Chapter 1
3D Archaeology and Cultural Heritage: Where Are We Today?

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Abstract Although the basics of 3D technologies developed rather early on, only today are we seeing a steep increase in the application of 3D technologies in archaeological practice. This volume aims to give a broad overview of possible applications in the field, but also to open a discussion about the challenges and problematic aspects of this method so far. Only if there is an awareness of the implications and challenges of implementing this new technology in the everyday practice of field and research archaeology can archaeology take full advantage of its possibilities.

Keywords 3D technologies in archaeology · Digital archaeology · Digital archiving · Data management · Photogrammetry · 3D scanning in archaeology

The application of new methods has had a lasting impact on our research questions, research setups and applied methodology – in short, they have deeply affected our understanding and practice of archaeology. Some of them have been labelled

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revolutionary, such as radiocarbon dating and dendrochronology or ancient DNA analysis (cf. Kristiansen 2014). The 3D capture of archaeological findings and artefacts may also be one such method, with the potential to revolutionise archaeological documentation.

An important foundation for 3D capture is the method of photogrammetry, which has a very long history dating back to the very beginnings of photography in the nineteenth century (Luhmann et al. 2014). The basic mathematical principles establishing the numerical relationship between the real-world object and its photographic representation were already developed and understood at that time. One important field of application was the metric recording of façades, a technique used by the German Albrecht Meydenbauer to record a range of important architectural monuments in the German Reich and neighbouring countries. In addition to monuments such as the cathedral in Worms or the Haut-Koenigsbourg in Alsace, he recorded the ruins of Baalbek from 1902 until 1904. His efforts count among the earliest attempts at the preservation and documentation of cultural heritage via photogrammetry (Luhmann et al. 2014; Grimm 2021).

During the first half of the twentieth century, analogue photogrammetric methods using fixed and rigid camera systems in combination with visual plotting systems were prevalent. The main application was mapping, mostly using aerial photography. Close-range photogrammetry was only rarely used, for instance in police work with specially developed systems. Subsequently, from the 1950s onwards, numerical methods were increasingly developed. Together with recent developments in computer vision, these methods enable a more flexible and accurate model reconstruction, including from arbitrary images and camera locations. From the 2010s onwards, a wide range of easy-to-use software packages came on the market, which enable quick and cost-effective close-range photogrammetry (Luhmann et al. 2014).

These tools made it possible to capture objects, such as archaeological artefacts, excavations, and even entire landscapes, in three dimensions with an accurate reconstruction of sizes and ratios, as well as accurate surface and texture representation. These methods not only enable the eye-catching display of digital models, but also enhance research possibilities (e.g. for their application in labour-cost studies, see Pakkanen et al. 2020; for a recent comparison of different methods for site recording, see Stamnas et al. 2021). Measurements can be taken more accurately during post-processing, while different mapping techniques can be applied to the data. They also make possible the integration of different datasets in a 3D space (e.g. in an integrated approach using GIS in Katsianis et al. 2008, to calculate the tonnage of a marble cargo in Roman ships in Parizzi and Beltrame 2020 and to map masons marks in Orabi 2020). In this way, these tools not only represent a new and more accurate approach to documentation, but also open a new dimension in which research questions can emerge (see Brysbaert et al. 2018, with examples of the application of 3D technology to the specific question of labour cost).

Nevertheless, until the middle of the last decade, the scientific value of the application of virtual archaeology (VA) and 3D archaeology was still being discussed, if not questioned, while the methods themselves seemed to remain constantly in a pioneering state, as suggested by the fact that this method was perceived as

revolutionary even into the mid-2010s (Lanjouw 2016; Vergnieux and Giligny 2016; De Reu et al. 2014). This situation is even more surprising if we consider that the first attempts to introduce all the relevant methods, such as CAD, virtual or photogrammetric 3D reconstruction, into archaeology had been made already in the 1970s, 80s and 90s (for an overview, see Lanjouw 2016).

One possible reason that these methods have only recently become widespread could be the increased acceptance and easy accessibility of computers and other digital tools. Not only have the costs of computer hardware and digital cameras decreased in the last decade (e.g. U.S. Bureau of Labor Statistics 2015), but software used in reconstruction, post-processing and analyses has become more user-friendly and efficient. Another possible reason is the increasing interconnection of the world, which has helped further promote these technologies since the advent of the internet in the 1990s. In this respect, the predictions and visions of various archaeologists formulated as early as the 1970s have only recently been fully realised (compare the following summaries of early views on digital archaeology: Frischer 2008; Lanjouw 2016; Hodel 2020). In 2008, Bernard Frischer and Anastasia Dakouri-Hild (Frischer and Dakouri-Hild 2008) collected a wide range of papers in *Going Beyond Illustration* and presented diverse methods for virtual and 3D archaeology that were thought to permit the scientific exploitation of these tools, which had previously been perceived as mainly fulfilling educational and visualisation purposes (Frischer 2008). In an anthology published in 2016 by Hans Kamermans et al. entitled *The Three Dimensions of Archaeology*, different papers presented various approaches to the scientific and research-oriented application of three-dimensional methods, while in 2018 Barry Molloy edited a topical issue in the journal *Open Archaeology*, with a focus on advances in the use of 3D models in archaeology.

