Chapter 11
Digital Archaeology Between Hype and Reality: The Results of a Survey on the Use of 3D Technologies in Archaeology

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Abstract Between January and March 2020, the EAA Community for 3D-Technologies in Archaeology conducted an international online survey on the current use of image-based 3D technologies. The aim was to gain broader insight into the application of image-based 3D technologies in archaeological practice and cultural-heritage management. The survey made it possible to determine the most important aims of the use of 3D technologies, as well as providing an overview both of the software and data formats used and of current archiving practices for raw and/or generated data. In this way, the main challenges for the further development of the techniques and the ongoing implementation of 3D technologies in practice can be identified.

Keywords Evaluating digital methodology · 3D documentation · Digital archaeology · Archiving digital data · Data processing

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11.1 Introduction

In the last decade, the use of 3D technologies in archaeology and cultural heritage has witnessed a progressive consolidation in most of its fields of activity. Nowadays, 3D techniques are a standard element in the archaeologist's toolkit. Moreover, these methods are not only used on site and in laboratories to document archaeological features and finds, but they have also proven their usefulness for tackling new research questions using 3D data (cf. Herzog and Lieberwirth 2016; Vollmer-König 2017; Howland 2018; Blaich et al. 2019; McCarthy et al. 2019; Pakkanen et al. 2020). Finally, 3D models also show great potential for use in public outreach and education (Hagenauer 2020; Unger et al. 2020).

However, the implementation of these techniques has not developed everywhere at the same pace or with the same goals and framework conditions. In some cases, these efforts started quite early, while in other cases they began only recently. The result is that many of the approaches remain individual (cf. Innerhofer et al. and Kruse/Schönenberger Chaps. 3 and 12 in this book, but also Winkler 2020). Thus, the landscape of 3D applications in archaeological practice is diverse and fragmented, and only recently have efforts been made to search for common ground at the international level (cf. the study VIGIE-2020-654 financed by the European Commission and hosted by the Digital Heritage Research Lab at Cyprus University of Technology: http://ec.europa.eu/newsroom/dae/document.cfm?doc_id=69940. Accessed 17 Jan 2021).

In order to acquire an overview of the various practical applications and individual strategies, an online survey was conducted between January and March 2020. The focus lay on questions concerning usage and archiving, as well as the professional environment of the participants. The survey was specially designed to cover the usage of image-based 3D technologies, because these are generally easy to incorporate into the pre-existing infrastructure of archaeological work environments, given that digital cameras and computer hardware are in most cases already accessible. Since the survey was designed as a pilot study into a relatively little-explored field of inquiry, it was kept quite broad, as were the possible answers. The target audience were archaeologists and other professionals from different working environments, such as institutional research (e.g. universities or academies), state monument offices (e.g. Landesdenkmalämter in Germany) and freelance archaeologists and technicians. There were no restrictions according to sub-discipline, meaning

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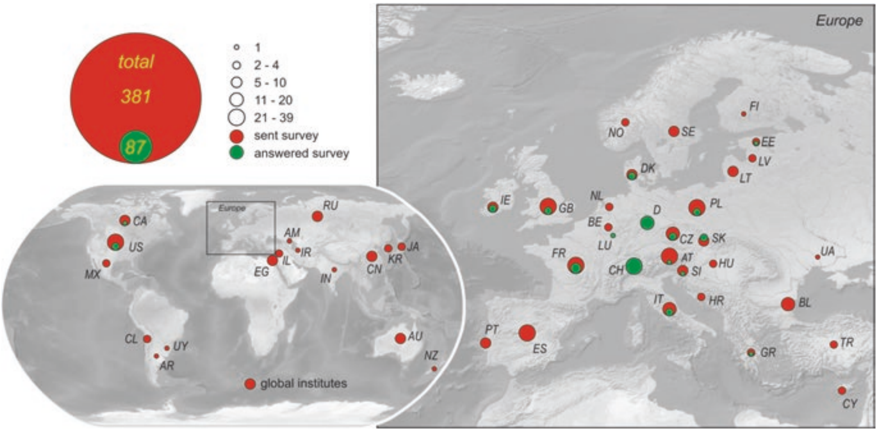

