. Less attention was given to material cultures studies outside the excavation context and the production of visualisations. These questions relate to processes of implementation of new technology and its ensuing procedures, the role of the visualising archaeologist in this process and associated issues such as the mechanisms behind the transfer of knowledge/technical know-how to a whole next generation of archaeologists – beyond 'democratisation of technology'. Therefore, the formulation of a framework informed by practice, irrespective of which technology, might be beneficial to all archaeological specialisms and sub-disciplines.

Recent voices have raised the point that theoretically engaged discussion has taken place since digital visualisation tools were first introduced (Beale and Reilly 2017a; Evans and Daly 2006; Opgenhaffen 2021a; Perry and Taylor 2018), but the bulk of papers are dedicated to technicalities and present case studies resulting in a "technical solutionism", pushing the theoretically informed discussion to the background (Gordon et al. 2016, p. 4). Other scholars still claim digital archaeology remains under-theorised, or that the gap between theory and practice is too large (Huggett 2015a, 2015b; Huvila 2017; Lanjouw 2016). Fortunately, most scholars do agree that a reflexive approach towards technology and practice can overcome this form of digital identity crisis. But how to proceed? How to perform 'reflexive' research? Several reflexive research strategies have been developed over the course of the years, most of them within the context of the Çatalhöyük excavations (Berggren 2014; Berggren et al. 2015; Berggren and Hodder 2003; Hodder 1997, 2003a, 2005; Tringham and López 2001). The analytical framework that the *chaîne opératoire* approach provides could be an expedient addition to the aforementioned strategies, and can extend to reflect on practices outside the excavation context as well, such as material culture studies.

The proposed integrated Tradition in Transition framework comprises all the aspects that "reflexivity" entails: technology, practice, agency, participants or stakeholders, tools, gestures, methods and techniques, knowledge, material, transmission, learning, interaction, and innovation. This reflexive reconstruction of the operational sequence of 3D visualisation may assist in locating the position of this community of 3D visualisers within the wider archaeological discipline, as meaning-making practitioners and contributors to the production of knowledge, with a firm embedded methodology that bridges method and theory. Ultimately, the integration of the two approaches into a new methodology bridges reflexive method with practice theory, enabling a critical awareness of current practice to the visual enquiry to ancient material culture.

Chaînes opératoires of visualising archaeologists

Visualisation framed

Before going into detail on archaeological visualisation practice, it is imperative to clarify the distinction made between *chaîne opératoire* and life histories and biographies of objects. In this dissertation, and within the broader framework of the Tracing the Potter's Wheel project, *chaîne opératoire* is limited to production and inherent creative practice and technical know-how. Consumption and repair are excluded from this methodology and TPW's overall theoretical framework, as they are concepts more commonly treated within the biography of objects framework. Consequently, it considers the initial production of the 3D model but does not explore subsequent archaeological knowledge production generated by the 3D artefact beyond the producer.

Reflexive research on current practice cannot be understood without a clear idea of prior practice. What is more, a tradition is something that has undergone a long development and is being maintained and replicated over time, invoking a "persistent force driving the future" (Bronner 2018, p. 69). To establish whether the tradition of archaeological visualisation has changed, or is changing into a fundamentally different digital 3D visualisation tradition, a clear understanding of practices beyond the processual paradigm is pivotal, which has been carried out elsewhere and on which some assumptions are based here.[38] An historical survey carried out by the author showed striking epistemological similarities between early illustrations, 19th century physical models and current 3D visualisations, and furthermore demonstrated that the use of digital technology has only recently started to change how archaeologists reason and create archaeological knowledge (Opgenhaffen 2021a). Archaeology's visual tradition has not been replaced by digital visualisation technology wholesale, despite the digital turn. After all, archaeologists still process largely the same data as those collected in a traditional fashion (Gordon et al. 2016),

38 Substantial research into archaeological visualisation tradition has been carried out by Stuart Piggot (1965; Piggott 1978), Stephanie Moser (2009, 2012, 2014; Moser and Gamble 1997; Smiles and Moser 2005), Sara Perry (2009, 2011, 2015) and the author, who has recently attempted to unite the histories of digital and "traditional" visualisation practices (Opgenhaffen 2021a).

and these are interpreted from existing paradigms not yet tailored to technological progress (Rabinowitz 2016). Most technology presented as something new is often rather old practice in disguise with ostensibly familiar looking outputs (Beale et al. 2017; Beale and Reilly 2017a; Edgerton 2008), produced from centuries old visual modes of representation (Moser 2009). By comparing *chaîne opératoires*, we may assess alleged differences or similarities between archaeological (sub)disciplines and specialisms. In this section, two *chaîne opératoires* of analogue (anno 2005) and digital 3D visualisation practices with an emphasis on 3D scanning of artefacts (anno 2020) are recorded in diagrams, followed by visual analytical comparison (Figs. **5.2** and **5.3**).

Two graphic representations of practices developed by archaeologists Jill Hilditch and Sander van der Leeuw respectively, are the foundations of the presented methodology. The first graphic is a table representing the TPW methodology as formulated by Jill Hilditch (Hilditch 2020, fig. 2.1), and the second represents a set of diagrams of "network representations" created by van der Leeuw. Van der Leeuw illustrates here the complexity of ceramic production on different scales, from material procurement to workshop organisation, and includes the social context in which the potter works (Leeuw 2020, figs. 13.1-7). The terminology associated with *chaîne opératoire*, for example techniques and methods, follows the latest work of Roux and Courty (2019).[39] The *chaîne opératoire* or "operational sequence" of archaeological (3D) visualisation can now be subdivided into five "events": selection, preparation, creation, post-processing and delivery. The sequences are understood and described as events in which a set of operations take place, as it combines the active nature of the enterprise with the element of time.

The entire sequence takes place within a social context, indicating not only that the visualisation is socially produced, but that social interactions during the visualisation process are authorising and maintaining the community of practitioners as well. Consequently, the visualisation of an artefact starts with the engagement between people and material, with an archaeological specialist studying material culture and who requires a visualisation. Figure **5.1** represents the visualiser within their personal remit, with fixed aspects of the *chaîne opératoire* reciprocally influencing the visualiser. This remit represents the circles with the visualiser in the diagrams (Figs. **5.2** and **5.3**). These aspects are (by no means hierarchically ordered) skills, which are learned abilities that range somewhere between technique, practice and experience, and gestures, the unconscious, physical motor movements to operate a machine or

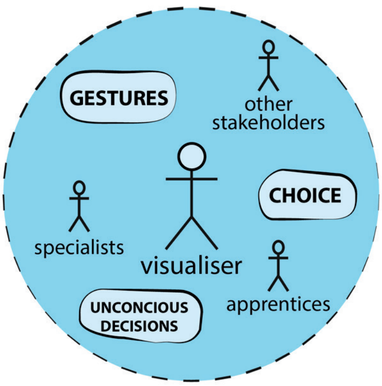


Figure **5.1**. The visualiser's personal social remit, in which (unconscious) choices are made and other participants such as apprentices and team members influence the decision-making process. Image: Loes Opgenhaffen.

39 This terminology is in turn based on a unified terminology created by lithic specialists to enable comparisons between technical systems to support technological studies (for bones, ceramics, lithics, and metallurgy alike, and now digital technology) (Roux and Courty 2019, p. 41).

to handle a pencil. Also, unconscious decisions are continuously taken and choices made, often but not always influenced by external factors and by engagement with the material itself. The element of choice affords or limits a certain way of handling and registration (on paper or on screen with a mediating tool), or associate socially with team members, students and other participants or stakeholders in the process. Furthermore, there is a reflexive engagement between the participants, the material and the tools here. For example, visualisers decide based on their technical knowledge (*connaissance*[40]) which techniques and tools are available and what these tools allow to be done with the material. Simultaneously, material features, such as colour (black) and hue, and an extremely curved geometry of the artefact affect the recording device. Lastly, every action and decision of the visualiser resonates in future events, which may result in the repetition of previous operations. As a result, the boundaries between the events are not fixed and the visualiser moves dynamically between the events.

Sequences in action

The event of selection

In the first event (Figs. **5.2** and **5.3**), the selection of material by the archaeological specialist is directed by certain research aims, but also the affordances of the material and the tools chosen to visualise it, blurring the boundary of the next event, the preparation phase. Information deemed important is communicated by the specialist to the visualiser, who needs to have at least a basic understanding of the material in order to process it accordingly. The visualiser communicates the material limits to the specialist.

The event of preparation

The visualiser may choose to dedicate additional 3D scans to capture the important features of the object that the specialist pointed at with more precision. This choice may then lead to a higher density of vertices or increased resolution of at least part of the digital reproduction. Similarly, in an analogue drawing, these parts may eventually be highlighted with a pattern, stroke or other coded convention. During preparation the visualisation aims are composed of a range of decisions that depend on multiple factors, both within and beyond the borders of this event, and the technical knowledge of the visualiser. Working conditions such as place (a state-of-the-art lab or a creaky old building), natural or artificial light and even traffic, all affect the visualiser's choice for the techniques, methods and tools to execute the visualisation. A technique is the "physical modality" to transform the artefact into a visual product; in the present case this is 3D scanning (Fig. **5.2**, anno 2020) and, 15 years ago, manual drawing (Fig. **5.3**, anno 2005). A particular method is "an ordered sequence of *functional operations* carried out by a set of elementary *gestures* for which different *techniques* can be used" (Roux and

40 The *connaissance* of the visualiser, or maker, is a difficult translation. The best translation would be "know-that", the mental scheme opposed to "know-how" or *savoir-faire*, which is the physicality of that mental realm (Jeffra 2020, personal communication).

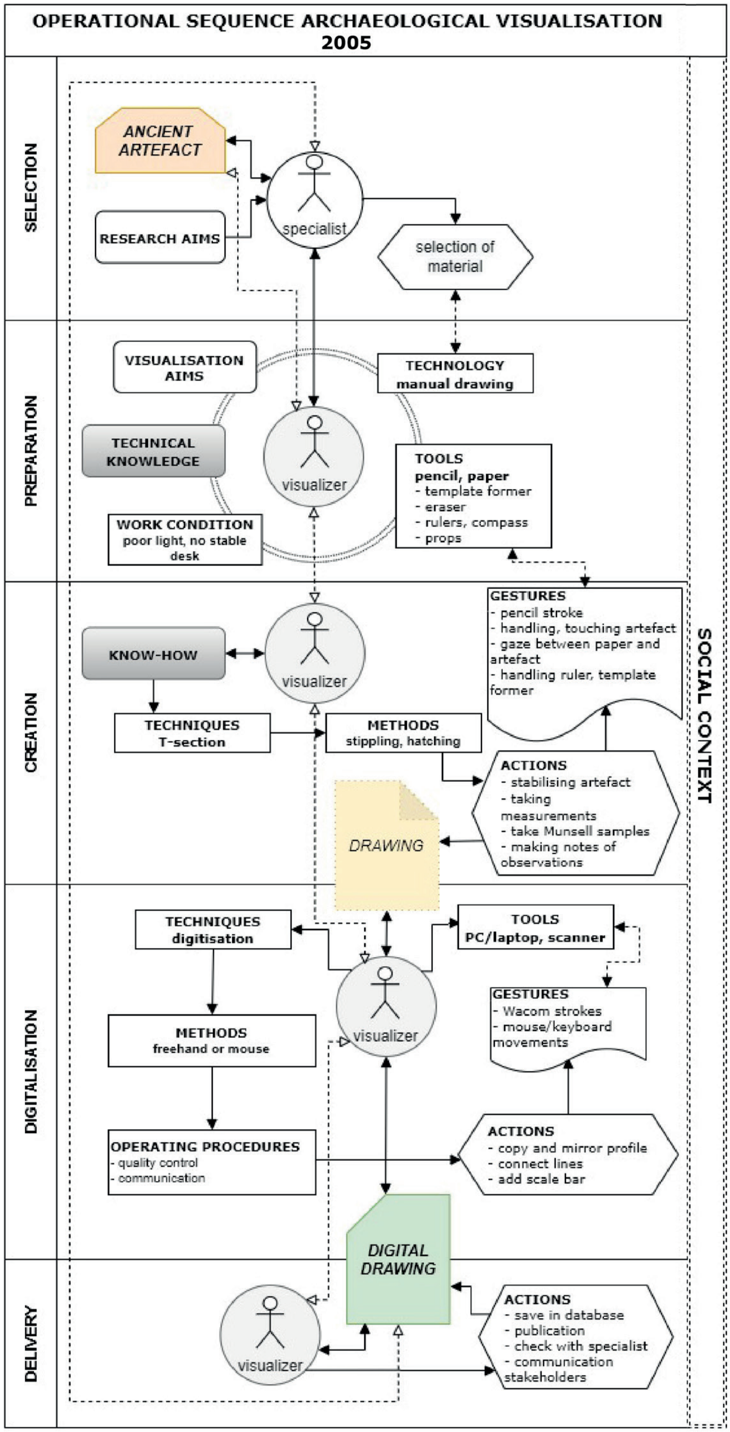


Figure **5.2**. The operational sequence of conventional archaeological visualisation in 2005. Image: Loes Opgenhaffen.

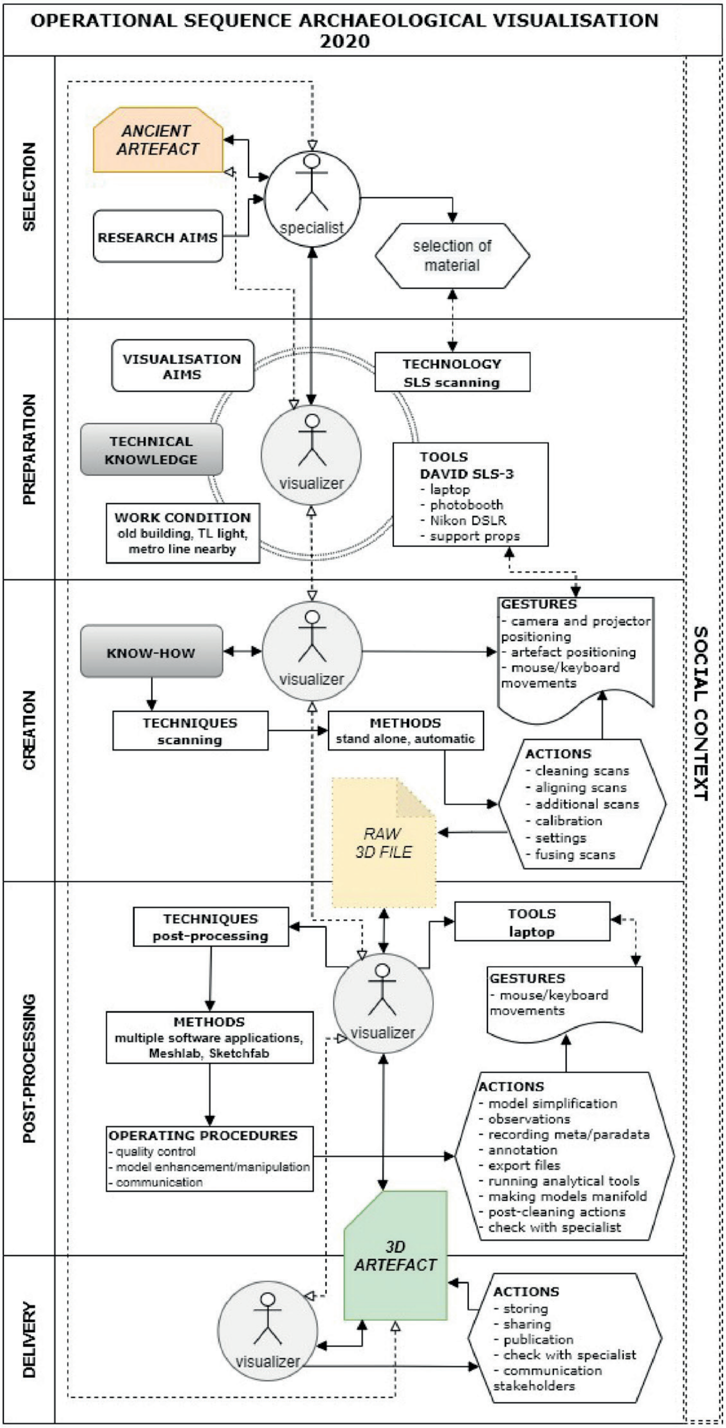


Figure **5.3**. The operational sequence of digital archaeological visualisation in 2020. Image: Loes Opgenhaffen.

Courty 2019, p. 41, emphasis original). The technique of Structured Light Scanning (SLS) is governed by several methods, for example the calibration procedure of a handheld Artec scanner is automatic, as opposed to the laborious calibration procedure of the DAVID SLS-3. In manual drawing, one can choose a method of pointing, lines or hatching to indicate depth and details. Lastly, tools can be either active or passive. Active tools are in this case the available brands such as NextEngine, Metashape or Cinema4D, Rotring pens and template formers, but also ancillary equipment such as Lego bricks and other props to support the artefact, portable photo booths, and DSLR cameras. Passive tools are for example manuals, tutorials or working plans.

The event of creation

Once the techniques, methods and tools are decided, and concomitantly the visualisation and research aim and material affordances, the technical knowledge can be physically performed. In this creative event operating procedures and series of actions and gestures assist in the execution of the visualisation methods. An operating procedure is "an implementation strategy of the *functional operations*" (Roux and Courty 2019, p. 43, emphasis original), similar to a workflow. This set of gestures is for example the positioning of the scanner device (mounting the tripod with the metal bar, cameras and projector), moving the handheld scanner around the artefact or the RTS prism pole around the feature, flying a UAV, software settings and parameters and pencil strikes, handling the artefact, postures and gaze (balancing above a grid tool or sitting in front of a screen). Actions involved in the method may include quality checks of the scans and observations made about the original artefact during the creative event.

The events of post-processing and digitalisation

In the event of the post-processing (digitalisation in 2005), the visualisation is further refined and enhanced with operating procedures such as running algorithms in analytical software, making objects manifold and watertight, simplifying models for presentational ends, exportation to multiple file formats, annotation of the models, and optionally converting 3D models into conventional 2D technical drawings. In 2005, this event encompasses scanning and digitalisation of analogue drawings in Adobe Illustrator or other image processing software, and placing a scale in the final technical drawing and perhaps adding supplementary information. The boundary with the prior event is fuzzy. Incomplete scans, or observations made while processing the 3D scans, may require additional scans or photographs. Actions such as communication with specialists and other participants or quality control may confront the visualiser with divergent expectations or standards of the specialist and other participants, forcing them to repeat the whole enterprise or even adapt certain methods to meet the demands.

The event of delivery

The final step in the sequence is the delivery of the visualisation to the specialist or participants. This act of sharing with participants depends on several other factors, such as storage space, online platforms and viewers, and copyright. Lastly, quality checks of online presentation or paper proofs may cause excursions back to the previous events as well, as the resolution for both paper and digital publication may be too low, or publishers suddenly demand supplementary data.

Reflections: transitioning technical traditions

The integrated descriptions of operational sequences from 2005 and 2020 are only possible because the division of operational sequences in the events of selection, preparation, creation, post-processing and delivery, have largely remained the same. One major exception remains: the post-processing event has replaced the digitalisation process (that had in turn replaced the event of inking). Layers of complexity have been added to each sequence, starting at the event of selection: the dimensionality and the geometry of the artefact complicate its capture by the digital apparatus, whereas this was less of an issue for analogue recording as there were codified standards to visualise dimensionality and features. The adoption of new digital 3D technology demanded new methods to visualise material remains, and heralded a wider range of techniques to choose from. The technical knowledge (*connaissance*) and know-how (*savoir-faire*) of the visualiser expanded drastically.

The visual outputs have become more complex too, yet often simplified and reduced to familiar 2D images in order to be publishable. A truly new visual vocabulary has not been fully formulated, leaving the old visual formats in a state of transition. The starting point, the archaeological material culture, has however remained the same, yet new methods and techniques demand different research questions and adaptation of recording strategies of that material, whereas the visual products do not provide the new answers yet. The practice of highlighting has not changed in essence either, and is now performed through a different method of recording and annotation of 3D models with tags. These tags visually direct the user through the model to places that are deemed important, similar to technical drawings, channelling directionality under the guise of "free navigation". Certain methods may have changed, but crucial acts such as visual accentuation led to the conclusion that the practice of digital visualisation is still visualisation, similar to Steven Ellis's statement that "digital illustration is illustration" (Ellis 2016, p. 65).

The proposed methodology meets the prerequisites of data *and* workflow transparency that old charters and new initiatives have pleaded for but never managed to achieve. The reconstruction of personal or project *chaînes opératoires* allows a detailed recording of the decision-making process of the visualiser. Detailed descriptions of workflows comprising techniques, methods, operative procedures and gestures during the visualisation process, i.e., the more generic operations should be published online, for example in blog posts and video tutorials.[41] Particular operations such as specific settings to produce the 3D model, geometric properties and particular contextual conditions that may have impacted the visualisation process should be recorded in object-

41 For example, this blogpost by the author: https://tracingthewheel.eu/article/workflow-series-sls-with-david

specific metadata records. All files should comply with the FAIR principles to ensure reproducibility of visualisation procedures and subsequent knowledge production.[42]

Reflections: the visualiser's position in transition

Not directly visible in the diagram (Fig. **5.3**), is that the increasing number of participants with whom the visualiser collaborates and communicates, for example drone pilots and GIS specialists, have an impact on the social organisation of the craft. As a result, the role of the digital visualiser has moved from a marginal to a more central and prominent position within research projects, and visualisation has concurrently become an integrated research method, instead of an auxiliary activity and final product.[43] Even though the visualiser is invisible in the digital image, they are virtually present in the recorded metadata, in which ideally technicalities, observations and the decision-making process are kept. This is contrary to the "old" practice of technical drawing, in which the decision-making process is usually not recorded, as if data transparency is considered unnecessary because the illustration is the data. The integrated role of the visualiser in research suggests that digital 3D visualisation is an archaeological practice, and the makers constitute a community of practice within the wider social structure of the archaeological discipline.

The old practitioners continue to collaborate alongside the "new" participants in the same social (academic or commercial) environment, and often have adapted their skillsets to new techniques. As a consequence, the role of the visualiser within the wider archaeological tradition is changing. Technical traditions may be explained in terms of learning modalities, as techniques are learned and transmitted within a social environment. However, the diagrams do not show where and in what context the digital 3D technology has been developed and how it came into contact with archaeology. Usually, hardware and software are not specifically designed for archaeology, but find their way into archaeology anyway through either interdisciplinary collaboration, the employment of external technicians or autodidactic experience. The latter option is suggested by the diagrams, which indicate the flexibility of archaeological visualisers to adopt, adapt and deploy new technology into their familiar practices. Illustrators adopted and internalised the lithograph, graphite pencils, watercolour, the T-section, tracing paper, theodolites, total stations, Adobe Illustrator and AutoCAD, and the Wacom. In the 2000s, 3D modelling packages and computing power became increasingly accessible and affordable, and low-budget and user-friendly 3D scanners, as well as very expensive devices, appeared on the market, in addition to open-source codes for SfM and SLS applications. With an already established digital framework these new techniques were relatively easy to learn with a certain familiarity. Finally, digital visualisation techniques are increasingly part of the archaeological curriculum, yet often at the expense of traditional recording and

42 For the FAIR principles see Wilkinson et al. 2016.

43 Of course, traditional illustrations and illustrators are considered pivotal to research, for example by General Pitt-Rivers and Sir Mortimer-Wheeler, or Alan Sorrell and Piet de Jong, but these are rather the exception than the rule, unfortunately.

illustration methods, and the consequent risk of de-skilling and loss of knowledge has been feared by some (Caraher 2013, 2016; Morgan and Wright 2018). Nonetheless, new skills are learned and practices adapted, which ideally produce new knowledge and simultaneously reconfigure the community. Whereas the mastering of new technology in the early days was reserved to highly specialised technicians of mystical allure, the open-source and DIY movement led to a democratisation of technology and a tendency to flatten traditional academic hierarchies, specifically within the communities of practice of digital archaeologists. Further research along the proposed line could determine the position and define the identity of the archaeological illustrator and visualising archaeologist in the new digital archaeological landscape.

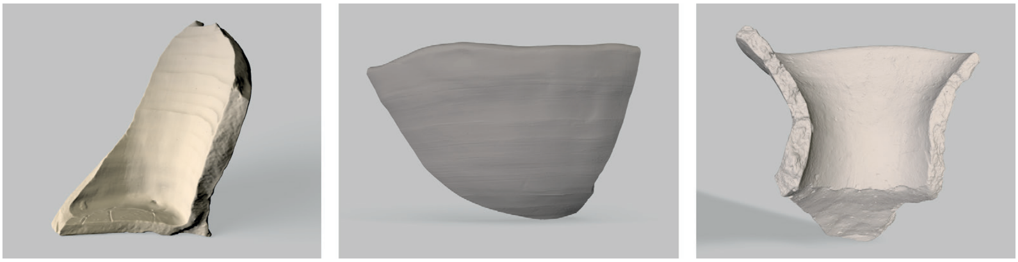


Figure **5.4**. Acquiring skill. One of the first scans with the DAVID SLS-3 and one of the most recent, with more details visible. Image: Loes Opgenhaffen.

Illustrating the application of the framework

Expanding personal skills and know-how

Further research should be carried out to compare *chaînes opératoires* on a macro-level to retrieve a full understanding of current practice, but a start can be made on a micro-scale by an autoethnographic analysis of my own changing practice. As an archaeologist with a classical training in fine arts, I became equipped with visual techniques derived from the arts which I then sought to apply to archaeology. Early stratigraphic drawings on a site in Greece were much appreciated for their aesthetic quality and found their way into frames on the wall in the study of the professor, but not into the publication. They were considered "too realistic". It turned out that my artistic visualisation methods could not be transferred unproblematically into archaeological visualisation practice. After subsequent training and gaining experience in archaeological illustration, I adapted, but not fully assimilated, my artistic skills to archaeological visualisation practice. I then realised that I was more able to express and emphasise in an effective way thoughts and observations with 3D visualisation technology (Ribes 2014), albeit within existing conventions and scientific expectations.[44]

44 Huvila and Huggett 2018 pointed out that the choice to adopt a particular technology depends on a wide range of scientific reasons and political factors which are often not made explicit. Initially, from a commercial point of view, I incorporated 3D scanning technology to enhance recording strategies, to more efficiently produce images and, from a scientific perspective, to use the 3D models as a base for more accurate 3D reconstructions of fragmented artefacts.

This technical knowledge assembled over the years enabled me to adapt relatively easily to a new device or piece of software, as well as turning this into know-how of methods and operative procedures. After experimenting and learning by doing with scanning technology (Fig. **5.4**), I developed specific methods and operative procedures tailored to specific tasks. Gradually, peripheral technology became subsumed into the *chaîne opératoire* of visualisation, skills expanded and the practice extended, to be finally transferred to other academic research projects[45]: the TPW project.

The section below describes the process of my visualisation *chaîne opératoire* as applied in the TPW project and follows the events in the diagram (Fig. **5.3**).

Event 1: selection

The TPW team works closely together. The team members point me to forming traces left on the surface of ceramic vessels – hard to discern with the naked eye – which should be captured in high resolution by the 3D scanner.

Event 2: preparation

In response, I inform my colleagues about the affordances of the ceramic material upon the SLS 3D scanner and vice versa, so that the selection of material is also tailored to the technology.

Event 3: creation

So far, the initial material interaction with the original artefact, as it swiftly shifts to an intimate relationship between the stationary scanner and the digital artefact as the scanning proceeds. During this creative event I become completely distracted from the artefact while scanning, wholly absorbed by almost mechanical operating gestures and motor habits, and responding to circumstantial events interfering with the scanning session. The handling of the original artefact is in the service of the machine and the visuals on the screen. The procedure has become a completely disembodied practice with regard to archaeological material, and becomes replaced by an embodied practice with the digital device. This is contrary to the practice of manual drawing, where I would have had an intimate, tangible experience with the artefact, and could have made direct observations.

Event 4: post-processing (or digitalisation)

Despite the seemingly perfunctory interaction with the 3D model on the screen, new data about the original artefact is revealed as well, whereas in manual practice observations were made in the previous event. In doing so, the scanner is not an extension of the body as the pencil is to my hand, but rather a prosthetic to the pencil; the operative procedures and gestures with the instrument make 3D scanning an embodied practice and as such a valuable "cognitive artefact" in the creation of archaeological knowledge (Huggett 2017).

45 For example, with technical and research papers such as Opgenhaffen et al. 2018; Revello Lami et al. 2016.

Event 5: delivery

The process of scanning and processing is minutely recorded as metadata in a spreadsheet, and together with several exported versions of the 3D artefact, entered into the database and made available online for future use and public display. Together with the specialist, the 3D model is tagged with information about the artefact.

Breaking the visualisation procedure into events enables us to analyse in detail the actions, choices and bodily gestures involved. The example of the autoethnographic analysis of the author's own practice has demonstrated to what extent the introduction of the 3D scanner affects the visualisation practice and forces even the body to adapt. Just like the pencil and the potter's wheel, the 3D scanner functions as an extension of the body, and is operated on an automatic, almost subliminal level. The digital device is a prosthetic of our previous tools and not of the archaeologist, and in relation to the body I propose to regard it as an orthotic instead. Orthotics do not replace something that is no longer there, but reinforce something not fully functioning and enhance (bodily) functionality and performance. The 3D scanner enhances the visibility of macrotraces in pottery and its visual output is much more versatile than its analogue counterpart, the pencil and the technical drawing. Digital orthotics enhance archaeological knowledge-making and by no means "self-amputate" (Chrysanthi et al. 2012, p. 8) or de-skill archaeologists (Caraher 2013, 2016) as a consequence of its assumed automation of traditional practices. On the contrary, they are complementary yet impose new forms of interaction and demand a new set of skills and know-how. The concept of bodily extensions and orthotics has been briefly touched upon, but needs further investigation in order to determine how this impacts creative practice and to establish their role in shaping the visualiser's identity as archaeological illustrator or visualising archaeologist.

Transferring technical knowledge and know-how

Students, or apprentices, are important participants in the TPW project and play a central role in the reproduction of a practice. The student is taught the *connaissance* or theory behind the visualisation strategy with manuals and tutorials, but there is only so much you can verbally transmit of a largely embodied practice. Similarly, ethno-archaeological research has demonstrated that artisans often cannot explain their practice in words, and offer 'to show' it instead. The student starts learning once she puts the theory into practice and truly "incorporates" the learned skills (Roux and Courty 2019, p. 4). Subsequent comparison of the visual products of the skilled archaeological visualiser and the student determines if the skills were transmitted successfully. Transmitting the practice is an interactive enterprise, in which both the tutor and the apprentice are participating in the reproduction and continuation of the practice, which shall be demonstrated by two examples.

Research master student Nina wanted to study specific shapes of Minoan pottery and TPW needed assistance in the processing of 3D scans. She was not able to study this material on location, but in this case the unprocessed 3D scans could serve as digital surrogates. Nina was not particularly interested in the technology, and had

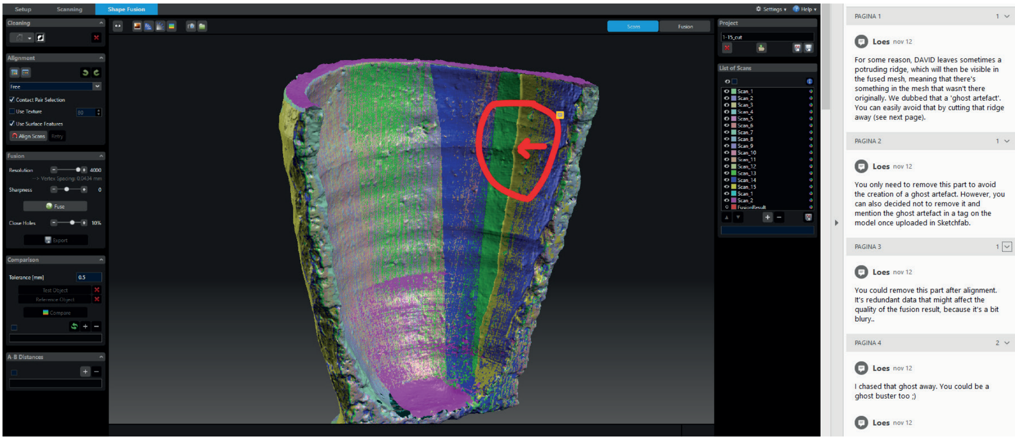


Figure **5.5**. Online training, assessment and feedback to Kelly by the author. Image: Loes Opgenhaffen.

only basic digital skills. Nonetheless, it provided her a unique opportunity to learn about this material in great detail, by means of the alignment and processing of the 3D scans. She learned to use the scanning software by following the detailed instructions of the manual and receiving ad-hoc help from the visualiser, usually "by showing" the solution. And indeed, while learning by doing, Nina, as she expressed herself, became intimately acquainted with the archaeological material. She then could connect her literature study of the archaeological context with the models by using the annotation functionality in Sketchfab. This interactive practice, however, did not change the social organisation of the TPW team, as the original student-teacher hierarchy remained the same, but the structure of educational knowledge transfer did indeed reach a new level.

Digital Archaeology master student Kelly reinforced the TPW team as a project-assistant to help with the 3D scanning of the project's experimental ceramics. Kelly was trained in the TPW workflow by working through the manuals and tutorials while 3D scanning. Due to the COVID-19 pandemic, assistance and the assessment of raw 3D scans took place online (Fig. **5.5**). Kelly scanned and processed two dozen vessels and produced 3D models with a fairly consistent output that reached almost the same resolution as the skilled operator who devised the workflow and wrote the manuals (Fig. **5.6**). Because I developed these, I could assess the quality of the 3D models and the student's performance. Kelly has been trained in recognising the important technological traces herself by the experimental archaeologist of the project, and has gained a profound understanding of the physical material as well. In doing so, her technical profile can be traced in the digital artefact which resembles that of the members of the social group (TPW) (Jeffra 2015a, p. 142). Kelly can now transfer her acquired skills as trained visualiser to other participants within this community of practice, or as pottery specialist studying ancient technology. The digital 3D visualisation practice has diffused boundaries, and could potentially be transferred to other communities of practice. By studying the performances of particular *chaînes opératoires* of archaeologists, such as those of Kelly and the author, archaeologists can trace how those performances (of individuals) become "enmeshed within a network of

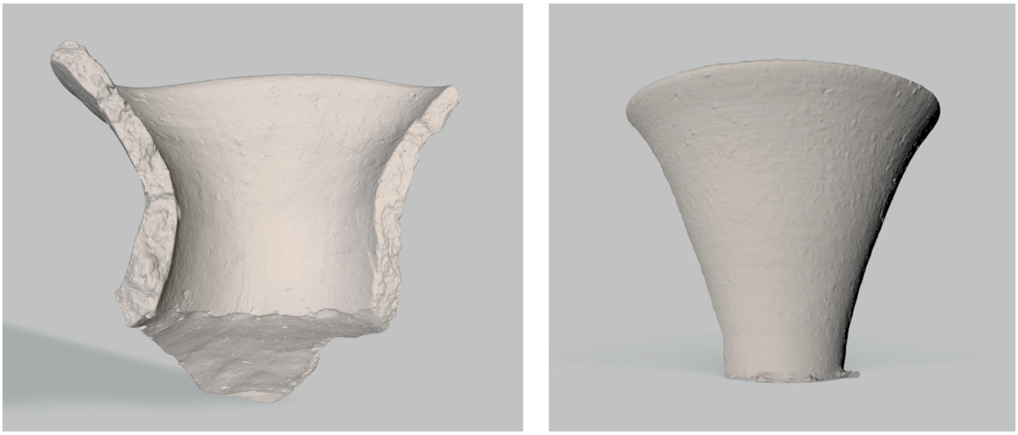


Figure **5.6**. Comparison of models of the author (left) and the apprentice (right). Image: Loes Opgenhaffen.

dynamic relations" of archaeologists and other disciplines (Hilditch 2020, p. 67). To trace this, to move between these scales, or to "zoom in or out" between practices (Huvila and Huggett 2018), more reflexive ethno-archaeological studies should be carried out, in which the proposed Tradition in Transition framework can provide direction.

Discussion and summary

The Tradition in Transition conceptual framework is designed to assess and document archaeological visualisation practices of artefacts of archaeological visualisers/illustrators and visualising archaeologists specialised, but its flexible structure could be expanded to other specialisations and material categories. The methodology can help to determine the position of the community of archaeological visualisers using digital 3D techniques in the chain of archaeological knowledge production. The aspect of learning takes an integral part in the identification of a technical tradition and its reproduction of a social group, this community.

To summarise, the Tradition in Transition framework comprises the following core topics, aims and preliminary results. First and foremost, it serves as a methodological implementation of the London Charter and Seville Principles, complemented with the FAIR Principles. The framework integrates the *chaîne opératoire* approach with reflexive theory, in which the maker, but also material agency, takes a key position in the methodology; it is a co-creative effort of machines/things and humans, as opposed to a techno-centric focus on digital tools. The transmission of technical know-how and skills, and thus learning, takes a central place in the framework. Lastly, it aims to create critical awareness with the visualising archaeologist or the archaeological visualiser about the adoption of and interaction with digital 3D technology, and helps to position the visualiser in the construction of archaeological knowledge.

An important insight that came to the fore when reflexively applying the framework on practice, was the realisation that the pencil and 3D apparatus are extensions of the body, or even prosthetic. The visualiser is hardly aware of its presence but the tool is enhancing (bodily) functionality and visibility of hidden material properties. Reflexive analysis further demonstrated that bodily gestures and mental choices have moved away from the artefact and are now directed to the operation of the machine and the screen. A new form of material interaction with the artefact has developed. New insights are generated by an intimate relationship with the digital artefact and software to process and enhance geometric properties.

A significant preliminary result that emerged when applying the *chaîne opératoire* diagrams on personal practice, is that new skills, *connaissance* and technical know-how entered the events of creating an image. One event in the chain has been changed already, but the technical tradition has not yet been replaced completely. It is in a state of transition.

By drawing on personal experience as an archaeological illustrator and visualising archaeologist, I have demonstrated how the conceptual framework can be implemented in research. The examples and diagrams show that the technical tradition of archaeological visualisation has not yet essentially changed, as the events have remained largely the same, but layers of complexity have been added. The tradition is shifting, and increasingly digitally literate students will further refine the technology and eventually cross social boundaries of older generations and eventually break the tradition. Only then will truly new knowledge be generated.

Future directions for a tradition in transition

The preliminary and introspective analysis of the *chaîne opératoire* of digital 3D visualisation leaves many questions open to further exploration. The 3D apparatus as an extension of the body, as orthotic or *Körperbild*, has been briefly interrogated, but a full understanding of the transition from the pencil to the 3D scanner, and the coaction between the visualiser and the scanner, has only been cursorily touched. And to what extent does the machine or software dictate how the archaeologist proceeds and carries out research? The personal example showed how the 3D scanner already dictates part of the selection of artefacts. And how powerful is the traditional archaeological gaze towards 3D images? How does this directionality affect our ways of interpreting archaeological material? Further research carried out along the scheme provided by the Tradition in Transition conceptual framework could give pointers to the impact of machine agency on archaeological interpretation. Beyond this is the important issue of the dichotomy between subjectivity and objectivity that digital technology tends to enshroud. Nevertheless, the issue is inherently present and treated implicitly when analysing a *chaîne opératoire* due to the central role of agency. Further, the practice of "pointing" or highlighting parts of the artefact and other subjective engagements between participants runs counter to the often-made claim that digital techniques are objective, because the translated data is "filtered" by human and material agency, "and according to individual agendas" (Rabinowitz 2016, p. 511), irrespective of the technique. The present study acknowledges the subjective nature of visualisation and the practice of subject making, and further elaboration with the proposed framework can explore this dichotomy in more detail.

The archaeological tradition of visualising the past is in a transitional stage. Digital technology has not fully replaced conventional practice yet, and visual outputs look remarkably familiar, as they follow a centuries old visual formula (Moser 2009). The fundamental events that draw up the series of actions to produce a visualisation have largely remained unaltered. Certainly, the *chaîne opératoire* has expanded with additional layers of digitally complex methods and operative procedures, and archaeologists and technology alike have adapted to the practice. This increased complexity is mirrored in the social organisation of the work environment as well, as more agents participate in the creation and visualisation of archaeological knowledge.

More ethno-archaeological research into visualisation activities and reflexive analysis of archaeological practice is needed to obtain a better understanding of how visualisation strategies have transformed or are in the process of conversion. A performative approach to the creative social enterprise that archaeological visualisation comprises has proved to be a valuable heuristic solution to disentangle the inner machinery of a community that has always endeavoured to improve its visual products. The Tradition in Transition conceptual framework integrates praxis-theory with a reflexive approach, and aims to provide the building blocks to reconstruct the operational sequence of a practice in the past and in the present. The inherent multi-scalar approach enables us to move between personal workflows, networks of communities of practice and the wider archaeological discipline as a whole, ultimately defining the position of digital visualisers within the discipline. The framework is especially designed to serve as a methodology to introspectively guide the application of digital 3D visualisation technology in research and to document the technical and decision-making process of the archaeological visualiser, permitting full transparency of practice and technology.

Chapter 6

A standardised method to record and visualise ceramic forming technology in 3D

Introduction

One of the principal aims of the present research and the wider Tracing the Potter's Wheel project (TPW), was to develop methods to enhance the communication and dissemination of research data about ceramic forming technology. Digital 3D scanning is no just a novel solution to multidimensionally recording forming traces in the surface of pottery; its greatest strength resides in the potential to communicate these traces and their meaning in an exceptionally comprehensive way. The increased accessibility of affordable technology presents an additional opportunity within this project: the intention was to find a low-budget scanning technique and to develop low-entry scan methods that less tech-savvy people could operate. Related to this was the aim to share this recording method in order to create standardised datasets. The reproduction of a shared method bolsters the comparability between the data, which ultimately should expand knowledge about ancient technological transfer. Finally, by embedding 3D models with associated data, they become meaningful 3D artefacts, another practice which can be standardised thanks to the way that workflows have been shared.

This chapter summarises the technique and the methods developed to digitally record pottery in 3D and in high resolution, which allows detailed morphometric analysis on submillimetre level. The methods and technique have been described step-by-step in the so-called TPW Workflow Series, published as open-access manuals in the TPW Knowledge Hub since 2019, and have been continuously updated according latest developments ("3D scanning" (Opgenhaffen 2020c); "Processing 3D scans to 3D models (Opgenhaffen 2020d); "Post-processing 3D models (Opgenhaffen 2020a)).[46] TAlso, other experiences with different scanning technology ("DIY solutions for obsolete scanners", Opgenhaffen 2021c) and several solutions for scanning difficult objects ("Excursions with DAVID", Opgenhaffen 2020e), as well as other 3D-related subjects such as 3D printing and holograms (Opgenhaffen 2019a and b), have been published in the TPW Knowledge Hub, in the shape of informative and publicly accessible blogposts. In this way, all data and information has been made publicly available in an easily accessible and user-friendly environment.

46 https://tracingthewheel.eu/page/tpw-workflow-series

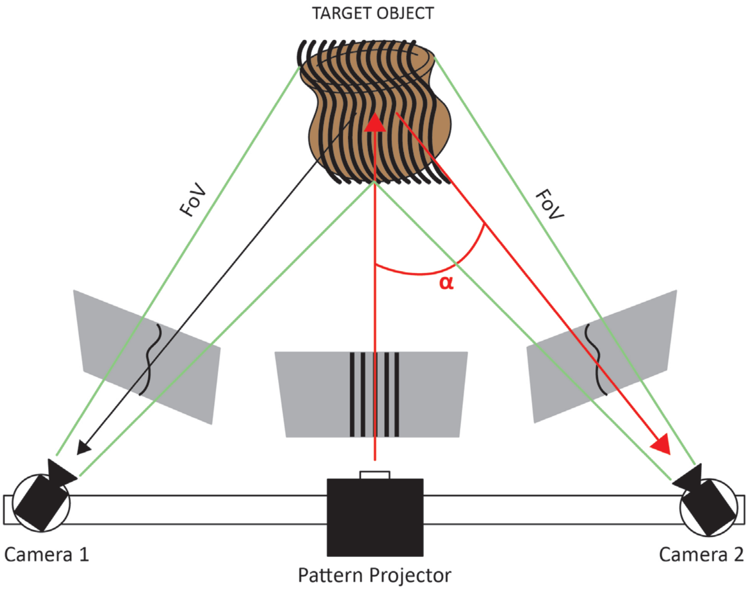


Figure **6.1**. Triangular setup of an SLS scanner. a is the triangular angle between projector, object, and camera. VoF is the Field of View, or line of sight, of the camera. Image: Loes Opgenhaffen.

The official workflows were developed by scanning modern pottery produced by the experimental archaeologist of TPW. This experimental pottery has been created with standardised, commercially available pre-tempered clay and fired in a programmable electric kiln, resulting in a very homogeneous typeset. Subsequently, the established scanning method was applied onto heterogeneous archaeological material, with different tempers, discolouration due to firing processes and painted decorations, causing the workflows to be further refined with additional operational actions and settings. Similar to the experimentally produced vessels, digital artefacts are crafted with great care, and this creative process permeates authenticity of a digital 3D artefact. The development of these workflows embedded in a publicly available system (and the method to document the technical metadata and intellectual and circumstantial paradata while scanning, described in the workflow "Democratising data" (Opgenhaffen 2020b)), warrants scientific transparency.

Finally, the main contribution of this dissertation to the neglected field of digital ceramics analysis is the presented method for digital 3D capture of ceramics, with the aim to record micro-topographies to retrieve technological clues about the creation of the artefacts. This object-oriented approach therefore adds to the already rich body of literature about 3D recording techniques deployed in excavations, architecture or monuments, virtual archaeology and 3D reconstructions.

What is 3D scanning?

There are several techniques to obtain 3D data, such as Long-Range and Short-

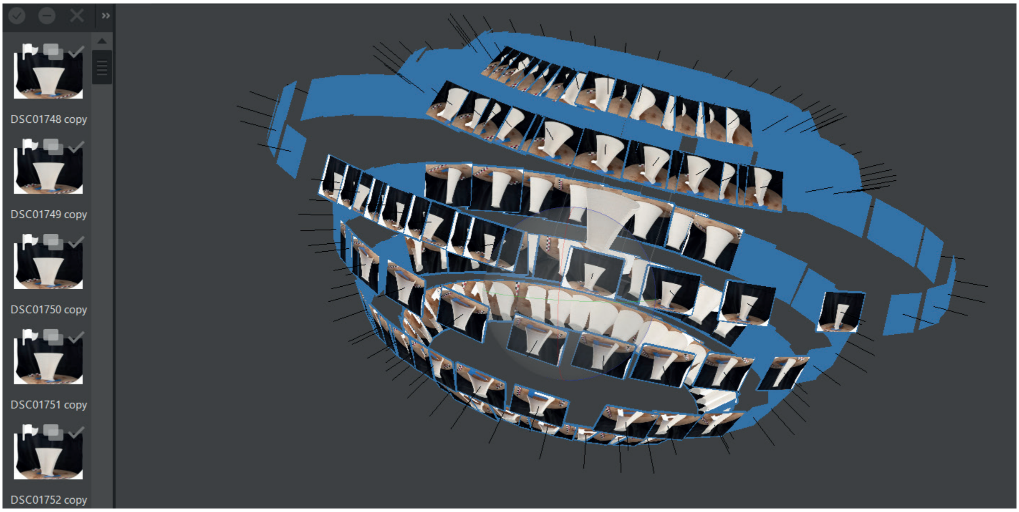


Figure **6.2**. The IBM procedure in Agisoft Metashape: a 3D model is constructed by taking a range of digital photographs from different perspectives and with enough overlap between the photographs. Image: Loes Opgenhaffen.

Range scanning, active (e.g., SLS/laser, LIDAR/ToF) and passive (e.g., IBM, stereo) techniques, stationary and handheld devices, and laser, Structured Light scanning (SLS) or Image Based Modelling (IBM; i.e., photogrammetry, Structure from Motion (SfM)) technology.[47] They are all non-contact and non-destructive techniques, which is ideal to record valuable and often fragile heritage objects. With laser scanning, a laser line is projected on the object's surface, while rotating mirrors (or "electro-optical technology", in the case of the NextEngine 3D scanner) sense that line (the reflected light bounced back), and another camera to capture the colour information. A laser scanning system basically measures the distance by calculating the time it takes for the laser beam to bounce back from the targeted surface. With both laser and light scanners, triangulation is used to determine the location of a measured point. The laser or light projector, the camera and the object (or, technically, the projected light or laser on the surface of the object) form together a triangle (Fig. **6.1**). Through calibration (either automated or manual), the distance between the projector and the camera is known, as well as the angle of the projector and the angle of the camera in respect to the projected light pattern, laser line or dot onto the object. The IBM technique constructs 3D models by taking a range of digital photographs from different perspectives and with enough overlap between the photographs (about 80%). Software such as Agisoft Metashape or Pix4D is then able to calculate and scale the measured information from the photographs and to reconstruct the data into a 3D model (Fig. **6.2**). In this dissertation, a method has been developed for Short-Range, active 3D scanning using Structured

47 The focus of the present PhD dissertation is on the 3D scanning of small objects. Therefore, it shall not elaborate about Long-Range scanning techniques for surveying, such as LIDAR (light detection ranging or laser detection ranging) or ToF (Time of Flight scanning), or almost inaccessible techniques such as micro-CT scanning (computed tomography, used in medicine or industry for internal and volumetric inspection of objects or people), which are not portable either.