In 2014, the need for best practices was addressed by an anthology aspiring to serve as a guideline in the 3D documentation of Cultural Heritage (Remondino and Campana 2014). The book covered a range of topics starting at the intersection of archaeology and geomatics, including papers on laser/lidar, photogrammetry, remote sensing, GIS and virtual reality. Three case studies containing practical insights were included at the end, while the body of the book focused on establishing the basic principles governing the application of these techniques to archaeology and cultural heritage. Other publications also pointed in the same direction, covering the methodological basics and providing first-hand case studies of the application of 3D techniques at excavations (cf. De Reu et al. 2014; Galeazzi 2016; Novaković et al. 2018).

Nonetheless, the widespread introduction of digital-capturing techniques poses new challenges: the acquisition and processing of 3D data produces a vast amount of data that needs to be archived (cf. Chen 2001; Zubrow 2006; De Reu et al. 2014). Since archaeologists must document each step, this also includes the documentation of processing steps and the modelling of 3D data. The interoperability and exchange of 3D models – not only between individuals, but also between programs – is not yet fully developed. Going through the 'chaîne opératoire' of 3D data, we encounter another challenge, namely that the visualisation and publication of 3D models for everyone also has its pitfalls, including data formats, the need for special software, limitations on web access and the question of copyrights. Who owns a 3D model?

The museum that possesses the find, the photographer or the individual who processed the data?

Still, for many archaeologists, not only the production, but also the handling of 3D technologies is new. Where are we now? And where do we want to take 3D technologies in archaeology and cultural heritage? This book provides an overview of the current applications and pitfalls of image-based 3D technologies in archaeology and cultural heritage. It also addresses existing practices and the use of 3D data for documentation, research and visualisation. It should not be seen as a comprehensive handbook, but rather as capturing the current state of 3D technologies in archaeology. As such, it is organised into five parts covering important aspects of 3D archaeology, such as its history and the context of its application, case studies showcasing different applications with a strong research focus, the presentation and organisation of 3D data, archiving and data management.

In Part I, following this short introduction, Jugoslav Pendić and Barry Molloy (Chap. 2) offer a comprehensive account of the application of 3D technologies in archaeology, while also highlighting some of the weaknesses seen so far and pointing out a way forward for future use. In contrast, the contribution by Florian Innerhofer, Thomas Reuter and Conny Coburger provides insights into the use and development of 3D technologies over the last 15 years in day-to-day archaeological practice at the Archaeological Heritage State Office of Saxony (Chap. 3).

Part II focuses on the gathering of 3D data via different case studies, attempting to give an overview of 3D technologies: i.e. what their current use is and what kind of data and methods are applied in different archaeological contexts. It covers a range of topics, from the documentation of larger archaeological sites, including standing remains, as in the paper by Clemens Brünenberg, Christoph Rummel and Monika Trümper (Chap. 4) on the Pompeian baths, to spatial analysis of the fragmentation processes of pottery using photogrammetry and GIS analysis, as applied by François Fouriaux (Chap. 5).

Going one step further, Part III is designed to present possibilities and workflows to enhance the study of archaeological material through the use of 3D technologies. Christian Horn, Mark Peternell, Johan Ling, Ashley Green and Rich Potter explore the advantages of 3D documentation in research on rock art, while also discussing problematic aspects of this technique (Chap. 6). Elisabeth Trinkl, Stephan Karl, Stefan Lengauer, Reinhold Preiner and Tobias Schreck used 3D technologies for typological studies and to produce an enhanced visual representation of Greek pottery paintings (Chap. 7).

In Part IV, the focus is on how to present and communicate 3D data to different audiences. Tracing the adaption of the potter's wheel technology, Loes Opgenhaffen, Caroline Jeffra and Jill Hilditch make use of 3D technologies and show how they present their insights, including metadata and paradata (Chap. 8). Commenting on the database they develop for the 3D documentation of bones, Jugoslav Pendić, Jelena Jovanović, Jelena Marković and Sofija Stefanović elaborate further on the topic of how to present 3D data and how to transmit insights to other researchers (Chap. 9). Kate Fernie focuses on the web portal EUROPEANA and the experience of making the visualisation of 3D data available on the web to a broad audience (Chap. 10).

Part V deals with the challenges relating to archiving all the data related to the use of 3D technologies for archaeology and cultural-heritage management. The survey of the current application of 3D technologies in archaeology by Marco Hostettler, Anja Buhlke, Clara Drummer, Lea Emmenegger, Johannes Reich and Corinne Stäheli gives a comprehensive overview of different groups and their needs when it comes to handling 3D data (Chap. 11). Kristin Kruse and Esther Schönenberger share their experiences from the archaeological department of the canton of Zurich, explaining how to document and generate 3D models, but also how to create a sustainable archive and data management system (Chap. 12).

This broad selection of topics ranging from data collection to analysis and presentation is intended to enhance our understanding of the current position of 3D technologies in archaeology. It demonstrates existing practices and workflows that are applied today, but also gives clues about possible pitfalls and how experienced users find ways to work around and potentially resolve them. Furthermore, it reveals not only flaws in the workflow of 3D documentation, but also the need to arrive at a fundamental agreement in archaeology and cultural heritage about the implementation and standardisation of the application across different groups of interest, one that not only covers current needs but also has a future generation of users in mind. The book closes by contextualising 3D archaeology as part of a larger digital world. Besides technical challenges the ethics of the digital and an awareness of the underlying power structures are key for a sustainable and revolutionising future (Chap. 13).

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