Fig. 11.1 Distribution and response to the survey

that the participants could have very different foci of expertise (e.g. numismatists, field archaeologists, Egyptologists, etc.) The survey was attached to 381 e-mails to institutions and individuals in 47 countries. It was also shared over social media (on Twitter and Facebook) and mailing lists. In total, 87 of the returned questionnaires were at least 80% complete (Fig. 11.1).

Even though the survey is not statistically representative, we were able to acquire an overview of the importance of 3D technologies with respect to their essential aspects, including the most important aims governing its general use, as well as the software, data formats and type of archiving employed. By means of these questions, we aimed to identify indicators of the challenges involved in the application of 3D technologies to archaeological practice. In the following chapters, we will present and discuss the results of the survey.

11.2 Results

11.2.1 Demographic Data

The survey reached a mainly European audience, with the majority of participants residing in Germany and Switzerland (Fig. 11.1). Over 70% of participants were male. In terms of age, 44% were 30–39 years old, 28% were 40–49 years old, 16% were 50–59 years old and only a few were older than 60 years. The participants mostly held positions within research institutions (i.e. universities, academies, etc.) or state monument offices. A portion of the participants worked as freelancers. The individual projects and positions were mainly connected to archaeology (in 80% of the cases).

11.2.2 Importance and Utilisation Objectives

In this section, participants were asked about their main objective in using 3D technologies, the usage context and how this task was allocated within their teams. The objective of this question was to assess the importance of 3D technologies for the participants, as well as the state of implementation in their working group or institution. For most participants, 3D technologies were of central importance to their projects, either as a means to an end (e.g. for documentation purposes) or as the main purpose of the project. When analysed according to field of work, participants at state monument offices and research facilities mostly considered 3D technologies to be a means to an end. Freelancers, by contrast, applied 3D technologies mostly in ‘particular situations’. Noteworthy were the numerous mentions of an ongoing test phase in all three fields of work (Fig. 11.2).

The important position occupied by 3D technologies was also reflected in the fact that one team member was usually responsible for the use of 3D technologies as a ‘specialist’. Only in the case of freelancers was it more common for a team member to deal with these technologies as an additional task (Fig. 11.3).

The most frequently mentioned goal for the use of 3D technologies was the documentation of excavations. This was followed by the targeted creation of 3D models for research, as products and, finally, for public outreach (Fig. 11.4).

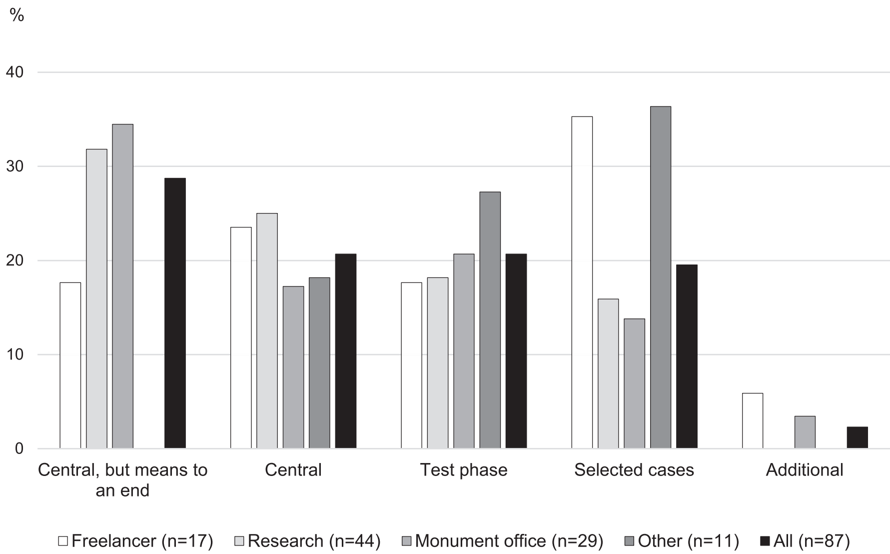

Fig. 11.2 The position of 3D technology in practice, broken down according to fields of work. Under ‘Other’ it was usually stated that the position varied according to the project