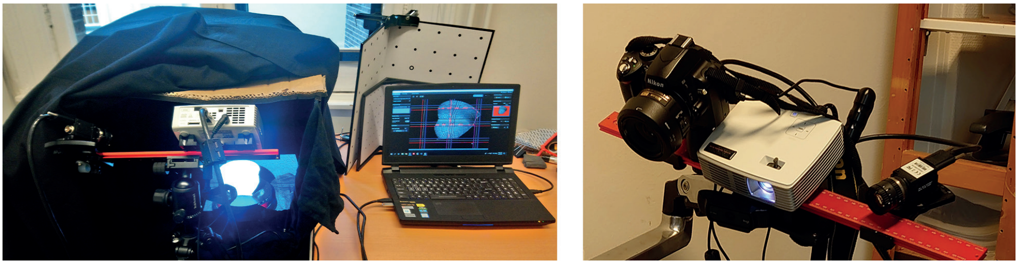


Figure **6.3**. The DAVID SLS-3 as used in the PhD project, with additional photobooth. To the right, an optional DSLR camera is mounted. Image: Loes Opgenhaffen.

Light technology with particularly the DAVID SLS-3, which was rebranded as HP 3D Structured Light Scanner Pro S3 in 2017, after HP purchasing DAVID earlier that year.

The DAVID SLS-3 scanner SLS system consists of a projector (a DLP projector), 1 or 2 monochrome machine vision (depth) cameras and, if the software allows it, a DSLR camera for optimal colour information (Fig. **6.3**). The projector projects a series of light patterns of stripes onto the targeted object. The light pattern then deforms as it hits the surface of the object, and this is captured by the camera (Fig. **6.4**). Then RGB (Red, Green, Blue) colours are projected to interpret the colour information (Fig. **6.5**). The deformation is subsequently analysed and triangulated into a mesh of that particular captured part of the object (Fig. **6.6**). To measure this deformation, the system first needs to determine specific parameters: camera–projector distance, angles between the directions of both the camera and the projector with the camera–projector distance, and the coordinates of the centres of the camera and projector. These can be determined by calibrating the system. The calibration is carried out by performing a set of measurements on two panels with a dot matrix, placed at an angle of 90 degrees. The several calibration panels represent different sizes (<30mm, <60mm, <120mm, < 240mm and so forth) (Fig. **6.7**).

The monochrome machine vision cameras of this particular DAVID-SLS3 do not record colour; rather, it is an interpretation of the colour based on greyscale image, similar to the algorithms behind current popular apps that are able to

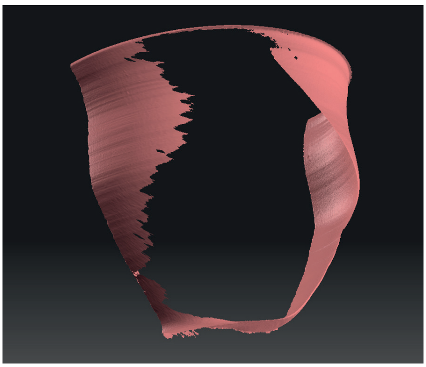


Figure **6.6**. The resulting mesh of one scan. Image: Loes Opgenhaffen.

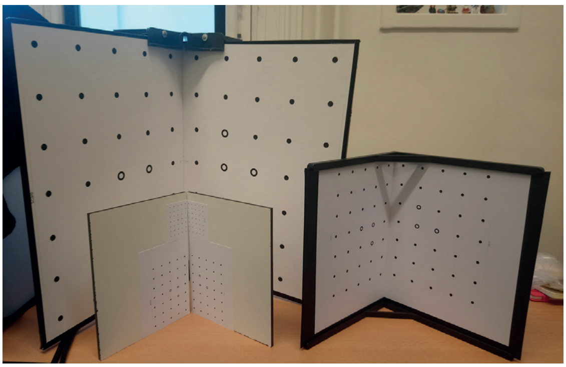


Figure **6.7**. The calibration panels of the DAVID SLS-3. Photo: Loes Opgenhaffen.

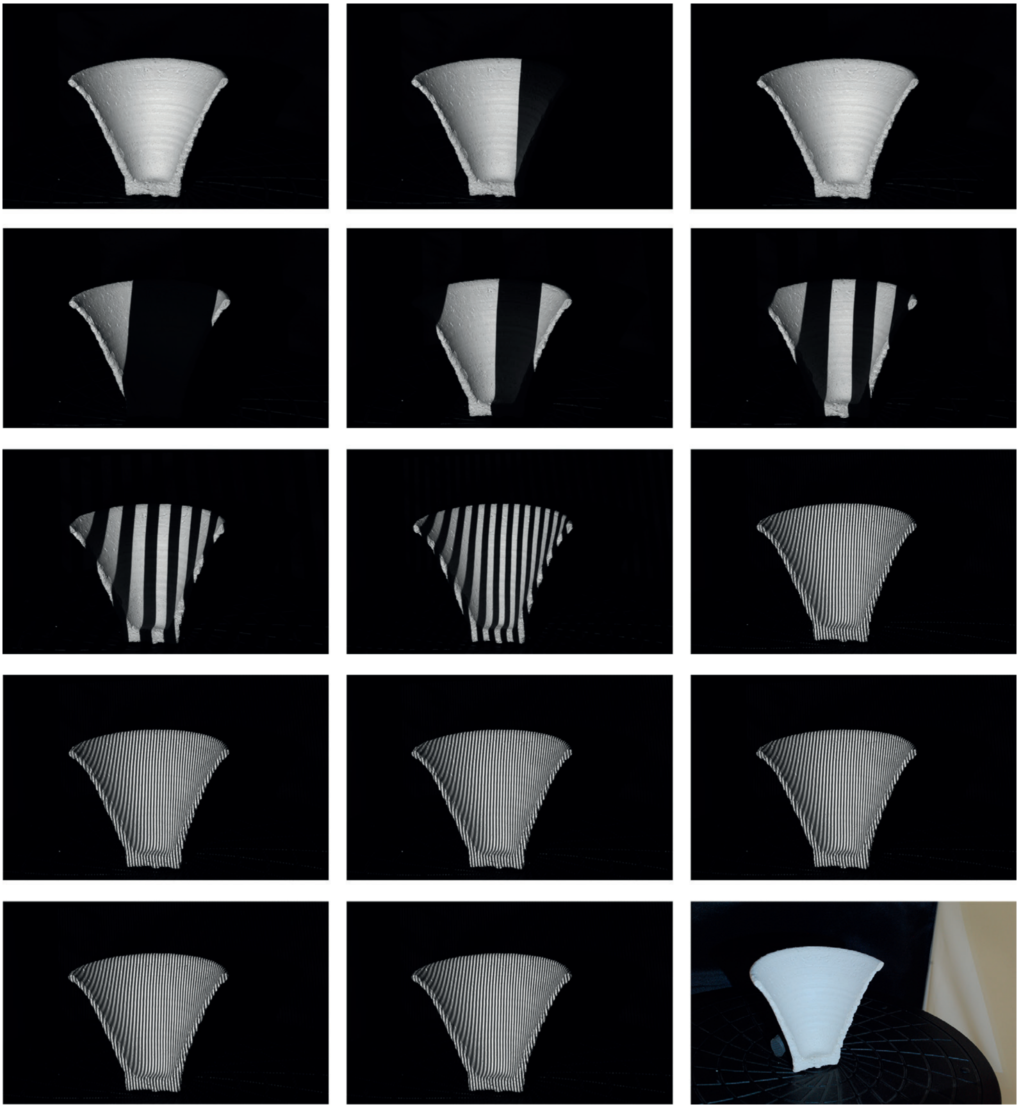


Figure **6.4**. The process of morphological data capture with different light patterns projected on the object. The image on the bottom right is the colour capture by the DSLR camera. Image: Loes Opgenhaffen.

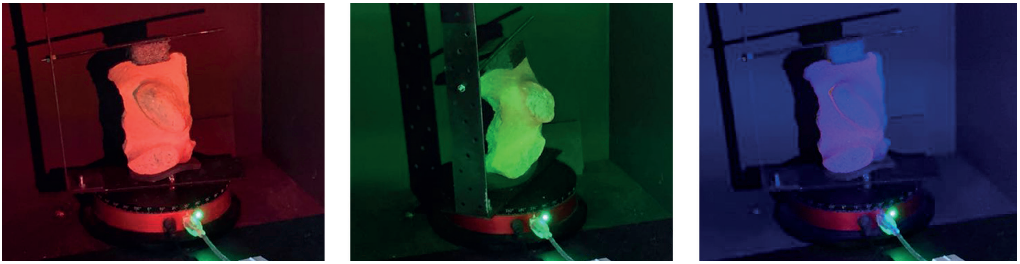


Figure **6.5**. Process of data capture: The projection of RGB colours. Photos: J.R. Hilditch.

Figure **6.8**. An example of basic circumstances of fieldwork. The portable scanner is installed using marble slabs and crates. Image: J.R. Hilditch.

colourise old black and white photographs. Depending on the scanner brand, the colour information is directly translated into an image file format such as JPG or TIFF (DAVID), or it assigns a colour to each captured point (Scan-in-a-Box). There are machine vision cameras that can capture colour, but these are more expensive and moreover unnecessary if the application of a DSLR camera is an option.

Handheld, portable 3D scanners, whether laser-based systems or SLS, can indeed save a lot of recording time and are able to capture larger objects. However, due to the articulating waving motion around the object this may cause a redundancy of overlapping data, creating huge file sizes and more time to clear the scans of "noise" (i.e., captured features unrelated to the object). The more advanced (and, almost universally, expensive) the software, the less noise captured. Moreover, these handheld scanners tend to be less accurate than stationary 3D scanners, due to their mobility. To capture almost invisible, macroscopic forming traces on ceramics, a stationary scanning device was therefore preferred.

Within Structured Light scanning there are technological differences as well: blue light technology is a more enhanced version of white light. Blue light has a narrower wave length whereas white light is a combination of all the colours in the spectrum.[48] As a result, scanners with blue light technology can capture better data from shiny and dark surfaces, and can deal better with interference of ambient light as it filters other light sources. DAVID is based on white light technology because it works with a white light LED projector.

48 https://www.capture3d.com/knowledge-center/blog/white-light-vs-blue-light-scanning (accessed 25 April 2022)

Giving the archaeologist a choice

Finding the right scanner for ceramics analysis[49]

Every now and then scanning techniques are compared and the results published. However, there is no one-size-fits-all solution, at least that is what most outcomes of these comparative papers share (Di Angelo et al. 2018). The choice of scanning technology and scanner brand depends on several factors, for example: the available budget, the nature of research and the goal of the data visualisation within the research framework, which ultimately determines the required resolution. Other factors that should be considered are of a more practical nature, such as time investment, the learning curve and the amount of maintenance of the device. In the case of ceramic analysis, where budgets are usually limited, TPW aimed to find an affordable, preferably off-the-shelf technology that could reach a high resolution nonetheless. Also, the technology needed to be easy to transport and installed on the often remote and basic circumstances of fieldwork locations (Fig. **6.8**). Therefore, to scan small heritage objects, comparing terrestrial laser scanners, LiDAR technology and million-dollar robotic 3D scanners with low-budget SLS technology would make no sense, as the first two approaches are designed to survey large surfaces and to fully automate recording processes (yet see, for example, Melendreras Ruiz, Marín Torres, & Sánchez Allegue, 2021).

In order to select the right scanner for the TPW project, the following technologies and techniques which all possess different capacities were compared:

- laser, SLS and IBM;
- blue light and white light;
- handheld and stationary.

Selected parameters for comparison were:

- pricing;
- quality of geometry (noise, vertex distribution);
- scanning and processing time;
- ease of use and learning curve;
- texture (colour) quality.

In the first year of the present research (2017), the HDI Advance r3x (with FlexScan3D software), the NextEngine Ultra HD and the DAVID SLS-3 were compared. In 2021 and 2022, the Scan in a Box, DAVID SLS-3 with two cameras, Artec EVA and Spider, NextEngine HD and IBM were also compared. As NextEngine in the meantime has been superseded by progressing technology as well, the post-processing of the scans was carried out in respectively CloudCompare, Meshlab and the HP Scan Pro software. Also, the scanning software FlexScan3D was used in combination with the

49 All data produced for this comparison can be consulted in Table **6B** and also downloaded here: https://uva.data.surfsara.nl/index.php/s/ihdyMEBZSLrsZUm.

DAVID SLS-3 hardware. FlexScan3D may well be the only proprietary software that facilitates DIY scanning hardware, and provides a solution to discontinued devices such as the DAVID. The results of the 2017 comparison are best presented as a brief summary, while it is possible to instead provide a detailed description of the more recent comparative analysis of 2021-2022. This is due to progressive insights over the years between the comparisons described here, the application of dissimilar parameters in the two experiments, and the creation of a different experimental dataset in the meantime.

The data of the small pilot survey performed at the beginning of the PhD project are not included in the 2021-2022 survey, but the table produced in 2017 shows a similar conclusion with DAVID having the best price-time-quality ratio (Table **6A**). Expensive machines such as the Artecs and the HDI Advance r3x may be either easier to operate or the software more flexible and controllable, but, as the following section will demonstrate, a skilled operator can create similar and even qualitatively better 3D models with reasonably priced off-the-shelf 3D scanners such as the DAVID. This quality is imperative for ceramics analysis which requires a high Level of Detail (LoD), and sample 3D models were checked by the archaeologists of TPW to assess the visibility of the forming traces.

For the present analysis (2021-2022), two experimental objects were used, 7.09A[50] for the DAVID, Artec EVA and Spider, Scan in a Box and NextEngine, and 4.14A[51] for the comparison between DAVID and IBM. 7.09A and 4.14A have the same shape (a bisected conical cup) and are produced with the same forming technique, but are tempered differently (coarse tempered and untempered, respectively). By "scan and fusion resolution" it is meant here the vertex spacing, or the distance between measured points. Vertex spacing is not, however, a good indicator for geometric quality and detailed surface features, as the (visual) results will show. It was not possible to measure the accuracy manually (thanks to the deviation between real-world and measured/recorded measures), so this is based on the specifications given by the manufacturer of the machine - if provided at all.

Description and review of the scanners and software

All scanners and software cannot operate without proper hardware, and even for the most low-budget IBM software, a powerful PC is required to obtain the best resolution. For scanning and processing the ceramic material of TPW, a laptop with an i7 7700HQ processor with 32GB RAM and an NVIDIA GeForce GTX 1070 8GB was used. For most of this comparative experiment, the above-mentioned setup was used, and sometimes also a laptop with a i7-6700K processor with 64GB RAM and an Nvidia GeForce GTX 980M 6 RAM. In special instances, a PC with 2 Intel Xeon CPU E5-2680 v3@2.50GHz processors and 192GB RAM and an Nvidia GeForce Titan X black 12MB RAM was deployed to process separate scans in CloudCompare and Meshlab. All technical metadata applied for each recorded object are summarised in Table **6B** and **6C**.

50 See https://tracingthewheel.eu/object/15667 for the object and further specifications.

51 See https://tracingthewheel.eu/object/15653 for the object and further specifications.

DAVID SLS-3

Previous experience with SLS technology, especially with DAVID (the SLS-1) and the HDI Advance r3x, made it easy to choose a DAVID again, because of its (once) flexible software and reasonable pricing of €4560 for the Pro kit. DAVID was acquired by HP in 2016, and rebranded in 2017 to HP Structured Light Scanner Pro S3, only to be taken out of production in 2020. DAVID is a modular scanner, which means that all components need to be assembled individually when installing the device. This modularity makes the scanner quite versatile; depending on the budget, the scanner can be extended with additional cameras and an automatic turntable. However, it can also be intimidating when opening the box, as it comes with countless cables, a licence key on a USB stick, a tripod, a guide rail to mount the projector (Acer K132 LED with DLP technology, 500 ANSI Lumens[52]) and the camera(s) (DAVID-CAM-4-M and 3.1-M, which are in fact FLIR cameras, with Computar 15I and 14D 12mm lenses), and the optional turntable. Furthermore, a photobooth was purchased to control lighting conditions (Fig. **6.3**). In DAVID's case, it was necessary to drastically reduce ambient light sources. Setting up takes about 30 minutes by an experienced operator, but this also depends on local challenges, which may increase installation time up to 90 minutes.

Despite the acquisition by HP and the subsequent loss of features, such as mounting a DSLR camera for true colour capture, the software still allows a great deal of control over the recording and processing of data. For example, it allows import of separate OBJ scans from scan data retrieved with other devices, and alignment and processing of the scans into a mesh. A disadvantage of DAVID was the fact that the calibration plates were made of glass, which reduced its portability. Fortunately, calibration files come with the licence key and they can also be downloaded from the HP website, so calibration panels in a more travel-friendly material can be fabricated. Calibrating with DAVID can be challenging, but with experience and persistence, can be done in about 10 minutes average (Fig. **6.9**). After calibration, a batch of objects of similar size and hue can be scanned (this selection procedure of similar material is described in chapter 8). The software HP Scan Pro 5.6.0 is quite straightforward to learn and good results can be obtained easily and fast. Depending on the research objective, incredible resolution beyond the promised 40 microns of the manufacturer can be reached (and an accuracy of ~0.05 %), although this depends on skill and especially time and scanning circumstances.[53]

TPW purchased a DAVID with a single camera (the DAVID CAM-4-M), but it was possible to scan using an additional camera and compare the results. Scanning with two identical cameras reduced processing time by 36 minutes (from approximately 50 to 14 minutes), increased accuracy and considerably eased the alignment of the scans. The alignment was still performed manually due to the nature of the shape, which

52 The more ANSI Lumens, the farther the scanning range. Projectors with more ANSI Lumens are also more expensive.

53 See for example this blog: https://tracingthewheel.eu/article/excursions-with-david (Opgenhaffen 2020e), where I describe the scanning process of a bacteria colony of less than 1 cm in width and reaching a fusion resolution (vertex spacing) of approximately 25 microns. Scanning extremely small objects, such as a malleus, takes just more time and a lot of patience.

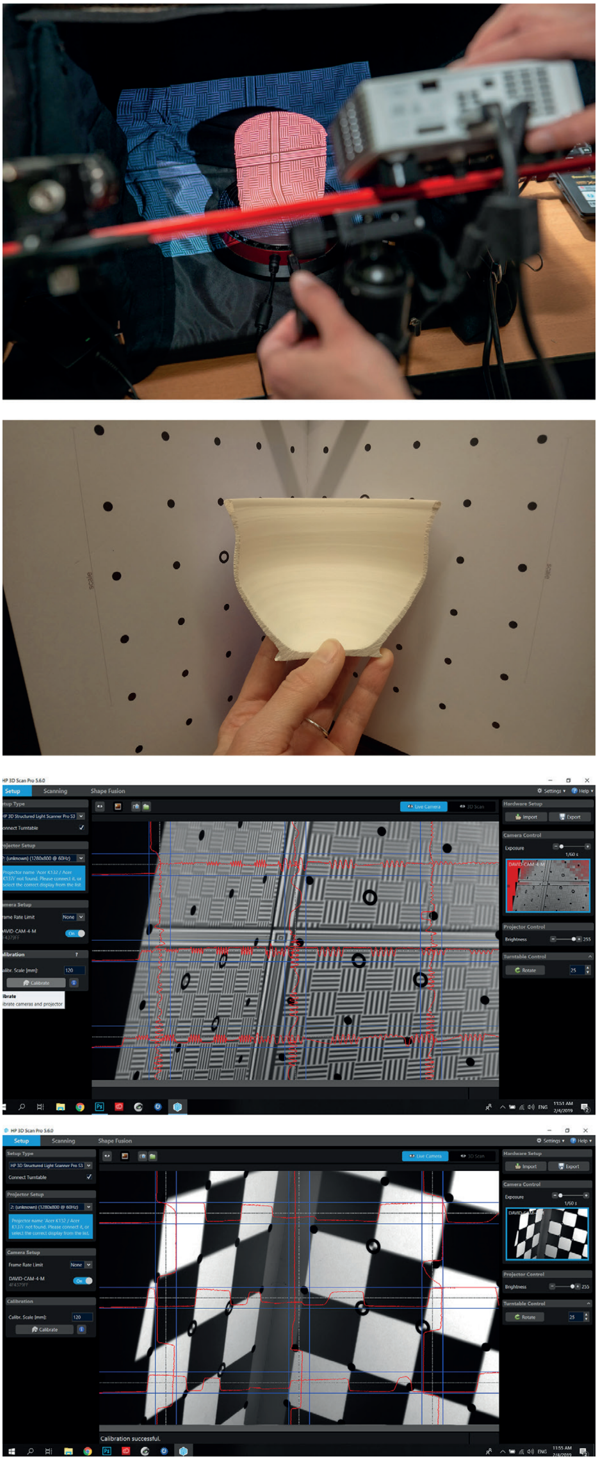


Figure **6.9**. The calibration procedure with the DAVID. Image: Loes Opgenhaffen.

the software finds hard to scan and align. The second camera, however, increased scanning time from 12 (for 22 scans) to 20 (for only 15 scans) minutes. The total time saved with two cameras as opposed to one was 50 minutes, from 80 to roughly 30 minutes, and it also improved resolution by 13 micron (from 0.0602 to 0.0499 mm).

Lastly, the textures of the differently produced 3D models were rather dark but quite detailed. However, for unknown reasons the two-camera texture was more reddish, and as a result appeared more unnatural than the one-camera texture.

DAVID and FlexScan3D

The same hardware set up with two cameras was then extended with a DSLR camera, possible when using different scanning software: FlexScan3D Lite 3.3 of Polyga. This software costs $500 and any SLS hardware set up can be used – including DIY – although the software recognises exclusively FLIR machine vision cameras of the Grasshopper and PTgrey type and the DAVID cameras. Furthermore, it only accepts legacy models such as the Nikon D40 and D60, and the Canon EOS Rebel T2i (Fig. **6.3**). For the present comparison, a Nikon D60 with a Nikkor 18-55 mm f/3.5-5.6 lens was used. FlexScan3D does not accept the automatic turntable of DAVID, so a wooden turntable was used instead. The FlexScan3D software follows the same calibration principals as the DAVID, albeit with its own dot-matrices printed on a single panel (Fig. **6.10**), which is put in three different angles of the scanner and approximately 60 positions during the calibration process. This process takes more time than DAVID, about 20 minutes for 60 calibration scans, including the calibration of the DSLR camera. Yet, similar to the DAVID workflow, a batch of objects of roughly the same size and hue can be scanned on the same calibration.

For the current experiment, it took 12 minutes to calibrate the scanner with only 13 scans. The scanning time took 12 minutes for 41 scans, and processing 43 minutes, with a total of 54 minutes to create a mesh of the conical cup. The fusion resolution was 0.0466 mm, and only performed 0.0033 mm better than the DAVID scanner with two cameras, yet took considerably more time to process. The photo quality, or texture, is closer to the actual cup than most textures produced by the other devices, as it is based on true colour capture. Finally, the learning curve to master the FlexScan software is steeper than the HP software, especially on the level of the calibration procedure and alignment.

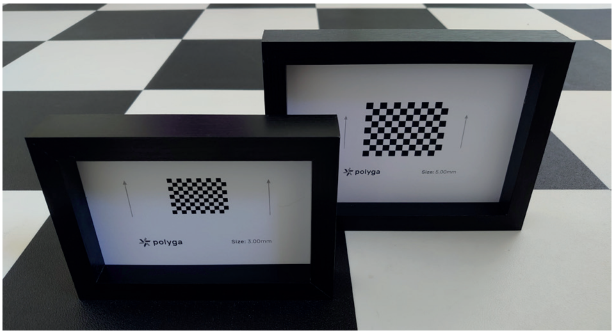


Figure **6.10**. The calibration panels with dot-matrices of FlexScan3D. Photo: Loes Opgenhaffen.

Figure **6.11**. The Scan in a Box FX setup. Photo: Loes Opgenhaffen.

Figure **6.12**. The NextEngine Ultra HD setup. Photo: Loes Opgenhaffen.

Scan in a Box FX[54]

Open Technologies' Scan in a Box FX structured light scanner was a good alternative to the discontinued DAVID, in both similar technology and pricing; € 4490, for the complete kit with two cameras and automatic turntable (Fig. **6.11**). According to the manufacturer, it should be able to reach an accuracy up to ~ 0.04 %. Unfortunately, FARO Technologies acquired Open Technologies in 2018, and cancelled the production of this budget-friendly scanner in favour of their own expensive 3D scanners in 2020. This type of scanner is modular as well, with lots of cables, a hardware key, a turntable, tripod, calibration panel with dot matrix almost identical to the one of DAVID, and a projector (ASUS S2 mini projector, same specifications as the DAVID projector) and two machine vision cameras (2MP) pre-fixed on a guide rail. The two cameras can slide within limits along the bar according to the size of the targeted object. The cameras are of a lesser quality than those of DAVID (2MP as opposed to 3.1MP and 4MP). No photobooth for controlled light is required for the Scan in a Box.

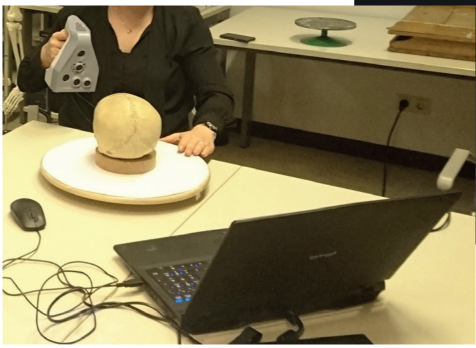
The scanner operates on Open Technologies' proprietary IDEA 1.1 SR 8 software. The calibration procedure is similar to FlexScan3D, in taking multiple scans of the calibration panel in different angles, yet the several locations of buttons and windows for different actions necessary to complete the calibration, is even more complicated than the calibration pipeline of FlexScan3D. The manual with instructions in extensive poster format does not clarify the supposed sequence of actions at all. Lastly, the turntable must also be calibrated with its own calibration board, but fortunately this goes quite quickly. The IDEA software automatically aligned the separate scans, which saved significant time and effort. If it couldn't align automatically, the scans were manually aligned by assigning 3 corresponding points in each scan, resembling the alignment procedure of NextEngine. For reference, with DAVID and FlexScan only 1 point is required. It took 30 minutes to make 22 separate scans, but only 2 minutes to align and process them. The fusion resolution, however, was only 0.1613 mm, which was reflected in the low number of vertices and small file size.

The two monochrome cameras capture colour by projecting red, green and blue onto the object and then reverse process the image channels, the same technique that DAVID and FlexScan3D apply. Unfortunately, the IDEA software exports the colour information as per-vertex in a PLY file. Due to this linking of colour information to the geometry, this information is then lost when exported to OBJ or if the model requires geometric simplification (decimation of vertices to reduce file size) while retaining high-quality texture. The result is that the textures of the Scan-in-a-Box models appear blurry.

NextEngine Ultra HD

The NextEngine Ultra HD is a pre-calibrated, shoe-boxed sized laser scanner (Fig. **6.12**), with the very precise accuracy of ~0.381%, priced $2995, including an automatic turntable. Unfortunately, due to Adobe's Flash kill switch in early 2021, the machine became nothing more than a box, as the software ScanStudio Pro runs on Flash.

54 Saxion University of Applied Sciences was kind enough to make the Scan in a Box available in order to write this review.



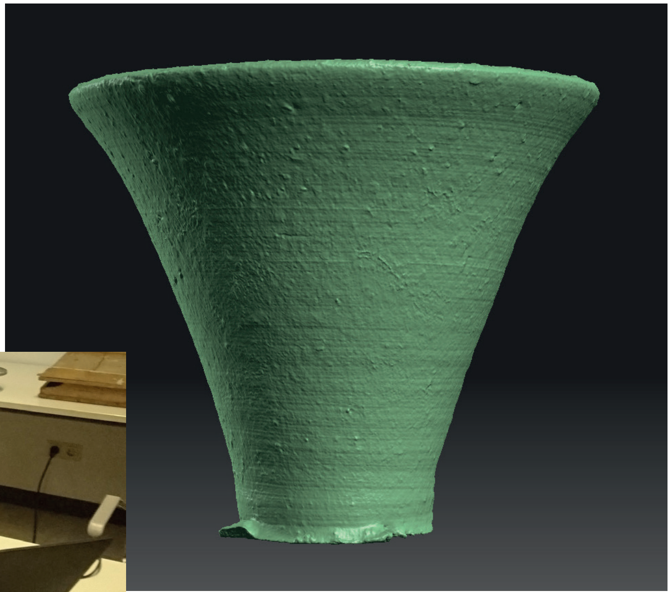


Figure **6.13**. The handheld Artec Spider. The scanning process can be followed live on the laptop. Photo: Loes Opgenhaffen.

Figure **6.14**. The resulting 3D model of the Artec Spider. The fine traces are clearly visible. Image: Loes Opgenhaffen.

Although the website is still online, NextEngine no longer provides any support or updates. Fortunately, ScanStudio still allows scans to be made, as well as cleaning and aligning the scans, saving them into a native file (.scn), and even exporting the separate scans into OBJ. In this way scans made with the NextEngine can be further processed and meshed in other modelling software, such as open-source programs Meshlab and CloudCompare, and even in proprietary software HP Scan Pro.

The software is very user-friendly, with the downside that it allows little flexibility or control over the settings. Scanning on its "highest quality" with the automatic turntable set on 12 steps takes 60 minutes, and with 4 additional scans to capture the rim and the base it took a total amount of 80 minutes. Alignment of the separate scans in ScanStudio follows the same principle as the IDEA software of Scan in a Box: at least three corresponding locations should be assigned in each separate scan. The cleaning and alignment in ScanStudio took about 70 minutes, after which the separate scans were exported to OBJ. The subsequent "fusing" of the separate scans into a mesh in HP Scan Pro took 7 minutes, and 24 minutes to "reconstruct" the scans into one mesh in CloudCompare on the same computer. The merging and reconstruction in Meshlab were performed on a much more powerful PC and took 12 minutes. The fusion resolution of the meshes in the three programs differs greatly: in HP Scan Pro this is 0.0218 mm (with a "depth threshold" of 0.1, which is with a calibration size of

120, a depth of 12), in Meshlab 0.0138 mm (but the octree depth was set to 8), and in CloudCompare (with an octree depth set to 12) a resolution of 0.0459 mm was reached (All details are presented in Table **6B**). Meshlab produced almost three times more vertices than CloudCompare and HP Scan Pro, which is reflected in the file size.

Lastly, in the overall experience with NextEngine, which is again confirmed with this experiment, the NextEngine produces "dirty" meshes with much noise. The software does not remove the overlapping parts, resulting in unnecessarily large files. Interestingly, the reconstructed meshes in other software produced better textures than the native software.

Artec EVA[55]

The Artec EVA is a handheld structured white light scanner able to make fast scans of objects of medium size with an accuracy up to ~0.1 mm, costing €13.700. This is a great scanner when a high level of captured detail is not essential. In case of TPW and the very fine forming traces, it was already clear that the EVA would not meet the requirements of this project. The Artec EVA runs on Artec Studio 16, which has quite a user-friendly interface with icons indicating the operations, and the scanning process can be viewed in real-time. Indeed, scanning went fast, yet it encountered difficulty in capturing the concave curved interior. It had therefore to be scanned in sequences in which the object was turned in different angles, which then needed to be aligned. Processing took only 5 minutes, leaving a total of 25 minutes to produce a mesh of a resolution of 0.1048 mm. The model is rather undetailed, smooth even, and has noise along the edges of the vessel.

Artec Spider[56]

The Artec Spider is another handheld structured light scanner, based on blue light technology (Fig. **6.13**). It should reach an accuracy of ~0.05 mm and a 1.3 MP texture resolution, and comes with an educational price of €17.500. It can scan smaller and larger objects than the EVA at an equally fast speed yet with a higher resolution. The scanning software is Artec Studio 16 as well, and follows the same procedure as described for the EVA. Despite being suited to scan smaller objects, it witnessed similar problems as the EVA with scanning a conical cup of 10 cm in height. It had to be scanned in sequences as well, which took 20 minutes. The cleaning, alignment of the batches, and subsequent meshing of scans took 40 minutes, resulting in a clean model with a resolution of 0.1025 mm and with a substantially higher detail than the EVA. The fine traces indicating wheel use are clearly visible even after decimation (Fig. **6.14**).

Image Based Modelling - Agisoft Metashape

The 3D model of conical cup 4.14A was created by TPW's project assistant Vasiliki Lagari, as she has experience with image-based modelling. Experience is important when comparing the time-factor, and all the other models have been produced with

55 I am indebted to Maarten Sepers of DDEA, who was so kind as to lend me the Artecs to do the comparison.

56 This Spider was purchased in 2016, but was upgraded to a Space Spider in 2021.

much experience. The following description is based on the detailed report written by Lagari.[57] Agisoft Metashape is an application that enables creation of 3D models based on photogrammetric triangulation of imagery derived from digital cameras (although legacy data, i.e., digitised analogue photographs, can be used as well) to generate a point cloud, which is then processed into a 3D model with a high-quality photographic texture (Fig. **6.2**). An educational Professional licence costs $549, a standard educational licence $59. A good camera is required too, and for this project an ILCE (mirrorless) camera Sony A6300 (24.2MP) with a 50 mm lens was used, costing about €1000. Furthermore, a photobooth for controlled lighting and a manual turntable and targets (for measurement and scaling) were used. Metashape allows a choice of "accuracy": high, medium and low. What this accuracy encompasses remains unknown, as many factors may affect the accuracy, such as camera calibration, targets, camera orientation, photo resolution, camera calibration, and photo redundancy.

211 images over 6 rotations of the turntable were recorded photographically, which took 40 minutes. The processing of the images took approximately 210 minutes, which consisted of several events. First, the RAW images were imported in Adobe CameraRaw to convert them into high-quality JPGs (300 dpi). The duration of this operation was 20 minutes. Secondly, the JPGs were masked in Adobe Photoshop (this is also a feature in native to Metashape) to remove captured data in the background, which took about an hour. Not all background was removed; due to the white and homogeneous character of the vessel some background data was required to support the alignment of the images. The modelling of the images into a mesh consisted of three operations. First, as the vessel was recorded in two batches (or "chunks", as it is called in the report), for each side of the conical cup the two batches of about 100 photos needed to be aligned individually. The alignment of each batch took about 10 minutes. The building of the mesh from the depth map, however, took about 1 hour for each batch. Finally, the two batches of 211 photos could be aligned (30 minutes) and a dense point cloud created in 69 minutes, and from there a mesh built in 12 minutes. Due to the lack of distinct features in the surface of the cup, the accuracy had to be set on "highest", after it failed to align both batches on a lower accuracy, hence faster processing time. It resulted in a resolution of 0.15 mm. Ultimately, over 3,5 hours was needed to create a high-quality 3D model of this conical cup.

Though it was initially thought that a lack of sufficient experience with Metashape led to the large time investment in producing quality 3D models, Lagari, with much experience in IBM and SLS scanning, confirmed the tedious and laborious process of 3D modelling of objects of this particular kind of featureless objects. She admits she could also not choose to mask the object, though that would slightly increase the alignment time. Furthermore, the two batches could have been exported to OBJ, which could then be aligned and reconstructed into one mesh in Meshlab, saving considerable time. Lastly, Lagari mentions that "if the main goal is to present the texture, then medium quality models are adequate along with high quality texture", as is often the purpose of models generated with Metashape.

57 The report can be found here: https://uva.data.surfsara.nl/index.php/s/YcTrWQ8aFnIMac0

Figure **6.15**. The HDI Advance r3x. Image: Loes Opgenhaffen.

HDI Advance r3x

The HDI Advance r3x structured light scanner of LMI Technologies is based on white light technology (Fig. **6.15**). It consists of two 2.8MP monochrome machine vision cameras with 12 mm lenses and a DPL projector, and runs on FlexScan3D software. It claims to reach a scan accuracy of 0.045 mm and a maximum resolution of 0.075 mm for small objects of a size up to 200 mm. The price of this scanner was €21.500. It was used in the exploratory comparison between different 3D scanners for the present project in 2017, and produced 3D models with an average resolution of 0.05 mm.

Analysis and comparison

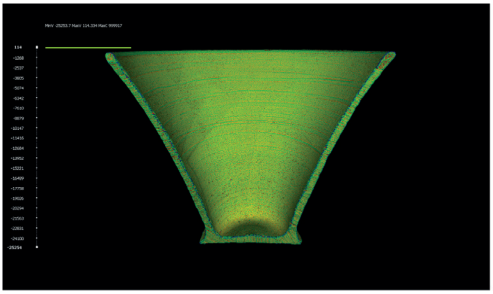
Standardising the data

In order to create comparative models, all models were decimated to have about 1.000.000 vertices, with a resolution (vertex spacing) of approximately 0.16 mm. This number of vertices preserves to a reasonable extent the topography of the surface, that is, the level of visible detail.[58]

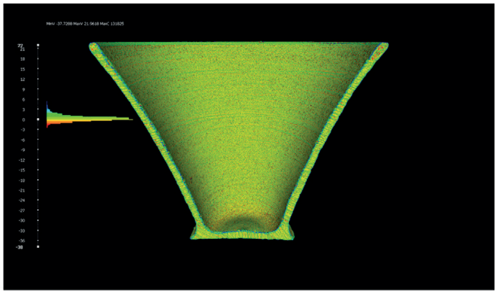
Visual inspection

Machine algorithms can compute and analyse the quality of the geometry of the different scanned outputs, but they cannot determine if the models show the details the archaeologist wishes to see, as machine vision follows different rules. However, algorithms, or filters and shaders as they are called in open-source analytical software

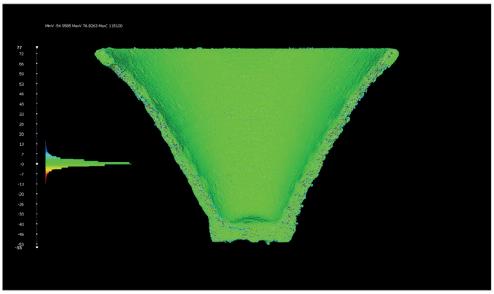
58 The models can be found in this Sketchfab collection: https://sketchfab.com/tracingthewheel/collections/scanner-comparison-tradition-in-transition-phd and downloaded via this link: https://uva.data.surfsara.nl/index.php/s/iNPwdJdsMmR0e0C



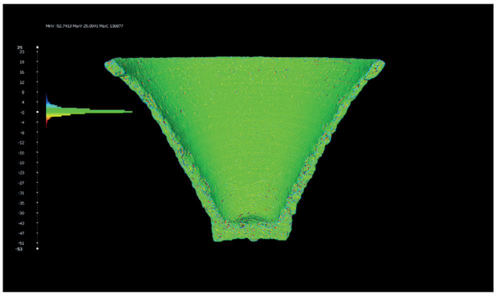
4.14A DAVID SLS-3 with 1 camera



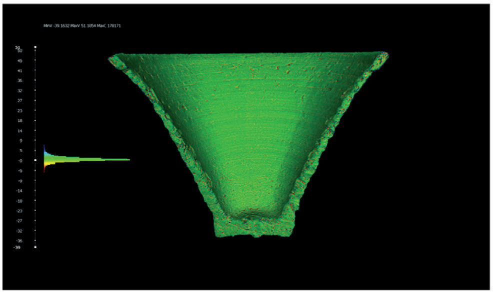
4.14A Metashape



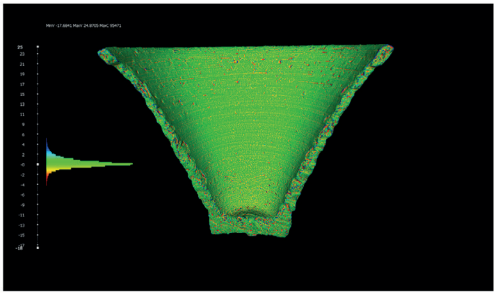
7.09A Artec EVA



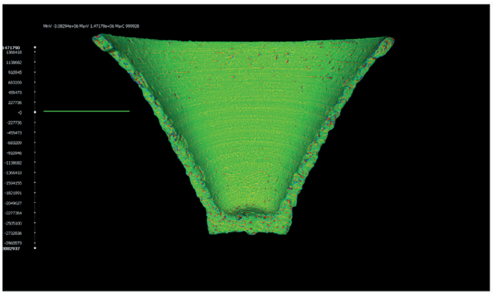
7.09A Artec Spider



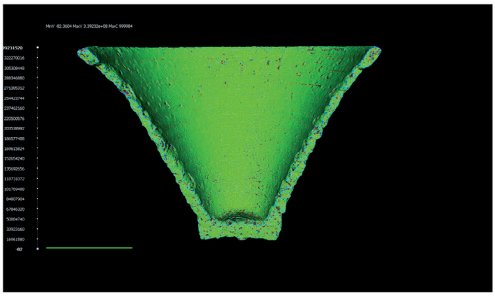
7.09A DAVID SLS-3 with 1 camera



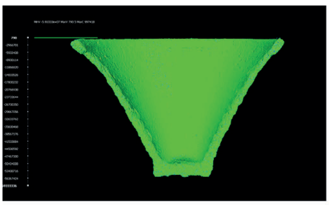
7.09A DAVID SLS-3 with 2 cameras



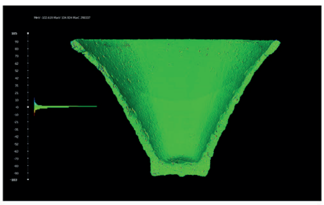
7.09A DAVID SLS-3 with FlexScan3D, 2 cameras+ DSLR



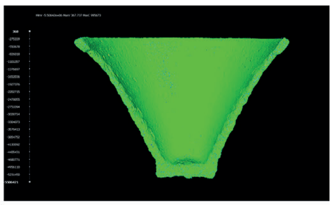
7.09A Scan in a Box



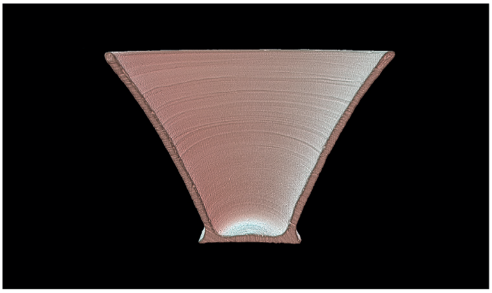
7.09A NextEngine processed in CloudCompare



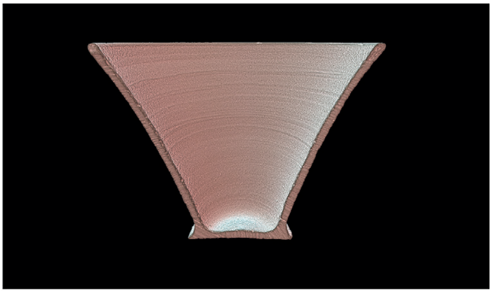
7.09A NextEngine processed in HP Scan Pro



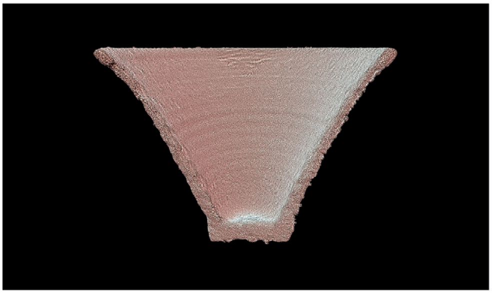
7.09A NextEngine processed in Meshlab



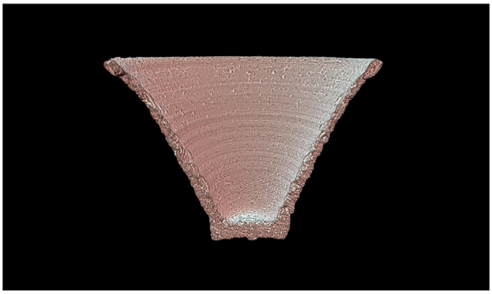
4.14A DAVID SLS-3 with 1 camera



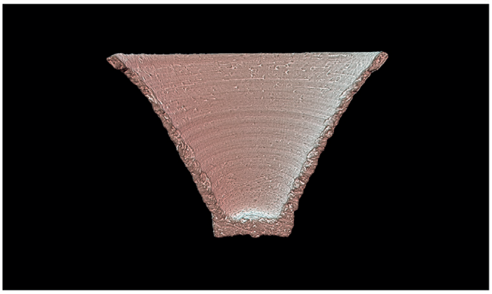
4.14A Metashape



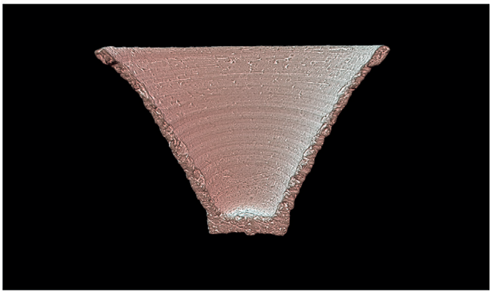
7.09A Artec EVA



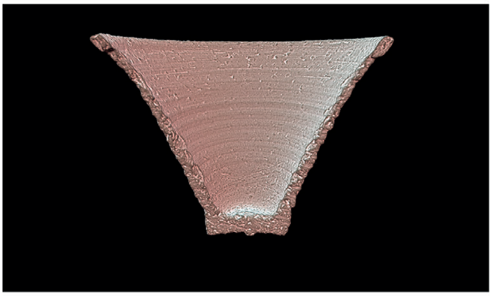
7.09A Artec Spider



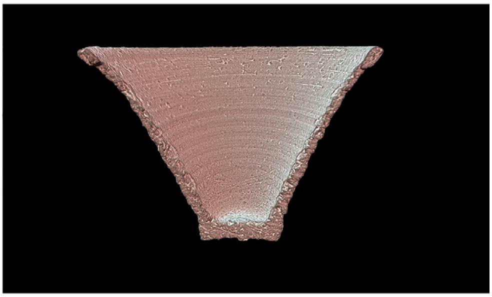
7.09A DAVID SLS-3 with 1 camera



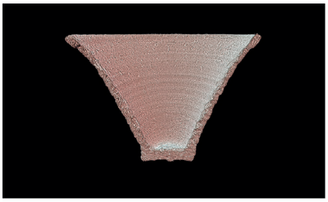
7.09A DAVID SLS-3 with 2 cameras



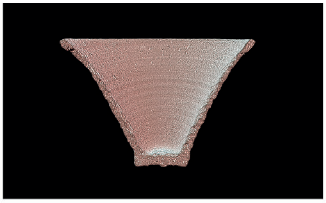
7.09A DAVID SLS-3 with FlexScan3D, 2 cameras+DSLR



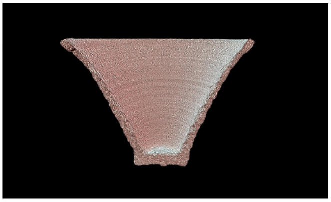
7.09A Scan in a Box



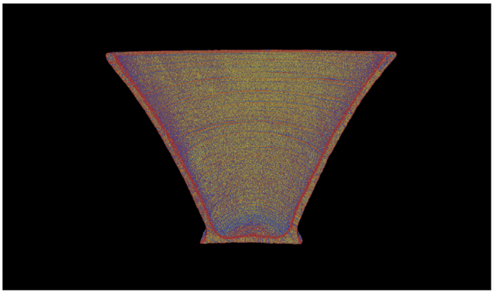
7.09A NextEngine processed in CloudCompare

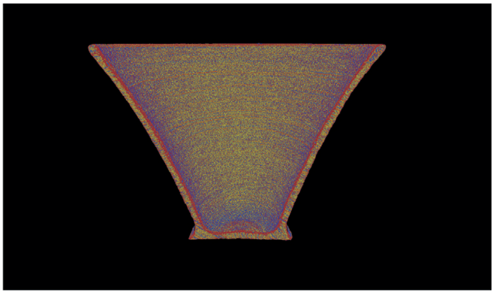


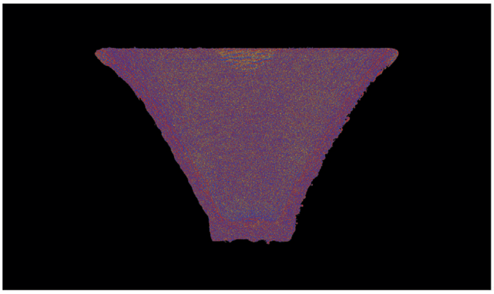
7.09A NextEngine processed in HP Scan Pro

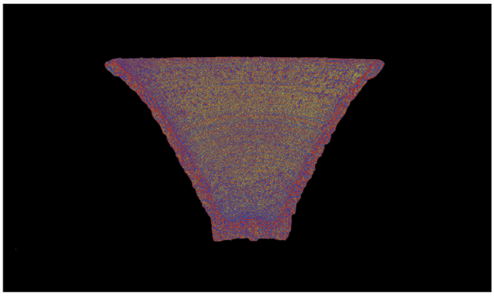


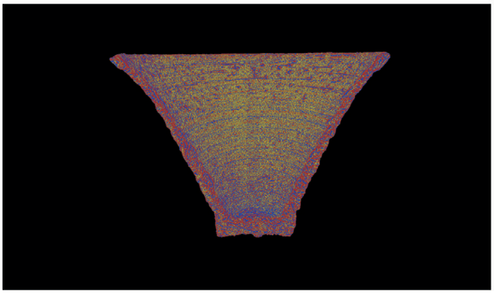
7.09A NextEngine processed in Meshlab

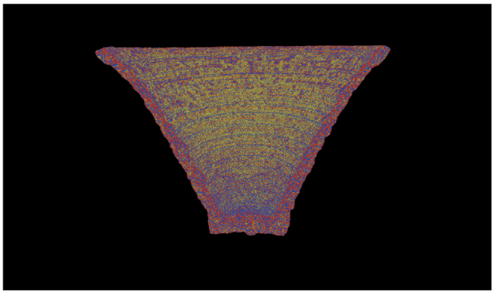

4.14A DAVID SLS-3 with 1 camera

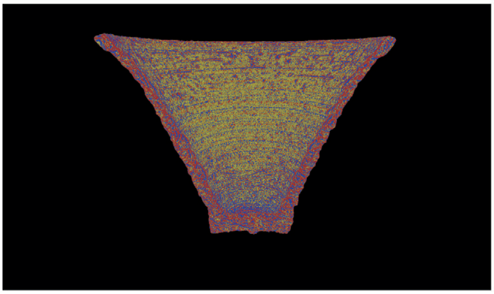

4.14A Metashape

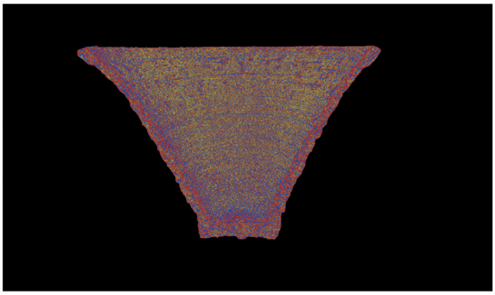

7.09A Artec EVA

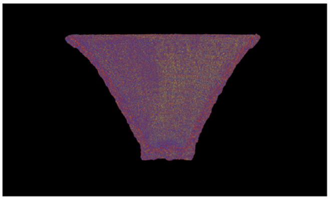

7.09A Artec Spider

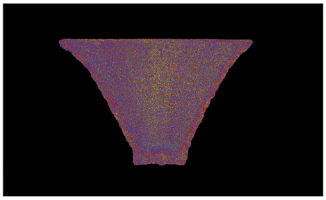

7.09A DAVID SLS-3 with 1 camera


7.09A DAVID SLS-3 with 2 cameras


7.09A DAVID SLS-3 with FlexScan3D, 2 cameras+DSLR


7.09A Scan in a Box


7.09A NextEngine processed in CloudCompare


7.09A NextEngine processed in HP Scan Pro

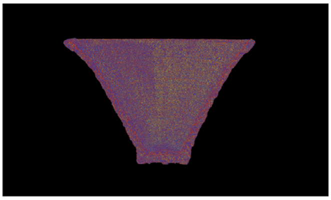

7.09A NextEngine processed in Meshlab

Figure **6.22**. The original photographs of pots 4.14A and 7.09A. Photos: C.D. Jeffra.

p. 100: Figure **6.16**. The 3D models of pots 4.14A and 7.09A produced with the different the 3D scanners, and rendered with the Colorize curvature (APSS) filter in Meshlab to show the quality of the model. Image: Loes Opgenhaffen.

p. 100: Figure **6.17**. The 3D models of pot 7.09A produced with the NextEngine and processed with CloudCompare, HP Scan Pro, and Meshlab, and rendered with the Colorize curvature (APSS) filter in Meshlab to show the quality of the model. Image: Loes Opgenhaffen.

p. 101: Figure **6.18**. The 3D models of pots 4.14A and 7.09A produced by the different the 3D scanners, and rendered with the shader Radiance Scaling/Lit Sphere in Meshlab to enhance the visibility of the morphological features in the model. Image: Loes Opgenhaffen.

p. 101: Figure **6.19**. The 3D models of pot 7.09A produced with the NextEngine and processed with CloudCompare, HP Scan Pro, and Meshlab, and rendered the shader Radiance Scaling/Lit Sphere in Meshlab to enhance the visibility of the morphological features in the model. Image: Loes Opgenhaffen.

p. 102: Figure **6.20**. The 3D models of pots 4.14A and 7.09A produced by the different the 3D scanners, and rendered with the shader Radiance Scaling/Colored Descriptor in Meshlab to enhance the visibility of the morphological features in the model with colour codes. Image: Loes Opgenhaffen.

p. 102: Figure **6.21**. The 3D models of pot 7.09A produced with the NextEngine and processed with CloudCompare, HP Scan Pro, and Meshlab, and rendered the shader Radiance Scaling/Colored Descriptor in Meshlab to enhance the visibility of the morphological features in the model with colour codes. Image: Loes Opgenhaffen.