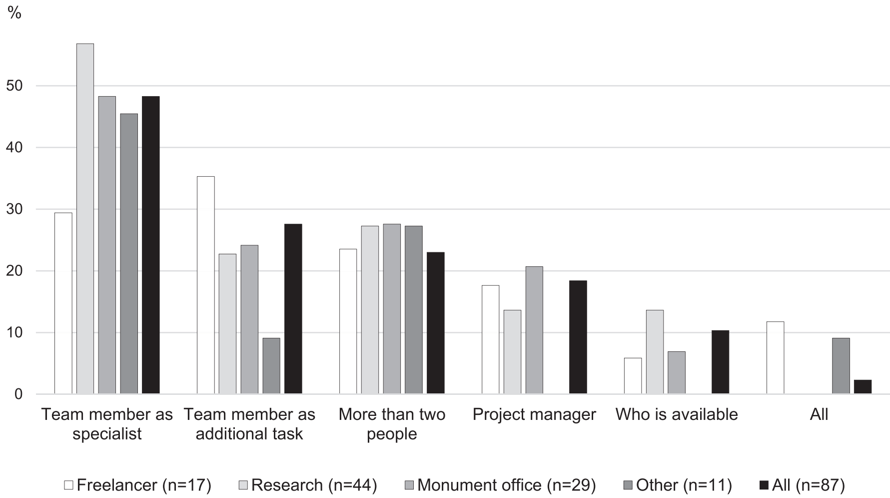

Fig. 11.3 'Who on the team works with 3D technologies?' The answers are sorted by the different fields of work

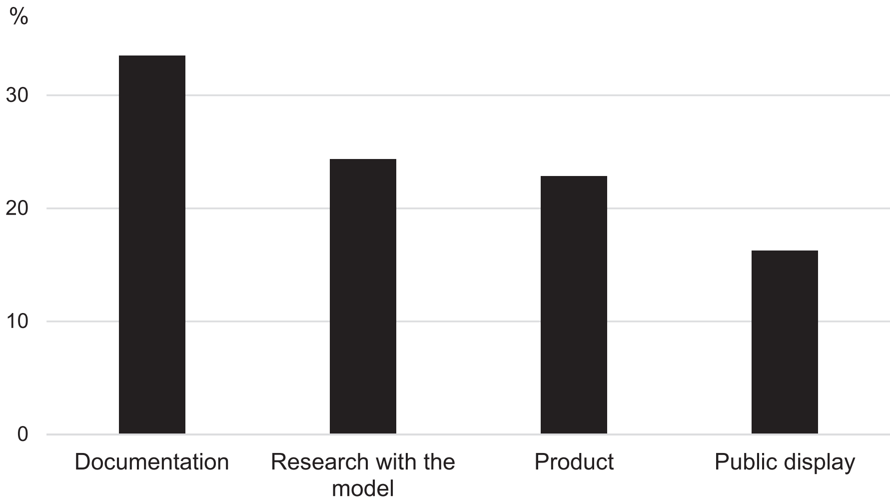

Fig. 11.4 Aims for the use of 3D technologies; 100% = 197

11.2.3 Software and Data Formats Used

This section of the questionnaire aimed at surveying the most common software applications and data formats used by the participants. In the questionnaire, seven software applications were listed as possible choices. There was also an option to