Meshlab[59], could indeed be useful to optically enhance the perceptibility of traces. Figures **6.16-6.21** demonstrate this potential, and show simultaneously the geometric quality of each model (Figs. **6.16** and **6.17**). Figures **6.18** and **6.19** are generated with the *Radiance Scaling* shader in Meshlab, with the following parameters: display mode on *Lit Sphere*, enhancement set to 0.48 and transition to 0.56, and the "invert effect" tick box activated. The colourful red-blue-yellow images in figures **6.20** and **6.21** are created with the same shader, but with other parameters: display mode on *Colored Descriptor*, enhancement set to 0.11, and the invert effect tick box activated. The images show that the SLS models reveal most details (excluding the Artec EVA), with DAVID SLS-3 dual camera at the top, followed by the Artec Spider. This graphical overview generated with Meshlab filters also demonstrates the additional potential of 3D models for ceramics analysis, to support and complement human visual inspection. This potential is further explored in the last section.

Full reliance on only computed numbers is inadvisable, and complementary human visual inspection of the several scanned and processed outputs should be taken into consideration as well, in order to eventually determine which scanning technology and technique is best suited for the analysis of ancient pottery technology. The following overview compares the different scanners visually. Figure **6.22** shows the original photographs of conical cups 4.14A and 7.09A, which the experimental archaeologist takes within a controlled light to identify and document forming traces. These photos serve as a comparative baseline and to show the complementary analytical power of 3D models.

DAVID SLS-3 single camera vs. IBM

Conical cup 4.14A was very difficult to scan due to the curved shape and the untempered fine white clay particularly, as this hardly left any distinct morphological features or colouration for the software to automatically align. This cup was scanned with the DAVID SLS-3 with 1 camera. Structured light scanning allows to manually align the separate scans, whereas this is impossible with IBM software. The fusion resolution of the SLS model is 0.05 mm, as opposed to the IBM model with 0.16 mm, and this difference is visually reflected in the following description. Figure **6.23** shows the exterior of the 3D models. The photogrammetric model renders the features sharper than the SLS model, although the fine horizontal parallel ribbed striations are less pronounced in the photogrammetic model. Additionally, due to the lens focus, the details become less sharp at the upper and lower sides. The geometry and level of detail (LoD) of the SLS models is maintained overall.

The interior of the models shows a different picture (Fig. **6.24**). Due to the technology, the photogrammetric model is slightly blurred and less features can be distinguished. The DAVID model on the other hand, shows signs of vibration during scanning, which leaves so-called ghost artefacts (for more information see the section on ghost artefacts) in the geometry (the vertically running lines). Arguably, the photographic texture of the photogrammetric model is superior to the SLS models (Figs. **6.25** and **6.26**), and far closer to the original, white colour (Fig. **6.22**).

59 https://www.meshlab.net/ (accessed 9 May 2022)

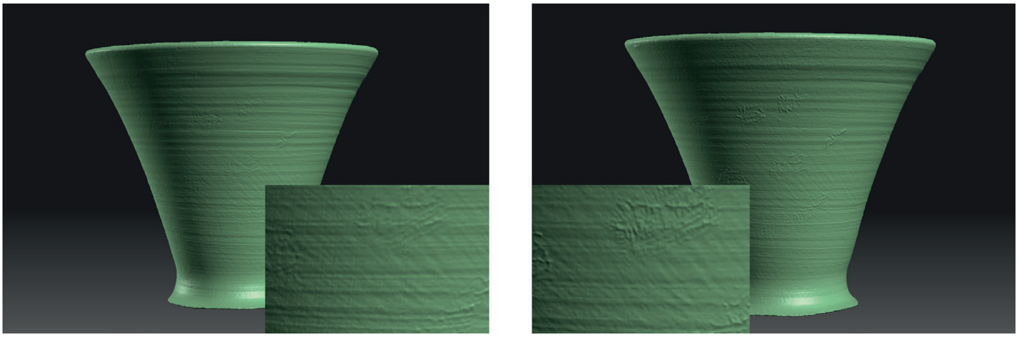


Figure **6.23**. The exterior of the models of pot 4.14A produced with the DAVID SLS-3 single camera (left) and IBM (right). Image: Loes Opgenhaffen.

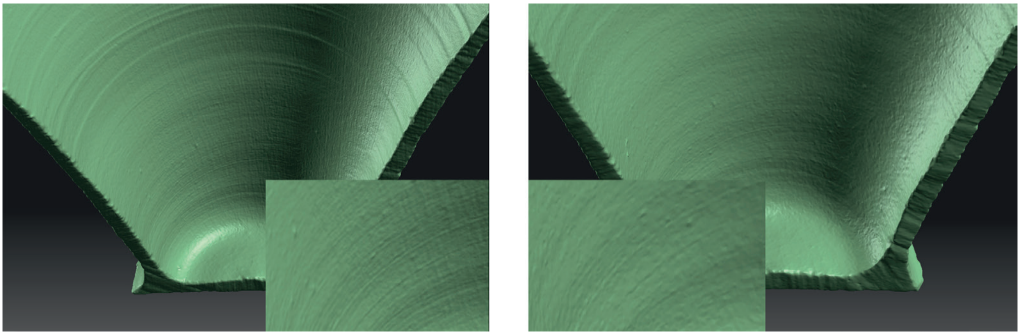


Figure **6.24**. The interior of the models of pot 4.14A produced with the DAVID SLS-3 single camera (left) and IBM (right). Image: Loes Opgenhaffen.

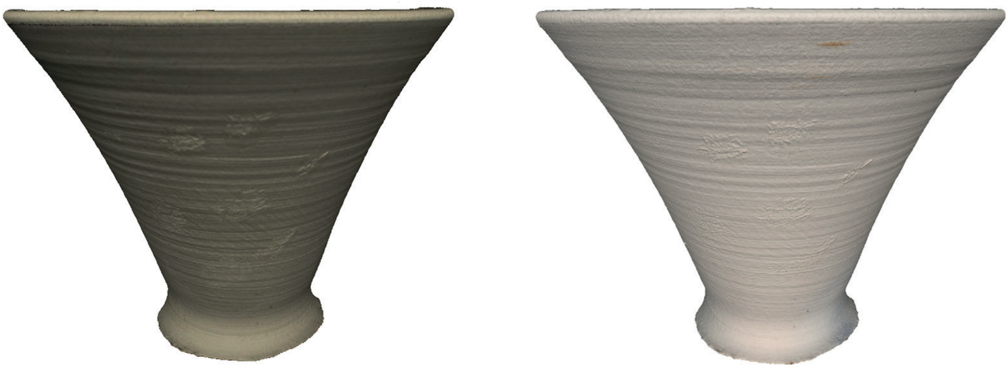
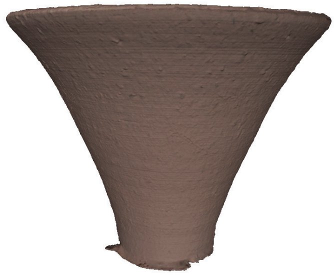


Figure **6.25**. The textured models of pot 4.14A produced with the DAVID SLS-3 (left) and IBM (right). Image: Loes Opgenhaffen.

7.09A DAVID SLS-3 with 1 camera



7.09A DAVID SLS-3 with 2 cameras

7.09A DAVID SLS-3 with FlexScan3D, 2 cameras+ DSLR

7.09A Scan in a Box

4.14A Metashape

7.09A NextEngine + HP Scan Pro

7.09A NextEngine + Meshlab

7.09A NextEngine + CloudCompare (no texture)

Figure **6.26**. The textured models of pot 7.09A produced with the SLS and laser scanners. Image: Loes Opgenhaffen.

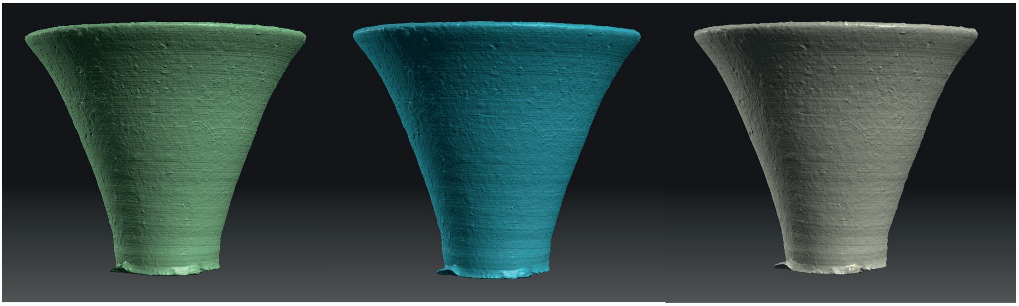


Figure **6.27**. 3D models produced with single to multiple camera-systems of DAVID. Image: Loes Opgenhaffen.

IBM can produce incredibly detailed models, but the LoD is due to focal issues of the camera lens not equally distributed throughout the model. Furthermore, it took 250 minutes to produce the model (although this can be reduced significantly if the workflow is adapted as suggested earlier), as opposed to the 85 minutes of the DAVID with a single camera. DAVID seems to perform better overall if a high LoD is required and photo texture is not important.

DAVID SLS-3 single camera vs. dual and triple cameras in combination with FlexScan3D

At first sight, all models created with DAVID seem equal in quality (Figs. **6.27**). The measured resolution shows indeed an increase in quality the more cameras are deployed (0.0602, 0.0499, 0.0466). However, it should be mentioned that at the same time more scans were made (15, 22, and 41, respectively), increasing the amount of data (and thus, vertices) which results in a rise in resolution (see Table **6B**). In numbers, FlexScan3D with the additional DSLR camera seems to score best. Visual inspection, however, renders a different image as the details seem blurrier. The exterior of the models created with the single and dual cameras are visually equal, but here again, the interior makes the difference. The additional camera enabled correction of the Field of Depth (FoD) and performed better in LoD. The features are sharp overall in the dual camera model, whereas they become blurred in the middle of the interior and in the bottom of the single camera model. The number of cameras also affected the production time; an additional camera may increase scanning time, while decreasing processing time due to improved accuracy, hence overcoming alignment issues. Scanning with a dual camera system also prevents the creation of ghost artefacts. Scanning a complex object with two cameras takes about half an hour, rather than 85 minutes with a single camera system. The combination of FlexScan3D with DSLR camera is not recommended in the specific case of the analysis of ceramic forming technology, as high-resolution and photorealistic texture is not a requirement, and it takes a total production time of 54 minutes. A dual camera system, albeit more expensive than IBM (€5850 instead of approximately €1800), saves a lot of time on labour and produces high quality models.

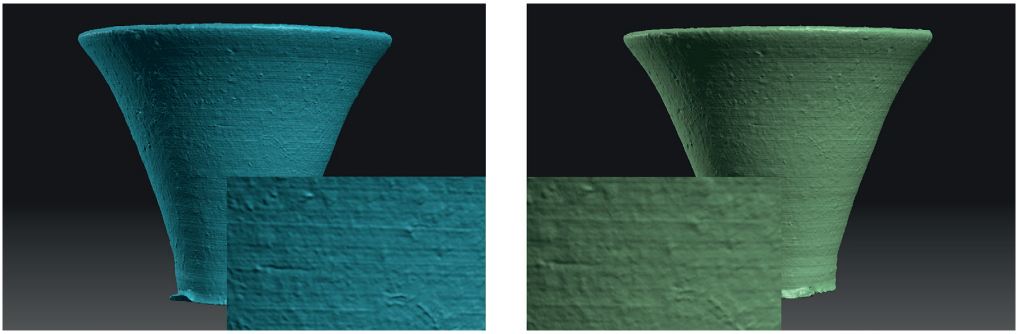


Figure **6.28**. Details of 3D models produced with a DAVID dual camera system (left) and the Scan in a Box (right). Image: Loes Opgenhaffen.

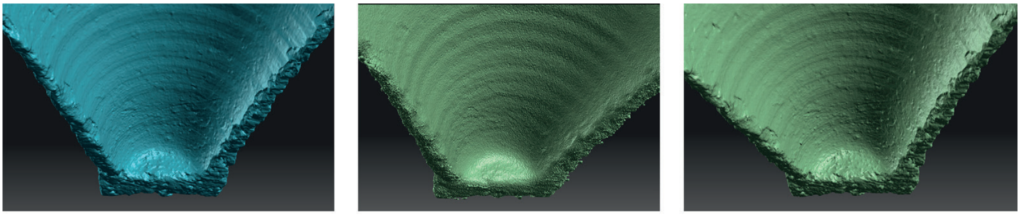


Figure **6.29**. Visual comparison between the DAVID and the Artecs. Image: Loes Opgenhaffen.

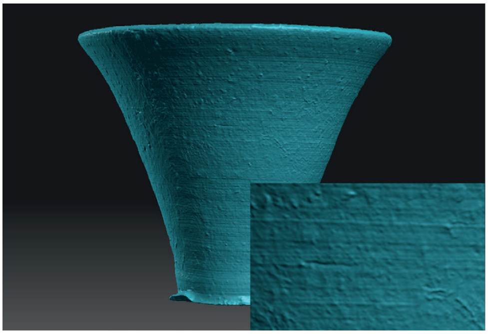
DAVID SLS-3 dual camera vs. Scan in a Box FX

It is immediately obvious that the DAVID beats the Scan in a Box due to the superior cameras: 4MP for DAVID as opposed to the 2MP of the Scan in a Box cameras (Fig. **6.28**). The geometry and photo texture of the Scan in a Box model is blurred and less detailed (Fig. **6.26**), which is confirmed by the measured resolution of 0.0499 mm for DAVID and 0.1501 mm for the Scan in a Box. For both models 22 scans were made and processed in roughly 30 minutes. However, the calibration procedure and the HP software of the DAVID is far more user friendly than the cumbersome calibration process and multiple buttons and actions of the Scan in a Box and the IDEA software. Although the DAVID and Scan in a Box dual camera systems do not differ greatly in price and time investment; DAVID performs better for fine grained research on ceramic technology because of its high-quality output.

DAVID SLS-3 dual camera vs. the Artecs

The Artec EVA is left aside from this discussion, firstly for the resolution and visible quality of the geometry is below any standard in the documentation of pottery (Fig. **6.29**), but more significantly due to the price of €13.700 (€12.300 with educational discount), which most projects or departments cannot afford.[60] The visible quality of the model created with the Artec Spider, on the other hand, is surprisingly good for a

60 Also, the Artec was mainly tried because it was there and available, while it was known this device would not be suitable for this type of ceramic analysis.



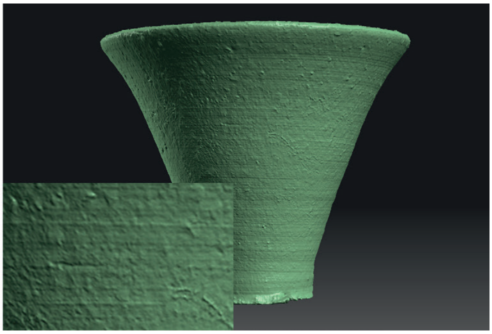
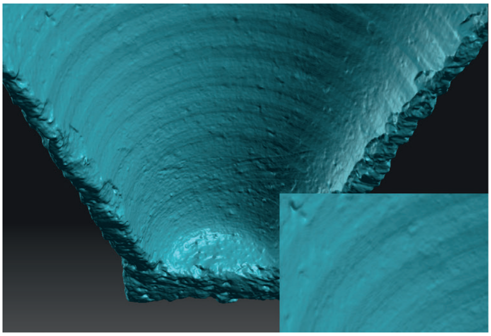


Figure **6.30**. The exterior with details of the 3D models produced with the DAVID (left) and the Artec Spider (right). Image: Loes Opgenhaffen.



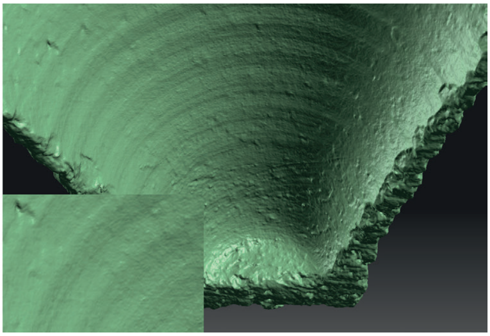


Figure **6.31**. The interior with details of the 3D models produced with the DAVID (left) and the Artec Spider (right). Image: Loes Opgenhaffen.

handheld device and a relatively small and morphologically homogeneous object. On the exterior part, the morphological features of the Spider model are even slightly sharper, albeit sufficiently visible on both models (Fig. **6.30**). On the curved interior, however, again the DAVID exposes a more stable and sharp distribution of the traces, especially visible on the left upper side of the models (Fig. **6.31**). The measured resolution is in favour of DAVID too: 0.1026 mm for Artec Spider against 0.0499 mm for DAVID. Lastly, the price of the Spider, €17.500, and the time invested (almost one hour), is beaten by DAVID, with a price of €5850 and a total production time of 28 minutes.

DAVID SLS-3 dual camera/HP Scan Pro vs. NextEngine/ScanStudio/Meshlab/CloudCompare

Clearly, the DAVID SLS-3 dual camera system produces models of an exceeding quality compared to the NextEngine output (Fig. **6.32**). Having much experience with the NextEngine, this was to be expected. The models are messy and the scanning (80 minutes for 16 scans on "highest" quality) and cleaning and aligning time in native ScanStudio (70 minutes) is an extremely time-consuming task. More interesting therefore, is what different processing software can do with the exported separate scans. The measured resolutions of the processed meshes differ substantially: 0.0218 mm for proprietary software HP Scan Pro, 0.0138 mm for Meshlab, and 0.0459 for

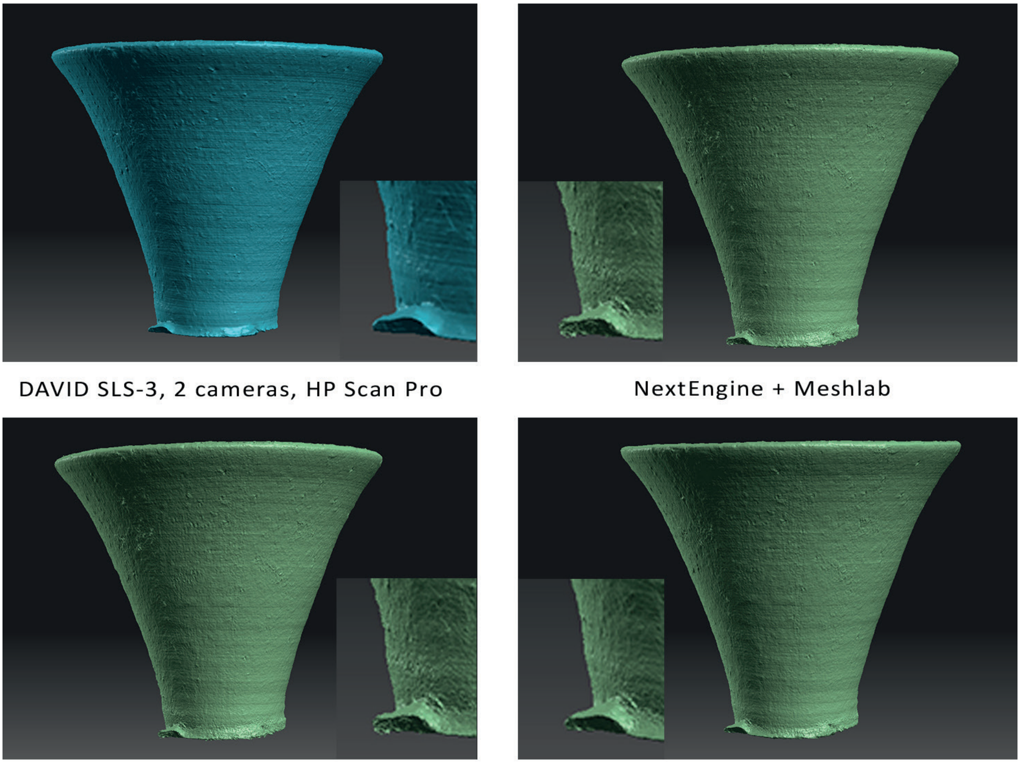


Figure **6.32**. Comparison between the results of the DAVID and NextEngine scanners, and processed with different software. Image: Loes Opgenhaffen.

CloudCompare. The parallel ribbed striations in the surface of the ceramic vessel are barely visible, as is the wiping mark in the interior surface. HP Scan Pro produces least noise, but at the cost of detail. A higher octree depth should technically increase the LoD. However, the Meshlab output generated with a lower octree setting shows slightly sharper features nevertheless, but also a bit more noise and minor misalignments. Overall, the visible differences in merged meshes produced by CloudCompare and Meshlab are negligible, as well as the processing time (CloudCompare was set on a higher octree which increases processing time, and was carried out on a less powerful computer). Manual alignment is easier and more intuitive in CloudCompare, whereas Meshlab (specifically version 2022.02) preserves texture information and provides more filters and other options. Of course, all tasks work easier and faster in proprietary software HP Scan Pro, but at the cost of flexibility and control over settings.[61]

61 The unknown authors of an online article in GIM International carried out a comparative study of Meshlab and CloudCompare, applying the same tools, as well, and came to similar conclusions ("High-Precision Laser Scanning for Cave Tourism", 2016).

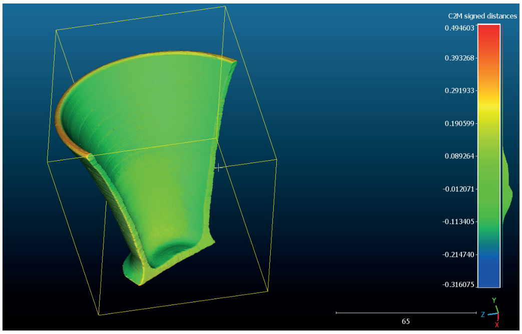


Figure **6.33**. Computed Cloud-to-mesh distance between the DAVID and IBM models, which are a good match in quality. Image: Loes Opgenhaffen.

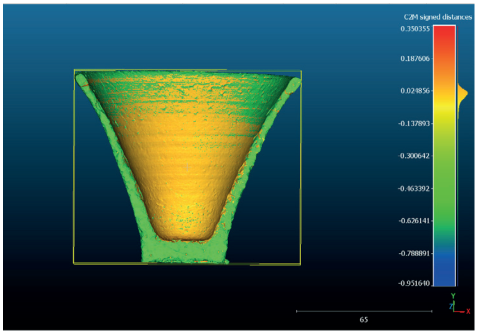


Figure **6.34**. Computed Cloud-to-mesh distance between the DAVID and the Artex Spider models. The yellow indicates more deviation of the Artec, which is to be expected with a handheld scanner. Image: Loes Opgenhaffen.

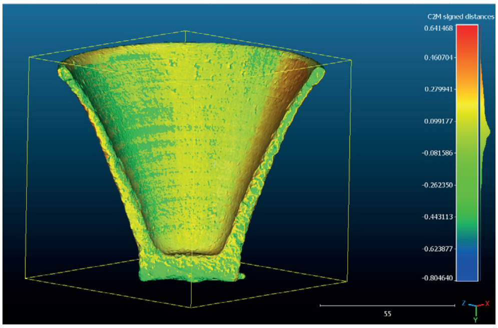


Figure **6.35**. Computed Cloud-to-mesh distance between the DAVID and the NextEngine models. The NextEngine model does not match very well with the DAVID model. Image: Loes Opgenhaffen.

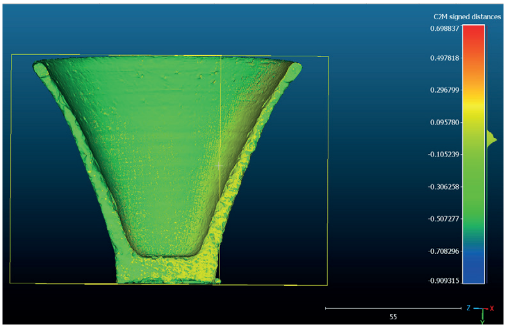


Figure **6.36**. Computed Cloud-to-mesh distance between the DAVID and the Scan in a Box models. The geometry matches quite closely, perhaps due to the similar calibration procedure. Image: Loes Opgenhaffen.

Computational analytics

The 3D models were further inspected by running computational analytics on their geometry. In open-source software CloudCompare, the models were compared by applying the *Cloud-to-mesh distance computation* algorithm (the C2M tool). This algorithm calculates the standard deviation of the relative mean distance between two meshes in Euclidean space (Ahmad Fuad et al. 2018). It also analyses "the noise in the data and the registration errors and the density variations of both the meshes"[62], meaning how even the vertices are distributed throughout the model. This is an important indicator of, for example, a restriction in data capture by the machine. This is in many cases rendered visibly on the interiors of the models. Figure **6.33** displays the computed cloud-to-mesh distance of the photogrammetric model

62 https://www.cloudcompare.org/forum/viewtopic.php?t=1631 (accessed 6 April 2022)

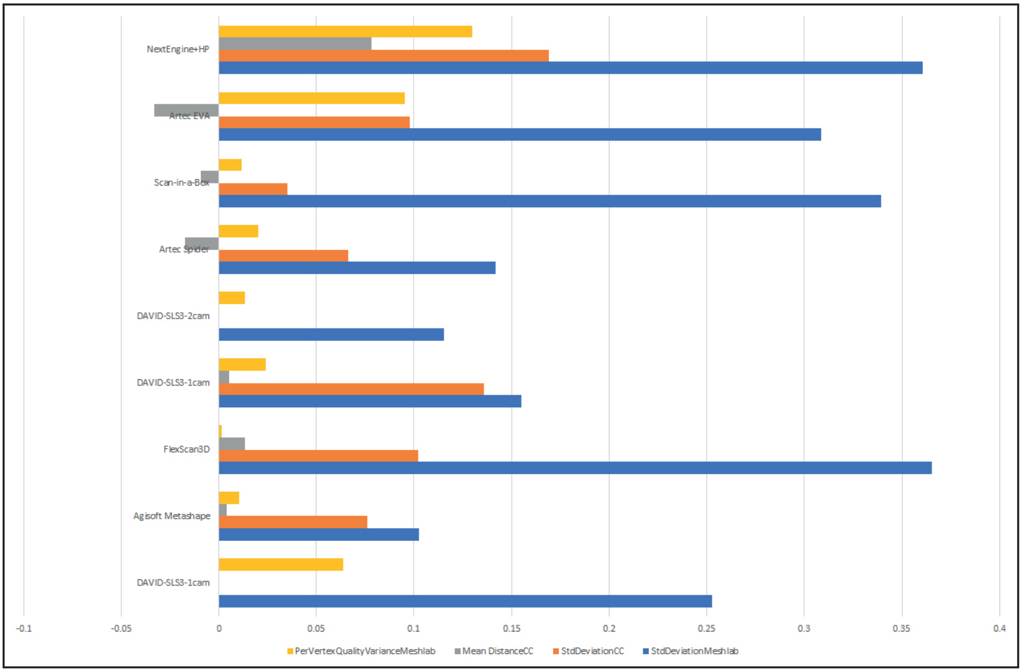


Figure **6.37**. Chart with the computed figures from both CloudCompare (CC) and Meshlab. It shows that the DAVID, Artec Spider and IBM models are best suited to study ceramic forming technology. Image: Loes Opgenhaffen.

and the SLS model in CloudCompare. The chart shows that difference in quality is almost negligible, however, the coloured models indicate a deviation in distance, or uneven vertex distribution, on the lower interior where the colour turns from very green to lighter yellowish green. This discolouration, or deviation, is even more clear in the comparison between the DAVID SLS-3 dual camera model and the Artec Spider model. Here, the interior moves to dark yellow (Fig. **6.34**). A similar trend is visible in the comparison between DAVID and the NextEngine (Fig. **6.35**). However, an anomalous computation comes from the comparison between the DAVID and the Scan in a Box, where CloudCompare calculated a relatively low deviation (Fig. **6.36**). Perhaps this is due to the similar calibration procedure. The deviation in the Artec model can be explained as the device is pre-calibrated and handheld. Also, the NextEngine is pre-calibrated, which may have caused deflection as well.

When the computed numbers are turned into a chart and compared with numbers with a different algorithm in Meshlab, it becomes clear DAVID indeed outperforms the Scan in a Box (Fig. **6.37**). The algorithm – or filter – applied in Meshlab is the *Colorize curvature (APSS)* (Algebraic Point Set Surfaces, developed by Guennebaud, Germann, & Gross, 2008). This filter calculates the mean curvature of each vertex and colourises its quality. The filter basically indicates the level of detail: the more curved, the more relief, the more morphological features. Completely green means no details, yellow to red means a good amount of visible detail. The variance between the curvature of the vertices and the standard deviation between them is provided in numbers as well. This

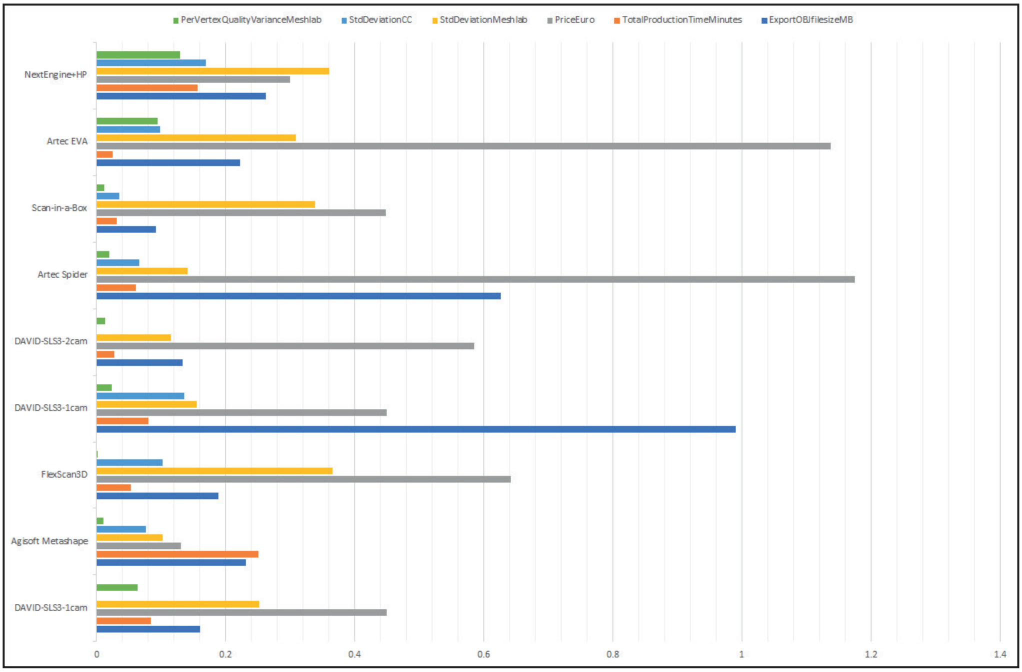


Figure **6.38**. Comparative chart combining the computed figures with the parameters price, file size, and production time. DAVID and IBM/Metashape have the best price-quality ratio, whereas DAVID the best price-quality *and* time ratio. Image: Loes Opgenhaffen.

filter was applied to the individual meshes (Figs. **6.16-6.17**), and the numbers entered in the excel sheet in order to compare it with the data generated with CloudCompare.[63]

The chart drawn from these numbers shows that the Scan in the Box indeed has a high deviation, though CloudCompare suggested otherwise (Fig. **6.37**). It furthermore confirms the low quality of the models created with the NextEngine, Artec EVA as well as the DAVID SLS-3 single camera. Although the dataset is very small, the chart also seems to indicate the level of skill of the operator of the scanning technique. Although all three operators applied exactly the same workflow[64], the project assistant who used the DAVID SLS-3 single camera to create the 3D model of 4.14A, had the least experience, yet considerable experience with other 3D scanning technology such as IBM. This is reflected in the standard deviation and variance of the Metashape model, which slightly outperforms the DAVID dual camera system. The project assistant who produced the model of 7.09A with the single camera system had already developed quite some experience by the time she scanned this conical cup. In comparison, the author has been 3D scanning for several years, with the caveat that the model was created with the dual

63 The figures in this chart have been converted in order to compare the data in a single chart. CloudCompare works with millimetres, whereas Meshlab with percentages of the mean deviation. As the chart was principally designed to illustrate the point rather than to provide hard scientific data, the Meshlab data was accommodated by decimating the figures (by adding a zero in front of the numbers). The numbers below the chart are therefore relative numbers, as C2M and APSS data is anyway. The converted numbers can be found in Table **6D**.

64 The third operator was project assistant Kelly Papastergiou.

camera system. This enticing interpretation should be further explored with more data, which is available, in order to analyse and assess the skill of the operator. Finally, this chart persuasively demonstrates that the structured light scanners DAVID and Artec Spider, and IBM produce the qualitatively best models to study ancient ceramics technology.

The final parameters that should be further compared are price, the size of the 3D model (OBJ export) for storage and sharing ends, and production time. In order to visualise the combination of different types of technically incomparable figures, the data has been modelled to create a comprehensible chart (Fig. **6.38**). The chart shows that the Artecs are clearly too expensive in relation to the quality of the 3D models. The NextEngine and Scan in a Box are pricewise competing with DAVID, but the quality of the models and the time invested to produce them are disproportionate to the DAVID systems. The addition of FlexScan3D is only needed if high quality photographic information is required or hardware is orphaned of software, but if this is the case, IBM/Metashape is favoured. However, the time needed to produce a high-quality model that shows the necessary traces is surpassed by the DAVID dual camera system.

Based on the combination of the pilot survey in 2017, the visual inspection, and the computational data, the DAVID performed best in price-time-quality ratio. In particular, the folded calibration boards in a 90 degrees angle of DAVID, as opposed to the one-sided panels of FlexScan3D and Scan in a Box, are a huge advantage. If everything is positioned in the right way, it only takes one push on the button and DAVID does the rest, as opposed to the exhaustive positions and scans and operations needed to get FlexScan3D and Scan in a Box calibrated.

Finally, it should be remarked that, with the exception of the Artecs and Agisoft Metashape, the production of *all* reviewed scanners and FlexScan3D software has been discontinued in the course of the PhD research (2017-2022). In the following sections a few examples of DIY and open-source solutions are provided. These open-source codes are often less user friendly than expensive software with a user friendly and intuitive GUI.

Scanning with DAVID. A standardised 3D recording and visualisation method for ceramic analysis

Introduction

The previous comparative analysis has also made reference to the development of the skills of the operating archaeologist. Experience and continuous refinement of the workflow for SLS scanning led to an increased average resolution from 0.07 mm in 2017 to 0.04 mm in 2021, and a decrease in noise and ghost artefacts, especially with the dual camera solution (Fig. **6.39**). The assessment of skill and the element of choice are important aspects of the operational sequence (*chaîne opératoire*) of a practice, whether this is archaeological visualisation or ancient pottery making. Chapter 3 demonstrated that 3D scanning and analysis is not yet part of the practice of

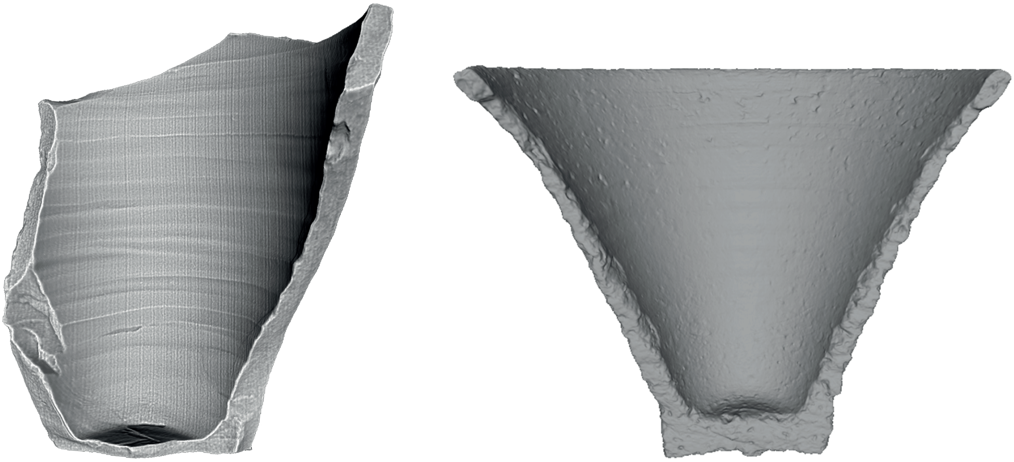


Figure **6.39**. Two 3D models scanned with the DAVID from 2017 (left) and 2021 (right). Image: Loes Opgenhaffen.

archaeologists specialised in pottery technology. There have been ad-hoc applications in this particular specialisation, but these are rare and at best published as best practice. This chapter, specifically this section, provides a detailed description of the workflow developed during this PhD research for high-resolution documentation and presentation of ceramic artefacts with low to medium budget 3D scanning solutions. These workflows have been informally published as part of the "TPW Workflow Series" on the TPW Knowledge Hub[65], and are only summarised here. These workflows focus now on structured light scanning with specifically the DAVID, but the structure of the workflows serve as a matrix to further develop a standardised method of 3D recording for ceramics analysis. Finally, these workflows permit full transparency of the production of data of this particular project, and successive reproduction of the method enables the production of similar and comparable datasets.

3D scanning[66]

The first version of the workflow "Structured Light Scanning with DAVID" appeared in late 2017 as an internal manual for students to learn operating the DAVID SLS-3 single camera system. The workflow was developed while working with an existing experimental dataset of wheel-fashioned pottery created by TPW member Dr Caroline Jeffra during her earlier research. The workflow was further refined during two fieldwork trips in Greece in 2017. In the pilot campaign, which was primarily designed to develop a collaborative project workflow, it was possible to mount an additional DSLR Nikon D3300 camera on the DAVID setup, which was still running on DAVID 5 software at the time. This provided excellent real

65 https://tracingthewheel.eu/page/tpw-workflow-series

66 This workflow has been published here: https://tracingthewheel.eu/article/workflow-series-sls-with-david (Opgenhaffen 2020c)

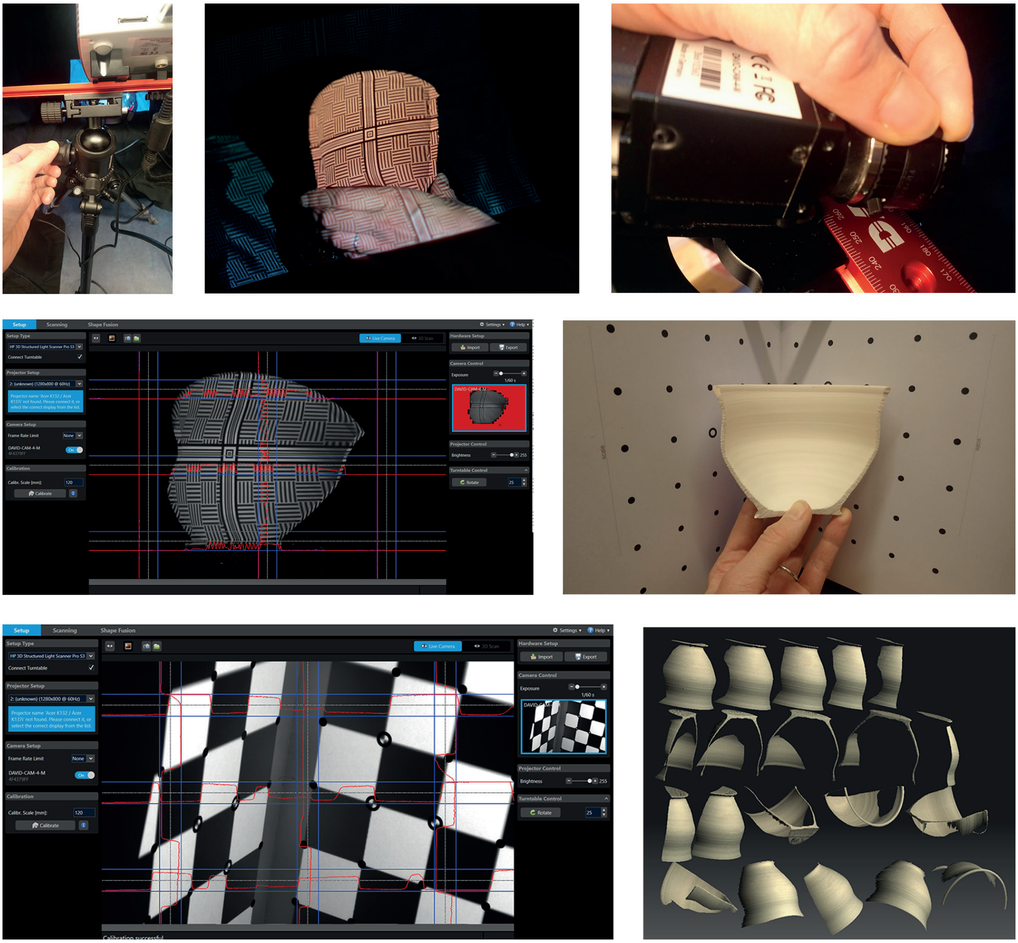


Figure **6.40**. The operational sequence of 3D scanning with SLS technology. Image: Loes Opgenhaffen.

colour information. Regrettably, DAVID 5 was rebranded to HP Scan Pro 5 soon after, leading to consequent restrictions, such as not supporting DSLR cameras.

Scanning heterogeneous archaeological pottery required an adaptation of the workflow which was based on homogeneous experimental material. Issues such as colour hue, contrasting surfaces (from firing or decoration), and difference in colours on interior and exterior of fragments forced an adaptation of calibration and scanning procedures. Instructions applicable to all SLS systems were developed. The second version of the workflow was published on the TPW Knowledge Hub in Summer 2020. This workflow was expanded with DIY tips for fabricating calibration plates, and installing the ideal scanning set up with a photo booth covered with black cloth to reduce light interference. Black absorbs light, so the completely darkened photo booth enables to capture exclusively the targeted object, reducing background noise. This reduces, and in most cases even prevents the need to clean the separate scans, and speeds up the process.

In 2021, a second, dissimilar machine vision camera became available (the DAVID

CAM-3.1-M with Computar 14D 12mm lens). This opened up the possibility to increase scanning resolution and decrease processing time thanks to the correction of the second camera. However, two different cameras (a 4MP and a 3.1MP) required additional steps in the installation and calibration stages, so the workflow was further expanded and updated.

The following steps comprise the operational sequence of 3D scanning (Fig. **6.40**):

1. GENERAL PRACTICALITIES

Hardware requirements (PC power, disc space, USB ports, etc.), software installation, hardware installation of the 3D scanner, photo booth, turntable (Fig. **6.3**).

2. POSITIONING THE PROJECTOR AND CAMERAS
3. CALIBRATING THE CAMERA(S) (Fig. **6.9**)

This also includes instructions to mount a dissimilar machine vision camera and a DSLR camera with other software such as FlexScan3D.

4. CALIBRATION
5. SCANNING SEQUENCE

This includes connecting with an automatic turntable or working with a manually rotating turntable. In order to retrieve full coverage of the surface of the object, a sequence of scans from different angles of the objects should be taken. Therefore, the turntable rotates the chosen number of iterations. A 360° rotation in usually 12 steps should create sufficient overlap between the scans to find corresponding features, and additional single scans can be made to cover the upper and lower parts of the objects.

6. INTERACTING WITH THE 3D OBJECT

Besides basic interaction with the 3D object such as rotating and panning, primary rough alignment of the separate scans is described in this step as well. This rough alignment is necessary to ensure full coverage of the surface.

7. SAVE PROJECT AND EXPORT

It is important to export the data into commonly accepted files, such as OBJ. The separate scans can each be exported to OBJ; this enables other users to further process the scans in other, preferably open-source software.

Processing 3D scans[67]

The procedure "Processing 3D scans" was initially developed as an internal manual for students in January 2018. In Summer 2020 an updated version was published online on the TPW Knowledge Hub, as part of the TPW Workflow Series. After scanning, the separate scans form together a complete object, which should then be fused, merged, or reconstructed, depending on the software, into one solid mesh: a 3D model. The software is usually able to automatically align the separate scans when there are enough distinct overlapping morphological features to connect – "align" – the separate scans. However, due to the morphological complexity of archaeological

67 https://tracingthewheel.eu/article/tpw-workflow-series-processing-3d-scans (Opgenhaffen 2020d)

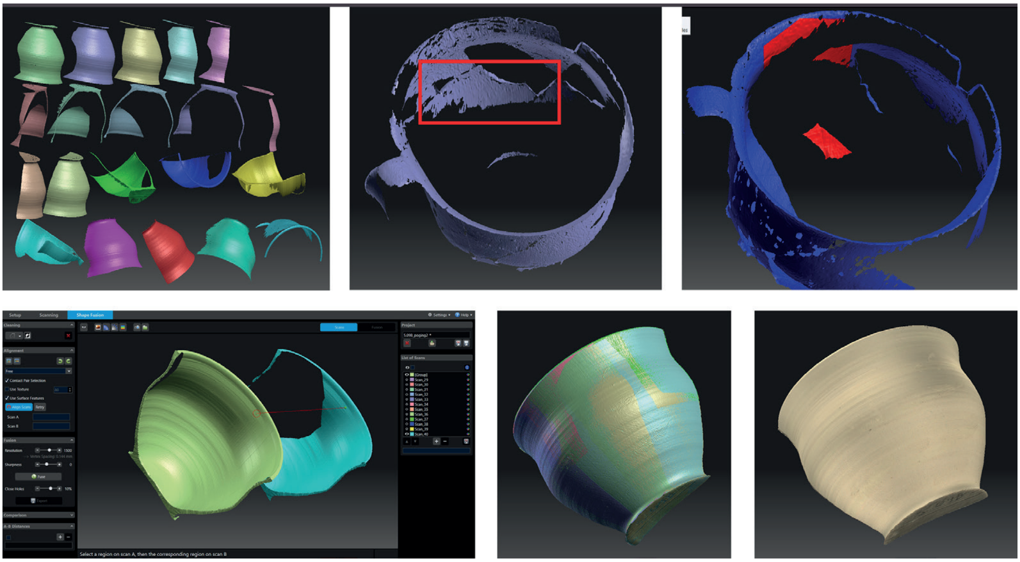


Figure **6.41**. The operational sequence of processing 3D scans into a 3D model. Image: Loes Opgenhaffen.

ceramics, especially in the case of sherds with sharp or thin edges, or symmetrical objects with a homogeneous colour and smooth surface, the software encounters difficulties in aligning the scans perfectly, that is, without "misalignments". These misalignments then cause ghost artefacts, artefacts that do not exist in the real-world object. Misalignments are rendered as sharp ridges as a result of the edges of the scans that did not connect seamlessly. This cannot always be avoided, but manual alignment can decrease or even prevent the generation of misalignment artefacts. Another important part of processing is the cleaning of the scans.

This processing workflow describes these processing actions which can be summarised in the following steps (Fig. **6.41**):

1. GETTING STARTED

This step explains how and where to choose a native project file or to import other OBJ files into the HP Scan Pro 5 software. It furthermore provides information about the relevant icons and buttons and how to select scans.

2. CLEANING THE SCANS

Sometimes the scanner captures part of the background which should then be removed manually. Other cleaning tasks consist of cutting away redundant or distorted overlapping parts of the scans. If too much data has been cut away, or an entire scan accidently deleted, the separate scan saved as OBJ can be imported to fill the gap.

3. ALIGNMENT

Here, the several methods to align the separate scans are explained. The successfully aligned scans can be combined into groups, reducing the list of scans and maintaining an overview of what has been done. Also, in the case of assembled scans of large objects, i.e.,

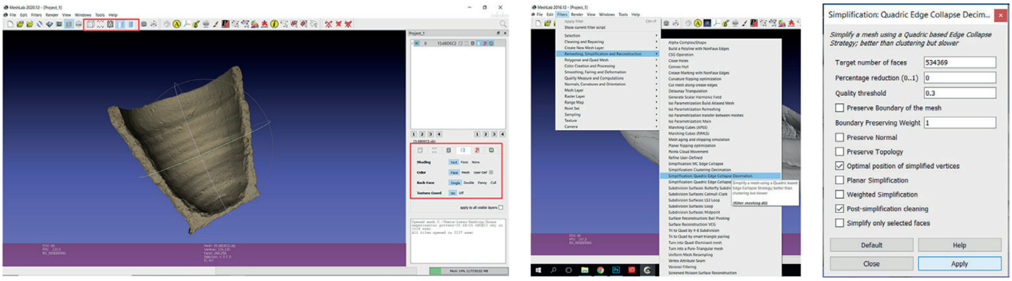


Figure **6.42**. Functionalities in Meshlab for post-processing 3D models. Image: Loes Opgenhaffen.

objects scanned from multiple positions, can be grouped in for example "upper part" and "lower part".[68] Complex objects that required a multitude of scans can be grouped as well.

4. FUSION

Fusion is here the merging of the separate scans into a single mesh.

5. EXPORT

The fused 3D models should be exported to commonly accepted formats in order to promote accessibility of data.

Post-processing[69]

To further improve the accessibility of 3D models, the large files often exceeding 1 GB need to be simplified, or "decimated", to sizes that are manageable on less powerful computers and for online presentation. However, too much simplification may cause loss of detail, which is unacceptable for the ceramic specialist. The decimation is performed in open-source software Meshlab, which is widely used in archaeology and heritage. This process is described in the TPW Workflow Series "Post-processing 3D models" on the TPW Knowledge Hub, and consists of the following steps (Fig. **6.42**):

1. GETTING STARTED

This step describes where to download Meshlab and which settings should be applied.

2. NAVIGATING IN MESHLAB
3. DECIMATION

Here it is shown which algorithm, or filter as they are called in Meshlab, and which settings works best to decimate files. It also explains the number of vertices or faces and which file sizes should be used to retain a high LoD.

4. EXPORT

Other functionalities in Meshlab are described briefly in the online workflow as well, to show how to perform quick visual enhancements. The topic of data visualisation and visual enhancement of forming traces will be further discussed in the last section of this chapter.

68 For an example of scanning large (and tiny) objects: https://tracingthewheel.eu/article/excursions-with-david

69 https://tracingthewheel.eu/article/tpw-workflow-series-post-processing-3d-scans (Opgenhaffen 2020a)

Democratisation[70]

The TPW Workflow Series "Democratising 3D Data. Recording the process of 3D scanning and processing" explains why it is important to keep a record of the process of documenting and visualising archaeological 3D data, which is in this dissertation elaborated in detail in chapters 7 and 8. The focus in the workflow is placed on expanding reproducibility of datasets through the replication of workflows, ultimately fostering the comparability of data. The recording of working processes and data retrieval also promotes scientific transparency, and reveals the level of *manipulation* of the production of so-called "raw data", and the construction of a hierarchy of kinds of data (raw data, metadata, paradata). In the TPW Knowledge Hub, however, all data is grouped together without making a clear distinction or separate tab for metadata and paradata, because all this data defines the 3D artefact and imbues it with meaning. Another important issue that the workflow ensures is the accessibility of data in order to encourage (re)use of data. In summary, this workflow reflects the London Charter for computer-based visualisation of cultural heritage, which was created to guide visualisation processes and to warrant scientific transparency, especially Principles four on documentation and six on access (Denard 2012), as well as the more recently defined FAIR Principles to guide the description, storage and publication of scientific data (Wilkinson et al. 2016). The solutions provided in the TPW Workflow Series to democratise data can be summarised as followed:

1. THE PROCESS

The TPW Metadata Sheet is a spreadsheet that indicates which data and circumstances to document, and provides explanations, for example, descriptions of each entry (Table **6E**).

2. HOW TO RECORD

This part explains where to find technical metadata in Meshlab and HP Scan Pro.

3. ACCESSIBILITY: MULTIPLE FILE EXTENSIONS

The exportation to different file extensions such as OBJ and PLY and sizes facilitates accessibility, reuse of data and compatibility. However, be aware that different processing software, or even the same software, may produce different results at different times, a glitched also experienced with Agisoft Metashape by Tracy Ireland and Tessa Bell (2021). What is more, is that operators with varying skills may produce diverse outputs of same datasets as well.

3D Scanning experimental and archaeological wheel-fashioned ceramics

Material challenges and technical solutions

Ceramics are a difficult category to scan with structured light technology. Fortunately, most selected sherds and pottery shapes can be scanned more or less easily with the

70 https://tracingthewheel.eu/article/tpw-workflow-series-democratising-3d-data-recording-the-process-of-3d-scanning-and-processing (Opgenhaffen 2020b)

Figure **6.43**. Texture map representing all scans made to capture as much of the surface as possible of a closed vessel such as this rhyton. Image: Loes Opgenhaffen.

proposed method, but specific features can obstruct the scanning process, such as curved shapes and fragments, closed shapes, tiny holes in, for example, strainers, smooth surfaces, shiny surfaces due to glazed or slipped surfaces, black surfaces, black decoration, discolorations and high contrast variation in colour hues (very black and very bright), thin and sharp edges of fragmented material. Through experimentation, experience and tips and tricks found elsewhere and adapted to aims of the development of this particular scanning method for ceramics, most of these challenging issues can be solved.

Closed shapes are unresolvable, except when having access to a micro-CT scanner or X-ray device. Of course, a profile of the interior could be reconstructed in order to make the 3D model solid, but this is undesirable in the case of research into forming traces. Fortunately, it is also more convenient to the archaeologists of TPW to perform tactile and visual inspection of broken closed vessels in order to determine the wheel-forming technique, because they too need access to the interior of the pot. However, it does occur that a semi-closed shape has to be scanned, such as part of a rhyton (a conical drinking vessel). The consequence is that only a part of the interior can be scanned, where the projected light and the cameras have a visual reach (Fig. **6.43**). According to the developed selection protocol (chapter 8), such a time-consuming object would only be selected to be scanned if at least some of the traces on the interior surface can be recorded. The solution is, just as for objects of very fine, featureless clay and smooth surfaces, to increase the number of rotations and manually to make additional scans from different angles to increase machine visibility.

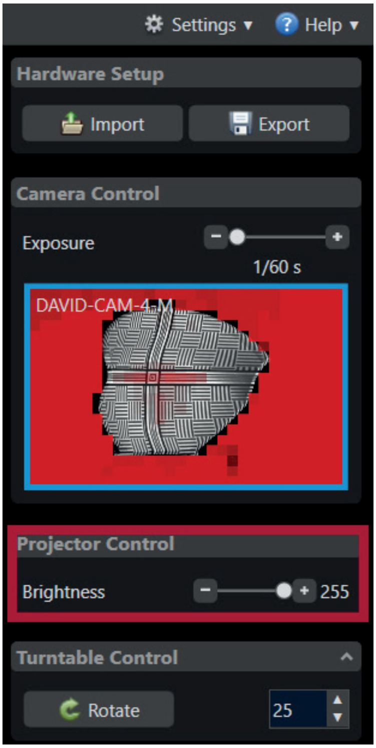


Figure **6.44**. Screenshot of the Projector Control viewport of the HP Scan Pro software to show how to overcome extreme colour hue contrast. Image: Loes Opgenhaffen.

Small holes follow a similar procedure as closed shapes; a fully "watertight" (complete coverage of the surface) surface of the interior of the narrow shafts can only be reached by automatic filling of the uncaptured inner parts. To the ceramics analysts of TPW this forms not a problem, as the technological clues are to be found on the surface of the vessel.

An object usually can be scanned fully with an average of 12 rotations, and two to four additional manual scans of the object turned manually in different positions, to capture the top and lower sides of the object. In the case of thin-walled, fragmented objects, 12 turns do not provide enough overlap to find corresponding features to align the separate scans, when it makes the turn from the interior to the exterior. Additional intermediate scans or scans from the object in a different position should be made.

Structured light scanning, as the name indicates, projects light patterns onto the targeted object. Shiny surfaces reflect the light, with as a result that the patterns are unclear and too bright, and the machine vision cameras are unable to properly capture the surface data. Black, on the other hand, absorbs light, so the surface cannot be captured. It is often the case with archaeological ceramics that the surface is covered with a black, shiny slip. A solution is, if allowed by the conservator, to apply talc powder on the surface to create a mat effect.

Lastly, hue also has an effect on the calibration. The surfaces of archaeological pottery often vary in colour tone due to fluctuations during firing or by secondary burning, causing a dark or blackened exterior and bright coloured interior, or vice versa. Calibrating the object on only one hue is therefore not advisable. A trick is to adjust the aperture of the camera on the darkest colour of the object and to then lower the brightness value in the Projector Control in the HP Scan Pro software, until red disappears from the calibration plates in the Projector Control viewport (Fig. **6.44**). After successful calibration the brightness should then be lowered to its default.[71] This solution is applicable to most SLS scanning systems.

71 For more detail about this workflow: https://tracingthewheel.eu/article/workflow-series-sls-with-david, sections "Calibrating the camera" and "Calibration procedure".

Ghost artefacts

The term "ghost artefacts" was coined at the beginning of the present research, when strange, unnatural features in the virtual surface of the scanned object were observed, which were absent in the real artefact. It turned out that DAVID, and any other high-resolution scanning device, is very sensitive to background circumstances. The archaeological department ACASA of the University of Amsterdam is located in a late 19th-century building with wooden floors in the middle of the city centre, near an underground metro and a tramline. The metros and trams, colleagues passing by, conservators slamming doors, visitors touching the equipment all cause vibrations. These vibrations are captured when scanning the object, resulting in a series of vertically parallel running lines in the geometry (Fig. **6.45**). The best circumstances to scan are concrete or solid floors. These lines can also be caused by interfering light, especially TL light, and even breathing next to the projector, invisibly and unknowingly distorting the projection of the patterns. A bad calibration may result in similar recordings, which should be first ruled out. A solution is, partially at least, to create a light-restricted environment with a black photo booth or box.

Other ghost artefacts are created by the aforementioned black and shiny surfaces. The uncaptured surfaces leave "holes" in the translated geometry. These are then filled – or not, if not required – by the software. These fillings are smooth, unlike the rest of the recorded surface, and as such are clearly recognisable. Misalignment of separate scans are often responsible for artificial artefacts as well, causing sharp ridges in the geometry (Fig. **6.46**).

It is therefore crucial that the scanning circumstances and other causes of ghost artefacts are recorded in the paradata, so that users can trace and identify the cause of the unnatural features. The ghost artefacts should be indicated in the 3D model as well. A dedicated collection on Sketchfab has been created where ghost artefacts can be recognised in a similar way as the wheel-fashioned traces.[72]

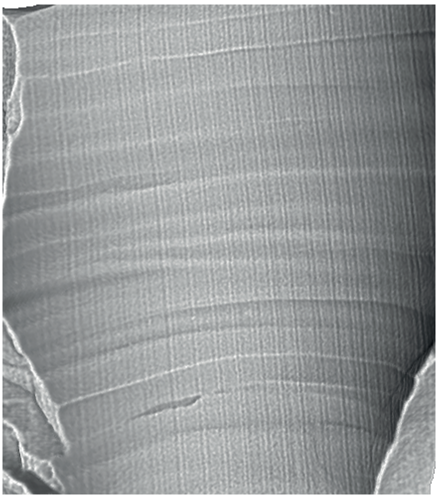


Figure **6.45**. Example of a ghost artefact. The vertical lines are caused by vibrations during scanning and are not present in the original artefact, but exist exclusively in the digital 3D artefact. Image: Loes Opgenhaffen.

72 https://sketchfab.com/tracingthewheel/collections/ghost-artefacts

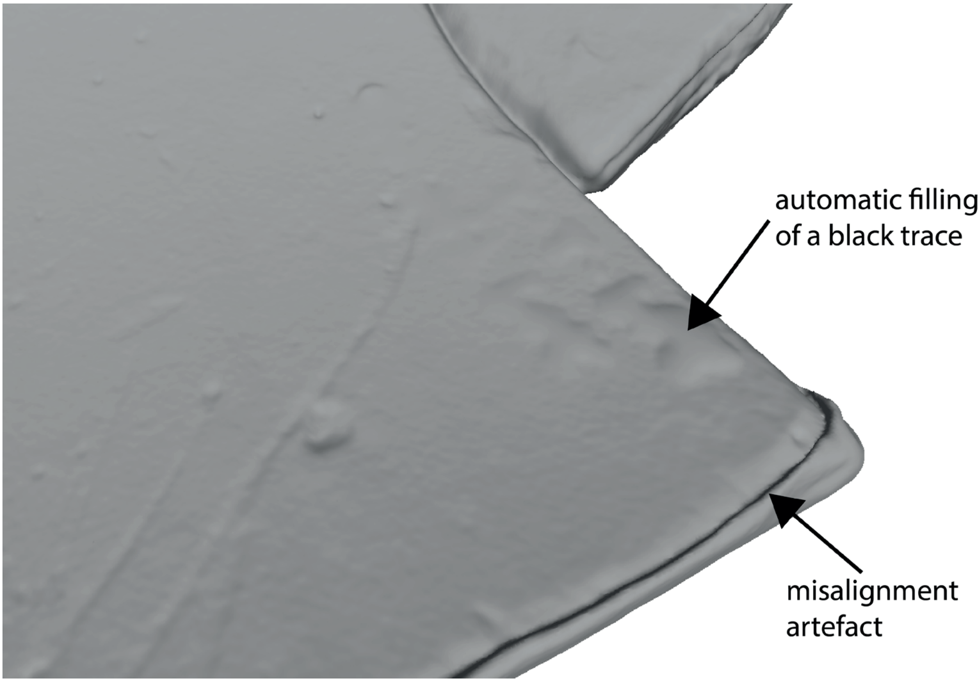


Figure **6.46**. Examples of ghost artefacts caused by holes in the scanned data and misalignment of the separate scans. Image: Loes Opgenhaffen.

Obsolete technology and DIY solutions

In the five years of this doctoral project, the production of most of the deployed scanning technology has been discontinued. This does not mean the developed scanning method is irrelevant. On the contrary, the proposed method for high-resolution scanning for ceramics analysis is the first, large-scale and project-based impetus towards a standardised set of principles and requirements to create 3D models tailored to this archaeological specialisation. In spite of the emphasis on the technicalities of 3D scanning in this chapter, the focus was implicitly on the choices, actions and operations of the operating archaeologist, which informed the technical workflow. It is clear that the operator needs at least a basic understanding of the archaeological material, to identify the important features, to adapt and adjust the machine to the material.

Nevertheless, with the exception of the Artec scanners, all scanners explored in the comparative experiment are no longer in production. Even Polyga seems to have suspended the distribution of FlexScan3D Lite separate from its scanner models, although, at the time of writing, they still advertise this software for DIY scanning, and the successor of the HDI Advance r3x, the Polyga Carbon XL, is still running on FlexScan3D.

It is only a matter of time until HP Scan Pro and FlexScan3D are not supported anymore, similar to what happened to the NextEngine scan software ScanStudio, due to the Flash killswitch. And it can only be guessed what effect Windows 11 will have, as it already does not support high-end processors of PCs which are only a couple of years old.

Fortunately, there are a few open-source DIY solutions, for which existing systems such as the DAVID hardware can be used. Daniel Moreno and Gabriel Taubin have developed a code[73] and a manual[74] which is made available through the website of Brown University School of Engineering.[75] However, running such open-source software is a laborious enterprise compared to proprietary software. Sometimes the investment in an expensive device or software returns itself compared to the costs of human labour. The TPW blog post "DIY solutions for obsolete 3D scanners"[76] describes how to build a 3D scanner, which is also done in greater detail, yet with less advanced equipment, by Hesam Hamidi on Instructables Circuits.[77] If high-resolution is required, as is the case in the present research on forming technology, machine vision cameras are preferred over webcams. A more expensive DPL projector, preferably based on blue light and with a minimum of 500 ANSI Lumen, will increase the resolution as well. Finally, IBM is a very good alternative to expensive DIY 3D scanning, albeit not in time investment either.

The scanning results: a 3D dataset of forming traces

The 3D scanning activities of the present PhD research resulted in a total of 328 3D models, excluding the models produced with the other scanners. 155 models are archaeological, none of them yet published or accessible at the time of writing.[78] The experimental datasets delivered 173 models, of which 155 are published open-access on TPW's Sketchfab page[79], and 65 in the TPW Knowledge Hub.[80] Figure **6.47** shows a few examples of forming traces indicating the use of a wheel-fashioning technique. The 3D models of these experimental vessels are collected in two Sketchfab collections: the "Reference Collection of Wheel-Coiling traces"[81] and the "Reference Collection of Wheel-Throwing traces".[82] In some of the 3D models the traces are annotated, some are not. These two collections can be used to practice the recognition of traces with and without the help of annotations. To learn what to recognise is explained in "The TPW training set on wheel-coiling traces". For the purpose of this collection, the traces were singled out from the 3D models in 3D modelling software Cinema4D and enlarged. These models can be downloaded and printed in 3D, in

73 http://mesh.brown.edu/calibration/software.html (accessed 1 May 2022)

74 http://mesh.brown.edu/desktop3dscan/ch5-structured.html (accessed 1 May 2022)

75 Unfortunately, I could not test this source-code myself, but every SLS system follows the similar protocols, and the procedure described in the accompanying manual resembles that of the procedures od FlexScan3D and older DAVID software.

76 https://tracingthewheel.eu/article/obsolete-technology

77 https://www.instructables.com/DIY-3D-scanner-based-on-structured-light-and-stere/ (accessed 1 May 2022)

78 This is due to the exceedingly tedious procedure to obtain a publication permit of the Greek government.

79 https://sketchfab.com/tracingthewheel

80 https://sketchfab.com/tracingthewheel

81 https://sketchfab.com/tracingthewheel/collections/reference-collection-of-wheel-coiling-traces

82 https://sketchfab.com/tracingthewheel/collections/reference-collection-on-wheel-throwing-traces

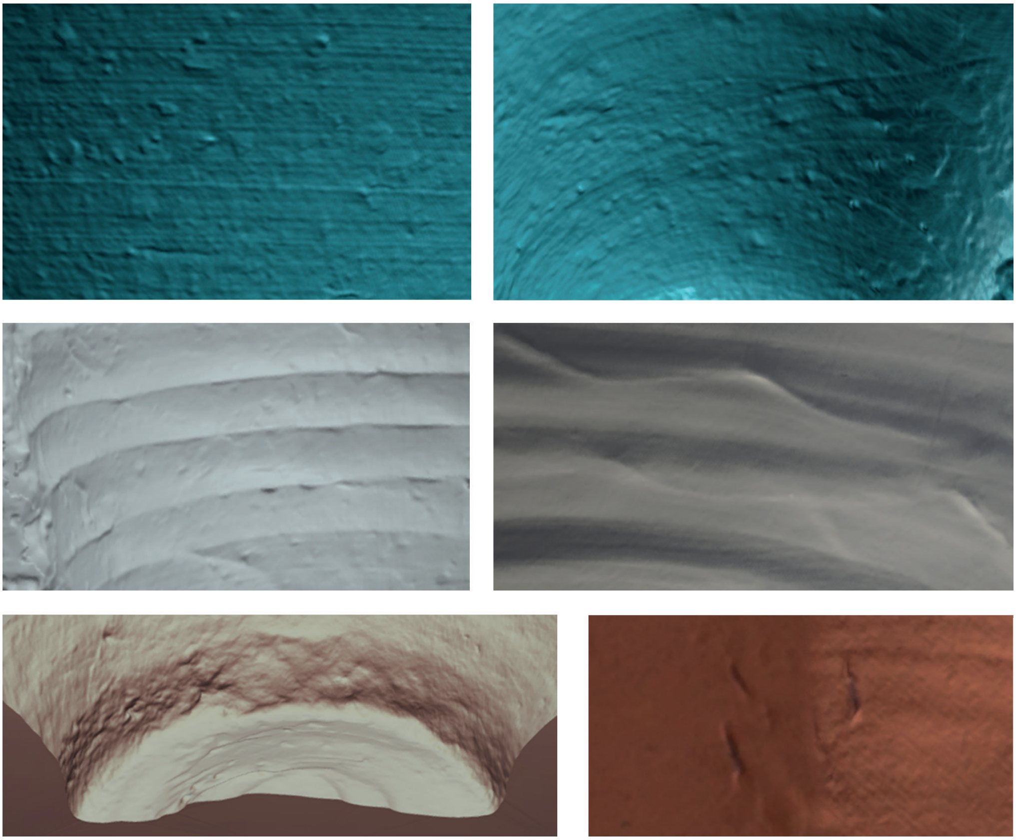


Figure **6.47**. Examples of forming traces in the 3D models produced with DAVID. Image: Loes Opgenhaffen.

order to gain tactile experience in recognising the traces as well. Because these models were based on information from an older dataset, and not produced with the final method, 3D models of more recently scanned vessels were added which show the traces in greater detail. This educational aspect is further elaborated in chapter 8.

Applying filters to enhance visibility

Besides geometric quality, the data visualisations in figures **6.16**-**6.21** also demonstrate the potential of computational visualisation by this enhancement of the visibility of geometric properties (i.e., topographical features), which represent forming traces. The greatest advantage begins with the ability to turn off the colour information or "texture" (not to be confused with the archaeological understanding of texture as a material property). By removing the decoration or slip layers, the topographical surface of the vessel is revealed (Fig. **6.48** A and D). The features of this recovered surface can subsequently be enhanced with so-called filters in Meshlab. Through an exploration of most filters and shaders in Meshlab, it can be concluded that the *Colorize curvature*

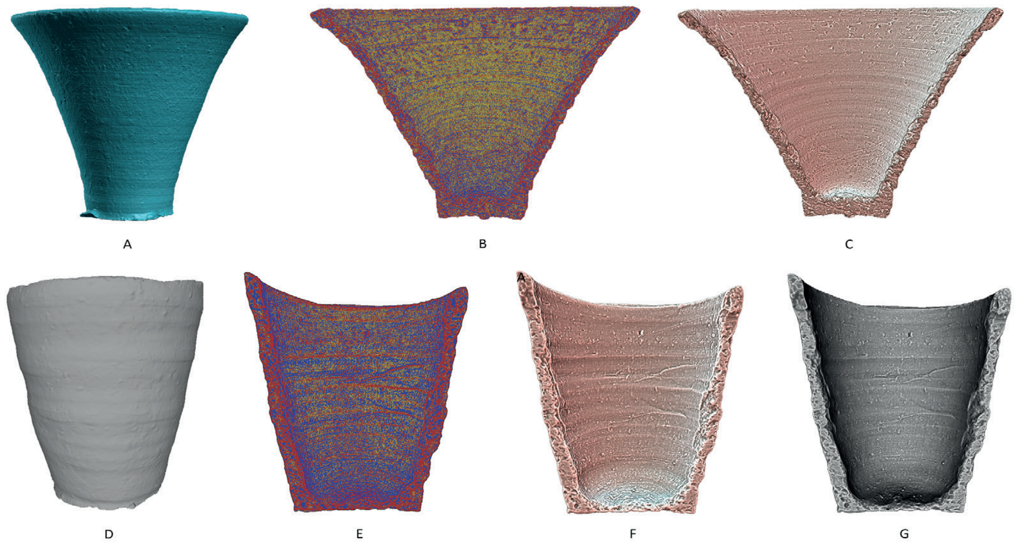


Figure **6.48**. Example of the visual enhancement of a 3D model of an experimentally produced vessel, showing clearly show traces of horizontal concentric parallel ribbed striations and incompletely joined coils. Image: Loes Opgenhaffen.

(APSS) is the most useful filter to assess geometric quality as well as a first indication of visible traces, as it is based on the curvature of the vertices, that form the relief of the surface. The tool assigns a colour too: green designates the smoothness of the surface, meaning no distinct morphological features. Figure **6.16** (7.09A DAVID SLS-3 with 2 cameras) represents a 3D model of an experimental wheel-thrown vessel, and clearly shows horizontal concentric parallel ribbed striations (formerly known as fine rilling) indicated by fine yellow lines (red and blue mean more curvature in the surface). This is caused by the application of rotative kinetic energy (RKE), in this case caused by the use of a turning wheel while the potter's hands manipulate the lump of clay. The slightly wider yellow lines with a red dot to the right (i.e., deeper curvature/sharper relief), represent imprints (drag marks) caused by inclusions in the clay. They indicate the rotating direction of the wheel. The curvy yellow lines at the bottom of the vessel represent wiping marks when the wheel stopped turning.

The application of shaders further exaggerates morphological visibility. Particularly suited for identifying forming traces is the *Radiance Scaling* shader. *Radiance Scaling* offers different shaders, such as the *Colored Descriptor*, and has been applied to two experimental models of a wheel-thrown (Fig. **6.48** A-C) and a wheel-coiled vessel (Fig. **6.48** D-G). This shader clearly indicates horizontal concentric parallel ribbed striations with blue lines in the same experimental vessel which was first inspected with the *Colorize curvature* filter. The wiping marks at the bottom of the vessel are more clearly marked in blue with this shader (Fig. **6.48** B). Fissures, which indicate incompletely joined coils, are marked by the *Colored Descriptor* with thick wavy red lines bordered with blue (Fig. **6.48** E). Another enlightening shader is the *Lit Sphere* (Fig. **6.48** C, F and G). This shader amplifies the relief with contrasting light, which can be a useful interpretative tool for a trained specialist. The colour shader and

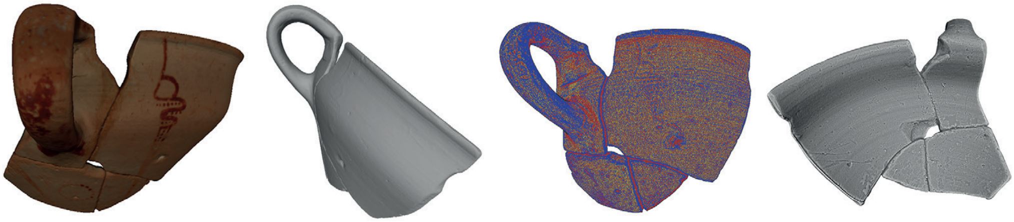


Figure **6.49**. The visual enhancement of a Late Bronze Age kylix from Tsoungiza, Greece, showing evidence of the application of RKE. Image: Loes Opgenhaffen.

curvature filter, however, may serve as a convenient explanatory and communication tool to visually direct and inform less experienced persons about forming traces.

When applying the filters to archaeological material, interesting observations come to the fore. The *Colored Descriptor* applied to this kylix from Tsoungiza (Greece), evidently shows horizontal concentric parallel ribbed striations with a blue descriptor, which indicates that RKE was applied during manufacturing (Fig. **6.49**). At the lower side of the fragment, however, the topography of the surface appears less regular (labelled yellow) and do not show signs of concentric parallel ribbed striations. The red colour points either to painted decoration or topographical irregularities, such as shallow dents in the surface. The *Lambertian Radiance Scaling* renders the concentric parallel ribbed striations visibly clear, but these get increasingly blurred and the topography increasingly irregular towards the centre of the kylix (Fig. **6.49**). This may point in the direction of the wheel-coiling technique used to produce the kylix, or the activity of manually attaching the stem of the kylix to the body, wiping away the RKE traces.

In addition, Meshlab offers a virtual measuring tape and a section tool. The great advantage is that these tools and pre-set filters are all available in one (open-source) software application, and, moreover, they can all be applied on the model (or multiple models) within the same session or project. The visual inquiry and subsequent analysis can be performed anywhere and at any time in the world. 3D models and open-source analytical software are more accessible technology than for example X-ray analysis and micro-CT, and may even reveal more technological clues.[83]

Finally, the colours can be used to specify and communicate graphically the traces and their significance to peers and public, in an unprecedented intuitive and comprehensible fashion. How exactly these technological clues about ancient potting practice are communicated is explained in the next two chapters dedicated to the architecture of the open-access project database (chapter 7), and the proposal of a framework to reach specialist and non-academic audiences with the support of such an online research environment (chapter 8).

83 Jeffra, Opgenhaffen, & Hilditch, forthcoming.

Chapter 7[84]

Balancing data storage and user functionality.

The 3D and archaeological data strategy of the Tracing the Potter's Wheel Knowledge Hub

Introduction

A major of the output of the Tracing the Potter's Wheel project (TPW) is an archive which captures and shares technologically-focused information about forming techniques for archaeological and experimental ceramics. From the outset, the project archive was designed to assist and enhance project research while simultaneously sharing data and knowledge with peers and the general public. In this light, the TPW archive has been designed as a dynamic learning tool which marries the stable storage of digital pottery information with a user-focused interface, complemented with additional open-access publications and resources. The project has also grappled with designing relational and contextually-rich data storage for 3D models and their associated information, particularly both metadata and paradata. 3D models are treated in this approach as an integrated part of the archive instead as a separately presented class. This diverse approach to data storage, knowledge and learning has coalesced into the TPW Knowledge Hub. The design and functionality of TPW's active, multivocal research knowledge hub is worthy of further discussion as it explicitly integrates these often-separated complementary perspectives on the archaeological data.

84 A version of this chapter has been accepted to be published as a book chapter in: Opgenhaffen, L., Jeffra, C.D. & J. Hilditch, "Balancing data storage and user functionality: the 3D and archaeological data strategy of the Tracing the Potter's Wheel Project". In: M. Hostettler, A. Buhlke, C. Drummer, L. Emmenegger, J. Reich & C. Stäheli (eds), *The 3 Dimensions of Digitalised Archaeology. State-of-the-art, Data Management and Current Challenges in Archaeological 3D-Documentation*. Springer Nature, New York.

Taking up challenges and forging strategies

A number of specific challenges exist in relation to the TPW's project goals for creating a stable and user-friendly repository of pottery records. These included the nature of the data types the archive is composed of, the interest in being guided by design thinking, and the project's understanding of the nature of a 'common vision' in pottery archives. Design thinking has a different approach from the usual problem-solving technocentric approach. Instead, it revolves around the idea of problem-finding from a human-centred approach (Clarke 2019, p. 13), seeking to locate the needs and understand the issue in the system that users are struggling with before then solving the technical problem. In other words, the developer never starts with the solution, but starts "determining what basic, fundamental issue[s] need to be addressed" and then "consider[s] a wide range of potential solutions" (Norman 2013, p. 2019). Design thinking consists of a series of challenges, some exciting, others more of a drawback, that also form opportunities as well and which occur within a social group. The design process can be divided into iterative but non-linear, reflexive phases. These phases include, but are not limited to: understanding the data types and users (visualised through a data wireframe, for example); observations of the circumstances (through comparison against other archives and platforms for data models and user experience); functionality assessment; prototyping (through which several designs are developed); as well as the actual building, testing, and launching of the database. This multifaceted approach to problems, or challenges, is a creative practice. A key benefit of this iterative process is that, when practiced in a transparent and coherent way, it can be applied by others and developed accordingly (see also *IDEO*).

In order to develop the archive platform, TPW sought the partnership of commercial developers, funded by a Dutch Data Archiving and Networking Service (DANS) Small Data Project grant (Klein Data Project, KDP).[85] TPW's partners at Kbell & Postman[86] employ a *design thinking* approach from a creative, user-oriented perspective, modelling and modifying from experiment and experience with a wide range of users. Within this partnership, the TPW team takes an academic stance, just as scientists take a more formal strategy towards problem solving, the goal of which is to learn from these attempts (Sarwar and Fraser 2019, p. 345). This is perhaps more properly called *designerly thinking*, which "links theory and practice from a design perspective" (Johansson-Sköldberg et al. 2013, p. 123). This leans more to the "layers of design" practice as formulated by Lawson and Dorst 2009 (Dorst 2011, p. 526), which is focussed on project, process and "field" (Bourdieu et al. 1999, cited by Dorst 2011, p. 526), or social context. The latter stands for a more deliberate way of reasoning in which diverse social groups are taken into account. Furthermore, it reflects on project-specific methods of data collection as well as the way that data is disseminated as meaningful archaeological information. Through the archive, knowledge is produced while mechanisms of receiving new data and knowledge from other disciplines are nurtured. This collaboration between commercial developers and academic researchers

85 https://dans.knaw.nl/en/ (accessed 27 May 2022

86 https://kbellpostman.com/ (accessed 27 May 2022)

working under the umbrella of design thinking is very fruitful in the development of a dynamic archive that suits the project and a wide range of targeted users.

The agile and particularly reflexive approach that design thinking can bring to archaeological practice is not restricted to the digital realm alone: problems such as data uncertainty already exist in the practice of collecting, recording and digitisation. The choice of what data to collect, what research is deemed interesting and informative in the first place (and which is negotiated over time, as argued by Börjesson and Huvila 2018, p. 14) is the basis of a database structure, and furthermore has an impact on archaeological knowledge-making. The first problem is encountered in the collecting phase: the ambiguous nature of archaeological data, being often fragmented and incomplete. Fragmentation and incompleteness are not appreciated in creating data models. Further, uncertainty about an object's specific forming method or a precise chronological date is hard to capture within a database model, let alone to query (Piotrowski 2019). Another frequent problem arises when data is collected under different circumstances and through different strategies, which can lead to inconsistencies in data patterns and resulting data accuracy. And although most data in the TPW project have been analysed and collected by the project members themselves, some data depends on archival data produced by other specialists that was recorded differently, impeding comparability and reproducibility (a pitfall described by Boast and Biehl 2011, p. 128). These inconsistent datasets are then difficult to compare, resulting in uncertain outcomes. TPW has overcome this problem by forging a strategy for the selection and recording prior to digitisation and manipulation, or "data context" (Huggett 2020, S12), which was applied during fieldwork and at diverse locations (Fig. **7.1**). This overarching strategy steers the selection procedure, description and photographic procedure, the standardisation of equipment, and 3D recording procedure and related metadata standardisation for the analogue and digital recording processes. Many potential data uncertainties are prevented by this consistent strategy. It should become apparent during the planned later phase of the database, when other specialists and projects begin to contribute a dataset to the TPW archive, that following the same selection, collection and digitalisation procedure is crucial. In this way it is possible to safeguard data accuracy, meaningful re-use and assembly of data and subsequent comparative analysis that form the basis of archaeological knowledge production.

Over the course of fieldwork and analysis, TPW has generated considerable data, composed of multiple file types for images, video footage, 3D models, and texts, as well as the contextual information for those files, including metadata and paradata. This large volume of data is, in fact, representative of a relatively small number of archaeological and experimental objects. But each object included in the database has its own solar system of associated data files which provide different perspectives on the object represented. Taken together, these many solar systems of data files, create a galaxy of relations between the objects. Although the objects studied are not the totality of the objects from any one site's ceramic assemblage, by capturing information about objects scattered across the universe of an assemblage, it is possible to understand some of the key features of that universe. These data represent a multiplicity of complementary perspectives on the objects themselves. In effect, data was collected

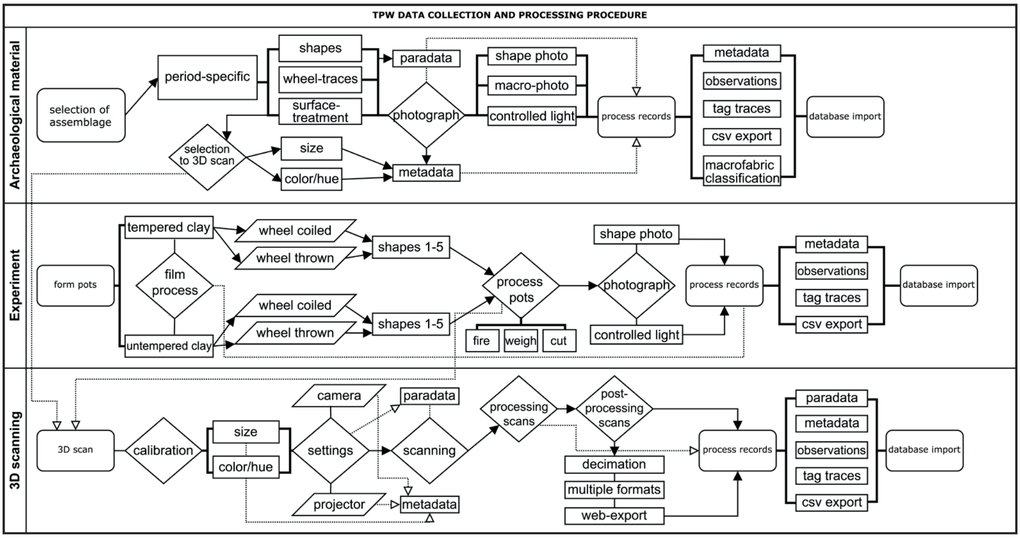


Figure **7.1**. Diagram representing the data collection and processing procedure. Image: Loes Opgenhaffen.

in different formats to gain different insights into the nature of a number of specific archaeological and experimental pots (Fig. **7.2**). This challenge was an important one to meet, because the value of making such an archive is the presentation of this complementary information in its context; file types need seamless interconnections to illustrate different points. A major difference between this archive and others is the integration of 3D models alongside other types of object representation; presenting all these different file formats side-by-side is essential for illustrating the complexity of that object. Additionally, this project does capture and present information about different kinds of pottery. The specific needs for presenting an archaeologically-retrieved object are different from presenting an experimentally-produced object and, as such, the kinds of information which populate the context also differ.

Current solutions for 3D models in archives

Today, digital 3D technology is applied in virtually every sub-discipline to document, analyse and (re)present archaeological data and heritage. Many archaeological 3D datasets are now available online and are often held up as examples of the democratisation of data and knowledge production. However, the standard varies considerably, as revealed in an exploration carried out by the TPW team into 3D repositories and online pottery archives. Our observations support the results of a thorough survey of "3D" digital heritage repositories and platforms by Eric Champion and Hafizur Rahaman (2020), and the study by Nataska Statham (2019), which offers a comparative analysis of several 3D platforms and their relation to prevailing international guidelines for preserving heritage (ICOMOS and UNESCO and the London Charter (Denard 2012) and Seville Principles (Bendicho 2013). Few of these platforms have significant user

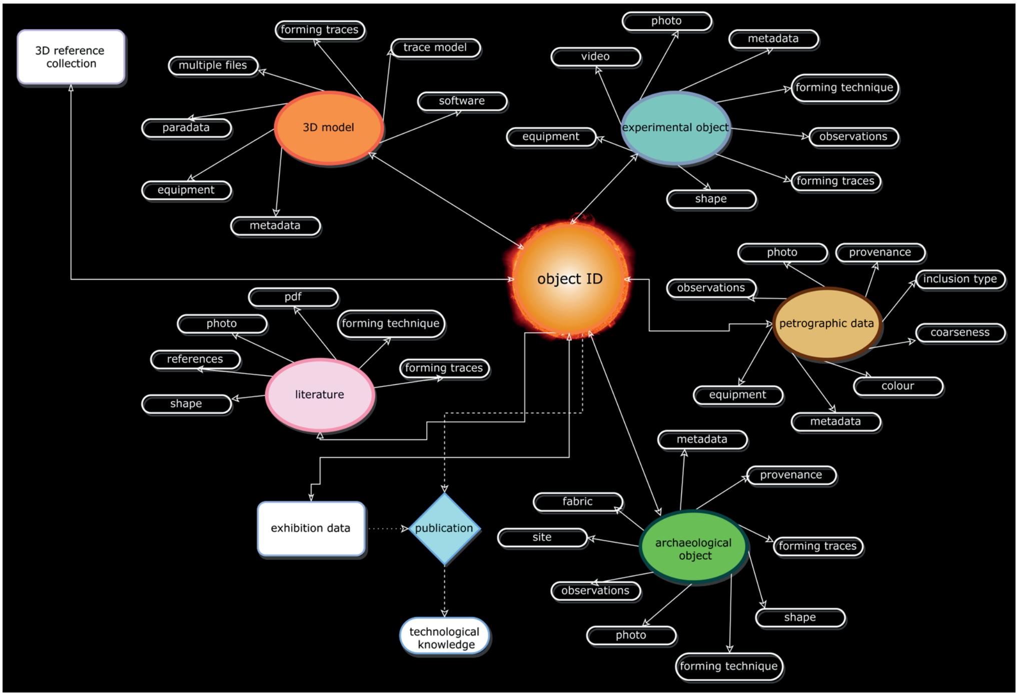


Figure **7.2**. TPW data types, data and metadata contexts represented as an interconnected constellation orbiting the object ID. Image: Loes Opgenhaffen.

participation or even interactive tools, nor do they have the possibility to annotate or contextualise the 3D content. Actual engagement by users through interaction with the model for topography or stylistic exploration, or by interrogating the underlying data – functionality for comparing 3D models (also with other media) and allowing comments or contribution of similar datasets – are virtually absent in these repositories. The democratisation seems therefore to take a one-way direction.

Digital archives and platforms

An increasing number of pottery databases are appearing online, which is a positive development. While in the early years of digitisation pottery archives tended towards a digital replication of a traditional catalogue (such as the Beazley Archive), an increasing number of initiatives aim to move beyond mere cataloguing and provide active repositories supported by rich media, tools to compare and study objects, and semantic searches. These projects, such as ArchAIDE (Anichini et al. 2020) and the "The Levantine Ceramics Project", have rich databases and appealing, clearly structured websites. ArchAIDE in particular has easy search functionality, associated vessel display, and has integrated 3D models with accompanying metadata through 3DHOP, and a tool to automatically identify pottery shapes.[87] A brief survey of online

87 Other promising online platforms for pottery identification, 3D visualisation and comparative analysis were the *Pottery Informatics Query Database* (PIQD, Smith et al. 2014), that aimed to go beyond digital archiving and presented itself as online, open-source tool

pottery databases leads to the conclusion that, besides some promising platforms as mentioned above, the level of data literacy, especially when it comes to visualisation and user experience, is markedly low. Indeed, it seems that these two concepts are fundamentally linked: if visual files are not immediately accessible and only lists of information are visible, then records are usually only accessible to specialists, due to reduced searchability and potential for comparative analysis. In this sense, these websites have poorly-considered design, which leads to reduced navigability and often prevents non-experts from querying the database. Another function which is often lacking is annotation of the 3D models, which improves their contextualisation and searchability, but is also critical for accessibility and comparative analysis, for specialists and non-specialists alike. Lastly, very few websites allow for comments on their data, another important element in stimulating comparative analysis.[88]

Pottery, and especially past potting practice, seems not to be the first choice for constructing and testing versatile 3D archives. A strong focus on disseminating research and cultural heritage in 3D is in excavation, architecture and 3D documentation of special finds. Good examples of digital archives with embedded 3D viewers include Dynamic Collections and 3D Icons Ireland.[89] The former uses 3DHOP to visualise, annotate and query artefacts from a reference collection, with familiar tools to the archaeologist such as lighting, measuring and sectioning, and to freely rotate the object. The system serves as an excellent complementary learning tool alongside the physical collection and has the functionality that allows students and other stakeholders to create their own collections, and to tag and make notes in an on the artefact, which can then be saved and shared as a json file (Ekengren et al. 2021). 3D Icons Ireland uses Sketchfab as an embedded viewer in a data structure that reads as an article, accompanied with other media. This narrative presentation of archaeological data common to projects is beneficial for users who might be unfamiliar with specialist catalogues and lists of raw data. This can be compared against the presentation of the *Cinema Parisien* in 3D reconstruction, carried out by researchers working within the framework of CREATE (University of Amsterdam). This 3D reconstruction is presented in reasonable quality using the Unity web player and is successfully connected to the database, which enables to request its underlying data (text and images) by freely clicking on any part of the building while walking through the movie theatre. Further, users are given the option of leaving comments (Noordegraaf et al. 2016).[90]

One example of a digital archive that does focus on potting practice is the Collections de la technothèque, an initiative of the Laboratoire Préhistoire&Technologie (*PréTech*,

to automatically extract data from scanned potsherds and provide rich (3D) contextual information. In 2015 it joined the CRANE project, after which it withered. The EU funded project GRAVITATE-EU, a digital platform offering tools for reassembling fragmented material, shape analysis and comparative analysis based on 3D geometry and semantic data, was never launched.

88 The British Museum online catalogue is one of the few to allow this function: https://www.britishmuseum.org/collection/

89 http://www.3dicons.ie/

90 Unfortunately, the interactive environment is no longer supported by the University of Amsterdam.

UMR 7055, CNRS / Université Paris Nanterre) to open access to the rich research material collections of the experimental and ethnoarchaeological repositories for prehistoric techniques.[91] Although there are no 3D models within the repository of ceramic forming techniques, their objective in allowing the public to consult their collections remotely, according to their level of interest, mirrors the goal of the TPW digital archive. A final mention should also be made of the ARKEOTEK organisation and associated online "Arkeotek Journal", which partners with *PréTech* to provide "un accès en ligne à ces collections référentielles qui constituent d'indispensables outils d'expertise" (*PréTech*).[92] Although it does not support 3D content, nor does it have a multivocal aim in addressing lay audiences, the core objective of ARKEOTEK was to create a knowledge base centred on the "archaeology of techniques". Here, experts share their research through the publication of not only datasets and results, but also the reasoning processes built upon them (Gardin and Roux 2004, p. 29), based upon the Scientific Construct and Data (SCD) format designed by Philippe Blasco. This practice-centred perspective is further elaborated by Dallas, who maintains the importance of not only the research dataset but also "processes related to the production of knowledge, its public communication and user experience in digital curation" (Dallas 2015, p. 192). It is this orientation which has informed the foundation of the TPW database.

There are few nationally-funded initiatives for managing this type of research-driven 3D data. One notable exception is the Archaeological Data Service (ADS) which has an embedded 3D viewer similar to 3DHOP (the same developers are behind it). ADS provides a highly detailed metadata-scheme[93] to record data-retrieval, postprocessing and technical specifications. Furthermore, ADS does not treat 3D data as a separate class or collection; rather it is integrated into the repository with an impressive level of flexibility in how a project can choose to present their 3D data.

On an international level, "Europeana" provides a platform on which European cultural data is displayed (but not hosted). By engaging with wider-ranging efforts such as these, there is less risk for projects of falling into obsolescence. Europeana does not support 3D content itself, instead relying on embedded viewers such as Sketchfab. Another supported format was 3D PDF, a promising format a decade ago but, as Flash is no longer supported, the 3D content can no longer be navigated online. For 3D models, Europeana has now the app Share3D[94] to link Sketchfab models and submit (limited) metadata to Europeana. In the dashboard, the metadata can be adjusted to Europeana standards, though these standards are not directly accessible, as entries must be shared with Europeana via an approved aggregator. In the case of archaeological material, CARARE is Europeana's designated aggregator. This is a suitable solution if projects have few 3D models, but with larger 3D datasets this

91 The experimental ceramics of TPW member Caroline Jeffra can be found on the following page:https://teknotek.pretech.cnrs.fr/s/fr/item?fulltext_search=Jeffra&fbclid=IwAR0_gKMvjcCKee2qOggmdww8l-Pk4RFszHSRPW5bOq7p1zkr8eOeeoKLPCE

92 http://www.pretech.cnrs.fr/programmes-labex/

93 For the detailed metadata scheme: https://archaeologydataservice.ac.uk/advice/Downloads.xhtml

94 Available at https://share3d.eu/, not to be confused with Share3D.com.

cumbersome pipeline of Share3D can be a huge and laborious task. Furthermore, the services provided by many aggregators incur yearly costs, an issue which has repercussions for the long-term sharing of data beyond the life of temporary projects.

With the exception of rare examples such as those described above, 3D models are still most often set apart as a visual data class, presented apart from other contextual data in '3D collections' within projects and project databases. 3D datasets should not be presented in isolation, and solutions must be crafted which integrate 3D models within archives while giving due attention to user experience of those archives. A 3D model only becomes a meaningful visualisation when embedded within its contextual information. Projects which fail to recognise this risk returning archaeologists into object-focussed antiquarians.

Viewers: Sketchfab and 3DHOP

A significant technical hurdle to fully integrating 3D models within a user-experience designed archive is the limited range of available viewers for embedding and presenting those models. The TPW Knowledge Hub is not exclusively a 3D archive presenting an exciting 3D collection, instead it is an archaeological narrative about past pottery technology and social interaction in which the 3D models are an integral part. For this reason, the 3D viewer must integrate seamlessly with other types of data presentation, allowing interconnections with those data and their corresponding file types. A number of essential functions have proven useful for including models within the archive. These include tagging and presentation tools, embedded analytical tools, and easy download options. These functions play an important role in allowing users to more fully interrogate the material based upon their observations in the models and other media shown alongside them.

Tagging and presenting models

A 3D model is not self-explanatory; tagging functionality embeds a 3D models contextual information within the model itself, rendering it a meaningful object. In doing so, tagging enriches the model and makes it a meaningful scientific representation of archaeological knowledge. Yet, the diversity of tagging and presentation needs for the field of archaeology may make it resistant to standardisation; it depends heavily upon the aims of the visualisation, which can be a 3D model of a monument, a multilayered excavation, or fragmented artefacts. Tagging also depends on many other related factors, from recording to presentation, and even teaching.

In the case of research in pottery forming technology, tags provide targeted description of specific model attributes, both relating to the data collection process as well as the morphology of the object being visualised. For example, TPW's SketchFab models often indicate the presence of forming traces, such as crevices, alongside ghost artefacts such as inward-projecting surface topography on a model where the physical object was darker in colour (Fig. **7.3**). Tagging furthers the aim of integrating models alongside other methods of data presentation (such as text, photographs and video). Sketchfab achieves this by providing user-friendly tagging functionality which can include links to related data, texts, and media within the database and to other websites. This enriches the model, making it informative and giving it a meaningful voice. Users can be guided in what to see and thus be informed, in the TPW case, about forming traces. In comparison, 3DHOP's tagging functionality is significantly less user-friendly, as the "hotspot" needs to be assigned in the code, a time-consuming task which is beyond the skill set of many archaeologists.

Analytical tools in model viewers

There are a number of analytical tools which archaeologists use when directly handling objects, and some similar functionality is available for interacting with 3D models. Sketchfab's most archaeologically-useful analytical tools are the matcap function in the model inspector, which enables turning off the texture, and the directional light tool, which both enable to inspect morphological features in more detail. It does not have a measuring tool, however, and a sense of scale is only possible if a scale bar is uploaded with the model. 3DHOP, on the other hand, provides a toolkit that enables detailed simulation of the physical analysis workflow. This functionality includes a torch to illuminate specific parts of the object, an option to turn the texture off, a measuring tool, and the possibility to make sections on different planes. The familiarity of these tools, and the expansion of functionality of matcap or texture removal, strengthens the case for using these viewers for research that enables study of objects which better approximates direct handling of these objects.

The TPW pottery archive

A wide range of online platforms are available, both with and without 3D content, which gives ample opportunity for researching solutions to fit the needs of the TPW Knowledge Hub. This diversity was both motivational and inspirational during the design process, informing the project on avenues to avoid specific problems in data representation, as well as how to address multiple audiences and user needs. Through this research, the need for a tailored solution became clear. Although not currently supporting 3D data, the DANS Small Data Project grant awarded to TPW enabled the project partnership with developers Kbell & Postman for the design of an active archive to be hosted by the University of Amsterdam. These experienced developers give a unique insight into user experience processes beyond the borders of cultural heritage, inspiring TPW to engage in more designerly thinking and reflect on the processes within the project in a more creative way.

As highlighted above, a major difference between the TPW Knowledge Hub and others is the integration of 3D models alongside other types of object representation. Each of the file types, and the types of objects described in those file types, have different metadata needs. Although metadata standards for cultural heritage exist in data models such as Dublin Core and CIDOC CRM[95], these do not specifically incorporate 3D

95 http://www.cidoc-crm.org/functional-units (accessed 27 May 2022)

content needs and requirements. The most important problem in these data models is that there is no clear definition of what kind of entity a 3D model is exactly and how to label it[96], and no system to record the metadata of a model yet, although CIDOC CRM is currently developing the CRMdig ontology and RDF Schema to encode metadata about digitisation processes, both 2D and 3D.[97] CIDOC is quite prescriptive rather than descriptive, which makes it inflexible and hard to apply in a diverse discipline as archaeology, with divergent (national and institutional) recording and documentation traditions. It proved extremely difficult for TPW's domain-specific pottery manufacturing traces and fabrics classifications to adjust to CIDOC. The Dublin Core is less extensive than the CIDOC CRM and thus more flexible for specific collections and specialisms, while the principal classes are compatible and therefore findable. A final example is the CHARM reference model, a semi-formal abstract reference model with a wide range of different users. CHARM is not prescriptive about too many details; users should define their own particular properties within this data model by using extensions based on "object-oriented conceptual modelling principles" ("CHARM").

Clearly, work remains to be done to translate these models into domain-specific language for more ready application to archaeological materials, particularly in the case of smaller projects who may not be able to outsource this important aspect of sharing their data. In order to prevent reinventing the wheel, the TPW model will adhere, where possible, to the CIDOC CRM framework while building forth on the concepts of the CHARM model. This approach to data combines prescriptive with descriptive models that will suit our research objectives, contributors and user's needs, and enables planned integration with Europeana.

The 3D models in the TPW database are classified as a piece of data relating to a physical object. The simple solution is to link the 3D model in the database via the object ID used for the original, archaeological or experimental, object. With that ID, the model will be automatically annotated and linked to its contextual data. This resolves the risk of isolating the 3D model while also preserving the visibility of the technical metadata and paradata about the choices of the archaeological visualiser. This paradata is captured in the workflow description for the entire scanning, processing and post-processing procedure, including choices for particular hardware and software, their settings, as well as parameters such as the decimation algorithms to simplify the models. This workflow is published on the project website (Opgenhaffen 2020a), and video tutorials about specific scanning solutions are in production. This transparency in

96 For example, in CIDOC CRM a 3D model can be either a Subject Depicted Information entity (E55 Type) or Object Title Information (E73 Information Object), as a 3D model is both an image and a data carrier. The CARARE metadata scheme calls it a Digital Resource (DR). In this scheme, information and data which describes the process by which the 3D data was collected (scanner and other equipment) and processed (software and parameters), is called paradata (elsewhere metadata), which can act as a quality control audit for the data. This should be recorded in a sheet and then listed as an activity in the metadata scheme. Different object identifiers, and even different definitions of metadata and paradata, prevent standardisation of cultural resource management, let alone foster a solid foundation for a common vision in pottery archives. See also CIDOC CRM Issues section: http://www.cidoc-crm.org/Issue/ID-342-3d-model-example-in-p138

97 http://www.cidoc-crm.org/crmdig/ (accessed 27 May 2022)

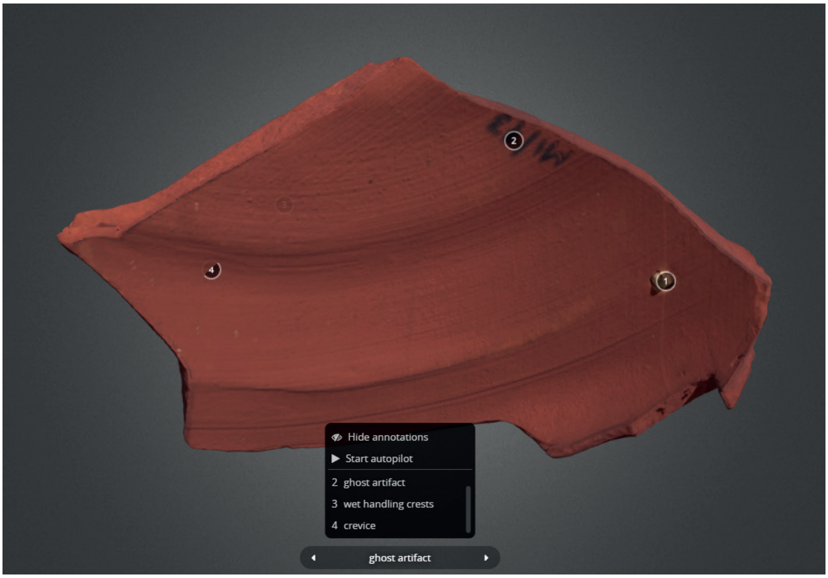


Figure **7.3**. Example of an annotated 3D model revealing information about both forming traces and "ghost artefacts": https://sketchfab.com/3d-models/m1-73-002dec-676cb1d9ae11431498544a98911d97bb

project workflows and data collection procedures are created with the FAIR principles in mind. TPW values these guiding principles to ensure transparency about data and methodology (Opgenhaffen 2020b), and to keep the data accessible and discoverable at all times (Wilkinson et al. 2016). Moreover, tutorials about workflows and the availability of rich metadata schemes enable the possibility to reproduce data collection and sharing, and to reuse data to increase knowledge about transmission of ancient technology.

TPW is currently using Sketchfab Pro to share and publish the 3D models of the experimental dataset (Fig. **7.3**). Although 3DHOP has better functionality for archaeological inspection, Sketchfab works faster in uploading and tagging the models. Despite Sketchfab being a commercial platform, the Pro version is free of charge for educational institutions. Sketchfab Pro enables models up to 200MB to be uploaded, which ensures a high degree of geometric data integrity, that is, not too much data is lost when decimating/simplifying the raw files to an acceptable format and size for online display. Indeed, TPW is well aware of the issue of ownership in the case of a profit-oriented enterprise such as Sketchfab, and so hopes to overcome this in the near future through an in-built viewer.[98] The Sketchfab models are embedded in the web interface,

98 The inhouse 3D viewer Voyager developed by the Smithsonian Institute, combines all functionalities of Sketchfab and 3DHOP and further adds storylines and tours through the 3D model. The source code of this viewer is available on GitHub (https://github.com/Smithsonian/dpo-voyager#readme). Sketchfab will ultimately be replaced by 3DWorkSpace/Voyager, an open science/interactive tool for 3D datasets, currently being developed by a collaboration of researchers from ACASA, the 4D Research Lab and CREATE of the University of Amsterdam and the Smithsonian Institute. This research project is funded by NWO Open Science Fund. 3DWorkSpace will adapt the Voyager by adding multi-authoring and commenting functionality, as well as expanding the annotation and narrative possibilities.

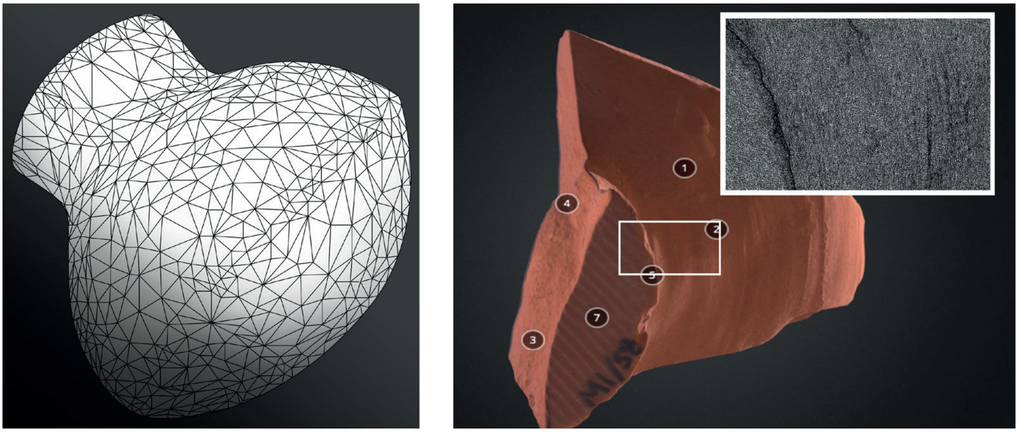


Figure **7.4**. Left: a 3D scan made in 2002 (after Rowe et al. 2002, fig. 8.1). Right: a 3D scan made in 2018. Image: Loes Opgenhaffen.

and the different file formats of the 3D model are provided as download files, such as the original scandata, the exported OBJs and simplified OBJs, PLY and STL files. Together with the technical metadata and detailed workflow description, the transparency of the entire workflow from scanning through to file processing is guaranteed, as are file compatibility and reproducibility of workflows. The ability to reproduce workflows and reuse original files ensures a consistent accuracy of data quality. Downloads also enable users to conduct further offline analysis, as well as to compare 3D models of artefacts in open-source software such as Meshlab. In particular, the 3D models of individual forming trace examples from the unique reference collection developed by TPW can be downloaded and 3D printed to function as a physical training set. Users can then inspect the traces in a tactile way, achieving a better understanding of pottery technology alongside the digital material showing greater contextual information.

An important issue, however, is whether it is possible to maintain the ideal of reuse, reproducibility and data assessment, given that ever increasing scanning resolutions and computing power regularly render hardware and software obsolete. This means the safeguarding of the contextual data is extremely important, as the hardware and 3D models can always be replaced. As an example, 3D models of pottery recorded in the early 2000s, consisting of a few dozen faces, are impossible to compare against 3D models of the same pots made today, which consist of a few million faces (Fig. **7.4**). Similarly, early 3D models do not have the level of detail that is required to identify particular manufacturing traces. Replacement of an early 3D model with a modern 3D scan produced according to the current recording strategy enables a detailed topographical analysis while maintaining the contextual data that was originally documented. The same procedure can be repeated in another two decades.

Archive architecture

The relational database is built with MySQL, and the platform with PHP (8) on top of the Laravel (8.0) framework. Laravel is a popular open-source PHP-framework providing scaffolding for web applications. This enables modular packages to be built on top of it to manipulate and maintain a web interface while running several applications. This, for example, allows for multiple data sources to be visualised while embedding external viewers. The platform is powered by the search engine Algolia to improve search results and especially ease search queries. It adds a search box to the website front end and supports simple text-based search approaches. As it indexes the TPW site, Algolia offers web search experiences comparable to Shopify webshops, which enables users looking for forming traces of pottery on the internet to find the information in the TPW database more easily and faster.

Static vs active

From the outset, the TPW Knowledge Hub was designed to facilitate future research into pottery forming techniques. Given the sheer scope of such research, not only in the Bronze Age Aegean but also in regions and periods beyond our TPW remit, it was acknowledged early on in the project that the archive might be supplemented by other reference collections in the future, to consolidate the known repertoire of surface macrotraces that relate to specific forming techniques. As a result, the project aims were adapted to create the foundations for a dynamic knowledge hub of wheel-formed pottery that could be extended to increase knowledge about past potting technology and technological transfer thanks to cutting-edge digital technology. Such functionality requires an archive that can be *actively* added to, or updated, through the inclusion of new datasets, which goes well beyond existing frameworks for archiving datasets. DANS facilitates the deposition of complete datasets, or static archives, with the capacity for a limited number of iterative updates and where each iteration is assigned an individual DOI. This situation appears overly reliant upon models for digital archiving of written text and ignores the dynamic opportunities that a more active archive can bring to researchers. The benefits of digital data repositories, whether static or active, allow information to become openly available and accessible, creating opportunities for re-use of that dataset in subsequent research. Perhaps as a result of the DOI attribution system, there is as yet no potential to create a digital resource that can be continuously updated, such as a repository/archive that has the ability to accommodate the research input of multiple teams/sources working towards a shared research goal. For this reason, TPW has deposited material into a research archive with DANS as a *static* archive in early 2021, as part of their Small Data Project incentive scheme. But in "an ideal data lifecycle", as Sarah Kansa Whitcher and Eric Kansa put it, an archive should not be a "final resting place" for data (Kansa and Kansa 2014, p. 225). Indeed, the authors believe a dynamic archive, one in which resources are updated as new research is undertaken, is an important part of communicating and contextualising research. By increasing opportunities for research collaboration, both present and future, the TPW project better fulfils its societal impact goals and moves closer to building new knowledge about the innovation of the potter's wheel. Therefore, the web portal to the *active* repository with a sophisticated back end will be hosted and maintained by the University of Amsterdam, enabling continued knowledge exchange between peers and the public.

Knowledge transfer and learning pathways

An important component of the TPW Knowledge Hub which was identified early in the design process is the integration of learning pathways to facilitate knowledge transfer (for more information about the concept of learning pathways, see Hilditch et al. 2021). With the knowledge that potting technology assessment is a growing field which all too often depends on extended periods of in-person object study, TPW sought to create solutions which could widen participation. Furthermore, many digital archives are designed for use by well-experienced users who have deep pre-existing knowledge of the field, which excludes participation by students or the general public. The solution pursued by TPW is the creation of resources to orient users in terms of how to use the archive, as well as how to perform data collection and analytical tasks presented within the archive: in effect, facilitating non-specialists into becoming partially specialised users.

Tutorials and other kinds of learning tools guide users through the database, which are tailored to their level: specialist, student or general public. These tutorials not only inform on topics such as how to use the archive or a structured light scanner, but also allows knowledge transfer relating to a number of topics including recognising wheel-forming traces, new insights in ancient technology, the role of 3D visualisation in archaeological practice, and 3D models of heritage objects for the mobilisation of knowledge transfer. The reference collection of wheel-forming traces is the visual portal where the investigation of potting technology begins. A trained specialist can readily dive into the details by browsing further through the displayed contextual items, or by a targeted search. At all times, video tutorials and explanatory blog posts are easily accessible to help guide the user from superficial to complex exploration through the data. Students, as well as the general public, can start with the visual representations in the main view port. These may either be detailed photos of fabrics and vessels obtained by targeted light photography (for which the metadata scheme and how-to DIY manual is also available) or 3D models (for which workflow tutorials and metadata schemes are available). Both photos and 3D models are tagged so that the forming traces are recognisable, and these tags contain links to further explanations. A multitude of different file formats of the 3D models are made available to download, and a dedicated part of the reference collection has models of single macrotraces that can be downloaded for 3D printing. This unique training set enables users to tangibly explore traces of forming techniques, as a tactile survey of the surface is an essential part in the process of identifying forming techniques that cannot be replaced entirely by virtual technology.

The clear research objective-directed database risks the creation of so-called ‘filter bubbles’ which affect data retrieval and use through the application of particular search tools, and especially impact the structure of the data (Huggett 2020, S12). The easy access and functionality ideally democratise the use and re-use of data that could contribute to new knowledge and shaping narratives, but the simplicity of these tools inevitably channel this shaping in a certain direction. However, as long as this risk is acknowledged, and transparency about research aims is maintained, this directional shaping is not necessarily an un-democratic approach. Project data was collected for wider communication of past technological changes, as well as how to recognise features indicative of those technologies. The archive also provides recording strategies that maximises reproducibility and ensure comparability between datasets. In this respect, a fluid and flexible re-assembling and re-use of data in an unguided and "free" way could lead indeed to interesting new interpretations by "local stakeholders" and third parties, but whether this truly produces new scientific knowledge is debatable.

Summary

Some challenges and solutions for presenting and curating 3D data alongside other types of archaeological data have been briefly introduced here. The 3D models captured by TPW form an integrated part of the multiple datasets represented by diverse media and file formats presented within the database. Overall, the web-based archive democratises interaction with archaeological knowledge by opening access to specialised archaeologists, students, and non-specialists alike.

The question remains, however: how can we establish a sustainable repository that actively fosters further research by future users? 3D models are exceptionally useful as a means to simulate and stimulate intensive object study in the field or lab, a point which is reinforced by thoughtful creation of storage and access solutions. The TPW project has ensured that its datasets have met the basic requirements of sustainable archiving, such as catering for data quantity and format, open access, and adequate infrastructure for long-term storage. However, these basic requirements, which many other projects are also currently meeting, do not necessarily foster strong interaction by users. On top of this, the commercial platform Sketchfab is dependent upon an economic profit model, whereas 3DHOP requires the continued investment of the Italian state and the European research framework, risking accessibility of the 3D models in the long term. Lastly, 3D models remain at present a volatile format, in which their accuracy relies upon the standards of ever-changing current technologies. Taking all these uncertainties into account, it is imperative that the contextual data making the 3D model meaningful should be stable, sustainable, and accessible at all times. For now, TPW seeks to exceed the requirements within existing data frameworks by depositing our data with the Dutch national digital data repository DANS, and by listing the objects on Europeana soon afterward.

The TPW team sought to push beyond balancing between stability and usability by supplementing the deposition of datasets with a custom-built, user-friendly web-based database, and has forged a strategy where integrated data management meets known project objectives (Fig. **7.5**). The TPW Knowledge Hub will promote learning processes for recognising wheel traces, and provide structured 'on boarding' or familiarisation for data collection techniques through manuals, learning pathways and guidelines.

Future directions

One of the project aims has been to stimulate research into how potter's wheel technology spread across the Aegean over time. A remaining, major task now is to advocate for others to make use of, and ultimately contribute to, this Knowledge

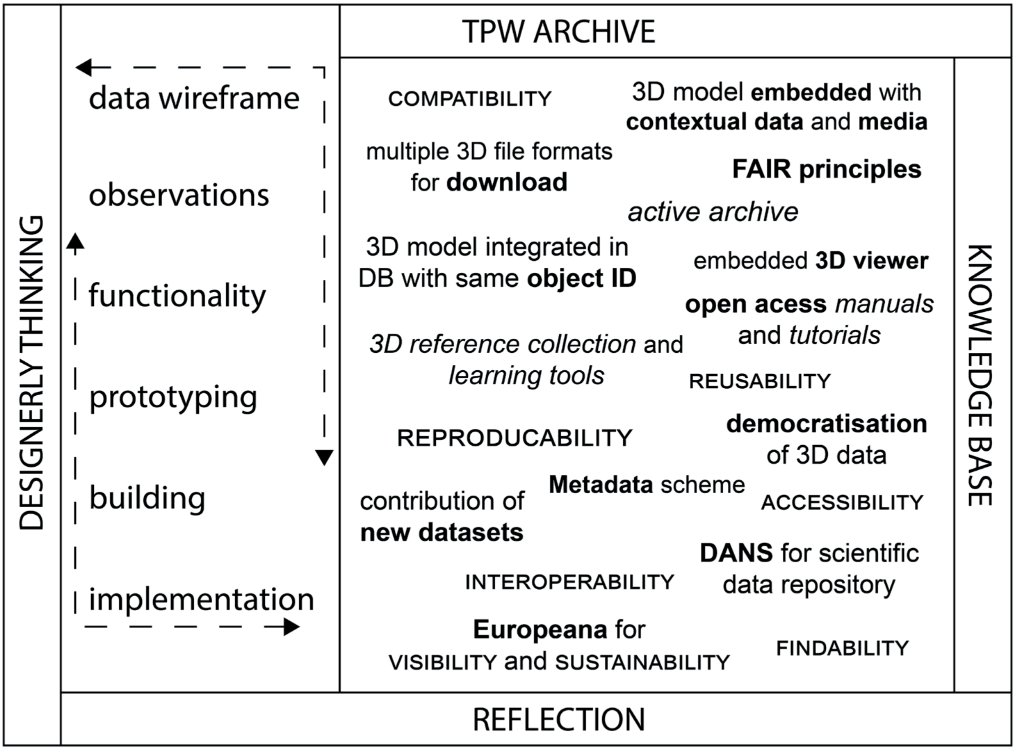


Figure **7.5**. Summary of TPW's workflow, *outputs*, **primary aspects** and GOALS in creating the active archive. Image: Loes Opgenhaffen.

Hub. This involves training other specialists to recognise and interpret evidence for pottery production technology, as well as encouraging gathering of further data on this topic. Potential users of the Knowledge Hub can be reached by presenting in specialist sessions on digital (3D) pottery archives, but widening engagement with general users must also be achieved through other means, such as interactive museum exhibits and online activities. By using a simple embedded viewer with integrated features alongside the wider contextual information of TPW datasets, and enabling multiple download files, the 3D reference collection has a special role to play in helping users to transition into the role of a specialist in an interactive and even tactile way.

Chapter 8[99]

Archives in Action.

The impact of digital technology on archaeological recording strategies and ensuing open research archives

Introduction

This chapter contributes to the academic debate concerning the application of 3D modelling of cultural heritage by placing focus on the reflexive and methodological approach of research practice, tools and techniques used in the creative process. Tracing the Potter's Wheel (TPW) and its resulting project archive the TPW Knowledge Hub is taken as a case study to illustrate the practice of creating and facilitating the multiple uses of diverse audiences of an archaeological research archive. The digital 3D visualisation of archaeological ceramics forms an integral part in the project, and while investigating ancient practice, archaeologists' own practice and dealings with new technology comes to the fore as well. In this present practice, 3D recording is part of a larger process of collecting, documenting, archiving and sharing of archaeological data in a research-driven digital archive. In this archive, the TPW Knowledge Hub, users can contribute, analyse and re-use not only archaeological data such as photographs, videos, 3D models and textual data, but also metadata including tutorials on how to use 3D scanners to record certain categories of archaeological objects, in this case wheel-fashioned ceramics. These 3D workflows can then be applied in other projects in order to increase comparability between datasets.

Subsequently, the analysis of archaeological archiving practices may then be compared with existing, analogue recording and documentation practices. Archiving is here understood as not only the moment of deciding which research data is archivable, but also as a practice selecting archaeological objects to study. In addition, archiving is also understood as the process of recording those objects with different

99 A version of this chapter has been accepted to be published open-access in the onlne journal *DAACH*.

tools as well as the documentation of this process, which itself is archived alongside the object. Despite the application of digital tools, to what extent has the practice significantly changed, however? Further, digital technology has enabled both expert and non-expert audiences to become engaged in archaeological knowledge-making at the lab and the trench, and interpretation "at the trowel's edge" (Berggren et al. 2015; Berggren and Hodder 2003), rather than unilaterally presenting a package of conclusions at the end of a project (although the interpreter's voice in the entire chain of archaeological knowledge production has been contested recently by Sara Perry (2018)). But has this multivocal approach in archaeology also impacted the creative choices in archive design (for example, in the deployment of particular digital technology, database organisation and interface design, and collection and recording procedures beyond the realm of excavation or built environments. See, for example Strupler and Wilkinson, 2017, where they discuss re-use and reusability of field data)?

Over the past quarter century, reflexive practice as promoted by Ian Hodder (Berggren and Hodder 2003; Hodder 1997, 2003, 2005) has resulted in a growing awareness of archaeological praxis, the technology used in outreach activities, and an increasing number of studies are dedicated to these issues (for example, Berggren et al. 2015; Lukas et al. 2018; Morgan and Eve 2012; Opitz and Johnson 2016). The present research complements this existing reflexive and multivocal approach in excavation and museum activities by addressing ongoing "lab", or post-excavation research instead, and follows somewhat different and challenging routes to enthuse and involve the general public into an archaeological research project. What shall become clear is that some aspects of typical collecting and recording methods, and their inherent gestures and actions, are hard to digitally classify, let alone channel into existing metadata categories. This is due to the creative and dynamic nature of the archaeological discipline and its myriad (national) research traditions, as well as its focus on the reconstruction of past human behaviour, making it hard to realise attempts to capture and standardise all facets of past and present human practice (after Bowker and Star, 1999).

The affordances of digital devices and impact on collection and recording strategies of the TPW-project have been analysed to assess what practitioners actually do while interacting with their tools. In doing so, it might be unravelled how these physical and intellectual processes of differentiation and classification in a given practice – with its methods and gestures – are translated into database structures and metadata categories. Finally, an outreach model will be presented to address diverse audiences to use archaeological project archives and to stimulate public participation into archaeological research and knowledge production.

From data repositories to archives in action

Digital-born archaeological archives with 3D content either focus on the publication of excavation data and reports, such as the "Archaeology Data Service", "Open Context", "tDAR", or are aimed at 3D reconstructed architecture linked to a database (Clarke 2016; Dell'Unto et al. 2016; Huurdeman and Piccoli 2021;

Noordegraaf et al. 2016). Other archives are oriented toward the presentation and pedagogical value of 3D collections (Ekengren et al. 2021), or to a lesser degree on projects that focus on non-site specific research such as (3D) pottery databases (for example Anichini et al. 2020; Di Angelo et al. 2021; "The Levantine Ceramics Project"; "Europeana"). Research into the impact of digital technology upon archives and how this transformed archiving practices in research environments, however, has received less attention. Current research often treats digital archives as static entities which may be searchable and offer data as downloads at best, although this trend is increasingly challenged (by, for example, Cameron 2021).

Yet, at their introduction, new technologies such as the printing press, lithography, photography, film, computers and the world wide web did and still do have an impact on archiving practice. In particular, digital media seems to have led to a "general storage mania" (Røssaak 2010, p. 11) and "fetishisation of data" (Sørensen 2017). Everything has to be recorded and stored, in order to safeguard transparency and permanency of the collection and reasoning process, or so it seems to be thought. However, amassing research data without proper access can easily become a dead archive, "billions of files lie like sediment in the cloud, in hard drives" (Cameron 2021, p. 4). And unused archives are not the typical collections in which institutions are eager to invest money to maintain and sustain them. Fortunately, there is a growing attention for data management and curation in the academic world (Dallas 2015; Faniel et al. 2018; Richards et al. 2021). There is also an increasing body of literature on archiving practice in archaeology and heritage (Bauer-Clapp and Kirakosian 2017; Benden and Taft 2019; Faniel et al. 2018; Kansa and Kansa 2018; King and Samford 2019)[100], and research into digital collections and archives concerning the "accessibility" of digital data, "finding aids for collections" (for example, King and Samford 2019), or on "data availability" that might be reused by researchers (Faniel et al., 2018; Huggett, 2016, 2019, and for an apt analysis of actual reuse, (Geser 2021; McManamon et al. 2017a; Sobotkova 2018; Wilkinson et al. 2016). However, these papers typically focus on the accessibility of digital repositories and the ease of finding and (re)using data once within the archive. How potential users are reached and informed about the existence of these important digital archaeological collections and overarching platforms remains an issue largely untouched. An analysis of who these users are exactly is also rarely studied (although there are some attempts, for example, McManamon et al. 2017a). The current debate revolves around the uses of data, instead of the users of data, and overlooks the *human* performative process of archiving and the creation of data as an essential interceding principle between these two elements. For instance, Angela Labrador regards archaeological databases to have "social lives" (Labrador 2012, p. 238), as they reflect socially informed creative practice but also exist beyond its making. The online archive can also be perceived as a "contact zone" of knowledge creation (Boast and Biehl 2011, p. 119), exchange and transfer, and as a place of learning, by all kinds of participants, from laymen to apprentices and specialist scholars. In short, the digital-born archaeological research archive is a socially

100 For example, see several Special Issues dedicated to archives in Advances in Archaeological Practice.

constituted, living and infinite environment about past and present human activity.

Moving forward with the idea of a living and, as such, progressing archive, we bump into the paradoxical notion that archives can both arrest time, as it preserves data for an indefinite time, and activate data through its subsequent use and ensuing knowledge generation. Akin to Eivind Røssaak's (2010) idea of an "archive in motion", the concept of the "archive in action" is introduced here, which is an ongoing process where data and archiving practices are used, reproduced, and re-used (or "recycled", as Jeremy Huggett (2018) prefers) through a series of actions by members of a community by employing digital, web-based technology. This social engagement performs – as well as facilitates – a tradition of knowledge producing practices of archaeologists (Paalman et al. 2021, pp. 3–4), a practice that is in its essence profoundly human yet overshadowed by the "datafication" of archaeology (Huggett 2020, p. 2; Kansa 2016, p. 467).

Archives reconstruct multiple intricate narratives about past and present human behaviour. The examples presented here are about ancient technology, specifically the introduction and uptake of the potter's wheel into an existing potting tradition, as well as the application of digital 3D technology in a current archaeological visualisation tradition to analyse those ancient ceramics. Modern digital technology enables archaeologists to record and analyse these past practices more efficiently and in more detail. Additionally, the technology enables the archaeologist not only to disseminate conclusions to specialist and lay audiences, but also provides the potential to include non-specialists into the reconstruction of the past. Finally, digital research archives can act as powerful pedagogical tools in training students to become members of the community of archaeologists practicing a certain specialism.

Notwithstanding the difficulties of recording intangible human processes, the layered design and multiscalar use of TPW's Knowledge Hub reflects the complex workings of current and ancient practices nonetheless. This is represented by the availability of all kinds of data and the possibility to navigate and zoom in and out, for example, between the particular detail of a macrotrace to the mundane of a recording procedure, or from a production strategy to 3D metadata standards. This oscillation elevates the research project archive to a site of situated learning and exchange of knowledge and experience, and serves as a boundary object between several communities of practice (Bowker and Star 1999). Used in this way, digital archives have the potential to draw together multiple communities of practice, of visualisers, digital archaeologists, pottery specialists, experimental archaeologists, professional potters, amateur potters, and many more. The traditionally separated practices, conventions and procedures of digital, visualisation, experimental and science-based communities of archaeologists are shared in this research archive, and subsequently used and learned by specialists, novices and lay persons who could then become a member of any of these communities and contribute to them with their own data and experience.

Despite the good democratic intentions of disclosing archives to the public, how do archaeologists know what non-experts expect to find or want to know? How can the TPW team member define their position in society to determine what data and knowledge should be recorded and shared, and with whom? To gain understanding of how specialists, apprentices and lay audiences receive, use, learn and contribute to the project archive, what follows is a preliminary analysis assessing how this active and dynamic learning environment is experienced and perceived by its users. Following that, the survey and analysis should determine if digital technology still affords, or perhaps even amplifies, a kind of materially dislocated yet very situated learning by its participants.

Archiving practice: an introspective analysis from an archaeologist's perspective

A framework to analyse archaeological archiving practice

A transparent archiving practice is the foundation for an accessible, inclusive and sustainable archive. In this chapter, a deeper understanding of the processes of how creators and users find, receive and use the archive, is achieved by paying methodological attention towards the architecture that constitutes it. This architecture is shaped by the archaeologist's practice and choices in selecting, collecting and documenting artefacts. These activities do not happen in isolation, but by interacting with other agents – people, archaeological data and tools – and in space and time. As such, the architecture of the archive can be seen as a metaphor; similar to a real edifice, the archive's architecture is adapted, renovated and rebuilt over time to meet current aesthetic fashion, technological innovations and constructional requirements, and information standards, whereas the overall appearance may remain virtually the same.

By bringing the metaphor of architecture in practice, it can be assessed to what extent archaeological archiving trajectories have been changed by the uptake and deployment of new recording and communication technology and changing societal standards. Did the operational sequences of recording practice remained unaltered, only changed superficially, obfuscated by a digital smoke?

Methodology

The Tradition in Transition methodology applied to analyse the archival practice of the TPW project. The layered approach considers a technical process as a meaningful sequence of performances and actions on matter in order to create a thing – whether this is digital or physical –, a process entrenched and occurring within a given social context. These performances and actions are associated with knowledge and technical know-how (Gosselain 2019; Lemonnier 1993; Leroi-Gourhan 1993). In a similar fashion, in the context of digital archiving, the approach can be expanded with the conceptualisation of archiving practice of Fiona Cameron, who states that the collection of data is "a series of actions directed to framing the past and making judgments about what should be carried forward to the future" (Cameron 2021, p. 4).

By treating the archive as an "information artefact", which consists of tools, systems, interfaces and devices to store, track and retrieve information (Star et al. 2003, p. 244), the framework also draws from STS methods too. The combination of these methods enables the application of a kind of reversed social engineering or "infrastructural inversion" (Bowker and Star 1999, p. 34), a reflexive method to bring hidden practices behind digital infrastructures to the surface.

Exploring a project-based archiving practice and subsequent user experience of the archive can be expanded by an autoethnographic (as introduced to archaeology by Edgeworth 2006, 2014) and introspective approach (as proposed by Huggett 2015) which draw from feminist theory and affective, critical archiving (Brilmyer 2018; Caswell and Cifor 2016; Douglas and Mills 2018; Evans et al. 2017; Srinivasan 2017). Firstly, an autoethnographic approach helps to create an awareness of the relational roles of researchers in knowledge producing practice, and how this affects data collection, curation and interpretation (Douglas and Mills 2018, p. 263). The critical perspective enables researchers to convey personal knowledge, demonstrating the inner mechanisms and successful application of the proposed method. This process is recorded in the TPW project as paradata - here understood as the intellectual and personal information related to the documentation process of our interaction with artefact.

As history is indeterminate and changes over time, so too is the narrative of the continuously rephrased past as well, as new voices enter the debate and old ones disappear. The autoethnographic approach therefore secondly allows an analysis of how other stakeholders participate in ongoing archaeological research and interact with the archive, hence producing a different kind of knowledge. This is reflected in the archive; traditional (archaeological) archives were hardly accessible, and the interpretation of the data in the archive was reserved for the institutional elite (Putnam, 2016). Digitisation processes enabled more groups to enter the archive and to participate in the formulation of the archaeological narrative. 3D content even broadens the historical debate as they invite participants to engage with the 3D representations of cultural artefacts rather than relying on textual descriptions or static representations alone, and to better interrogate the data for themselves, while the original material remains untouchable behind glass or in inaccessible storage rooms controlled by governments or (academic) institutions. Transparency of data, design and practice, and ease of use of the archive are the result of an ongoing negotiation by these groups (Star et al. 2003).[101]

Working from the Tradition in Transition framework to investigate archaeological archiving traditions, the risk that archives and archival practices become inaccessible black boxes of data and practice is averted. The description of the creation of an archive in this chapter and its subsequent uses provides an example to serve as a reflexive and praxeological approach of how scholars can perform and disseminate research transparently. In this way, the proposed approach and recording strategy responds to Jeremy Huggett's call for an introspective approach to archaeological practices (Huggett 2015).

TPW had set itself a challenge to make invisible work visible because archives hold, beyond just object data, "a memory of work that has been done" (Bowker and Star 1999, p. 253), an insight derived from early digital classification practice that resonates in recent information work today: "born-digital heritage and its collection therefore are

101 I am aware of the current transparency debate in archive studies, especially in critical and radical archiving. In case of marginalised groups, full transparency can be unethical and undesired due to sensitive data (for example, Caswell and Cifor, 2016). Also access to stable internet prevents large groups from using online archives, risking inclusive archives to become exclusive instead. The GreenIT lobby warns furthermore that digitising and subsequent online storing and sharing has a devastating impact on the environment.

about what we have done; what we value; how we thought about something; and what we experienced in the past that we see now as significant" (Cameron 2021, p. 4), which represent the practices of that work as well. The Tradition in Transition framework conceptualises archiving archaeologists as making choices, a choice to adopt new digital technology and learn how to use it in order to enhance analytical practice, to retrieve more archaeological data and, ultimately, create new knowledge about past behaviour. The implementation of this framework into archaeological archiving practice, enables to map this practice which allows to identify, describe and assess the impact and efficiency of digital technology on practice. Furthermore, the open access publication of this mapped practice provides transparency of practice in all its facets, from tools to settings and social relations. Therefore, the TPW data, architecture and procedures, including decision-making processes, have been documented and mobilised in order to be learned and reproduced. How TPW has done that will be described in the next section.

Reflexive praxis: the generation of data and the making of an archive

In order to determine if TPW has adapted familiar practice to new digital tools, the digital camera and 3D scanner are chosen to analyse the impact of digital devices on current recording practice and how these practices are reflected in the project's digital archive. This disruption of research tradition may actually result in new types of data obtained by the new devices, which may ultimately lead to a different kind of knowledge.

Selection and documentation procedure in the field

TPW's aim is to find evidence of wheel-forming techniques to gain fine-grained insights into technological transmission between communities in the Late Bronze Age Aegean. Therefore, the team starts with selecting vessels according to size and shape. Then, a quick visual and tactile scan is made by the experienced experimental archaeologist to assess if the vessel is a viable candidate for in-depth analysis. Further analysis is carried out with the help of manually directed light, by touching the surface (moving the fingertips gently over the surface to tangibly retrieve information about how the pot was built) and sometimes with a small handheld digital microscope connected to a laptop to enhance visibility (a Dino-Lite). The traces are then documented with a DSLR camera tethered to a laptop via open-source camera controlling software digiCamControl, in combination with targeted light in a controlled light environment (a completely darkened portable photobooth) (Fig. **8.1**). Additionally, but not always, pictures are taken with the Dino-Lite as well, which is controlled by Dino-lite's proprietary software for image examination and capture. All the optically discerned traces are described in a paper notebook and back in the office entered in the database, along with the photographs.

Macroscopic fabric analysis of the break and surface is then performed to determine a rough provenance of the vessel. This is done by the experienced eyes of the science-based archaeologist and frequently also with the Dino-Lite, which allows the taking of digital pictures to support the ocular observations (Fig. **8.2**).

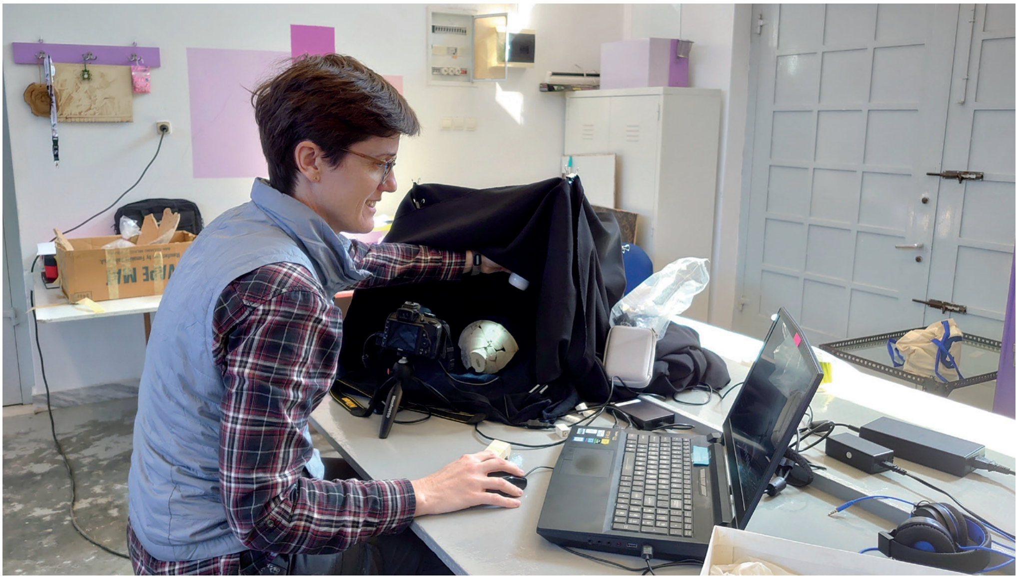


Figure **8.1**. The recording practice using digital photography by experimental archaeologist Caroline Jeffra. Photo: Loes Opgenhaffen.

The diagnostic features indicating the source of the clay are project-dependent, are described on a piece of paper, in a Word document, or in an excel sheet, and to be eventually transcribed into a database. These features, or classifications of entities, are described as well, and more advanced microscopes can be connected to a computer to enhance visibility and to capture digital photographs.

These photographs can be digitally manipulated (or "enhanced") to increase visibility of inclusions and technological traits to support the interpretation based on observations. This type of analysis requires an intensive and intimate interaction with the material and the analytical tool, involving delicate gestures to control the light, scale and sharpness. Occasionally, a sample of the material is selected for thin-section analysis in order to perform additional in-depth analysis with a microscope in the lab. However, this is often done once the entire assemblage has been studied to allow for representative samples for further analysis. Thin-section analysis can increase the resolution of the information about the provenance of the raw materials and provide more data about the composition of the clay paste. Such data can provide insights into the technological behaviours employed during clay paste processing (thereby strengthening the identification of a community of practice through the performance of specific production sequences).

Finally, a subset of the investigated selection is digitally scanned in 3D by the digital archaeologist. High resolution 3D scanning of often morphologically complex archaeological artefacts is a slow process. Unlike digital optical devices, whether controlled from a laptop or not, the nature of the technology of the 3D scanner does impact the selection of material. Structure-from-Light (SLS) is the technology deployed in the TPW recording practice. As the name already suggests, it involves the projection of light patterns onto the surface of the target vessel. A

Figure **8.2**. The recording and analytical practice using a digital Dino-Lite by analytical archaeologist Jill Hilditch. Photo: Loes Opgenhaffen.

camera then records the distortions of the patterns where the light hits the surface. It also records the colour information of the vessel (the texture) as a photograph.

To determine the exact location in space, the software needs to calibrate the machine, which is stationary. Patterns printed on boards (calibration boards) are to be positioned on the location where the artefacts will be scanned. This location needs to be completely black, because black absorbs light, which reduces background noise. The calibration boards are of different sizes that correspond to the size of the artefacts. The machine also calibrates on the colour hue of the vessels. These parameters affect the process of material selection. The experimental and scientific archaeologist have to make a choice of which objects from those they documented and analysed have priority to be scanned in 3D, as only about 40% of the total of selected vessels can be scanned and the selections for 3D scanning are generally important or highly suitable examples. The sub-selection then has to be organised according to size and colour hue, which for analogue recording practices is usually less of an issue. The selection and documentation practice are therefore extended and adapted by the employment of new technology.

The 3D scanning process itself creates vast metadata, which is documented as well. For example, the calibration files are saved so that calibration information of specific scanning batches can be traced back. Also, circumstances are noted, such as light conditions, the stability of the floor and building and foot traffic of visitors. These factors all affect the scanning conditions: light interferes and disrupts the pattern projection, even minimally-unstable floors cause vibrations which are unwittingly captured by the machine, creating "ghost artefacts" (digitally generated traces that do not exist in reality) in the reconstructed digital geometry. Visitors passing by cause vibrations as well, or can accidently move the scanner or object.

During scanning, all of the operator's focus goes to the screen and the machine

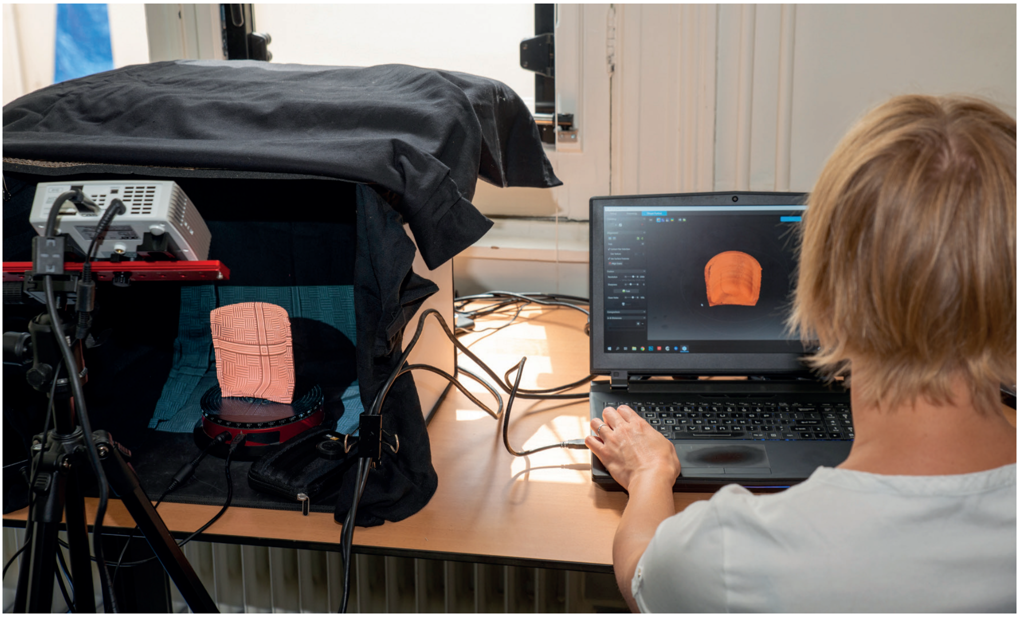


Figure **8.3**. The recording practice with a digital 3D scanner by digital archaeologist Loes Opgenhaffen. Photo: A. Dekker.

(Fig. **8.3**). The artefact's position is sometimes adjusted for visibility by the camera, to achieve full coverage of the surface. As a result, this new technique is a disembodied addition to the archaeological practice of the visual inspection, as the material interaction is completely in the service of the machine. The traditional visual inspection, however, can be performed digitally on the digital 3D model with interactive 3D tools, but disconnected from the tangible original artefact. As such, the practice becomes expanded and dislocated, yet it does not comprise a completely new way of visual inspection but mimics digitally an analogue practice.[102]

Post-processing practice in the lab

So far, the wider public does not have access to the selected data yet. However, from the post-processing phase onwards, the outside world impacts the way we save and present the data obtained in the field.

Back in the office, the collected data, which consists of digital photographs, paper notebooks, digital documents and 3D scans, has to be processed and integrated to form one coherent dataset. All targeted light photographs are entered in Adobe Lightroom, through which all metadata (such as camera and lens types, aperture, photographer, date and time, etc.), observed macrotraces, and basic physical characteristics of the object pictured, is written to the photo metadata files through a tagging system. Subsequently, the photo-by-photo metadata is

102 The complete technical workflow can be found here: https://tracingthewheel.eu/article/workflow-series-sls-with-david

then exported from Adobe Lightroom using the plugin ListView to the web-based database. This is a manual and laborious task that involves a lot of screen-gazing and clicking, but the actual interaction with the original artefact, and the actions of ancient potters that they represent and which are tagged, are never far away.

Additionally, in order to understand the traces left in the ceramics by past potters, the experimental archaeologist produces pottery in similar shapes and forming techniques (wheel-throwing and wheel-coiling). The familiarity gained through creation of, and the ability to derive comparisons from, these objects mean that she can identify which trace on archaeological material was created by which action(s). The production of these modern examples of ancient shapes is recorded on digital video from one to two angles, so that all actions and gestures of the potter can be captured. This video material is then time coded and prepared for sharing in Adobe Premiere Pro before being uploaded to the TPW database and YouTube, and assigned to the products, the pots, and the traces, both modern and ancient. All the experimental vessels are studied in a similar fashion as the archaeological artefacts in the field – photographed, described and 3D scanned – and documented and entered into the database.

The 3D scans made in the field are post-processed back in the office, in order to leave more time in the field for the actual scanning of artefacts. The post-processing consists of hours of semi-automatic and manual "alignment" of the separate scans. Furthermore, the scans require to be "cleaned"; unclear and irrelevant parts ('noise') are removed manually from the scans. This involves a concentrated gaze at the computer screen while intensively hovering and heavily clicking with the mouse. This cleaning process consists of a chain of almost unconscious choices and decisions on what to remove and which parts are deemed relevant. When the computer is unable to automatically align the scans itself, the operating archaeologist has to identify visually matching features. All these choices, number of scans, "fusion" (creating one geometry from the separate scans) and export settings, are recorded and entered in the database, in order to preserve transparency and reproducibility of the practice. Although most attention goes to the digital geometry and visual integrity of the scanned result, observations of the actual represented artefact are sometimes made and communicated to the other team members.[103]

Lastly, the aligned 3D models are exported to different file formats and simplified (decimation of the number of vertices while preserving the overall topology of the model) in Meshlab to create smaller file sizes. All changes made to the geometric properties of the 3D model, such as decrease in vertices and the removal of duplicated vertices, and the settings and parameters of this process, are recorded in the metadata fields of the database. Different formats and sizes are necessary to preserve accessibility, interoperability and usability of the models by fellow researchers for further analysis and interested parties. The repetitive actions and physical gestures involved in this final processing stage of the documentation practice suggest a misleading disembodiment between original and digital 3D artefact – as there is no seemingly material interaction with either of the artefacts. In the final archiving stage, the 3D models and their meta-

103 The complete technical workflow can be found here: https://tracingthewheel.eu/article/tpw-workflow-series-post-processing-3d-scans

and paradata are entered into the database and embedded with the aforementioned other media and related data. The 3D models are uploaded to a web-platform and enriched with information by tagging the macrotraces, that is visually indicating the traces in the surface of the model with geometrically linked annotations (tags) and text. This set of actions means that the operating archaeologist requires, besides having technical skills, knowledge of ceramic forming technology. The operating archaeologist should able to recognise forming traces, with the naked eye and during the 3D scanning process, in order to assess if the relevant parts of the vessel are recorded sufficiently. This later tagging stage involves real interaction with the digital artefact, and includes visual inspection in a traditional fashion: rotating the object, zooming/panning, directing light over the surface (if the functionality is available) and identifying the trace. Finally, the 3D models of the open access online platform are embedded in the TPW Knowledge Hub (that is, once all necessary permissions have been granted by the relevant cultural institutions). In this Knowledge Hub, the 3D models and other media and data are presented in a visually coherent way.[104]

Transitioning practice: layered complexity

By describing minutely the practice of collecting and recording while creating an archive, the increased complex layering of a particular archaeological tradition becomes visible. Rather than replacing an older recording technique, the new tools instead add methods and actions to the existing operational sequence. For example, photography has been part of the systematic archaeological recording and documentation sequence for over a century, but the technological innovation of the digital element to photography enables the creation of a vast archive of ancient forming technology, which can be published in its entirety, and publicly, due to the adoption of web-based data systems. The recording and, especially, processing procedures, however, require more intermediate steps than in the analogue era, as more data about the data needs to be recorded in order to safeguard intellectual and empirical transparency.

Digital 3D scanning is, however, an entirely new method to the practice of recording, archiving and ultimately data visualisation. The 3D scanner enforces a different kind of material interaction between device, operator and artefact, and its operation is distinct from previous, analogue visualisation methods. It increases recording and documentation time in research into ancient technology and affects the selection procedure of artefacts. The event (or sequence) of post-processing is far more complex than the digitisation process of hand drawings in for example Adobe Illustrator and the act of 2D scanning before that. The multitude of actions necessary to create a 3D model and the subsequent additional actions to generate models that are also usable by other stakeholders – as well as the metadata to document the tools and operational actions involved – significantly exceed analogue practice. However, the possibility to now perform visual inspection and analysis with virtual

104 The complete technical workflow can be found here: https://tracingthewheel.eu/article/tpw-workflow-series-democratising-3d-data-recording-the-process-of-3d-scanning-and-processing

versions of familiar tools (such as the torch and sections), from a desk anywhere in the world (removing the cost of travelling to museums, excavation depots and paper archives with limited accessibility) and with associated information instantly available with the digital artefact, enhances analogue practice in an unprecedented way. Printing the artefacts in 3D can return a different aspect of physicality, as the tactile inspection of ceramics is irreplaceable and indispensable in learning trajectories.

Reflection: An enhanced practice

It may be concluded from the discussion so far that a different collection practice is affecting the answers that are generated from the analysis of the increased amount of data. This analysis depends on the organisation and design of the digital research archive that allows the availability of the material. Complex data systems are required that go beyond passive storage of raw data, but serve as active knowledge generating tools supported by metadata derived from collection to data entry and interpretation. Such archives respond to democratic calls from societal developments, and enable full transparency of the entire chain of research, within of course the boundaries of European directives[105] on open data and the re-use of public sector information (which research data of universities is) and national and international privacy laws (AVG, GDPR). The reflexive, praxeological approach of data archiving enables the reproduction of workflows which ultimately enhances comparability between (increasingly vast) datasets. The resulting interpretation of these large amounts of data and their comparison could lead to new knowledge about, in this example, past potting practices and present archaeological knowledge practices.

The tradition of creating archaeological project archives may not have changed in its essence, but the way these archives are organised and designed have changed the way data is curated, shared and published. The digital possibilities afford the opportunity to publish all photographs and 3D models, whereas previously only a selection could be published due to the limitations of traditional paper media. Moreover, these media are dynamically enriched with associated data and metadata, supporting the reasoning process of the archaeologists who created it, while allowing other stakeholders to inspect, correct and create observations as well. Traditionally, at least in the particular case of ceramics analysis and more specifically research to pottery forming technology, this reasoning process remained a mystery and was not published with the scant printed visual evidence, with one major exception: the online journal ARKEOTEK. Although it does not facilitate 3D content, the principal objective of ARKEOTEK is to create a knowledge base centred on the “archaeology of techniques”, similar to the TPW Knowledge Hub mission, but without the multivocal component. Here, experts share their research through the “hybrid” publication of not only datasets and results, but also the reasoning processes built upon them by linking the arguments to the evidence (Gardin and Roux 2004).

The greatest advantage afforded by digital technology resides, however, in the

105 European directive 2019/1024 on open data and the re-use of public sector information (https://eur-lex.europa.eu/eli/dir/2019/1024/oj) (accessed 21 February 2022)

presentation of the data and the use of the archive by specialists and non-specialists alike. An active archive may serve as a knowledge hub, a place where different voices meet each other, forging new insights and interpretations about people in the past. The next section will explore the dynamics of such potential uses.

Reaching diverse groups of targeted users for a project archive

Description of the TPW Knowledge Hub

The organisation of the TPW Knowledge Hub[106] reflects the integrated practice of the project just described, as well as data and information about wheel-forming techniques and traces. The Knowledge Hub revolves around two focal points: as a place of knowledge exchange and as a place of learning. Both are based on a shared practice, visualised and communicated in different ways. Knowledge exchange takes place in the domain of "Collections", where datasets of members of the community of practice of pottery forming specialists are shared. These datasets may consist of experimental objects or archaeological artefacts. In the section on "Learning", both specialists, apprentices and interested lay persons can find procedures and workflows for 3D recording and collecting, as well as Learning Pathways on, for example, how to deposit datasets or to learn about forming traces. Finally, the section "Research" brings together the knowledge about ancient wheel-forming technology that has been gathered and created.

Collections

From the outset of the Tracing the Potter's Wheel-project, it has been the aim to not only publish its own datasets, but also to design the web-based archive as a place to collect and host similar datasets on the topic deposited by peers. The sharing of datasets enhances comparative potential, and increases knowledge about the uptake and adaptation of new technology such as the wheel into existing production strategies.

The object page consists of a large media viewer accompanied by four or five tabs, representing Overview, Description, and Forming of the documented vessel – either archaeological or experimental. The object page may be expanded with a tab for a 3D model if available and, in the case of an experimentally produced object another tab showing a Production Video. The media viewer represents a high-resolution photograph. Below the viewer there is a gallery of thumbnails showing the total amount of photographic documentation. In the tabs, metadata and paradata associated with the primary data are located together and are directly visible. This integrated demonstration of *data* represents the performative nature of data, and makes no hierarchical distinction between "raw" data, technical "metadata" or the intellectual "paradata", as all this data informs its creation and imbues the item with

106 https://tracingthewheel.eu/

meaning.[107] In this sense, there is no real authority of the original over the digital 3D artefact, as the original is simply out of reach to other voices. This understanding of associated, contextual data, such as the remarks and description of the 3D scanning process and videos demonstrating the process of making each individual experimental pot, is the direct visualisation of the project's collaborative practice.

The Overview tab provides data about, for example, the shape and forming technique, but also clay type and the name of the potter (in case of an experimental dataset). The Description tab gives further data on the part of the pot represented ("object component") and the traces observed. It also provides technical details about the image and image capturing procedure (exposure, ISO, lens used, etc.), as well as the opportunity to download the file. The Forming tab gives information exclusively about the object represented, such as observed traces and forming technique. The 3D model tab gives technical specifications about, for example, the scanner model, resolution, calibration details, information about export settings and the simplification procedure, the name of the maker of the 3D scan, and practical circumstances such as light conditions. Lastly, several downloads are made available of both raw scan files as several exported file types.

Research

The Collections section is first of all the place to publish datasets that form the backbone of research. The research that these datasets represent will be introduced in dedicated blogs. Other research outputs, often conventional forms of publication, can be found in the Research Outputs section. Ultimately, the collections are the place to exchange knowledge; commenting functionality on visual media can help specialists to find out more about the object, for example, to identify traces missed by colleagues or to correct traces or interpretations. This functionality, which is at the time of writing only available under the 3D models on Sketchfab[108], can instigate constructive discussions on the subject, and can be identified as a new form of scholarly reasoning beyond traditional scientific exchange and knowledge transfer.

Learning

Actions such as commenting on objects, learning to recognise forming traces in ancient pottery, reproducing a collection practice, navigating through the database or obtaining practical skills in 3D scanning, all constitute archaeological knowledge producing

107 For more information about the project's definitions of metadata and paradata, see Huggett 2019, 2020, section 2; Labrador 2012; Opgenhaffen et al. in press; Sørensen 2017; Srinivasan 2017.

108 This limited functionality through Sketchfab will ultimately be replaced by 3DWorkSpace, an open science/interactive tool for 3D datasets, currently being developed by a collaboration of researchers from ACASA, the 4D Research Lab and CREATE of the University of Amsterdam and the Smithsonian Institute. This research project is funded by NWO Open Science Fund. 3DWorkSpace will adapt the open-source Voyager 3D digital curation tool suite by adding multi-authoring and commenting functionality, as well as expanding the annotation and narrative possibilities.

practice. TPW is developing Learning Pathways (LPs) to introduce novices and specialists alike to the community of practice dedicated to studying pottery forming. LPs are powerful pedagogical tools that enable the raw data to be enriched with arguments and synthesis for a wide audience.[109] By following the FAIR principles[110], LPs ensure reproducibility, comparability and sustainability of digital scholarship by acting as interlinked articles and data which together demonstrate the entire research trajectory from data selection and collection to analysis and interpretation.[111] They furthermore represent the paradata, or reasoning process and knowledge production behind the data, while simultaneously preserving transparency and the possibility to reproduce the practice including all gestures and inherent choices. LPs break data in the Knowledge Hub into different comprehensible bits tailored to students in technological research to ceramics or digital applications in archaeology. Other LPs may guide specialists through the Knowledge Hub, acting as user guide. Although most LPs are in the design stage, some examples can already be given to illustrate the complexity and rich potential that such a framework can offer: The Reference Collection and the TPW Workflow Series.

The Reference Collection

The experimental dataset of wheel-formed pottery created by TPW forms a reference collection that can be used to compare traces with archaeological examples, as well as to learn how to recognise traces in the pottery. This can be done either by browsing through the objects and by searching for particular types of traces in the search bar, or by going to the external 3D Reference Collection on Sketchfab (which is also integrated in the object viewer in the Knowledge Hub), where dedicated collections can be found. These collections are "The Reference Collection on Wheel-Coiling Traces"[112], "The Reference Collection on Wheel-Throwing Traces"[113], and "The TPW training set on wheel-coiling traces".[114] The specific forming traces in the 3D models in these collections are indicated by tags: visual clues in the model specifying the type of trace and an explanation about the trace. However, not all 3D models have those annotations, allowing students to learn to observe the traces themselves. Familiar tools, such as panning and rotating, but also directing light to highlight parts of the surface of the

109 For a more elaborate explanation about LPs, see Hilditch, Jeffra, and Opgenhaffen, 2021.

110 The FAIR principles serve as guidelines, not standards, to facilitate the findability, accessibility and comparability of scientific data and workflows as well. For more information see Strupler and Wilkinson, 2017 and Wilkinson et al., 2016.

111 For more information about the database structure and workflows see www.tracingthewheel.eu and (Opgenhaffen et al. in press).

112 https://sketchfab.com/tracingthewheel/collections/reference-collection-of-wheel-coiling-traces

113 https://sketchfab.com/tracingthewheel/collections/reference-collection-on-wheel-throwing-traces

114 https://sketchfab.com/tracingthewheel/collections/the-tpw-training-set-on-wheel-coiling-traces

represented vessel, enable to partly simulate the physical practice of pottery analysis.[115]

The collection with the training set contains a selection of 3D models with clear traces and 3D models of traces, which have been extracted from pots and modified to enhance visibility (through exaggerating the traces by adding more depth or by enlarging them). These models can be downloaded and printed in 3D to be used in courses on recognising forming techniques, as tactile exploration is equally, if not the most important, part of identifying forming traces.

The TPW Workflow Series

The practice of archiving pottery in 3D has been synthesised into practical workflows called the TPW Workflow Series. These descriptions are either written as a manual to guide 3D scanning and processing step by step[116], as informative blogs about how to make data democratic by recording the creative process[117], or tips and tricks about different scanner brands and DIY solutions.[118] Besides being valuable learning tools for students, these workflows can be (re)produced by other specialists in order to create quantitatively and qualitatively similar datasets, which will enhance the comparability of datasets and subsequent knowledge production.

Critical thoughts and issues about digital archives such as the TPW Knowledge Hub

An appealing and intuitively navigable website is crucial in user-centred design. Unlike other archaeological databases and websites, the developers of the TPW Knowledge Hub were first and foremost concerned with what the archaeologists of TPW would like to communicate and to whom exactly. Therefore, they first designed several mock-ups of layouts, after which the technology and system was adapted, instead of the other way round. This resulted in a website with a database in a gallery format. What furthermore distinguishes the Knowledge Hub from other databases is that 3D content is considered as complementary and not as a separate class.

According to ceramic specialists, the resemblance of the digital navigation and interactive tools to analogue practice, make the digital counterparts intuitive to use. The annotation functionality (native to several 3D viewers such as Sketchfab, 3DHOP and Voyager), however, adds an informative layer to the original artefact, as panning and rotating a 3D (or any) artefact does not convey much if not know what to look for. This annotation goes by "tagging" the traces in the 3D vessel. In these tags, information about the trace is provided and optionally enriched

115 See footnote 109. The embedded 3D viewer Sketchfab will be replaced by Voyager, which has more tools and functionality. Additionally, 3D WorksSpace will be applied to create LPs.

116 https://tracingthewheel.eu/article/workflow-series-sls-with-david

117 https://tracingthewheel.eu/article/tpw-workflow-series-democratising-3d-data-recording-the-process-of-3d-scanning-and-processing

118 https://tracingthewheel.eu/article/obsolete-technology

with hyperlinks for further reading. Perhaps the greatest advancement is the Knowledge Hub as a whole: specialists can access and analyse the material from their desk anywhere in the world. However, at the time of writing the Knowledge Hub is still under construction, and, for example, a comment functionality per object has yet to be implemented. Only then truly collaborative research can start.

Nevertheless, there are some issues that not only TPW but all archaeologists and heritage specialist should be aware of. An ongoing problem is true accessibility of data. TPW's principal aim is to have peers to share their datasets using the Knowledge Hub and to exchange knowledge by participating in discussions on these shared objects. Despite TPW's democratic intentions, a complex mesh of transnational directives and national laws of governments, institutional incentives and even personal willingness of publishing data (Tsiafaki and Katsianis 2021), financial and technological availability, deter full disclosure of archaeological data in (digital or analogue) open access archives. This situation risks the exclusion of stakeholders other than privileged scholars from engaging with the data and participating in the production of new knowledge. This is not the place to fight the power concealed in and maintained by archives, but it is hoped that governments and institutes will take notice and start stirring along current societal waves, away from traditional ideas about proprietary rights to the past.

Another form of exclusion is that institutions, projects and scholars, with limited budgets or residing and working in remote areas, cannot have full access to the Knowledge Hub. Poor quality or lack of broadband hinders using the Reference Collection and to interactively engage with for example the 3D models and YouTube videos. Related to exclusion is the directionality of "free search". Who decides what a user can find?

Related to this is the standardisation of data and its organisation, with as inherent consequence a degree of direction. Archaeologists determine what to select and document of an already fragmented past, and decide what is lost (Bauer-Clapp and Kirakosian 2017). Fortunately, archaeological projects increasingly provide transparent documentation and argumentation indicating what is not recorded and why, which at least prevents obsolescence of data. Nonetheless, a rigid search functionality affects, but also directs, data retrieval and use through the application of a particular search vocabulary. As the search labels are connected to the filters, and the filters to specific semantic data in the database on which TPW built its narrative, the search is always directed. As a result, users are required to enter concept labels from a predefined set of specialist vocabulary that follows traditional standards, a problem already recognised a decade ago by Robin Boast and Peter Biehl (2011). Does this new technology based on older conventions obstruct the generation of new knowledge and chance discovery, or is this an acceptable consequence of a community-driven research-project database with clear goals?

Finally, how do we know what people are looking for and what do we want them to look for? An important insight is that non-specialist users are looking for *information* (Huvila 2008, p. 17) and not the abstract data or individual records that digital archives tend to provide. By placing emphasis on the activities of producing experimental pottery, and analysing and recording ancient pottery, TPW's active archive has more explanatory power about past human potting practice, as well as what it is that archaeologists do. This is what the TPW project is keen to communicate and share, but how do we measure and assess potential users (persons) experiencing the Knowledge Hub, and how the information is perceived? The next sections explore these pressing aspects.

Research to the User Experience of digital archaeological archives

The creator, user and archive-system meet through the interface. The user friendliness of the interface determines how smooth those interactions (operations and actions) run between data, media, its contributors and participants and different environments or visualisation levels (2D, 3D) (Lewis 2012, p. 1267). Therefore, the development of an archive with optimal and inclusive usability is pivotal. These aspects afford how not only the use of the system is learned, but also facilitates how the knowledge is transferred and learned and new knowledge generated. Understanding the mechanisms of the interface from a social, use/user perspective or "the role of humans in complex systems" (Salvendy 2012, p. xvi) enables to assess to what extent of the participatory goals of the archaeological archive are met and discloses co-creative processes of situated learning and knowledge production. Little research into 3D user interfaces in heritage has been carried out so far (for an overview on 3D-related projects for heritage and a 3D user interface, see Huurdeman and Piccoli, 2021), and often user needs and usability are not the core objective.

Fortunately, this focus on data use, user interfaces and functionality of digital archives is shifting towards users as humans and true participation in archives. For example, uses and experiences of students using 3D collections to learn about artefacts have been preliminary investigated (Ekengren et al. 2021). Others have explored the aura and authenticity of 3D models by deploying user evaluations (Cardozo and Papadopoulos 2021). Lisa Börjesson recently mapped which information systems are currently in use to share archaeological information, in order to assess how archaeological knowledge is organised (Börjesson 2021). Analysis of the uses of tDAR revealed that contributors "use content to preserve, make available" their content, and that it has been used for research into family and local histories (McManamon et al., 2017, pp. 242–245). An excellent survey on "community needs" among archaeologists and heritage specialists carried out by researchers from ARIADNEplus did not extend to (re)uses of publicly accessible repositories beyond the academic community (Geser 2021).

These are exemplary attempts, demonstrating a nascent attention towards understanding the users (Huvila 2008) and the "expectations, experiences and perceptions of the implications" of the public engaging with digital archives in archaeology (Andresen et al. 2020, p. 185). However, the actual processing of comments of lay-persons and "engaging users as contributor[s] is still very rare" (Andresen et al. 2020, p. 204; Jansson 2017, p. 516). This has parallels to a similar observation made in museology, where "these voices … rarely are they recorded in an enduring way in the museum's catalogue" (Boast and Biehl 2011, p. 122). As a result, no set of standards or guidelines exist as of yet that facilitate the assessment of the user experience and user needs of online archaeological or heritage archives (Champion 2019; Huurdeman and Piccoli 2021), with a focus on the *learning* experience and subsequent knowledge creation.

It appears that persons have become quantifiable users (McNeil 2020). But experience, learning and affect cannot be tracked with visitor or download numbers, as they do not really inform what people are doing – engage and interact with the data and internalise the information. So, the lamentable outcome is that the user does not really take a central place in the creation and assessment of archaeological archives. How to achieve a more central role for our targeted users? In the following section the results of a survey to the experience of users will be presented.

Who will experience the TPW Knowledge Hub? Introducing user personas to archaeology

The FAIR principles are a good starting point to disseminate research data, but they are not about human interaction. The principles are designed from a machine-actionability perspective (Wilkinson et al. 2016), based on the idea that people increasingly rely on computational applications to find and manage data. Although TPW adopted these principles successfully into the digital infrastructure of the Knowledge Hub to organise and manage all project data and associated knowledge, we do need to know *who* and *how* we envision actual humans to find and use the data, and how TPW would like to receive and create new knowledge through the interaction with peers and public.

Over the last decade or so, at least outside academia, user experience (UX) design has taken a central role in what people do, desire, exchange and want to achieve (Sherratt 2021). User experience takes a broader perspective and considers the entire chain of interaction of the person with the machine or product, including affect and perception, in order to improve usability and the inherent transfer of knowledge. In academia, however, there is no (nor should there be) marketing point of view of "a product", but it has, for good reason, become an ethical obligation to disseminate academic results and knowledge to the public. Giving instructions on how to interact with the media and data in the Knowledge Hub are key in good UX design. But how do we know how these instructions are received and if they work? And will the instructions work for all kinds of users, i.e, is the interface design responding in an intuitive manner to different audiences, and is the design appealing in the same effective way? Designers often get the question to design something useful for "everyone", which risks overcomplexity, "over-choice" and ultimately design for "no-one" (Miaskiewicz and Kozar 2011, p. 428). For that reason, adopting and implementing a Persona Model with specific descriptions of different target users could be beneficial to scholars.

TPW has adopted the design thinking approach, which is a human-centred way to explore, predict and design online interactive behaviour, in alignment with the project goals (chapter 7; Opgenhaffen, Jeffra, & Hilditch, in press). UX is rooted in this approach and serves as a method to develop the human-centred system of the Knowledge Hub (Ritter and Winterbottom 2017). User personas help in ascertaining the interactive behaviour of the system (Zellhöfer 2014). User personas are not actual persons, but rather are *imagined* composite biographies[119] or "hypothetical archetypes"

119 After https://www.productplan.com/learn/user-persona-vs-buyer-persona/ (accessed 19 January 2022)

(Cooper 1999, in Nielsen, Larusdottir, and Larsen, 2021, p. 330), based on research and experience to describe characteristics, needs and goals of actual people. They allow for consideration of how users may want to interact with the data in the Knowledge Hub. Ideally, this could have helped the TPW team and the developers of Kbell&Postman to locate and understand learning difficulties already in the design stage (Pruitt and Adlin 2006, p. 8). However, TPW has adopted this approach in a later stage to improve the beta version and public outreach ends. Subsequently, adding visual cues to guide the users through the Hub, improve the user interface (UI) with optimal intuitive functionality and navigation (Ritter and Winterbottom 2017), while shaping the information architecture underlying it. Several aspects depend on determining a user persona, such as research aims and the targeted impact of the system.

Creating user personas are, in a way, a kind of "applied ethnography" (Norman 2013, p. 222). It ideally starts by collecting data about existing persons by employing interviews, field studies, surveys, user testing, tracking and beta version feedback (Pruitt and Adlin 2006, p. 8). This research-based approach is further strengthened if personal experience is included into the personas (Nielsen et al. 2021), whereas assumptions on targeted users, or assumption-based personas, usually do not add to the creation of a stable persona and leads to more work in adapting the UI (Marshall et al. 2015; Nielsen et al. 2021). Concepts such as age, gender and ethnicity, for example, are thought to cause assumptions. However, if the level of inclusivity of the Knowledge Hub is to be assessed, these aspects should be inquired. John Pruitt and Tamara Adlin advise to "embrace the challenge of communicating information about users through narrative and storytelling" (Pruitt and Adlin 2006, p. 37). Narrated personas can, besides being crucial in architecture and UI design, also assist in the development of user guides and LPs. I took inspiration from the Persona Template as proposed by Marli Ritter and Cari Winterbottom (2017, p. 133), which has been further refined along the guidelines of the User Profile Model developed by Jessica Sherratt for UX Collective (Sherratt 2021). It resulted in the "TPW's Persona Template" for UX design for archaeological projects.

The following steps describe the procedure of creating personas, as formulated for the Knowledge Hub, and for finding users and experience assessment of archaeological project archives.

Step 1. <u>Start with a research statement</u>: **What** are the research goals and aims of the website and/or system? **For** whom? **To what end**? What should be achieved and should be the impact?

For TPW this would be firstly to facilitate specialists and students to use and reproduce TPW's archiving practice and workflows; for laymen, students and non-specialised archaeologists to learn about ceramic forming technology/ recognise traces; and to finally collect more data, so that more knowledge about the uptake and transmission of technology in the past is generated.

Step 2. Define the motivations of certain groups to find, search and use the data in the TPW Knowledge Hub:

- Demographics (education, age category, whereabouts).
- Who needs to be reached and why (occupation, profession)?
- Motivation of the user (interests and activities).
- Degree of digital literacy and available technology (i.e., devices, internet connection).
- What research practice is employed?
- What do people want to achieve/need/require?
- User scenarios (map the bottlenecks and potential frustrations).
- Empathic approach: understanding the experience.

Step 3. Things we want to assess:

- The **effectiveness**: which specified users can achieve what particular goals we want them to achieve? How easy do they get from A to B?
- How **efficiently** are the specified users going from A to B? Which resources are they using to get the desired results?
- Level of **satisfaction**: are the users happy or frustrated in their navigation through the system to obtain the results? How will this affect other potential users, if the system receives bad recommendations?

Step 4. Develop a survey through a questionnaire and/or interviews based on the information stated above to gather additional information if needed.

Step 5. This questionnaire can be adapted after beta-testing to inquire end-user experience and feed-back.

I have designed a UX model (Fig. **8.4**) that summarises and guides the UX design process of archaeological archives. It is a layered model representing the design process and assessment of the UX of an archaeological archive. The goal of the archaeological project and archive is always prominent, and the needs and desires of the targeted users and the aims of the archaeologists are clear. Once the main issues are identified, the problems and solutions layer enable to address the needs, behaviours and motivations of the users (problems), in order to improve the experience to access, navigate and use the platform. Once these are solved, the next layer offers understanding of the personas and the identification of the level of digital literacy and motivation to learn and/or contribute to knowledge production, the system can be disseminated to the targeted users based on the personas. The TPW's Persona Template (Fig. **8.5**) guides the construction of these personas. This diamond-shaped template summarises the different aspects that make up an imagined protagonist of a targeted user group. The project or platform's goal takes, again, a central position and always stars in the description, implicitly or explicitly.

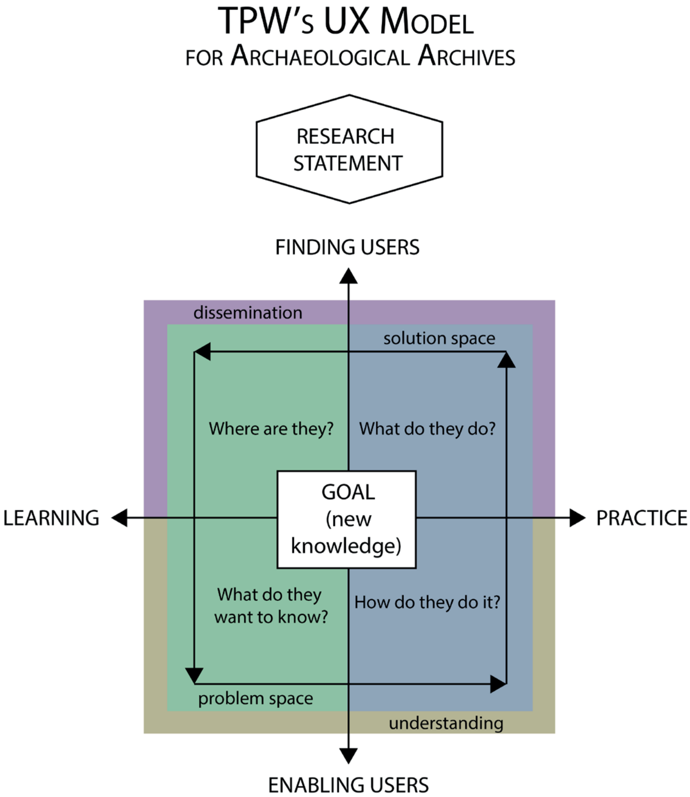


Figure **8.4**. The TPW's UX Model for Archaeological Archives. Image: Loes Opgenhaffen.

The questionnaire

A questionnaire was developed to identify who is visiting and using the Knowledge Hub, how they experience it and what they think of it. It is also designed to inquire what specialist users miss or expect to see in the Knowledge Hub, something we dubbed "User Desirability". The questionnaire was initially intended for end-users, but it informed the construction of user personas as well.

The questionnaire[120] is divided in five sections, which are all accompanied by a small introduction to explain why we want to know these things. The first section is set up to map the background of the users, in order to create a safe and inclusive digital environment. It includes questions about professional occupation, education and possible limited ability. The second section is dedicated to the learning experience of the Knowledge Hub, in order to inquire how people found the Knowledge Hub, navigated between the different sections within the website, perceived the information and used the data to learn about forming traces in pottery. The third part is oriented

120 The questionnaire can be found here: https://docs.google.com/forms/d/e/1FAIpQLSc2GHiUrONJambAI7k8Wxz0gMcvuzRZycpGvU44HibGUGoapA/viewform (accessed 26 January 2022)

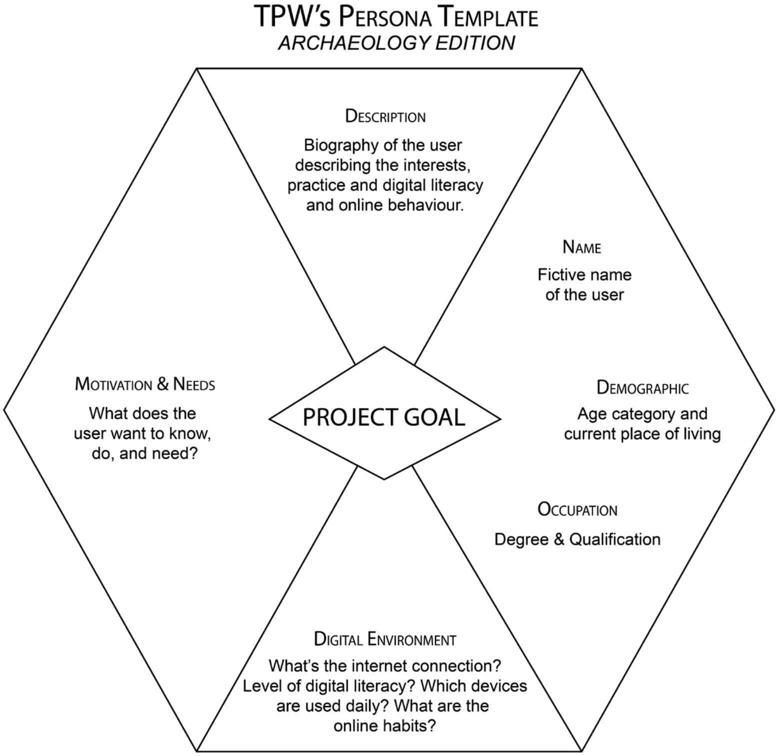


Figure **8.5**. TPW's Persona Template. Image: Loes Opgenhaffen.

on the workflows that have been published on the website, to assess if they are clear and useful to people and if they would adopt and deploy them into their own practice. Actual user experience of particularly the Reference Collection and the objects in the database, is analysed in the fourth section. Lastly, in the fifth section, the general impressions about the design and functionality are queried, such as navigation between different assets including photos and 3D models. The survey was launched mid-November 2021, when the Knowledge Hub was still being refined, and is still running.

Complementary to the online questionnaire, personal informal interviews were taken among academic, specialist and lay persons. The preliminary responses of the questionnaire (n=14) and interviews (n=11) are too limited to generate decisive conclusions, but already adaptations to the system and design could be made, and user personas developed. The aim is to officially launch the Knowledge Hub alongside the opening of the final exhibition of the Tracing the Potter's Wheel project, in October 2022. Through this hybrid exhibition, discussed in the following section, the project envisages to reach a greater audience beyond the specialist realm. The outcomes of this survey and testing of the proposed framework to determine targeted "audiences" and create true societal impact of archaeological project archives, will be published in a final paper.

The general idea is that UX metrics have to be quantifiable and for that (Tullis and Albert 2013), the observations have to be translatable to numbers. The usability of a system, however, such as the navigation between the different types of media and search functionality, can only be truly assessed when it has been tested with real users interacting with it (Ritter and Winterbottom 2017, p. 7). As experience is something inherently volatile and personal, open questions in the questionnaire are devised to identify those experiences.

Preliminary results of the questionnaire

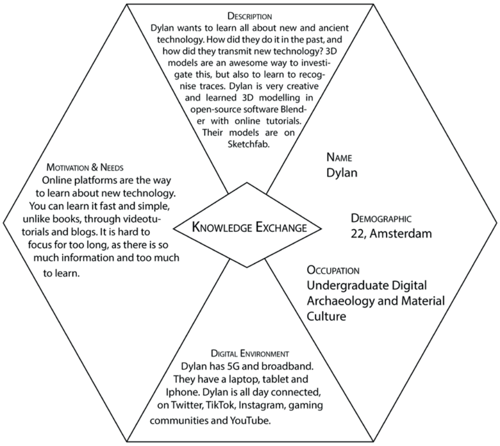
The respondents of the questionnaire mostly occupy an academic position or are trained archaeologists active in the field (n=12). Most are specialised in ceramics technology or material culture (75%), and 3 in digital archaeology (21.4%). Other (complementary) specialisations reported are building techniques and potting. An average proportion of the participants heard about the Knowledge Hub via colleagues (50%), family/friends (28.6 %), social media (14.3%), online search on pottery technology (7.1%), and at a conference (7.1%). Half of the respondents were Dutch, others Belgian, German, French, Greek, Portuguese and Italian. Interestingly, the question about ethnicity did not result in a diverse outcome as most reactions correspond the nationality.

Most of the respondents have read the posts about forming technology and had a look at the (3D) reference collection (71.4%) and learned something new (92.9%). A positive outcome is that, if applicable, 57.1% would implement the reference collection as a learning tool in their curriculum, and all respondents would recommend the Knowledge Hub to colleagues. In the third section about the currently available workflows, however, 42.9% of the participants did not find the workflows, and when they did, 35.7% responded they were not relevant (as of yet), which is to be expected considering the specialisations (ceramics and material culture) of the respondents (42.9% responded "not applicable"). However, the workflows are not only designed for digitally literate archaeologists, but also aimed to be adopted in research practice to ancient forming techniques.

In the fourth section about the user experience, only a small number of participants have used the reference collection to compare material (23.1%) – and they were 75% successful in identifying traces, of which 66.7% would use the reference collection in the future.

In the fifth and final section about the design and functionality of the website and database as a whole, 71.4% of the participants think it has a clear usability and a positive design, and 21.4% are neutral about it. The search functionality was not received outstandingly: only 33.3% received the expected results, and 50% received only partly relevant and partly strange results, and it was commented that it was a difficult experience to query the database. Exploring the database was considered either easy (50%) or a bit difficult but manageable (35.7%), and it was reported as easy to navigate between different media (85.7%) and associated (meta and para) data (61.5%), and quite easy to explore the 3D content (64.3%). The participants spent a moderate amount of time exploring the Knowledge Hub: almost half of the respondents stayed 10-15 minutes, whereas 21.4% more than 15 minutes and 21.4% 5-10 minutes.

Finally, three respondents remarked in the final comment field that the overall impression, when first entering the website, the information is quite overwhelming, with "crowded pages".



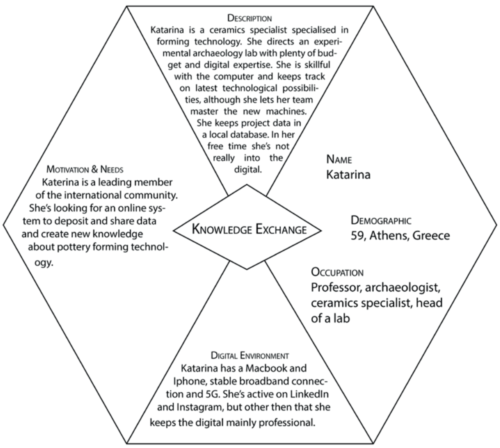


Figure **8.6**a-e. Different types of user personas TPW aims to address. The personas range from younger and older lay persons with an interest for archaeology, to students and specialists with limited internet access and specialists with good internet access. Images: Loes Opgenhaffen.

Insights from informal interviews

When talking personally to different user groups – lay persons and colleagues – these remarks of the three respondents are confirmed: particularly a non-specialist, lay audience perceive the website as too massive and intimidating and hard to focus for a long time, and did not complete and submit the questionnaire because it was "too difficult". Other lay persons were very excited about the 3D models and videos, which are considered the most interesting and least abstract form of information. A very positive outcome of the informal interviews with archaeologists is that they recognise TPW's practice reflected in the organisation of the Knowledge Hub, especially in the presentation and organisation of the object/media viewer accompanied by associated data. A number of members of the community of practice of ceramic technology specialists have confirmed informally an intent to contribute datasets to the Knowledge Hub. Some students (including student-assistants) in digital archaeology and material culture (n=6, both academic and applied sciences) have successfully reproduced the 3D workflows (see Opgenhaffen, 2021, and the 3D models on Sketchfab).

TPW's user personas

What conclusions can be drawn from this? The information on the website, especially the landing page, has been adapted accordingly to divide the information in more concise and manageable chunks. There is a separate User Guide, a less dense menu header and submenus should now direct more clearly to the blogs and workflows. A major insight is the fact that only one lay person has filled out the questionnaire. From personal communication it became clear that although non-specialist users like to read about 3D printing, rotate 3D models and watch the potting videos, the information about traces is not reaching them. It can be determined that their online behaviour is different from the specialists who are already acquainted with the material and tend to stay longer on the website, contrasting against uninformed persons who lose interest within five minutes. Together with the observations of museum audiences obtained during a small exhibition of the project called "Tracing the Conical Cup"[121] (Norman's "applied anthropology", that is, to "go out there"), this proved to be valuable information for the creation of user personas (Fig. **6**a-e). These can then inform how to guide and inform these user groups through the Knowledge Hub, and how to reach them through particular media channels associated with specific user personas, among which museum networks.

With these personas in mind – albeit informed by a very limited user base, and therefore presented here as a potential example – TPW can promote the Knowledge Hub in more targeted ways. It became clear that not everyone can be reached, but specific groups can be designated to be addressed, while creating an open and an as transparent as possible environment. The community of established specialists has been informed through academic and specialist channels, but other archaeologists, potters (both artists and amateurs), museum visitors (or the greater mass of people who do not visit museums) and even students are a greater challenge to approach and to excite about

121 https://tracingthewheel.eu/page/exhibition (accessed 31 January 2022)

Figure **8.7**. The blacklight traces-station of the Conical Cup exhibition, designed by Caroline Jeffra. Photos: Caroline Jeffra.

ceramic forming technology and related research practice. How can a potential user find and use a Knowledge Hub about a subject they did not know existed and were not looking for either? More data is required from the online survey and observation on the ground, however, this chapter aimed to provide stepping stones to guide such an inquiry.

TPW's project exhibitions[122]

TPW's Knowledge Hub has been principally designed along project aims and needs, experiences derived from the community of practice of specialists in ceramic forming technology. Collaboration with museums and institutions through the organisation of the small international (pilot) exhibition *Tracing the Conical Cup*, further fostered its design.[123] At this exhibition, observations could be made from and informal interviews with museum visitors, which provided many insights

122 This section was not included in the published version, because it requires more research to museum practices. Museum practice is not one of core objectives of the PhD project, but is planned to be investigated as postdoctoral and collaborative project output paper of TPW nonetheless. Therefore, the section mainly demonstrates the potential of 3D technology for public outreach, and to serve as an example of the "applied ethnography" approach to develop user personas.

123 https://tracingthewheel.eu/page/exhibition

Figure **8.8**. The touch-table at the Conical Cup exhibition. Photo: Loes Opgenhaffen.

about how they perceive and interact with the exhibited material. The Tracing the Conical Cup exhibition ran in September and early October 2019 at the National Heraklion Archaeological Museum and The Netherlands Institute at Athens.

The exhibition took the ordinary, mass-produced yet iconic Minoan conical cup as focal point to demonstrate how archaeologists do what they do when they are not excavating, and which modern techniques they use to study past technology. Five stations demonstrated the innovative techniques that shed light on ancient production. The first station contained reproduced cups with traces indicated with fluorescent paint, which would reveal themselves when visitors point a black-light torch at them (Fig. **8.7**). Another station was the touch-table. Here, visitors could touch the material, reproduced ceramic pots and 3D printed plastic pots, and learn to identify the traces themselves (Fig. **8.8**). A third station was a movie displaying the analysis of the fabric (visitors were trying to touch and navigate their way through it, but the movie wasn't interactive). Other stations were less interactive, but appeared to be attractive as predominantly selfie-hotspot: the "pop-art" station with 42 identical and colourful 3D printed cups in pop-art style, demonstrating the mass-production of these cups in the past and their similar use as disposable cup in the present. The "holo-box" too was popular, a reproduced conical cup in which liquid was virtually being poured, through projection on a glass plate positioned invisibly in front of the vessel. Lastly, a movie was projected showing the practice of TPW: the manufacturing of the cup by the experimental archaeologist, the fabric analysis by the analytical archaeologist, and the 3D scanning and printing process by the archaeological visualiser.

What the visitors appreciated most, however, was not so much the interactivity with the material, but the contact with the archaeologists. When visitors entered the room, they were uncomfortably touching or hesitantly looking at the material, at first disappointed that the material was "not real" (as in modern). The archaeologists of the TPW team, who were working in the exhibition room, would then approach them, grab a cup and ask: "what can this pot tell us?" As such, the vessels "came alive" and people were able to connect the information offered in the exhibition to objects on display elsewhere in the museum.

This was of course an exclusive experience; archaeologists are not tour guides and cannot stay full-time at their exhibition. Nevertheless, the unique insights gained by this kind of "applied anthropology" towards the visitors (Norman 2013), could inform the user personas that will help to promote the archive and improve the design of the project's final exhibition, in which the Knowledge Hub will be more explicitly integrated.

Another, final exhibition is planned in autumn 2022 and to be held in the Allard Pierson Museum in Amsterdam, in collaboration with the local ArcheoHotspot.[124] ArcheoHotspots was initiated by the Allard Pierson Museum but is now supported by several national foundations on various locations, and largely driven by passionate volunteers who strive to promote archaeology to a large audience through active participation in running projects. By using the networks and media channels of the museum and ArcheoHotspot, archaeological projects such as TPW's can inform and invite communities which are otherwise out of range.

The difference between the pilot and the final exhibition is that the focus will be shifted from an object-oriented towards a practice-based perspective: how and why archaeologists perform research. In doing so, people visiting the exhibition will be introduced to both past and present technological practice, and simultaneously become users by accessing the Knowledge Hub through QR codes displayed throughout the exhibition and museum collection. These QR codes can be references to individual objects, as well as to video tutorials, blogs and workflows. The new exhibition will be extended by a virtual companion which supplements and complements of the physical exhibition, fully embedded in the Knowledge Hub, to offer greater accessibility and inclusivity, and continued exploration at home. Furthermore, the artefacts in the exhibition and the Knowledge Hub are not isolated, but embedded in a much larger framework of data collection and exchange, which allows to study and construct a narrative about past human behaviour through technology and practice. The museum exhibition acts in this way as the user interface, facilitating the otherwise invisible information about the story of that artefact in a wider context: how it was made, what this means and how archaeologists came to know this. The complex concept of technological trajectories and connectivity is conveniently explained by applying this hybrid, intuitive, multi-level, and performative method.

Summary and future directions

The archaeological archiving tradition is in transition. The analytical tools and practices in the archaeological toolkit have remained largely the same, albeit replaced

124 https://archeohotspots.nl/archeohotspots/ (accessed 31 May 2022)

with digital surrogates. The intimate, tactile and visual practice of physical inspection of the archaeological material, has in particular cases been affected by the deployment in this practice of digital recording devices, such as a 3D scanner. However, the publicly published 3D content enables a different kind of embodied practice with the original artefacts, which can now be visually interrogated by anyone anywhere in the world with similar yet virtual tools. The introspective analysis of TPW's archiving practice and description of the online archive, has demonstrated that the adoption and implementation of digital (3D) visualisation technology into archaeological collection and recording practice in particularly the specialisation of ceramics analysis, is transforming the archive from a passive storage facility towards a dynamic place of sharing and exchanging archaeological knowledge about pottery forming technology.

The issues and outcomes of this chapter may be summarised as follows. The point of departure of the chapter was the statement that a digital archaeological project archive is not a passive repository of data, but a dynamic and participatory environment of data and knowledge exchange and learning. Furthermore, the digital archive could be a transparent site of collaborative scientific reasoning based on the shared data in the archive. The premise for a transparent process is to place equal importance on sharing data and on sharing (project-based) archiving practice, which enables the creation of similar datasets that increases their comparability and reproducibility. In order to guide the mapping of this practice, the reflexive and praxis-oriented Tradition in Tradition framework has been applied. By scrutinising and analysing the sequence of actions, tool-use and inherent gestures of and interaction between the members of TPW (following the *chaîne opératoire* approach), the impact of the digital tools could be assessed. But not only that: the mapping of archiving practice and subsequent open access publication in this journal and on the TPW Knowledge Hub, creates the potential to advance the *practice* to a standardised *procedure*, if adopted, adapted and further refined, and reproduced by other members of the community of practice of pottery specialists. An important insight that came with this framework is that it can be applied as infrastructural inversion: as a reflexive method to bring hidden scientific practices behind digital infrastructures to the surface. This is what makes the archive not only a data repository, but an open space for exchange of experience and expertise between specialists (Boast and Biehl, 2011), as a dislocated yet situated *lieux the savoir* (Huvila, 2018) and place of encounters between human and non-human encounters (Cameron 2007; Ireland and Bell 2021). As such, the performative nature of the archive, as a dynamic social space where archiving continues as its multiple usages of data and procedures create and add more data and diverse knowledge, this recurrent motion of archiving practice beyond the trowel's edge and storage room, as a multivocal research process.

The reflexive approach pushes further democratisation of digital archives as opposed to analogue archives by disclosing virtually archaeological material outside the inaccessible excavation and museum storages and showcases. This material can now be studied be other experts from all over the world, widening the debate on forming technology from linear presentation of a few slides of archaeological material on physical symposia, to an interactive discussion about any fragment from Argentina to Amsterdam; ultimately increasing knowledge about forming technology.

Yet specialised archaeologists are not the only targeted audiences of TPW. From the outset, the collection and recording procedure was designed to be shared with apprentices and interested lay audiences as well, as a new kind of interactive learning aid. Especially the experimentally produced ceramics were aimed to form an online reference collection about ceramic forming traces and techniques. Usually, analogue reference collections are limited to a few specialised academic institutions, but online they become accessible to all. A few specialists have already indicated that they would adopt the online reference collection with 3D content into their curriculum, and the very preliminary responses from the online survey showed that non-specialised archaeologists plan to use it during fieldwork as well, as a comparative resource.

Lastly, to include other voices than archaeologists, and to create a user-friendly digital system accessible and usable to multiple designated communities, the user (rather than the uses) of data should take a central position. The following notions and approaches were developed to meet expectations and reach people. An archaeological project should start with adopting a user-oriented instead of a system-oriented survey to experience, because this will make a user a person again, and moves the focus on data uses to persons using data. Design thinking is one such user-oriented approach, and it should be implemented at an early stage of database development and UX design. To determine and improve the UX of the project archive, user personas are a valuable way to determine anticipated and targeted user groups.

The infrastructure and technical know-how have arrived at advanced stages and have been implemented at a few institutions. But digital recording is not an end goal in and of itself. It is merely a technique to advance the study of past human behaviour and society as well as present research into this. A last case in point is that opening up an archive to all does not necessarily mean that everybody needs or will use it, or is able to find it. It has been acknowledged in this chapter that not every social group can be reached, but that the archive should be designed in a way that it is open and welcoming to everyone nonetheless. Transparency of *practice* is key here. By disseminating data and practice in an open and active infrastructure, other stakeholders are offered the possibility to use the material in the archive in order to understand what moved past people when practicing technologies and how present archaeologists engage with this. This movement keeps the archive in action.

Chapter 9

Discussion

Introduction: Drawing things together

The principle aim of this research project is to explore how modern 3D technology could be applied to an inherently visual and tangible specialisation such as ceramic analysis, in particular the technological analysis of forming techniques. This study is part of the larger project Tracing the Potter's Wheel (TPW), in which different techniques and specialisms are combined to investigate technological transfer in the Late Bronze Age Aegean. Assigned with the specific task to explore how high-resolution 3D scanning and resulting 3D models could enhance the study of forming traces, I optimistically started the project under the assumption that my background in 3D visualisation would easily and unproblematically transfer the skills and techniques to this field in archaeology. This personal example illustrates the wider issue of the little awareness archaeologists have of the impact of current (digital) technology on their own practice and subsequent knowledge production. What kind of data and knowledge is produced with the application of new technology? These questions quickly arose when the theoretical approaches and methods of the TPW project to assess how technology had an effect on past societies, with a focus on the potter's wheel as such a technological innovation, were applied to the present study. This insight led to the main theme of the dissertation, which is to assess to what extent the technical tradition of archaeological visualisation in general and object-based visualisation in particular, has changed due to the adoption of digital 3D technology.

To determine to what extent the visualisation tradition has been adapted or even changed, chapter 2 explored the history of archaeological visualisation practice with specific attention to artistic innovations and new technology, in order to identify what current practice actually entails. It has combined the history of archaeological visualisation with the recent history of digital archaeology, which were hitherto considered separate specialisms with their own histories, identities and practices. Chapter 3 followed the historical approach with a brief overview of the advent and development of digital 3D scanning and modelling and the subsequent introduction and adaption of this technology into archaeological practice concerned with object visualisation, and ending with a state-of-the-art of these technologies in ceramics analysis. The current uses and abuses of terminology related to 3D visualisation in archaeology were examined in chapter 4, with a focus on the volatile characteristic of terms such as high-resolution and accuracy - which are dependent on the available technology available at present - and the subjectivity of digitally generated images. The fifth chapter presented a newly developed reflexive and praxeological methodology called Tradition in Transition, which is designed to critically map and assess current archaeological visualisation practice. The methodology was expanded with the designerly thinking approach in technical chapter 7, which described the development of TPW's database from a User Centred Design approach (UCD), which is further implemented in chapter 8 on archival practice with User Experience (UX) design. In this chapter, the concept of user personas was introduced to archaeology. Chapter 6 has been dedicated to the development of a standardised method for high-resolution 3D scanning of archaeological ceramics with a focus on enhancing digitally the visibility of forming traces, which have been published online in the TPW Workflow Series. This enhanced visibility was brought to a next level in its online interactive presentation as described in chapter 8. This chapter demonstrated how is this collection and recording practice reflected in the resulting digital-born project archive. It concluded with the proposal to apply an extended version of the Tradition in Transition methodology to promote archaeological project archives with 3D content to a diverse audience.

Due to the nature of the PhD project, which consists of published (chapters 2 and 5) and accepted (chapters 7 and 8) journal articles and other types of digital publications (parts of chapter 6), not all research questions as posed in the introduction (chapter 1) were specifically addressed in the chapters of this bundled dissertation, and will be discussed in this chapter.

Finally, this chapter aims to answer how modern 3D technology could be applied to an inherently visual and tactile area of expertise such as ceramic analysis, and specifically the technological analysis of forming techniques. The discussion summarises and critically assesses the outcomes of the different sub-projects, and will conclude to what extent the archaeological tradition of visualising objects has changed or not.

A flexible and reflexive methodology

An enticing technological analogy could be drawn between the uptake, adaptation and transmission of the potter's wheel in local potting practices in the transition from the Middle to the Late Bronze Age Aegean, and the nature of the adoption and application of new (digital 3D) technology in a distinct visualisation tradition in 21st century archaeology. This by no means direct analogy forms the inspirational starting point of the present research project to explored how both past and modern practices respond to the introduction of an innovation of new technology. The agile nature of the Tradition in Transition conceptual framework, which builds on reflexive and praxeological approaches derived from sociology, allows the framework to be tailored to address other archaeological practice as well, by drawing from theory and applied approaches such as STS and UCD. The framework bridges method and theory and has been developed to perform critical analysis of current archaeological visualisation practice and the assessment to what extent this has changed or has been adapted to the new technology.

More attention should be paid to the actions of archaeologists perform with their instruments and how they impact or even replace existing practice ("amputate"), is often accounted in archaeological literature (Chrysanthi et al. 2012; Witmore 2006). As such, the Tradition in Transition framework provides guidance to answer questions raised in an increasing body of theoretical literature focused on the impact of the digital on the discipline on the one hand, and practical issues raised by hands-on case studies deploying digital 3D visualisation technology, on the other. The combination of the framework and the 3D documentation procedures for pottery published in the TPW Workflow Series, is the practical and up to date solution to the limitations of the guidelines provided by the London Charter. These were defined when digital 3D technology was in its infancy and therefore much-needed at the time, but did not become widely adopted in object-based visualisation projects, as has been observed recently (Opgenhaffen et al. 2021). 3D devices became a standard addition to the archaeological toolkit over the past 15 years, and several of the guidelines have become common knowledge, for example the point of transparency of the research and visualisation process (Principle 4: Documentation[125]), but new issues and needs have emerged. For virtual 3D reconstruction or restoration of artefacts and architecture, the Extended Matrix is a perfect application tailored to document the inherent reasoning process of reconstruction (Demetrescu 2015, 2018), and for object-based documentation and public outreach this is complemented by the Tradition in Tradition framework and the TPW Knowledge Hub. Additionally, the framework can act as a base structure to add layers of required complexity in for example visualisations of architectural construction as well, and could therefore be applied to all kinds of archaeological visualisation.

Unlike other research to the impact of digital 3D technology on archaeological practice, which generally draws from postmodern theory and contemporary archaeological thought, Tradition in Tradition builds on fundamental archaeological theory and applies this to the digital. The *chaîne opératoire* approach has been employed by TPW to interrogate ancient technological processes by breaking them down into stages while preserving the social context in which things were created. The PhD project has expanded this approach with the current reflexive movement towards practice in archaeology, and it has applied it to assess present digital visualisation and archiving practice. Indeed, applying a *chaîne opératoire* approach to map the process of virtual reconstruction has been suggested before (Hermon 2012), and others proposed to formalise the approach by bringing archaeology and process mining together with pairing these practices (Brysbaert et al. 2012). However, a full understanding of *chaîne opératoire* as provided in chapter 5, makes the approach a much more effective tool that goes beyond mere mapping of reconstruction stages and the recording of paradata, or a simplified representation in a flowchart as in the case of process mining. For example, technical reasons and social conditions are responsible for the adoption or rejection of digital innovations in existing visualisation strategies, and may result in the generation of new, or other kind, of knowledge, as tradition warrants knowledge

125 https://www.londoncharter.org/introduction.html (accessed 2 March 2022)

production altogether (Roux and Courty 2019, p. 6). Chapter 3 has confirmed this notion of ensured knowledge generation. The chapter demonstrated that the automation of a particular process with 3D technology (replacing manual drawing practice and classification of pottery shapes), did not automatically lead to new knowledge, despite the production of increased quantities of familiar-looking (digital) data. This argument of the reproduction of similar knowledge with digital instruments, is further demonstrated by the comparison between the author's personal practice in chapter 5, and the description and analysis of TPW's collaborative archiving practice in chapter 8. Digital tools resulted in added layers of complexity in the events that make up the existing operational sequence, but the visual products representing forming traces merely reflect observations and identifications already made or known by the archaeologists.

The impact of the introduction of digital technology in archaeological practice has been demonstrated by the reflexive analysis of the creation of the TPW Knowledge Hub in chapters 7 and 8. The complete digital archiving practice and resulting digital (3D) visual data, has laid the foundation to potentially change archaeological research to forming techniques through the creation of a born-digital archive. That being said, the archaeological record will not change and remains the primary source of discovery, inspection and first analysis. The tangible and physical aspect cannot be replaced, but this part of a practice, as has been shown throughout this dissertation, which has been adapted to the affordances of digital tools nonetheless. Therefore, digital 3D tools can only augment this practice to some extent, constrained by the agency of both archaeological material and machines.

The development of archaeological visualisation

Tracing tradition

The complexity and challenge of identifying traditions, is demonstrated by Bruno Latour and his study to the historicity of things and discovery, for which he used the scientific work of Louis Pasteur (Latour, 1988, 1999, chapters 4 and 5 specifically). This work suggests that the causes leading to an invention (the killing of microbes by Pasteur through the process of pasteurisation) or innovation (the structured light 3D scanner) should be found in a larger social and technical context or network; other scientists provided the building blocks leading to the invention, whereas peers authorised the new invention by reproducing it. In other words, by studying what things and people "were doing before and after" the discovery (Latour 1999a, p. 145). It furthermore shows that the effects of the technology can only be assessed in retrospect, that is, over a long period of time, in which the inscription device such as the 3D scanner or visual product (as fact) is reproduced by members of the community. Therefore, it cannot be decided yet if the visualisation tradition is "emerging" (Beale and Reilly 2017a) or replaced altogether. If it was, we would not wonder. The causes of the adoption of digital 3D visualisation technology may be identified as they occur at present, but the effects that new technology on practice on the long term cannot be assessed yet, as only a decade or two have passed since the introduction and subsequent deployment - besides a hand-full of pioneering studies in the 1980s and 90s.

If a new visualisation tradition had arose, digital 3D technology would not be used to produce conventional 2D images, and familiar tools such as a measuring tape and a torch would not be used to mimic human sensory gestures. What can be measured, fortunately, is the extent to which digital 3D recording techniques are changing the way archaeological visualisers (archaeologists and external illustrators alike) produce artefact. To determine what current archaeological visualisation entails and to understand how new technology has been adopted and adapted in the past, the historical analysis sketched in chapter 2 did not make a distinction between traditional, analogue visualisation and digital visualisation, as they both share the same history. Usually, reflexive studies to digital archaeology commence at processual archaeology in the 1960s, when scientific methods and the use of quantitative data became common practice in the New Archaeology. Research to the analogue archaeological visualisation generally does not treat digital methods; others have used case studies to images of prehistoric men, photography, physical models or plaster casts, to illustrate the power of the image and changing epistemic roles of the pictorial in archaeological intellectual processes.

Despite the transforming courses affecting archaeological practice and knowledge making, such as the "pictorial turn" (Mitchell 2002), "digital turn" (Beale and Reilly 2017a; Boast and Biehl 2011; Caraher 2016; 2019; Garstki 2017; Huvila and Huggett 2018; Huvila et al. 2018), the "material turn" (Olsen 2010; Olsen et al. 2012; Witmore 2006), and more recently the "creative turn" (Beale and Reilly 2017a), these spinning processes did not seem to have coalesce into a wholly new archaeological visualisation tradition. The archaeological world is still turning although perhaps at an accelerated pace. The strong focus in archaeological literature on how the digital impacted and changed archaeological knowledge making, has largely overlooked archaeological visualisation practice, despite the fact that the discipline relies and always has relied on visualisation to translate, mobilise and communicate that knowledge. Thus, the answer to what extent digital tools changed the knowledge making tradition, resides for a large part in what it is what archaeologists do and what their visualisations resulting from these practices mean; e.g., what a 2D image is and what a 3D artefact does. This has been surveyed in chapter 4 through the examination of contemporary uses of an unstandardised terminology to denote digital visual outputs. The review clarified how understandings and epistemological implications of terms such as "model", "replica" and "visualisation" affect visual archaeological thinking, as they mean different things but are often used uncritically and interchangeably. The review concluded that in the present research, "visualisation" as process and "3D artefact" as a crafted, active research object should be applied, at least in the context of practice.

Building forth on Beale and Reilly's (2017a) proposal to consider the creative, generative aspect of archaeological practice, combined with Mitchell's suggestion to analyse visualisation practice and resulting visual outcomes from an historical point of view, it was possible to analyse the specific moments in time when new technology or media was introduced and disrupted archaeological visualisation, such as lithography, photography or the digital 3D scanner. This historical perspective complemented the further reflexive analysis of current practice with the Tradition in Tradition methodology, that includes agency of human (the visualiser or illustrator) and machines (the 3D scanner and the pencil) in the chain of archaeological visual production.

Traces of past practice in present visualisation

To overcome the single dimensional limitation of the paper medium, 16th-century artists such as Maarten van Heemskerk started to depict statues from different sides. This way of representing multiple viewpoints became standard archaeological practice in later times. Later artists portrayed antiquity by blurring imagination and reality in restoration practices or by dramatised representations of ancient architecture to spark the imagination of how splendid the Roman buildings once were. Such artistic practices reflect the desire to know how these objects may have looked like, as well as the belief from contemporaneous scientific practice that new knowledge could only be achieved through sight and seeing, by the detailed visual description of the artefact. For example, a new technology such as the lens could enhance vision, and thus knowing. In the course of the 19th century, drawing became an epistemological tool, and the resulting illustrations represent a conceptual shift from *knowing* to how they *came to know* their relative chronology and cultural attributions. Illustrations increasingly received a role as research method to guide and to structure archaeological interpretation, and to visually compare shapes to further refine classification systems. Physical models, cork models and plaster casts received a similar role as well, to record and situate contextual archaeological data and interpretations. They enabled to mobilise entire excavations (into scale models) and finds (plaster casts) as a convenient vehicle to communicate the data and resulting insights to fellow scholars and the public. Eventually, the artistic innovations and scientific applications led to a shared visual literacy and a standardised method of communication and knowledge exchange. Today, artefacts are visualised as they are in its present state, and serve as an object of research and as evidence on itself. They are regarded as mutually active in the process of *knowing* what the represented object means in a larger context, in the past as well as to present society.

The antiquarians regarded illustration as a way of doing research, and details in the drawing were seen as facts: the illustrated artefact became evidence. Similarly, geometric properties of digital 3D artefacts are commonly regarded as evidence as well, and serve as a research tool to deduce new information, although increasingly the agency of both visualiser and tools in their production is acknowledged as well. That latter conception takes a central place in the present study, and regards the making of a 3D artefact as a heuristic and social practice. Antiquarians collaborated with illustrators and craftsmen (printers, clients, etc.), which made the visualisation as much a social as a technical product. 3D artefact fulfils a similar dual role as being an active participant in archaeological knowledge making practice.

The historical overview has furthermore shown that visualisations of the past, be it reconstructions or artefact illustrations, have always been constructed through a contemporary framework, whether socio-culturally or stylistically. Renaissance images reflected Christian or Neoplatonic and Humanist ideals. The 19th and 20th-century reconstructions of Alma Tadema and Piet de Jong represent not only ancient life, but clearly reflect Victorian social life and contemporary architectural styles. The impact of these images in present visualisation practice is still visible, as it is hard to not reconstruct Minoan palaces in the Bauhaus-style of De Jong. Could similar social settings and style be identified in contemporary digital 3D visualisations? Or are they neutral images, because they are digital? For example, a 3D model of a scanned pot from 2004 is clearly recognisable as being fabricated in the early 2000s, whereas we cannot identify a particular style here in an artistic sense. In beautifully, highly realistic rendered reconstructed landscapes produced with software such as VUE, this particular software can be identified in the reconstruction by the trained eye nonetheless. And to what extent can current archaeological thought be observed in the visual outputs, similar to those historical visualisations? As suggested earlier, this sort of impact can only be identified in retrospect. However, as the creative process is increasingly documented, the development of "digital" archaeological thought could indeed be traced in a near future through the analysis of the metadata of the 3D artefact.

Other old methods that define present practice still, have derived from the first systematic seriation attempts, which developed by visual association of grouping objects together on paper. Today, this classification and identification of pottery types can be executed automatically. Standardisation in pottery drawing, with the T-section, is still common practice, also digitally. Conventions and codes were invented to direct the viewer to details deemed relevant by the antiquarian. Search filters and modern tags in 3D artefacts directs the user's attention to traces deemed relevant by the TPW team. Last case in point, it was believed the image could speak for itself, similar to the present belief by some that 3D artefacts are mathematical reproductions with revelatory power on their own.

If archaeology would move away from publication on paper and 3D datasets became accepted academic publications instead, section drawings would be an obsolete medium. Shapes could be automatically identified without sections, based on other digital patterns and shape descriptors, and the identification and amounts of types could be automatically generated into tables and visualised in graphs. Linked Open Data would facilitate references to the 3D artefacts embedded in contextual data stored in online databases.[126] 3D artefacts would be visually inspected with the application of feature recognition and semantic algorithms.[127] Visualisation practice and visual literacy would be completely different. Although there are some current projects working into the direction of such aforementioned future tradition, archaeological visualisation is

126 The possibilities of LOD and 3D artefacts are currently being explored in the project "3D WorkSpace", funded by the NWO (Dutch Research Council) Open Access program, and directed by Dr Jill Hilditch in collaboration with the 4D Research Lab and CREATE of the University of Amsterdam. My role in this project will be the development of Learning Pathways (LPs) to create such enriched 3D artefacts.

127 The GRAVITATE (Geometric Reconstruction And noVel semantIc reunificaTion of culturAl heriTage objEcts) project funded by the ERC Horizon2020 program, aimed to provide such a platform. The prototype looked very promising, but, unfortunately, the program ended and the platform was never launched.

still all too familiar. 3D visualisation has not radically emanated into a new visual tradition. The methods, ideas and knowledge at the core of archaeological visualisation have not changed but are in a process of digitalisation and automation. For example, European and nationally funded programs have made promising attempts, but so far these solutions have not become adopted for several reasons, for example due to the exclusive promotion to digitally oriented stakeholders or unattractive and user-unfriendly interfaces, which makes it hard to diffuse the new technique to other non-digital archaeological specialisms. Nevertheless, innovations in visualisation technology do emerge and are explored, but just as the potter's wheel was not incorporated in existing potting traditions everywhere, and wheel-throwing did not replace other techniques in the Late Bronze Age – so is the current state of visualisation tradition of representing pottery: in transition, but not replaced. This present study does not deny, however, the strong potential of digital 3D visualisation technology for the visualisation of specifically forming traces. On the contrary, I contend that a consolidation of computational thinking, new technology and existing visualisation strategies will result eventually in a creative tradition of archaeological knowledge data and knowledge visualisation.

Two previously separate worlds of visualisation practices – digital archaeologies and archaeological illustration – were brought together in one historical overview, demonstrating that the two share the same legacy of knowledge making. This approach has shifted focus to the creative practice of the visualising archaeologist and the coaction of the maker, the digital tools and the visual output in the archaeological process of knowledge production. This should ultimately heighten the awareness of the long tradition of visualisation practice in which *all* archaeologists are taking part in. The historical survey has led to the conclusion that the visualising tradition is currently at a *transitional* stage towards a blended creative practice of doing archaeology.

Re-presenting the black box

Visualisation as transparent translation

When regarding the act of visualisation as a translation of things, this thesis expands Bjørnar Olsen's and co-authors ontological question on *what* archaeologists are *representing* with their "visual media in archaeology" (Olsen 2012, p. 86), with asking *how* archaeologists have been *visualising* things through time. Studies to archaeological visualisation have long focussed on the visual outputs as distinct from other archaeological (representations as) evidence or practice, and often have overlooked visualisation as being socially produced. Furthermore, as was already determined in chapter 2 and in the above section, a visualisation functions both as a product and as a practice, recalling Latour's (1990) idea of inscriptions or "immutable mobiles". The act of visualising is a heuristic, creative practice of the operating archaeologist, in which the crafted 3D model becomes an original digital 3D artefact in itself (after Huvila, 2017), functioning as active object in multiple domains at the same time (research, public, education, etc.). The analysis of the process of the creation of a digital 3D image, discloses the previously kept concealed construction of the visual output and will reveal its social production.

This is contrary Latour's contention that, once the data is inscribed in the visualisation, it becomes a material embodiment of a closed and maintained 3D artefact (Bruno Latour 1987). This 3D artefact-as-black box would obscure the process of digital (and analogue) visualisation and the participation of the multiple actants in this creative process. Then, once the 3D artefact has been established and mobilised, other actants will reproduce the 3D artefact as evidence in the creation of archaeological knowledge, yet maintain familiar knowledge simultaneously. Deconstructing the black box through the detailed description of the process of creation, or the workflow, and the acknowledgment of the people and technology involved in this practice (in the metadata), produces another form of inscription (after Latour, 1999). The *chaîne opératoire* approach as applied in the Tradition in Transition framework, is in the case of archaeological visualisation the appropriate methodology to deconstruct or break down the chain of creation, including the tools and techniques applied. As a result, this description of the practice has the potential to become a procedure (the new inscription). When successfully mobilised and accepted by the community, the new procedure is then reproduced, resulting in similar 3D artefacts.

Detailed descriptions of technical workflows and archiving practices are described in chapters 6 and 8 respectively. The workflows about 3D scanning, processing, documenting and sharing are intended to serve as protocols. The reflexive description and analysis of TPW's practice of collection and recording of artefacts, and the process of translation of the forming traces in artefacts into an archive, could become the prototype of an archiving procedure for specialists in ceramic technology. This prototype procedure can be further refined with input by and experience of members of the community of ceramic specialists. By recording the practice of visualising archaeological artefacts and making that process fully transparent - including elements of human choice, local circumstances affecting 3D scanning, machine agency, multiple stakeholders and their interests and project goals, technical specifications and settings, and the material affordances of the archaeological object impacting the machine's performance – and sharing these in an open access digital environment, archaeologists are able to prevent blackboxing of the visual result, of the digital 3D artefact; quite opposite to Latour's view that the blackboxing of technology and scientific facts is eventually inevitable.[128] The digital 3D artefact is a such a translucent box, an active data recorder and presenter.

This is perhaps the greatest advantage of the digital as it allows to record, connect, save, share and disclose processes that were previously impossible to literally enmesh in an analogue visualisation of an archaeological object. The digital 3D artefact embodies this creative information, as well as it is able to take in subsequent analytical results and interpretations of its users. Being a powerful epistemological tool as well as

128 The author is aware of the greater complexity of the term blackboxing as understood in STS (as process, as socially produced, together with its technology being black boxed). However, in digital archaeological approaches it seems to be understood as it was originally in engineering (a black box as closed system, as a given), and often to be used analogous to scientific transparency.

data container, it forces the scholar to be explicit and transparent throughout the entire course of research. Ideally, future uses of the 3D artefact should be recorded in the same digital environment as well, otherwise new evidence retrieved from the artefact or modifications to the 3D model, may risk to become blackboxed nonetheless. This loop of keeping the 3D artefact documented and updated can eventually boost archaeological knowledge production (about ancient forming techniques and technological transfer) in unforeseen ways. However, a note of caution should be considered as the frequent call for standardisation of procedures risks the re-production of more of the same, a similar but not essentially "better" or "new" kind of knowledge about the past. This is an issue of which both visualising and digital archaeologists should be aware of.

A framework to map translation and unfold the black box of practice and technology

So, how did this transparent approach to visualising archaeological data with the Tradition in Transition methodology inform about the various roles makers and tools have in the process of knowledge generation? Did the opening of the visualised box present new insights? The present research has shown (chapters 2, 5 and 8 in particular) that the epistemological strength does not reside in the image of the object itself, but that its meaning is constructed and imbued by its makers and subsequent users. The historical overview has demonstrated that images have been produced in a social context and with the latest technology to translate the object and mobilise the discovery and related knowledge from its original location. However, until recent times the visualiser and other participants in the process of meaning-making were excluded from the visual product, as well as the reasoning machinery responsible for its creation. This invisibility of creators and creativity revealed itself when I transferred my experience and methods in 3D visualisation to the TPW project. This project showed not only how technology had an effect on past societies, but incidentally provided a mirror to the researchers too, that redirected the archaeologist's gaze to the gradual deployment of digital technology in their own existing scholarly tradition.

Fortunately, the enmeshed epistemic roles of both maker, non-human participants, users and the visual product in the chain of knowledge production is slowly but increasingly receiving attention of the community (Berggren and Gutehall 2018; Edgeworth 2006c, 2014; Morgan and Wright 2018; Morgan et al. 2021; Sapirstein 2020; Westin 2014). Colleen Morgan and colleagues studied and compared analogue and digital drawing practice as "mental models" in order to determine the impact of technology on knowledge construction. They demonstrated that any form of drawing is central to knowledge construction and that, if this practice is replaced completely by digital tools, and therefore become disconnected with the material, apprentices would lose the ability to create "mental models that support the understanding of these remains" (Morgan et al. 2021, p. 627). A slightly different conclusion was reached by Philip Sapirstein through an auto-ethnographic study of recording a temple in 3D, in which he successfully demonstrates the advantages of digital 3D recording in especially time investment and accuracy but acknowledges the loss of direct contact with the material remains. He is left wondering how the virtualised experience influences subsequent intellectual processes of interpretation (Sapirstein 2020). But is this different kind of experience and delayed interpretation necessarily negative? Or is it a new opportunity to construct knowledge?

These kinds of ad hoc methods and case studies to analyse current visualisation practice are small but important steps towards a changing practice, but they are also hard to compare. And despite some warnings that standardisation could limit the creative practice of archaeologists, the mapping of current visualisation practice with 3D technology requires a guiding framework which enables the comparison of such practices when they have been documented in a similar fashion. The Tradition in Transition provides such a framework. It responds to recent calls for an introspective digital archaeology, with an awareness of the impact of the deployment of digital 3D technology on practice and inherent skills, the archaeologists' interaction with their tools and archaeological material in a given social environment, and subsequent knowledge construction (Caraher 2016; Garstki 2019; Huggett 2015a; James 2015; Molloy and Milić 2018; Morgan and Wright 2018). Tradition in Transition draws from profoundly archaeological theoretical approaches, rather than computationally-informed approaches, as suggested by Sara Perry and James Stuart Taylor (Perry and Taylor 2018). Because the technology is digital, this does not automatically mean the archaeological material and essential human concerns about the past should be addressed by computational theoretical insights, but informed by social theory and reflexivity as well. As an example of its effectiveness, I have applied the framework to assess to what extent my own visualisation practice has changed due to 3D technology, and how I transferred these new methods and skills to students (chapter 5). The aspiring aim is that Tradition in Transition will be widely adopted by other visualising archaeologists, in order to compare similarly mapped practice on a larger scale, enabling the reconstruction of a particular visual archaeological technical tradition.

The point of departure of the Tradition in Transition framework is a fundamental archaeological approach that TPW applies to investigate ancient technological trajectories: the *chaîne opératoire*. The approach allows to divide a practice into several steps which consider methods, skills, gestures, social relations, archaeologist-machine interactions and embodied actions. The framework includes (auto-) ethnographic and reflexive approaches towards personal experience and collaborative practice as well, particularly in relation to the deployment of new visualisation technology. This step-by-step approach answers specifically to Perry and Taylor's plea for a framework in which techniques and methods "can be embedded *as they are adopted*" (Perry & Taylor, 2018, p. 14, emphasis original).

Despite these reflexive calls by some digital archaeologists, 3D recording techniques are still often considered as objective translation devices, and digitally generated 3D artefacts as mathematical, objective representations which can be queried automatically with an algorithm (Hermon and Niccolucci 2018; Roosevelt et al. 2015a). Indeed, the technology enables enhanced measured accuracy and visual properties of the research object. However, when creating a visualisation, digital or analogue, the archaeologist/visualiser/technician needs to have at least some basic understanding of the material to be visualised, in order to produce an effective 3D image that renders the traces and other significant properties effectively, and to communicate these traces to a targeted audience. Literature study and the application of Tradition in Transition on my own practice in chapters 5 and 6, have demonstrated that both fabrication as use of a 3D visualisation (on a computer) is completely dependent on human actions and technological choices. It is a fundamental subjective enterprise. What is more, is that the affordances of the material and the machine may govern the operator's actions and affect the scan results and processed 3D artefact. Experimentation with 3D scanning technologies in chapter 5 showed that the projected light pattern of a SLS scanner cannot cover all parts, similar to the capture range of a camera lens in case of a photogrammetric approach. The material limits the machine when, for example, the part behind a handle or the interior of a closed vessel such as a Minoan rhyton, are difficult to capture, as the light projection or machine's vision is hindered by the vessel's morphological characteristics. The operating archaeologist has, in response, to perform many actions and specific gestures to position the artefact in such a way that most of the surface is covered by the light pattern, and position the equipment and adjust machine and software settings, so that ultimately the object is fully captured by the machine vision devices. In this respect, digital technology has a direct impact on the practice and actions of every archaeologist involved in the study of that particular ceramic object.

As a former illustrator, I have identified an almost complete loss of direct interaction with archaeological artefacts when I moved from documenting with a pencil to digital recording with a 3D scanner. Whereas previously tactile inspection and translation onto paper was a heuristic set of actions, the embodied experience became displaced from the artefact to the machine recording the artefact. But drawing has its dimensional and temporal drawbacks too. The 3D scanner is in this respect not a prosthetic of the archaeologist, but that of the pencil, and an orthotic of for the archaeologist: it enhances human visuality. What are the epistemological consequences? Did archaeology lose an epistemological tool, or does it create knowledge in a different stage in the reasoning process? The latter seems to be the case. The visualiser or illustrator has lost its prerogatives on first discovery through haptic and visual observation. Neither did this move to the event of creation with the 3D scanning technique (see fig. **5.3**), but instead to either the event of processing the scans into a 3D model (if performed manually, which is an intimate interaction with the separate scans, often in close range to find corresponding features between scans), or after the event of delivery. The delivered 3D artefact is used by the archaeological researcher by either visually inspecting it digitally (mimicking the traditional, tactile practice with virtual tools, such as applying directional light with a torch, slicing or a measuring tape), or by running analytical software and algorithms to automatically identify features and traces. The role of the visualiser as well as the tools in archaeological knowledge production is, as a result, definitely changing. The tradition has not been fully replaced yet, as not all illustrators have adopted 3D scanning technology nor did all archaeological companies and institutions – usually due to insufficient expertise or financial reasons.

Transitioning processes of knowledge transfer

Digital 3D visualisation technology has impacted processes of learning and how students and other participants or stakeholders "construct their knowledge" about archaeological material and ancient societies (Ekengren et al. 2021, p. 343). Although analysis of the impact of digital 3D technology on formal education and knowledge construction of students is beyond the scope of the present dissertation, a few insights obtained from informal training can be presented, as the Tradition in Transition conceptual framework is inherently concerned with learning, technical transmission and knowledge transfer (chapter 5). Among the few publications dedicated to exploring effectiveness and usefulness of the application of digital 3D technology in formal archaeological education (Derudas and Berggren 2021; Ekengren et al. 2021; Morgan and Wright 2018; Peuramaki-Brown et al. 2020) and learning in museum settings (Gardiner 2019; Jeffra et al. 2020; Paardekooper 2019), less attention went to the impact on teaching practice or how archaeology students learn to deploy 3D technology themselves in their own research (with the exception of Morgan & Wright, 2018). One of the original aims of the present study was to investigate how 3D printing technology could complement and enhance learning about ceramic forming technology, but the COVID-19 situation prevented full integration in courses and ensuing analysis.

The different 3D technologies applied in the literature enabled completely new forms of (remote) digital teaching and web-based learning. However, the type of knowledge resulting from it, did not change or even diminished in case of full digital learning (Ekengren et al. 2021). Informal inquiry to similar web-based teaching on material culture through 3D artefacts due to the COVID-19 pandemic, seems to confirm this decline in knowledge construction. Students who received a hybrid approach with access to both material objects and 3D artefacts, performed better at the exam. Teachers observed that direct contact, "looking over their shoulder" to follow and guide the interpretation process of archaeological materials by students, is crucial in learning.[129] Students will still need to leave the online classroom to have hands-on experience with the material (Peuramaki-Brown et al. 2020). This physical interaction is crucial in understanding and subsequent knowledge construction of the artefact *and* the 3D artefact, and as such the 3D artefact plays a complementary role (Ekengren et al. 2021, p. 346). Paola Derudas her work seems to confirm this as well, as students were trained first in the field where they learned "traditional documentation", and education was then "expanded" with 3D technology. This prior experience with the actual material environment and artefacts as well as the epistemological processes of hand drafting and measuring, is essential in understanding the workings of its digital counterpart. Such an integrated approach is very valuable, even more so when the students are taught beyond the mere operation of the 3D visualisation tools, in order to create awareness among the

129 Kim Pollmann, personal communication, for the BA-course "Materiële Archeologie" (Material Archaeology) (2020) at Saxion University of Applied Sciences; Martina Revello Lami, personal communication, for the BA-course "Material Studies" (2020-2021) at Leiden University, with references here: https://www.universiteitleiden.nl/en/news/2020/03/the-future-of-experiencing-the-past (accessed 28 May 2022)

students of the potential blackboxing of (any) technology (Sapirstein 2020, p. 152).

As part of their skill set, students in archaeology should be able to recognise forming traces which correspond to different forming techniques of pottery. Touching the surface of pottery to feel the irregularities is an important first survey. Only on a few occasions could I deploy the physical 3D printed training set of forming traces, mostly in a handful of guest lectures in BA and MA courses. However, the students communicated that the blended approach of the haptic experience and the online 3D model with tags and embedded information (provided with an QR code attached to the 3D print), provided a clearer image of a forming trace. A 3D print of a macrotrace, just as an archaeological artefact, does not convey information in itself. It needs a trained eye and prior knowledge. The QR code provides this. The online 3D model is tagged with information about the trace. Sometimes, the trace is so faint and is stretched further over the surface than the tag covers. This can be visually and sensually traced in the 3D printed example. Smaller traces, on the other hand, can be inspected in greater detail in the online model, without losing the tactile experience. The tags and accompanied information refer to additional information, such as videos of making pottery (which gives meaning to both the trace and the model) and different forming techniques and methods, but also technical information about the production of the 3D model. This should encourage critical thinking about how 3D data has been produced, how accessible this technology has been made, as well as the accessibility and transparency of the scientific process that produced knowledge about the forming traces. Such a "blended" or rather "expanded" application of 3D technology in teaching and research, is another advantage in the transmission of knowledge to not only students and future members of a community of practice, but also in communication of archaeological results and knowledge to a wider audience.

Entry into different communities of practice through learning by doing has been demonstrated in chapter 5. By applying the Tradition in Transition approach onto my personal practice to analyse how this changed by adapting to the introduction of new technology in different professional and academic environments, I was also able to investigate how I transferred my new techniques and methods to students and assistants. The digital workflows I created could almost without intervention be adopted and reproduced by the apprentices while they were learning the techniques by doing. However, some actions, gestures and particular settings could only be transferred in action, by showing and observation. Previously, in analogue practice, these students and assistants would have remained invisible technicians in the presentation of the data. Now their names are logged in the metadata of the archaeological record, as well as their choices and responses to circumstances while documenting the archaeological material in 3D. They have become active and visible participants in the archaeological reasoning machinery, instead of passive consumers of handed down data and knowledge. The obtained technical knowledge ascertained that the apprentice could now enter the community of practice of archaeological visualisers, digital archaeologists and even ceramic technology specialists. They have gained knowledge about the archaeological material as well through the extensive interaction with the object while processing the 3D scans, or because they involved in the collection and recording of the material itself.

The TPW Knowledge Hub is currently being designed as a place to data share and exchange knowledge, where forming traces and inherent meanings of ceramic objects can be discussed directly in and with the 3D artefact. As a result, the presented research could not offer a final analysis of learning, but the preliminary outcomes of the questionnaire published in chapter 8, showed that users of the Reference Collection in the TPW Knowledge Hub were able to interact with the 3D artefacts and learned to recognise macrotraces in the pottery. Expanded teaching possibilities and increased direct exchange and communication functionality by this new technology, did indeed start to change processes of technical transmission and knowledge transfer. Traditional and bleeding edge techniques to transfer skills and technical know-how co-exist in one archaeological visualisation practice.

The fact that a member of the TPW team determined that wheel-throwing did not replace a pre-existing potting practice, but rather complemented it, has been identified due to experience of the specialists, by direct tactile and visual inspection of the physical material. The digital optical devices merely confirmed what was already suspected, and the 3D database reflects this prior knowledge. Students, however, can learn about the studied data and shared knowledge of specialists, by inspecting them online, and prepare themselves for actual, physical inspection on-site. To conclude, the kind of knowledge may not have changed, but larger quantities of data and existing knowledge can now be communicated in a more effective and visual way than before, and surely more democratically too, as more people beyond the project and community can engage in the reconstruction of this particular narrative of technological transmission in the past.

Enhancing ceramics analysis with 3D technology

So far, the benefits of archaeological theory for digital archaeological visualisation have been discussed, especially how TPW's methodology which centres on the *chaîne opératoire* approach, has inspired and shaped the Tradition in Transition framework for the mapping and analysis of practice in the present. But what can 3D technology do for TPW and specialists in ceramics analysis? Digital 3D visualisation technology has become a common utensil in the archaeological toolkit, especially in excavations, landscape archaeology, architecture and the occasional 3D presentation of special artefacts, as has been attested in chapters 2 and 3. Nevertheless, little to no effort has been directed to implement the new technology into analytical approaches towards the bulk of finds in archaeology, ceramics. Indeed, over the past two decades several projects have focussed on the automation of traditional processes such as classification and drafting of pottery. The intention of these projects was, and still is, in some current projects, to increase "efficiency" in time-labour ratio, and to produce more accurate (i.e., objective) representations by reducing human intervention, and to process ever larger quantities of archaeological data into conventional visual outputs. Very few studies into specifically pottery manufacturing have applied 3D technology. The grand challenge remains, then, how this technology can be applied to an inherently visual and tangible specialisation such as ceramic analysis, and specifically the technological scrutiny of forming techniques, the core assignment of this study.

One of the main objectives of TPW was to better understand the interactions that facilitated the transmission of the potter's wheel in the Bronze Age Aegean. In order to identify wheel-use in a ceramic assemblage, not only imported vessels should be analysed for the introduction of the potter's wheel, but also local pottery. To do so, all pots bearing traces of rotatic kinetic energy (RKE) are to be situated in local *chaîne opératoires*, or ceramic production sequences, in order to assess if local potters were applying the wheel. By analysing these operational sequences, in which skills, gestures and technical know-how play an important role, different wheel-use methods such as wheel-coiling and wheel-throwing, can be determined. TPW's methodology to investigate how and when these methods appeared and manifested in this area, consisted of three specialisations which have been integrated in one approach: experimental archaeology, compositional analysis (fabric analysis), and digital archaeological methods. Experimental archaeology allows the identification of wheel-forming traces in ceramics, fabric analysis of ceramics the determines whether it is produced locally or if its imported, and digital technology enables the visualisation and communication of these identified traces of wheel-use in potting communities across the Aegean in the Late Bronze Age. In order to recognise the macrotraces in the archaeological material, the experimental archaeologist produced generalised typesets of pots with suitable analogues for the archaeological vessels (Hilditch et al. 2021; Jeffra 2021). The experimental vessels were then studied and recorded with the same protocol as for studying archaeological material. The photographs and videos of these vessels, together with the tags of the traces and descriptive textual data, form a reference collection, to which the archaeological material can be compared. The experimental typeset has been scanned in 3D, and the resulting 3D models were embedded in the experimental data, and the macrotraces tagged in the model. This reference collection of wheel-fashioned pottery forms the core of TPW's most important output, the TPW Knowledge Hub for the study of ancient technological transmission.

Although I had adopted and adapted 3D visualisation technology such as 3D scanning and modelling into my own archaeological visualisation practice (chapter 5), and had applied the obtained skills and methods to ceramics before the start of the TPW project, I could not unproblematically transfer this practice to this other community. I had to adapt my practice to TPW's collaborative practice, and create a tailored technical workflow. The visual appearance of the 3D artefact depends on the research aims, such as the required level of detail necessary to identify a macrotrace, and thus affecting the resolution. Understanding of the affordances of both machine and material proved to be fundamental too in developing an integrated collection and archiving practice and technical workflows. Therefore, I had to learn to recognise macrotraces and the wheel-forming methods they represent. The other team members had to acquire some basic skills in processing and manipulating the 3D models as well, in order to comprehend and determine which shapes, textures and colour hues of the material the 3D device can capture. As a team, we could now adapt the collection and recording practice, but also establish how and to whom the resulting 3D artefacts should be presented and what we want to communicate with it.

Digital technology added layers of complexity to the practice of ceramic specialists, but the recognition remains a fundamentally tactile and visual act of inquiry of tangible material. However, all three specialisations applied already digital technology to some degree, such as digital photography and digital documentation in, for example, a spreadsheet or with a word processor, and ultimately the online database. Nevertheless, the implementation of 3D visualisation technology for large-scale recording in high-resolution is completely novel, and the integrated approach of the three components in the TPW project is unprecedented in this particular archaeological specialisation. This collaborative practice, with special attention to the deployment of digital technologies and how these impacts physical, on-site collection and recording, has been described in chapter 8. This practice could be transformed into a procedure, which can be reproduced in order to create similar datasets. The developed technical workflows, customised to meet the high-resolution 3D recording of ceramics, are summarised in chapter 6 and published in the TPW Knowledge Hub. What is more, these standardised workflows ensure data integrity, as similarly created datasets and analytical protocols improve comparability, which could ultimately lead to a greater understanding of ancient technological transmission.

The database behind the online TPW Knowledge Hub reflects this collaborative practice and workflows. Here, not only the archaeological data, contextual data, technical metadata and the protocols and workflows can be found, but also the paradata about the collection and recording of individual objects, and the reasoning processes behind it. Notwithstanding the bleeding-edge technology deployed, the accessibility of this paradata, of the documentation of the choices made in all stages of the process, from settings to circumstances, and from material features deemed important to archive to the geometric properties in a 3D artefact, acknowledges the inherent subjectivity of archaeological practice. This subjectivity is not eradicated by a digital device or the size of a point cloud. Archaeological material, digitised or not, is still interpreted by the archaeologist. The macrotraces are identified by the archaeologist, as well as the forming technique and the technological connections across communities.

Augmenting communication about ancient forming technology

Reaching multiple communities and diverse groups of people

The digital 3D artefact acts as a boundary object. It belongs to multiple practices (archaeological data visualisation, presentation and communication, archiving and ceramic analysis practice, and so forth), and as such this same 3D artefact functions, acts and is understood in diverse ways in different communities. In the case of TPW, these boundary objects are designed to participate in and between communities of practice, and are able to connect them without affecting the internal social organisation or knowledge structures (Wenger 1998, pp. 107–108). This is the greatest advantage of this digital technology, as it enables communication in unprecedented ways, connecting scholarly and lay audiences, but also several archaeological specialisations which have heterogenous understandings of the object. However, the 3D artefact is not the central gateway to archaeological information, as other 3D platforms tend to do. Instead, the 3D model is part of a bigger picture consisting of diverse digital media that together convey a narrative, and it is this constellation of data that elevates the 3D model to a digital artefact, imbues it with meaning. This layered approach enables persons using the Knowledge Hub to explore and learn about forming traces in different levels. The specialist would like to comment on identified traces in order to construct knowledge, whereas a digital archaeologist would like to know more about the technical specifications of the 3D model, and would find the technical workflow in the metadata. Preliminary results from the survey described in chapter 8 have shown that lay persons enjoy engaging with the 3D artefact and click on the tags, as well watching the associated production videos showing the potting process, which clarifies what the object represents. This exemplifies the multiple roles of the 3D artefact, as boundary object.

TPW has successfully adopted the FAIR principles into the digital infrastructure of the TPW Knowledge Hub to organise and manage its data and associated knowledge. However, the principles are not about human interaction but take a data-centric approach based on machine-actionability. As a response to this "technological solutionism" (Caraher 2019, p. 372), the CARE Principles (Collective Benefit, Authority to Control, Responsibility, and Ethics) have been developed to empower Indigenous Peoples and shift focus to how data can have a more equal and participatory role for people in terms of reuse (Carroll et al. 2020, p. 3). These latter principles expose the fact that data should be about people (in the past and present) and for people, and the McNeil's (McNeil 2020) observation that persons have become quantifiable users through processes of datafication. These insights informed the design of a human-centred system, and instruct how TPW and future archaeological projects envision actual persons to find and use the data in the Knowledge Hub.

My research has introduced professional approaches to archaeology aiming to improve the design, uses and promotion of archaeological project archives. Design thinking and the academic variant designerly thinking, and a customised model to create user personas are approaches to facilitate user experience (UX) design (chapters 7 and 8). The creation of user personas force archaeologists to determine who exactly the "audience" is who should use, reuse of and learn from the data, in order to achieve a truly societal impact. Targeted user groups, summarised and personified in a user persona, not be confused with social groups within communities of practice, also assess issues such as data literacy and internet access. The latter are often forgotten while democratic claims have been made because data has been made freely accessible. Yet, if a broadband connection and mobile data is limited or unavailable, interaction with 3D artefacts and downloads of large files will be severely impacted, and access, again, limited or even denied to marginalised groups. Among these marginalised groups could be members of the same community of practice of ceramic specialists, yet these members could have problems with accessing and interacting with the online system. The UX approach can anticipate such limitations and problems through the design of a stratified system. For example, people with limited internet access can are offered different file types and file sizes of 3D content as downloads, in order to engage with the models offline. Another solution is the disclosure of additional data such as photo data and protocols to visually inspect archaeological material without the support of 3D technology. The overall goal remains, however, to not only bring data to the outside world, but also receive data about forming techniques and macrotraces, and to facilitate a multi-layered platform the discuss the data and identified features to ultimately generate new knowledge about past human behaviour.

Sharing expertise, practice and knowledge

Despite the increased adoption and deployment of 3D technology in the archaeological visualisation tradition, the majority of the members of this community, and probably most of the smaller and less wealthy academic institutions and museums in general, cannot afford such technology or lack tech-savvy archaeologists. Fortunately, the present PhD research has demonstrated that high-resolution scans can be produced with a small budget and little technical experience. Workflows based on low-budget structured light scanning technology were developed, as well as DIY solutions to assemble an SLS scanner. By following the step-by-step instructions of these workflows, almost every archaeologist should be able to learn the necessary skills to scan and process ceramics in great detail. At the same time, these workflows ensure full transparency of TPW's data generation practices.

High quality 3D content in the online reference collection of wheel-fashioned pottery, provides unprecedented democratic possibilities and educational advantages. Whereas reference collections were previously bound to a few specialised institutions with limited access, the reference collection can now be disclosed to a vast interested audience. A profound move forward from its material counterparts is the fact that 3D artefacts can be a more powerful educational tool than any physical learning object, as specific indicative features can be digitally tagged and embedded with information. The digital material can be studied from a desk anywhere in the world, with familiar yet virtual tools, with all associated data and media instantly available. Archaeological objects can be compared manually with the 3D examples in the Knowledge Hub on either a mobile device at the excavation or at a computer screen in the lab. All 3D artefacts can be downloaded and digitally inspected and compared with other 3D models produced elsewhere, in open-source software such as Meshlab and CloudCompare.

Despite some critical notes and reservations, high-resolution 3D scanning and resulting 3D artefacts have greatly enhanced the study of forming traces. The presented research has demonstrated that low-budget structured light scanning (SLS) is the most effective technology to record extreme details such as macrotraces in morphologically difficult material. Simple digital filters such as radiance scaling and heatmaps, and simple tags in the model, enable to visualise hidden or obscure information about forming techniques that were previously problematic to describe and communicate. This enhances the specialist's vision and the visibility of pottery forming traces. The digitised pottery confirms and expands knowledge about the archaeological material as it has the potential to be visually queried and connected to a network of data. It is especially this augmentation of information in which its greatest epistemic power resides, as insights and ideas can be communicated visually to the outside world in a coherent way.

A critical and reflexive note on automating archaeological practice

At present, only highly trained and specialised archaeologists are able to identify macrotraces and forming techniques, and the analogue documentation laborious, with as consequence datasets remain small and comparability limited due to different analytical methods. Accelerating the routine and increasing data through automation seemed therefore a logical step in the pursuit of the potter's wheel, and was therefore one of the original objectives of this research. Several progressive insights prevented automating the process. Firstly, a vast amount of data is required to train an algorithm. 3D scanning of fragmented and geometrically challenging material, whether homogenous experimental or heterogenous archaeological material, in a resolution that captures the smallest detail, turned out to be immensely time-consuming. This slow recording process restrained the generation of a massive dataset. Secondly, to run the algorithm, other specialists would need to produce 3D models of similar quality. TPW is the first project that has adopted 3D technology systematically in ceramics analysis. These two factors diminish the success of the algorithm. Additionally, is that the construction of the reference collection of wheel-made pottery made the need for an algorithm utterly redundant. Archaeologists and lay people can now visually compare analogue material with the digital examples in the database. However, the decisive argument against automation is the aspect of learning. If archaeological practices are automated, this practice risks to be blackboxed together with the inner workings of the app. How do archaeologists identify a forming technique? Which macrotraces indicate such a technique and the various methods to manufacture a pot with that technique? How are students taught and audiences informed about past human behaviour if a machine number crunches the pots? Just because it is possible does not mean it is necessary or useful.

Theorising digital creative practice with Tradition in Transition

Archaeology is a fundamentally visual discipline, and digital 3D visualisation technology is beginning to take a central place in its creative practice. The reflexive interrogation of the implementation of the Tradition in Transition methodology in my personal and collaborative practice, together with the historical analysis of visualisation practice in archaeology, has demonstrated that the uptake and application of innovative (3D) technology in archaeology did not profoundly change the tradition, nor did it lead to a distinct discipline. As a knowledge-making instrument, archaeological visualisation is an integrated part of archaeology rather than a (sub-) discipline, for tools and methods do not constitute a discipline but *are* an invaluable part of its creation. Therefore, technology did not cause paradigmatic shifts, because visualisation technology is the inscription device to transfer archaeological knowledge.

In other words, the technology is not producing knowledge itself, but enables it. This concept resembles Kristian Kristiansen's idea that new information does not automatically mean change in intellectual reasoning process and archaeological thinking (Kristiansen 2014), as knowledge traditions are rather reproduced in a *different* way with 3D technology. The presented case study suggests that no profoundly different information about ceramic forming techniques was generated through the application of 3D technology. Identification of traces and techniques were confirmed by the digital 3D artefacts, more data was recorded, but, for example, no new types of traces were discovered that would lead to identification of a new technique or a particular potter. Interestingly, when following the line of thinking of Fiona Cameron (2007) and Tracy Ireland and Tessa Bell (2021), the 3D artefacts have become "traces" themselves, traces of an embodied practice of the collaborating TPW members and their digital devices, which are inscribed in the archive. These 3D artefacts-as-traces may be different and multidimensional, and it can be queried in an unparalleled mode resulting in enlightening visualisations provided by, for example, colourful heatmaps and radiance scaling filters, increasing the visibility of latent features, but does not convey latent information. However, 3D visualisation is a huge advancement for presenting in an instantly clear visual manner features and differences in the surface of pottery, and to communicate and discuss these visualised features with peers and public through the online TPW Knowledge Hub. In this way, the shape of the "*lieux de savoir*" has changed, but not the technical tradition itself (Huvila et al. 2018, p. 153).

To conclude, this dissertation and the formulation of the Tradition in Transition framework, contributes to the archaeological debate on visualisation practice and calls to theorise digital archaeological approaches (Caraher 2016; Huggett 2015a; Huvila et al. 2018; Olsen 2012; Perry and Taylor 2018). The proposed methodology allows to reflexively chart archaeology's creative digital practice of visualising artefacts and permits full transparency. In fact, the methodology meets the points listed by Sara Perry and James Taylor (Perry and Taylor 2018, p. 15) in their appeal for a reflexive theory for digital archaeology, as its flexible design embraces the complexity of practice, recognises the historicity of data and data visualisation practices, considers the social construct of practice including multivocality and public engagement, and recognises machine agency and interaction with digital systems. This appeal and other calls imply that the archaeological tradition is in motion due to digital innovations, and did not change as the theoretical foundations are not yet determined by the community. Tradition in Transition provides a cornerstone in the construction of a digital archaeological theory.

Chapter 10

Conclusions.

Future directions for a tradition in transition

Summary

A myriad of digital 3D tools and techniques have been progressively, yet in an unstandardised way, deployed in archaeological practice in last the couple of decades. However, they did not replace analogue visualisation tools wholesale; on the contrary, at the time of writing, they co-exist. This co-existence leads to the conclusion that the archaeological visualisation tradition in general, and object-based visualisation in particular, is in a state of transition.

A tentative analogy with this present practice was drawn from the introduction of the potter's wheel as innovation in local pot-making trajectories in the Late Bronze Age Aegean, in which it seems that several wheel-forming techniques have been applied in tandem for hundreds of years as well, even within communities. These ancient technological trajectories were investigated within the framework of the Tracing the Potter's Wheel project (TPW), of which this doctorate research was part. The TPW project uniquely combined experimental, analytical and digital archaeological approaches to analyse the uptake and spread of wheel-fashioning techniques across this region and through time. This approach provided a mirror that moved the archaeological gaze towards current practice, and how archaeologists respond to innovative technology themselves. Furthermore, the experimental and archaeological ceramics studied in this project formed the case study in this dissertation in order to develop a novel standardised method for 3D scanning for ceramics analysis.

In order to assess what exactly current archaeological visualisation practice entails in respect to digital 3D technology, and how this differs from an assumed past tradition, a historical survey of representational practices was carried out in chapters 2 and 3. The survey showed that digital techniques did not cause a shift in research strategies or the presentation of archaeological information. Rather, it added a layered complexity to a prevailing creative practice, as it requires more intermediate steps than in the analogue era, and more data about the data needs to be recorded in order to safeguard intellectual and empirical transparency (chapters 6 and 7). In the particular case of the graphic documentation of pottery, digital 3D techniques have been applied to automate traditional processes in order to be more precise and to produce ever more data. However, the resulting 3D artefacts remained strikingly familiar, and did not lead to new insights about the past on themselves – the close visual and tactile investigation of the original material itself by the TPW archaeologists, however, indeed showed new insights in ancient wheel-use. Chapter 3 furthermore revealed that the potential of 3D scanning technology for scientific research had hardly received attention in ceramics analysis, let alone in the study of forming technology. In order to enhance this digitally neglected archaeological specialisation, standardised methods to apply 3D techniques in research to forming technology have been developed and were described in chapter 6.

The chapters explicating terminology (chapter 4) and the presentation of the standardised method for 3D scanning archaeological ceramics with Structured Light technology (chapter 6), have demonstrated how a 3D model becomes a 3D artefact, as being carefully crafted by the creative archaeologist, and enriched with data to make it meaningful. The linking of the digital 3D model with associated data, this process of constructing an active research object, has been explained in chapter 7, which was dedicated to the architecture of the project database. In chapter 8, the database was treated as an information artefact, which consists of tools, systems, interfaces and devices, to store, track and retrieve information. It reflects the archiving practice of the project, from selection procedures of material to the documentation and visualisation of that material, as well as interpretations and subsequent uses by peers and public. Regarded as such, the archive is not a passive repository of project data, but a dynamic and participatory environment of knowledge creation, exchange of data and ideas, and learning – it is a Knowledge Hub. In order to create a user-friendly interface and to address targeted user groups, the present study has introduced design thinking approaches novel to archaeology, and has developed a model to support the definition of audiences.

In this research, (digital) archaeological visualisation has been considered as a craft, a creative practice fostering data generation and new insights about the past. This understanding of a creative practice entails attention for the interaction between multiple human and material/non-human digital agents in the process of translation of artefacts into visual formats. Technological choice takes a central role in this creative process, as it represents some factors behind the adoption and adaptation of new technology into existing visualisation practice. The performative acts of current (personal) visualisation and archiving practice were regarded throughout as the physical and digital manifestations of common mental schemes, which are learned through tradition. These performative acts were explicitly considered in chapters 5 and 8, and compared with the results from the historical inquiry, as outlined in chapters 2 and 3. This resulted in a greater understanding of what the current archaeological "digital" tradition is, and helped to determine that digital 3D visualisation is actually part of a longstanding, existing tradition, in which the digital has added complexity to the operational sequence of the practice, but did not change nor replace the tradition altogether – yet.

Practical results: Methods and a methodology

In order to undertake such reflexive research, the Tradition in Transition methodology has been developed to provide the theoretical underpinnings to guide the mapping, analysis and identification of current visualisation (chapter 5) and archiving practice (chapter 8), and functions as a framework to assess the proposed methods which constitute these practices. The methodological framework combines praxeological theory derived from sociology, particularly the *chaîne opératoire* approach and the concept of communities of practice, with reflexivity, enabling the interrogation of the incremental creative steps within technological processes that occur within a social environment. The *chaîne opératoire* conceptualises archaeologists as making choices, a choice to adopt new technology and learn how to use it in order to enhance analytical practice. The Tradition in Transition framework was further expanded with concepts drawn from STS in chapter 8, specifically from social studies to information work, in order to map archaeological archiving practice too. A significant insight that came with the extension with the later concepts, was that the methodology could be applied in this way as a kind of reversed engineering, in order to bring hidden scientific practices behind digital infrastructures and data organisation to the surface. Building on this conception of revealing hidden practices, Tradition in Transition also enables to provide transparency of the creation and decision-making progress of the visualiser, and prevents in this way the blackboxing of the 3D artefact. When mapping of the creative process from the directions of the framework, the inherent human factor in the mechanical process of 3D recording archaeological artefacts became exposed, as it turned out that the choices of the operator have a considerable influence in the final appearance of the 3D artefact. It implies the inherent subjectivity of creating (3D) visualisation despite the application of digital machines.

Due to its reflexive nature and orientation towards archaeological practice, Tradition in Transition is an answer to recent calls for an introspective (digital) archaeology to foster a critical awareness of what, and especially why, archaeologists do archaeology digitally. It furthermore contributes to the already established field of scientific virtual 3D reconstructions by providing a methodological and tailored solution to document the production of 3D artefacts in order to warrant scientific and intellectual transparency. The methodology is a practical solution to the unsuccessfully implemented London Charter and similar initiatives, and is complementary – as a framework – to the Extended Matrix due to its specific focus on (details of) objects and practice.

Digital 3D technology has never been deployed before in technological research to forming techniques of pottery, and certainly not on a large scale as in this PhD project. The project has shown that 3D scanning in a high resolution enhances archaeological vision for it can record macroscopic forming traces hardly visible with the bare eye. The developed method enables to scan ceramics in a high level of detail, and has been published online in TPW Knowledge Hub as part of the open access TPW Workflow Series. The 3D artefacts with forming traces are presented in the online reference collections of wheel-coiled and wheel-thrown pottery of the Knowledge Hub as well. They are designed as educational aids for students, specialists and lay audiences alike who are interested in learning how to recognise wheel-fashioning techniques.

The 3D artefacts are available in different file sizes and formats and free to download for subsequent visual and geometric inspection in (open-source) analytical software. A huge advantage is that this can be performed anywhere and at any time in the world. These high-resolution 3D artefacts and open-source software are a more accessible technology than for example X-ray analysis and micro-CT, and even may reveal more technological clues.

Lastly, to reach an audience for a research project such as Tracing the Potter's Wheel, the PhD research has developed the TPW UX Model and Persona Template for UX design. This model contributes to archaeological valorisation practice for particularly research projects beyond the trowel's edge. As uncomfortable as these user personas may seem, they are mainly meant to coerce archaeologists to specify their targeted "audience", to think through them and identify their needs, in order to create an exhibition or an effective and sustainable online knowledge base.

Future directions: Let's practice archaeology digitally

The present study has proven that archaeologists, and antiquarians before them, have constantly been adopting innovative tools to improve visualisation and guide reasoning processes. These tools and techniques, have always relied on vision as well as embodied practice. The 3D scanner, as demonstrated in chapter 5, is replacing the pencil and analogue visualisation techniques in order to mobilise data, yet entails a different embodied practice, dislocated from the recorded artefact. Furthermore, 3D software enhances archaeological vision, and as such supports the interpretation process of the archaeologist. Building on an earlier suggested idea of computational tools as prosthetics of the archaeologist (Chrysanthi et al. 2012), I have proposed to regard the 3D scanner as an orthotic instead, as the tool is enhancing (bodily) functionality and visibility of hidden material properties, which enable the specialist to reconstruct ancient technological processes.

The 3D apparatus as an extension of the body, as orthotic or *Körperbild*, has been succinctly investigated, and needs further analysis to obtain in-depth understanding of the transition from analogue to the digital practice, and the coaction between the visualiser and the scanner. Related to this synergy between human and machine, is the question to what extent the machine or software dictates the way the archaeologist proceeds and conducts research, which deserves additional consideration. Research carried out along the scheme provided by the Tradition in Transition conceptual framework, which draws from profoundly archaeological approaches with roots in sociology, can address and assess the effects of the concept of 3D technology as orthotics and machine agency on archaeological interpretation and knowledge production practice.

An example of direct impact of digital devices on human practice is the fast development of 3D scanners and the desuetude of technical brands. The present research has aimed to create awareness among archaeologists of this volatile 3D technology and the ephemeral quality of 3D content. Recording the creation and practice is therefore paramount, and demands continuous updating and adaptation of workflows. Fortunately, the power of tech companies can be avoided with open-source solutions, which were suggested in chapter 6, but need further testing and tailoring to archaeological practice.

The presented dissertation has laid the foundations for a standardised 3D scanning procedure for archaeological objects with Structured Light technology, and developed workflows to the document the meta- and paradata and to democratise and disseminate this data. These TPW Workflow Series are written concomitantly to the FAIR principles and promote the reproduction of these procedures in order to create similar datasets of wheel-fashioned ceramics. If these methods and the Tradition in Transition conceptual framework are to be widely deployed and further refined by experiences from other visualisers, if archaeologists practice what is proposed here and called for by several other authors, the similar generated datasets will provide firmer ground for future comparative research. The analysis and interpretation of these datasets by ceramic specialists could ultimately lead to new insights and perhaps a different kind of knowledge.

But before archaeologists can do that, they should first virtually shatter the digital 3D artefact to pieces and study the fragments in a wholly discordant manner. The last section in chapter 6 has shown some examples of how 3D artefacts could be studied digitally in an archaeologically unfamiliar and unprecedented mode. It forces us to look unconventionally at the material, to see it in a novel way. Unexplored algorithms and resulting visualisations of ancient ceramics may show features archaeologists cannot hitherto understand – what do the colours and enhanced features signify? This asks for further investigation. Seeing differently implies thinking differently, which indicates practicing inversely, with as a consequence operating in a distinct technical tradition of doing archaeology digitally. We are almost there.

List of published chapters

Chapter 2: *Visualising Archaeologists. A reflexive history of visualisation practice in archaeology*.

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Tradition in Transition.

Visualising innovation and change in past potting and present archaeological practice

Archaeologists specialised in ceramics analysis have identified traces the earliest use of the potter's wheel in mainland Greece in the Early Bronze Age II (2550-2200 BC). The wheel was not an indigenous invention but found its origins most probably in the Near East as early as the fourth millennium BC. The new technology then arrived through trade and travelling artisans, via Anatolia and the northern Aegean islands, eventually mainland Greece. What the archaeologists also discovered is that local potting communities adapted the wheel to their tradition of building and shaping the pot with coils of clay, and finishing the vessel with the rotational force of the wheel (attaching the coils, smoothing, further shaping, etc.). This resulted in a mixed technique called wheel-coiling. Not all pottery was made with the new technique, as many hand-built shapes remained dominant. The wheel did not seem to be a popular technological innovation and disappeared from the archaeological record by the end of the third millennium.

The potter's wheel then reappears a couple of centuries later in Minoan Crete, in the course of the second millennium (1800-1700 BC). Technological and experimental studies suggest that the wheel was probably an internal development in Crete and – as such a Minoan invention –, soon became diffused as a Minoan technological innovation across the Aegean as Minoan power expanded and interregional contact increased. The adoption and implementation of such new technology cannot occur by looking at imported vessels, such as was customary practice for imitating shapes and motifs from imported Minoan vessels in local pottery repertoires. A new technique could only be learned by direct observation of a travelling potter who had mastered the use of the wheel. Technical research has shown, however, that the adoption of the new technique was a slow process – if adopted at all.

These technological approaches in ceramics analysis suggest furthermore that the common assumption that Mycenaean pottery of the Late Bronze Age (ca. 1600-1100 BC) was predominantly wheel-thrown (in which the shape is drawn from a centred lump of clay while the wheel is rotating), can no longer hold, as new evidence suggests that several forming techniques co-existed by the end of the Late Bronze Age. The transition from wheel-coiling to wheel-throwing remains an underexplored issue, whereas it has huge implications for the transmission of technical knowledge, as wheel-throwing requires completely different set of skills, posture and gestures, and technical know-how.

By scrutinising how the potter's wheel was introduced and adapted, it can be investigated how potting communities were connected and configured through time, in order to ultimately reconstruct how the transmission of craft knowledge was entangled in interaction networks in the Bronze Age Aegean. The Tracing the Potter's Wheel Project (TPW) investigates the potter's wheel as technological innovation within this exciting chronological period and region. The project is directed by Dr J. Hilditch and hosted by the University of Amsterdam within the Centre for Ancient Studies and Archaeology (ACASA). The project uniquely combines theoretical perspectives on social interactions, technological processes and innovation, with experimental, digital 3D visualisation and analytical methods.

The presented PhD research is part of this project, and is assigned with the principal task to assess to what extent digital high-resolution 3D scanning and resulting 3D models can enhance the study of forming traces, and to develop a tailored 3D scanning method that could be adopted and reproduced by other ceramics specialists. This proved to be a challenge, not only because 3D technology had never been deployed before in such an integrated manner and on a large scale in this particular field of archaeological expertise, but also because of the inherently visual and tactile aspect of analysing ceramics. How to apply a technology with such intangible data outputs?

The dissertation takes off with a brief history of archaeological visualisation starting at the early Renaissance. This is certainly not the first historical overview, but is indeed the first with a focus on practice and technology and to combine this with the recent history of digital applications in archaeology, usually referred to as "Digital Archaeology". This is followed by in-depth research to the development of specifically digital 3D scanning, which was invented in a completely different area of expertise. It is then analysed how this technology then found its way into archaeology, and more specifically how it became applied in archaeological object-visualisation. The overview ends with the state-of-the-art of 3D scanning in ceramics analysis – which is, as it turned out, almost non-existent.

3D technology is not fully embedded everywhere, mostly due to the lack of technical expertise in combination with small budgets archaeological departments and projects suffer. And each project that has deployed the technology, tends to invent its own workflow. As a result, no standardised methods for 3D scanning have been developed, nor a common vocabulary. Additionally, the rapid development of technology cause terms such as "high resolution" to have a rather volatile character. A 3D scan produced at the highest resolution in 2004 is ineffective for detailed research to forming traces in ceramics at the time of writing. Nor is a 3D model an objective representation of the original artefact, due to the chain of choices of the operator made during the creation of the 3D model. Terms such as 3D model and replica, therefore, have been briefly investigated as well, in order to define a standard terminology for at least this dissertation.

The doctoral research offers a solution for the lack of a theoretical framework to direct the application and analysis of 3D technology in archaeological visualisation practice. This theory is not found in computation and information theory, but from fundamental archaeological theory instead. It proposes innovative methodology "Tradition in Transition", which combines reflexivity with praxeology and applies this to the digital. Reflexivity, an introspective approach to analyse the social roles of human action, is already well-implemented to analyse and document digital processes in mostly excavations. Praxeology, or practice theory, is concerned with human actions within a social context, and has its roots in sociology. A decidedly practical and useful approach within this theory to investigate human action, is the *chaîne opératoire*. This approach is also applied in the TPW project to expose ancient technological processes by breaking them into several stages. The social context in which the technical acts to produce a thing occur in each of those stages, is never out of sight. As an example of how to apply the Tradition in Transition methodology, I drew from personal experience: I analysed the development of my visualisation practice and subsequently assessed how I transmitted my new technical know-how and skills to apprentices. In addition, I also mapped the collaborative archiving practice of the TPW team, which exists of collecting, documenting, analysing and publishing archaeological in 2D and 3D. This detailed description of the collaborative practice, could serve as an example procedure for new research in the field of ceramics analysis, for which no integrated or standardised exist yet.

The Tradition in Transition approach serves a solution to the unsuccessfully implemented London Charter as well. The London Charter is a set of guidelines to document the visualisation process of heritage, in order to safeguard scientific transparency. These guidelines are – formulated in a time when 3D digital technology in heritage was in its infancy –, however, not clearly applicable, which has resulted in a myriad of "best practices". The scheme of Tradition in Transition can be used to map the visualisation process of objects – manually drawn or digitally 3D scanned –, including the choices and settings of the maker and the circumstances during the creation.

The principal task of the doctoral endeavour was, however, to innovate the specialism ceramics analysis. To do so, I first investigated several 3D scanning technologies and scanner brands, and compared the price-quality-labour ratio in order to determine which technology could be the most suitable to analyse forming techniques. Laser scanning, photogrammetry (3D reconstruction based on digital photographs), and "structured light scanning" (SLS, a technology based on the projection of light patterns onto an object and records these with industrial cameras) have been explored, out of which the SLS scanner DAVID SLS-3 was best in test. I then developed a method to create 3D models of artefacts with a resolution on submillimetre level, with a reasonably affordable scanner. Traces in the surface of the scanned vessel, hardly visible with the naked eye, can now be identified and enhanced with cutting-edge open-source 3D software. The method has been published online in the TPW Workflow Series and are accessible to anyone.

The 3D models have been stored in a custom-made project database, of which the structure has been described in this dissertation. This born-digital archive has not been developed to be a final resting place for data, on the contrary, it has been designed as an online knowledge platform where specialists, students and the public can access and use data and exchange knowledge: the TPW Knowledge Hub. An important aspect of this Knowledge Hub is the reference collection of forming traces. The 3D models of the experimentally produced pottery are linked to the photos, production videos, descriptive data, and observation made by the experimental archaeologist, and labelled with so-called tags marking the traces. Through these tags, people can in an interactive and intuitive manner learn to recognise the traces and how particular combinations of these traces represent different forming techniques. Embedded links in the tags refer to detail photos of the traces and the production videos showing how the traces got there. In this way, the TPW team transmits their collaborative knowledge and skills to members of the community of practice and the public in a transparent way. As such, the database represents and facilitates the transmission of technology.

To reach as well enthuse that audience for forming traces and archaeological methods, I was inspired by approaches from "User Centred Design" (UCD). Because, who exactly is this "audience"? How can we reach everyone, and is this even necessary? How do we know what the public wants to know? UCD methods can help grasping these issues, however, they have hardly, if ever, been applied in the valorisation of archaeological projects. To design a user-friendly interface and to keep the navigation through the website and the different media assets as easy and intuitively as possible, I implemented the "design thinking" approach. Instead of taking the usual problem-solving, technocentric approach to digital systems, design thinking works from a human perspective (human-centred) to anticipate a problem before they occur, the bottlenecks of the system.

Design thinking is thus deployed at an early stage of the design of the database and online environment. This implies that the desired user groups should be determines at this early stage as well. In order to do so, I investigated how archivists and sociologists specifically concerned with the social context of science and technology (Science and Technology Studies, STS), deal with digital archives and the ways different groups use and experience these, and design theory. In order to determine the desires, goals, digital literacy and connectivity of these groups, called "user personas", I have designed "TPW Persona Template". This template can be deployed when a database for an archaeological project needs to be developed. The definition of targeted user groups warrants an optimal user experience (UX). This is an absolute necessity in archaeology, as the level of user-friendliness and experience of archaeological database is generally underrated, with as a result that the public and even specialists loose attention fast, or even never heard of the database. To guide and encourage the design and UX of archaeological database from early stage in the development, I have developed the "TPW UX Model for Archaeological Archives". This could improve the valorisation of this kind of projects.

If archaeologists adopt the proposed standardised methods and techniques, or, in other words, if the practice (as procedure) is shared and reproduced by the community of practice of ceramics specialists, similar dataset of forming techniques would be produced. Comparable and shared datasets facilitate and improves the assessment of the data. And if applied on a large scale and with an audience, the archaeological chain of knowledge production might be changed, and with this the tradition. This dissertation, however, has demonstrated that archaeology has not reached that turning point yet, but is in a stage of transition.

Tradition in Transition.

Visualising innovation and change in past potting and present archaeological practice

Een traditie in transitie

Innovatie en verandering van pottenbakkerstradities in het verleden en de archaeologische praktijk in het heden in beeld gebracht

Archeologen hebben in enkele gemeenschappen op het Griekse vasteland aanwijzingen gevonden voor het eerste gebruik van de draaischijf in de vroege Bronstijd (ca. 2550-2200 voor Chr.). De draaischijf was geen inheemse uitvinding maar waarschijnlijk een Levantijnse, waar het vroegste gebruik al in het vierde millennium is waargenomen. Door handel en reizende ambachtslieden bereikte deze nieuwe technologie via Anatolië (het huidige Turkije) en de noordelijke Griekse eilanden, gaandeweg het Griekse vasteland. Wat de archeologen ook hebben ontdekt is dat de draaischijf werd aangepast aan bestaande lokale pottenbakkerstradities: de lokale pottenbakkers bouwden een pot met de hand op door middel van kleirolletjes en maakten het dan af (ringen aan elkaar bevestigen, gladmaken, verder vormen, etc.). Zij gebruikten daarbij de draaiende energie van de draaischijf, ook wel de *wheel-coiling* techniek genoemd in het Engels. Niet alles werd gelijk met de draaischijf gemaakt, vele handgemaakte vormen bleven naast de “afgedraaide” vormen bestaan. In sommige gemeenschappen werd de draaischijf zelfs helemaal niet opgenomen. Uiteindelijk bleek de draaischijf geen succesvolle technologie, om tegen het einde van het derde millennium weer van het Griekse toneel, oftewel uit het archeologisch bestand, te verdwijnen.

Dan verschijnt de draaischijf een paar eeuwen later weer in Minoïsch Kreta, ergens tussen 1800 en 1700 voor Chr. Technologisch en experimenteel onderzoek van archeologen suggereert echter dat de draaischijf een inheemse ontwikkeling moet zijn geweest, en zich – als Minoïsche technologische innovatie – snel door de rest van het

Egeïsche gebied verspreidt door de enorme expansie van de Minoïsche handelsmacht en de daaraan verbonden toename van interregionaal contact. De ontwikkeling van zo een nieuwe techniek wordt niet afgelezen door de imitaties van het aardewerk, maar door observatie van de reizende pottenbakker die de innovatieve draaitechniek meester was. Omdat volledig draaien compleet andere vaardigheden en technische kennis behelst, kon het alleen worden geleerd door directe observatie van een ervaren pottenbakker, die het op zijn beurt ook weer ergens geleerd moest hebben. Vervolgens werd de nieuwe techniek aangepast aan lokale maakwijzen. Toch blijkt uit technisch onderzoek dat de verschillende maaktechnieken naast elkaar bleven bestaan en dat de opname van de nieuwe techniek een traag proces is. De specialisten weten echter nog niet precies hoe de transitie van gedeeltelijk draaien (stationair met de hand met rollen opbouwen en afdraaien op de draaischijf) naar volledig draaien, *wheel-thrown* (waarbij een homp klei omhoog wordt opgetrokken en gevormd terwijl de draaischijf draait), in zijn werk ging.

In het project "Tracing the Potter's Wheel" (TPW) staat het onderzoek naar deze transmissie van technische kennis, waarachter sociale interactie tussen verschillende gemeenschappen schuilgaat, centraal. TPW richt zich op de draaischijf als technologische innovatie in de Egeïsche Bronstijd. Dit project wordt geleid door dr. Jill Hilditch en gefaciliteerd door het Centre for Ancient Studies and Archaeology (ACASA) van de Universiteit van Amsterdam. Het project combineert op unieke wijze theoretische perspectieven op sociale interactie, technologische processen en innovatie, met exprimentele, digitale 3D visualisering en analytische methoden. Met dit onderzoek kan worden bepaald hoe pottenbakkersgemeenschappen met elkaar verbonden waren en waren samengesteld, zodat uiteindelijk kan worden gereconstrueerd hoe de transmissie van ambachtelijke kennis was verweven met interactienetwerken in het verleden.

Het promotieonderzoek maakt deel uit van dit project en heeft als hoofdtaak te onderzoeken hoe digitale 3D technologie de studie naar vormingstechnieken kan innoveren, door onder andere speciaal toegepaste 3D scanmethoden te onwikkelen voor onderzoek naar aardewerk. Ook wordt onderzocht hoe de archeologische visualisatietraditie in het algemeen, en object-visualisatie in het bijzonder, is omgegegaan met de introductie van innovatieve digitale 3D technologie. Uiteindelijk kan dan worden bepaald in hoeverre nieuwe technologie van invloed is geweest op de huidige praktijk, en zodoende weerslag heeft op het archeologisch denken. Een uitdaging, want niet alleen is 3D technologie nog niet eerder op een systematische manier ingezet in dit specialisme, het is ook nog eens een intrinsieke visuele en bovenal tastbare manier van aardewerk analyseren. Hoe een technologie toe te passen die zulke ontastbare data genereert?

De dissertatie begint met de geschiedenis van de archeologische visualisatie vanaf de vroege Renaissance. Dit is beslist niet het eerste historische overzicht in de archeologie, maar wel het eerste dat zich richt op de praktijk en technologie en dit combineert met de recente geschiedenis van digitale toepassingen in de archeologie dat vaak met de aparte term Digitale Archeologie wordt aangeduid. Vervolgens wordt het historische onderzoek in detail uitgediept door het verloop van specifiek digitaal 3D scannen en modelleren onder de loep te nemen, dat is uitgevonden en ontwikkeld in een heel ander vakgebied. Dan wordt gekeken hoe het zijn weg vond in de archeologie in het algemeen en de toepassing en aanpassing van archeologische object-visualisatie in het bijzonder, om de historische analyse te eindigen met het gebruik in specifiek aardewerk analyse – dat nagenoeg nihil blijkt.

Omdat de 3D technologie nog niet overal is ingedaald, meestal door het gebrek aan technische expertise in combinatie met de kleine budgetten waarover de meeste archeologische projecten en departementen beschikken, zijn er nog geen gestandaardiseerde methoden ontwikkeld, laat staan een eenduidige vocabulaire of begrip van de ogenschijnlijk willekeurig gehanteerde terminologie. Daarbij komt dat door de snelle ontwikkeling van de technologie, termen als "hoge resolutie" een nogal vluchtig karakter hebben. Een 3D scan gemaakt met de hoogste resolutie uit 2004 is niet bruikbaar voor gedetailleerd onderzoek naar vormingssporen in aardewerk anno 2022. Noch is een 3D scan een puur objectieve representatie van het originele artefact, omdat er een heel proces van keuzes van de bediener van het apparaat aan voorafgegaan is. Termen als objectiviteit en subjectiviteit, evenals representatie, 3D model en replica, zijn daarom kort onderzocht, teneinde om in ieder geval een standaard terminologie te hanteren in dit proefschrift.

Deze dissertatie biedt een oplossing voor het ontbreken aan een theoretische kadervorming voor de toepassing en analyse van 3D technologie in de archeologische visualisatie praktijk. Die oplossing ligt niet in spannende computationele- en informatietheorie, maar put vooral uit fundamentele archeologische theorie. Het stelt een innovatieve methodologie genaamd "Tradition in Transition" voor die reflexiviteit en praxeologie combineert en dit op het computationele vlak toepast. Reflexiviteit, een introspectief middel om de sociale rollen tijdens handelingen te doorgronden, is inmiddels een breed toegepast concept om huidige digitale processen in vooral de opgravingspraktijk te analyseren en te documenteren. Praxeologie daarentegen, biedt de mogelijkheid deze praktijk in detail in beeld te brengen binnen een sociale context. Praxeologie, of praktijktheorie dat zich bezighoudt met het menselijk handelen, heeft zijn wortels in de sociologie. Een uiterst praktische en bruikbare benadering binnen deze theorie om de menselijk praktijk te onderzoeken is de *chaîne opératoire*. Deze benadering wordt ook actief toegepast vanuit het TPW project om de antieke technologische processen te belichten door ze op te breken in stadia. Binnen die stadia blijft de sociale context waarin de dingen werden gemaakt in het vizier. Als voorbeeld voor de toepassing van de methodologie, heb ik de ontwikkeling van mijn eigen visualisatiepraktijk onder de loep genomen en geanalyseerd hoe ik mijn technische kennis en vaardigheden vervolgens heb overgebracht op leerlingen. Ook heb ik de gezamenlijke archiveringspraktijk van het TPW team, die bestaat uit het verzamelen, documenteren, analyseren en publiceren van archeologisch materiaal in 2D en 3D, in kaart gebracht. De gedetailleerde beschrijving van deze gezamenlijke werkwijze, zou als voorbeeldprocedure kunnen gelden voor nieuw onderzoek in hetzelfde vakgebied (aardewerkanalyse, met in het bijzonder onderzoek naar vormingstechnieken), waar nu nog geen geïntegreerde en gestandaardiseerde procedures met een 3D element voor bestaan. Tevens biedt Tradition in Transition een oplossing voor de tot op heden matig geïmplementeerde "London Charter". De London Charter omvat een reeks richtlijnen om het visualisatieproces van erfgoed bij te houden om zo volledige wetenschappelijke transparantie te waarborgen. De richtlijnen zijn echter niet duidelijk toepasbaar, waardoor er nu een wildgroei aan ad hoc methoden is. Tradition in Transition kan als een schema worden ingezet om het visualisatieproces van objecten, of die nu getekend of 3D gescand worden, in kaart te brengen, inclusief de keuzes en settings van de maker en omstandigheden tijdens het proces.

De belangrijkste opdracht was om het specialisme aardewerkanalyse te innoveren. Daarvoor heb ik eerst een aantal verschillende scantechnologieën- en merken onderzocht en de prijs-kwaliteit-arbeidsverhouding vergeleken, om te beoordelen welke technologie het meest geschikt is voor de analyse van vormingstechnieken (gedraaid, handgemaakt of een combinatie daarvan). Van de laserscanner, fotogrammetrie (3D reconstructie van het object op basis van foto's) en *structured light scanning* (SLS, op basis van de projectie van lichtpatronen op het object en registratie met industriële camera's), kwam de DAVID SLS-3 scanner als beste uit de test. Vervolgens heb ik een methode ontwikkeld om met deze redelijk betaalbare en relatief snelle scantechnologie, 3D modellen van artefacten te produceren met een resolutie op micromillimeterniveau. Nauwelijks waarneembare sporen in het aardewerk worden met deze technologie vastgelegd en kunnen door middel van geavanceerde open-source (gratis) 3D software worden uitgelicht. De methode is online gepubliceerd in de reeks "TPW Workflow Series" en voor iedereen toegankelijk.

Deze 3D modellen zijn opgeslagen in de speciaal ontwikkelde project database, waarvan de structuur uitgebreid is beschreven in deze doctorale thesis. Dit volledig digitale archief is niet ontwikkeld als laatste rustplaats voor data, integendeel, het is opgezet als online kennisplatform waar specialisten, studenten en het publiek data en kennis kunnen uitwisselen: de "TPW Knowledge Hub". Een belangrijk onderdeel van deze Knowledge Hub is de referentie collectie van vormingsporen. De 3D modellen van het experimentele aardewerk zijn gekoppeld aan de foto's, video's, beschrijvingen en observaties gemaakt door de exprimenteel archeoloog en voorzien van "tags" die de specifieke sporen markeren. Zo kan op interactieve wijze worden geleerd hoe vormingsporen kunnen worden herkend en welke combinaties van sporen een techniek representeren. Links naar de detailfoto's van de sporen en productievideo's van de hele productie van elke experimentele pot, laten zien hoe de sporen tot stand zijn gekomen. Hiermee draagt het TPW team haar gezamenlijke kennis en vaardigheden op transparante wijze over aan leden van de *community of practice* én het publiek. Als zodanig representeert en faciliteert de database de transmissie van technologie.

Om dat "publiek" zowel te bereiken als te enthousiasmeren voor vormingsporen en archeologische methoden, heb ik mij laten inspireren door methoden uit de *User Centred Design* (UCD). Want wie precies is dit publiek? Kunnen we wel iedereen bereiken en is dit überhaupt wenselijk? Hoe weten we wat het publiek zou willen weten? UCD methoden kunnen hierbij helpen, echter is er nog nauwelijks gebruik van gemaakt voor de valorisatie van archeologische projecten. Om een prettige interface te ontwikkelen en de navigatie door de website en tussen de verschillende mediavormen zo eenvoudig mogelijk en intuïtief te houden, heb ik het concept *design thinking* als uitgangspunt genomen. Dit is een ander type benadering van digitale systemen dan de gebruikelijke probleemoplossende, technocentrische werkwijze. Het werkt vanuit een menselijk oogpunt (*human-centred*) om een probleem te vinden, oftewel te anticiperen, voordat deze plaatsvinden. Wat zouden de knelpunten in het systeem kunnen zijn?

Design thinking gebeurt dus al in het vroegste stadium van het ontwerpen van een database en online omgeving. Daardoor moeten de gewenste gebruikersgroepen ook al aan het begin van een onderzoeksproject worden vastgesteld. Hiervoor heb ik eerst onderzocht hoe men in de archiefwereld en de sociologie, met in het bijzonder de richting die de sociale context van wetenschap en technologie onderzoekt, omgaat met digitale archieven en de wijze waarop verschillende groepen deze gebruiken en ervaren. Het resulteerde in het concept van een "toegepaste etnografie". Ga naar de mensen toe en bepaal welke groepen bereikt kunnen en willen worden, stel hun wensen, doelen en digitale kundigheid en verbondenheid vast. Deze groepen worden in de mediawereld *user personas* genoemd. Deze user personas kunnen opgesteld worden met de speciaal ontwikkelde "TPW Persona Template", een sjabloon dat ingezet kan worden wanneer er een database moet worden ontwikkeldvoor een archeologisch project, om een zo optimaal mogelijke gebruikerservaring (*user experience*, UX) te garanderen. De mate van gebruiksvriendelijkheid- en ervaring van archeologische projectdatabases wordt namelijk nog wel eens vergeten of onderschat, waardoor veel publiek en zelfs specialisten snel de aandacht verliezen of zelfs nog nooit hebben gehoord van bepaalde voor hun ontwikkelde databases. Om het ontwerp en de gebruiksvriendelijkheid van archeologische databases al in een vroeg stadium te begeleiden en te bevorderen, heb ik de "TPW UX Model for Archaeological Archives" ontwikkeld. Dit zou de valorisatie van dit soort projecten aanzienlijk kunnen verbeteren.

Het streven is dat zo veel mogelijk specialisten de gestandaardiseerde methoden en technieken zoals voorgesteld in dit proefschrift, gaan gebruiken. Er wordt verwacht dat reproductie van een gedeelde praktijk (als procedure) door de community of practice van aardewerkspecialisten, soortgelijke datasets van vormingstechnieken van aardewerk zal opleveren. Gelijkwaardige en gedeelde datasets vereenvoudigen de vergelijking ertussen en zouden zodoende nieuwe inzichten kunnen opleveren. De voorgestelde methodes, indien toegepast op grote schaal en mét publiek, zouden wel eens de archeologische kennisproductie kunnen veranderen en daarmee de traditie. Deze doctorale studie toont echter aan dat de archeologie nog niet zo ver is, maar in transitie.

Tables

Type scanner	Inv. no.	No. of vertices	Resolution mm	File size	Time	Price
Artec Spider	M1/117	3111463	0.1011	335MB	16m	17.600 euro
DAVID SLS-3	M1/117	3269802	0.0715	839MB	32m	4.560 euro
NextEngineUHD	M3/127	7291610	0.10328	992MB	90m	2.500 euro
DAVID SLS-3	M3/127	5966067	0.0936	495MB	22m	4.560 euro
HDI Advance R3x	M3/127	1860968	0.05	150MB	135m	21.500 euro

6A. The comparative data of the pilot study in 2017. The DAVID has the best price-time-quality ratio

ScannerModel	Scan technique	CameraModel	No.of Came	Scanning/Processing Software	Accuracy %
DAVID-SLS3	SLS, stationary	DAVID-CAM-4-M	1	HP 3D Scan Pro 5.6.0	0.05
Agisoft Metashape	IBM	Sony ILCE-6300	1	Adobe CameraRaw; Adobe	
DAVID-SLS3	SLS, stationary	DAVID-CAM-4-M;	3	FlexScan3D Lite 3.3	0.05
DAVID-SLS3	SLS, stationary	DAVID-CAM-4-M	1	HP 3D Scan Pro 5.6.0	0.05
DAVID-SLS3	SLS, stationary	DAVID-CAM-4-M	2	HP 3D Scan Pro 5.6.0	0.05
Artec Spider	SLS, handheld			Artec Studio 16	0.05
Scan-in-a-Box	SLS, stationary	Scan-in-a-Box 2 MP	2	IDEA 1.1 SR 8	0.04
Artec EVA	SLS, handheld			Artec Studio 16	0.1
NextEngine	laser, stationary			NextEngine ScanStudio/HP 3D Scan Pro 5.6	0.127
NextEngine	laser, stationary			NextEngine ScanStudio/Meshlab 2022.02	0.127
NextEngine	laser, stationary			NextEngine ScanStudio/CloudCompare	0.127

ScannerModel	ScanRes. mm	FusionRes. mm	Comparison Res.	No.Scans	Texture	NotesScanningAligning	No.VerticesOrigi
DAVID-SLS3	0.1641	0.0555	0.1602	15	Y	Base underside does	7512159
Agisoft Metashape	0.15	0.1665	0.1665		Y	Type of images RAW;	1000002
DAVID-SLS3	0.1243	0.0466	0.1579	41	Y	Perfect alignment	12601291
DAVID-SLS3	0.1182	0.0602	0.162	15	Y	Rim doesn't align	6865637
DAVID-SLS3	0.1417	0.0499	0.1613	22	Y		9157805
Artec Spider		0.1026	0.1636		Y		4270475
Scan-in-a-Box	0.3002	0.1501	0.1613	22	Y	MeshGeneration:	1148202
Artec EVA	0.1	0.1048	0.1652			Noise, trouble with	2649983
NextEngine	0.06	0.0218	0.1593	16	Y	Alignment done in NE	10950695
NextEngine	0.06	0.0138	0.1673	16	Y	Alignment done in NE	33110122
NextEngine	0.06	0.0459	0.1644	16		Alignment done in NE	11905858

ScannerModel	No.Vertices Comparis	DecimationNotes	NativeFileSizeMB	ExportOBJ sizeMB	ScanPersonID	Processing PersonID	Scanning Circumstanc
DAVID-SLS3	999996	Removed 16 null	264	1601	VL/LO	VL	1
Agisoft Metashape	1000002		232	232	VL	VL	1
DAVID-SLS3	999932	PostSimplification	3600	1891	LO	LO	1
DAVID-SLS3	999986	Removed 158	1300	991	KP	KP	2
DAVID-SLS3	999990	Removed 48 null	405	1331	LO	LO	3
Artec Spider	1000002		627	627	MHS	MHS	3
Scan-in-a-Box	999986		92	92	LO	LO	3
Artec EVA	999961		217	222	MHS	MHS	3
NextEngine	1000098		1100	263	LO	LO	4
NextEngine	975675	Removed 16	5900	566	LO	LO	4
NextEngine	997419		2208	208	LO	LO	4

ScannerModel	HardwareS pecs	Equipment Other	ScanningTime Minutes	TotalProcessingTime Minutes	TotalProduction TimeMinutes	Field notes	Price
DAVID-SLS3	5	9	40	45	85		4500
Agisoft Metashape	5	10	40	90	250	All masked	1800
DAVID-SLS3	6	11	21	43	54	12 min	6420
DAVID-SLS3	5	9	30	50	80		4500
DAVID-SLS3	5	9	12	14	28		5850
Artec Spider	7		20	40	60		17500
Scan-in-a-Box	5	13	30	2	32	This was an	4490
Artec EVA	7		20	5	25	Experiment.	13700

NextEngine	5	12	80	77	157	70 minutes	3000
NextEngine	8	12	80	82	160	70 minutes	3000
NextEngine	5	12	80	94	174	70 minutes	3000

ScannerModel	PerVertexQualityMeshlabSingle	PerVertexQuality MeshlabSingle	StdDeviationMeshlab Single	StdDeviationCC withDAVID2c	MeanDistance CC
DAVID-SLS3	Min -25253.734375 Max	638.687744	25.272272	0	0
Agisoft Metashape	Min -37.728798 Max 21.961830	1.053172	1.026242	0.0762048	0.00396422
DAVID-SLS3	Min -3082937.000000 Max	13354356	3654.361328	0.102184	0.0132813
DAVID-SLS3	Min -45.170662 Max 53.378391	2.406889	1.551415	0.13572	0.0052431
DAVID-SLS3	Min -17.684063 Max 24.870457	1.327412	1.152133	0	0
Artec Spider	Min -52.741283 Max 25.004091	2.005184	1.416045	0.0663366	-0.01724
Scan-in-a-Box	Min -82.360420 Max	1.1508E+11	339233.7188	0.0352775	-0.00901863
Artec EVA	Min -54.958530 Max 76.826324	9.513275	3.08436	0.0980615	-0.0331244
NextEngine	Min -102.618874 Max 104.923790	12.996135	3.605015	0.169035	0.0782555
NextEngine	Min -5506421.000000 Max	30452404	5518.369629		
NextEngine	Min -59333336.000000 Max	3529551104	59410.02344		

6B. Table representing all data produced during scanning with the different 3D scanners.

Scanning Circumstances	1	Concrete building, stable floors, perfect scan conditions
	2	Old building with shaky wooden floors and nearby tram causing vibrations
	3	Concrete building, stable floors, weekend, perfect scan conditions
	4	Old building, wooden floors
Hardware Specification	5	i7 7700HQ, NVIDIA GeForce GTX 1070 8GB, 32GB RAM
	6	Scanning: i7-6700K; 64RAM, Nvidia GeForce GTX 980M 6 RAM; Processing: i7 7700HQ, NVIDIA GeForce GTX 1070 8GB, 32GB RAM
	7	i7-6700K; 64RAM, Nvidia GeForce GTX 980M 6 RAM
	8	Intel Xeon CPU E5-2680 v3@2.50GHz (2 processors), 192GB RAM, Nvidia GeForce Titan X black 12MB RAM
	9	Automatic turntable, black photobooth
	10	Photobooth; manual turntable; targets
	11	White photobooth, manual turntable
	12	Automatic turntable
	13	Manual turntable

6C. Legend of Table 6B, representing the scanning circumstances and technical metadata.

Manipulated data	Comparison Resolution	ExportOBJ filesizeMB	TotalProduction TimeMinutes	PriceEuro	StdDeviation Meshlab	StdDeviation CC	Mean DistanceCC	PerVertexQuality VarianceMeshlab
DAVID-SLS3-1cam	0.1602	0.1601	0.085	0.45	0.25272272	0	0	0.063868774
Agisoft Metashape	0.1665	0.232	0.251	0.131	0.1026242	0.0762048	0.0039642	0.01053172
FlexScan3D	0.1579	0.1891	0.054	0.642	0.36543613	0.102184	0.0132813	0.001335436
DAVID-SLS3-1cam	0.162	0.991	0.081	0.45	0.1551415	0.13572	0.0052431	0.02406889
DAVID-SLS3-2cam	0.1613	0.1331	0.028	0.585	0.1152133	0	0	0.01327412
Artec Spider	0.1636	0.627	0.061	1.175	0.1416045	0.0663366	-0.01724	0.02005184
Scan-in-a-Box	0.1613	0.092	0.032	0.449	0.33923372	0.0352775	-0.009019	0.011507952
Artec EVA	0.1652	0.222	0.025	1.137	0.308436	0.0980615	-0.033124	0.09513275
NextEngine+HP	0.1593	0.263	0.157	0.3	0.3605015	0.169035	0.0782555	0.12996135
NextEngine+ML	0.1673	0.566	0.16	0.3	0.55183696			0.30452404
NextEngine+CC	0.1644	0.208	0.174	0.3	0.59410023			0.35295511
Original data								
DAVID-SLS3-1cam	0.1602	1601	85	4500	25.272272	0	0	638.687744
Agisoft Metashape	0.1665	232	250	1800	1.026242	0.0762048	0.0039642	1.053172
FlexScan3D	0.1579	1891	54	6420	3654.36133	0.102184	0.0132813	13354356
DAVID-SLS3-1cam	0.162	991	80	4500	1.551415	0.13572	0.0052431	2.406889
DAVID-SLS3-2cam	0.1613	1331	28	5850	1.152133	0	0	1.327412
Artec Spider	0.1636	627	60	17500	1.416045	0.0663366	-0.01724	2.005184
Scan-in-a-Box	0.1613	92	32	4490	339233.719	0.0352775	-0.009019	1.1508E+11
Artec EVA	0.1652	222	25	13700	3.08436	0.0980615	-0.033124	9.513275
NextEngine+HP	0.1593	263	157	3000	3.605015	0.169035	0.0782555	12.996135
NextEngine+ML	0.1673	566	160	3000	5518.36963			30452404
NextEngine+CC	0.1644	208	174	3000	59410.0234			3529551104

6D. Table with the parameters which have been converted to accommodate the comparison.

p. 267: **6E.** The TPW Metadata Sheet. This excel-sheet can be used to document the process of scanning in order to provide full transparency.

Data	Explanation	Examples
ScanID	Unique number of the scanning session	
DatabaseID	Unique number in your database	
ScannerModel	Which brand was used?	DAVID-SLS3; Scan in a Box; NextEngine; Artec Spider; etc.
ScanTechnique	Technique used to create a 3D model, such as laser, photogrammetry or SLS	SLS
StillCamera	Type of camera	DAVID-CAM-4-M; Nikon D60
CameraQuantity	No. of cameras	2
ProcessingSoftware	Software used to scan and to produce pointclouds and 3D models	HP 3D Scan Pro 5.6.0; Agisoft Metashape
CalibrationBoard	Calibration board size	
Resolution	Vertex spacing, or distance between vertices of	
Accuracy	The accuracy of the scan related to real-world position, usually provided by the brand of the scanning device	
FusionResolution	The resolution after fusing (merging) individual scans into one model	
Sharpness	Manipulation of recognizable features in the geometry: to enhance visibility of these features or to smooth them	
CloseHoles	Set parameter to close holes in model	
PhotoQuantity	No. of photos	
ScanQuantity	No. of scans	
Texture	Does the scan come with texture?	Y/N
Remarks	While processing the scans (cleaning, alignment, etc.) choices are made and problems occur. These should be described in this field.	Two ridges are apparent on the exterior surface and small ones in the interior due to misalignment of the separate scans. 1 of the 14 scans were deleted (nr 31)
Vertices	No. of vertices raw	The number of vertices in the fused/merged native 3D model
DecimatedVertices1	No. of vertices after 1st decimation/simplification of the model	The number of vertices in the fused/merged 3D model after a decimation cycle. For TPW we decimate models to appr. 150-190MB excluding texture; about 500.000 vertices.
DecimatedVertices2	No. of vertices after 2nd decimation/simpplification of the model	The number of vertices in the fused/merged 3D model after a decimation cycle. For TPW we decimate models to appr. 30-50MB excluding texture; about 150.000-200.000 vertices.
DecimationCycles	Decimation cycles	1st decimation round about 3-5 times on quality treshold 0.3 in Meshlab (Decimation filter > Simplification: Quadric Edge Collapse Decimation (with texture)), 2nd decimation 2 additional times
DecimationNotes	What has Meshlab (or any other processing software) removed during decimation/simpplification	Removed 1 duplicated face and 62 duplicated vertices
NativeFilesize	Original, unprocessed file size	
OBJsize	Exported file size before post-processing	
OBJsizeDec1	OBJ size after 1st decimation process	
OBJsizeDec2	OBJ size after 2nd decimation process	
ScanOperatorID	Initials or name of the operator	
ScanProcessingID	Initials or name of the person processing the model	
Circumstances	The circumstances in which the scan was produced	Old building with shaky wooden floors and nearby tram causing vibrations; bright TL light or daylight; earthquakes, tornados?
PortionScanned	Some objects are not scanned in its entirety	
HardwareSpecs	What hardware was used to create and process the	i7 7700HQ, NVIDIA GeForce GTX 1070 8GB, 32GB RAM
EquipmentOther	What else was used to create the scans?	automatic turntable, black photobooth
ProcessingTime	How much time did it take to produce and process the	
FieldNotes	Anything happened that could interfere the scanning, such as calibration issues or people passing by, visitors? i.e. touching the set-up, slamming doors..	
PDF	Exported model to pdf or additional information shared in a pdf	
hp3dscanproj	file type; this is a native file of an HP scanner, but any native file type can be used here	
hp3dscanprojPROC	processed file type	
MetashapeProject	a(ny) photogrammetry output	
DAE	exported file type to increase reuse	
C4D	exported file type to increase reuse	
PLY	exported file type to increase reuse	
STL	exported file type to increase reuse	
U3D	exported file type to increase reuse	
OBJ	exported file type to increase reuse	
OBJdec1	exported file type to increase reuse	
OBJdec2	exported file type to increase reuse	
OBJ_SeparateScans	all scans exported separately to OBJ to be processed in other processing software	
OnlineLocation	Is the model published online? Please provide the url	

UvA