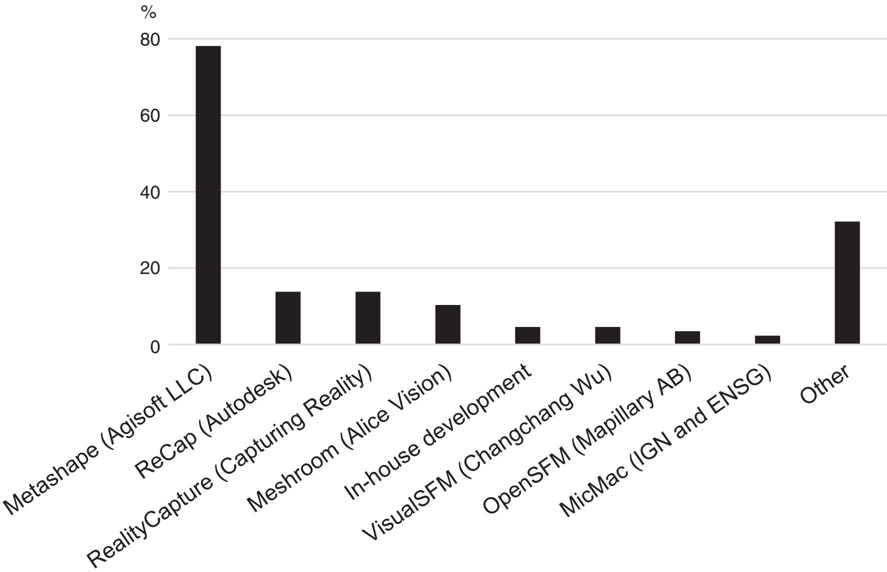

Fig. 11.5 Share of respondents who use specific software. Multiple answers were possible, which means that the sum of the percentage values is greater than 100; 100% = 87

indicate one's own developments or other alternatives, and multiple answers were possible (Fig. 11.5). In the answers, a total of 32 different software applications were listed, including 25 applications under 'other' (Table 11.1). The program Metashape by Agisoft LLC was by far the most frequently used. Other programs, such as ReCap Pro by Autodesk and RealityCapture by Capturing Reality, were named less frequently. Meshroom by AliceVision was the only open-source software mentioned in the top-four list and was used by 10% of the participants. The used applications can, for the most part, be categorised as 'complete solutions', which also include tools for georeferencing.

In order to query the frequency of the data formats used, a distinction was made between input and output data. By input data, we mean all data that is available before it is fed into processing software, while output data is the processed output, i.e. 3D models and digital elevation models, but also two-dimensional images, including, for example, orthophotos, unwrappings, profiles and the like. The boundary is to some extent vague and not absolute.

When it came to input formats, a limited, predefined selection of formats was offered, with the option to add additional formats. Multiple answers were allowed. Here, a similar picture emerged as in the case of software. A few formats were chosen most frequently (JPEG, TIFF and RAW formats, which were not further subdivided), but the total number of different formats was rather high (n = 21; Fig. 11.6).

In order to query the output formats, a predefined selection was given, with the option to mention additional formats. The results of the answers concerning output file formats are comparable to those for the input data, with only a few common

Table 11.1 Name (developer) and the number of mentions of the software solutions listed under 'Others'

Other Software Mentioned	Count
FARO SCENE (Faro Technologies)	3
MeshLab (Cignoni et al. 2008)	3
Artec Studio (Artec 3D)	2
Cinema 4D (Maxon)	2
CloudCompare (Daniel Girardeau-Montaut)	2
OptoCat (Breuckmann)	2
3DF Zephyr (3DFlow)	1
3DReshaper (Technodigit)	1
ArcGIS (ESRI)	1
Aspect 3D (Arctron 3D, Martin Scheuch)	1
Blender (The Blender Foundation)	1
CorelDRAW (Corel Corporation)	1
DEA (Digital Epigraphy and Archeology) (University of Florida)	1
GeomagicWrap (Artec 3D)	1
MODO (Foundry)	1
Pix4D (Pix4D SA)	1
Pointools (Bentley)	1
Rangevision Scan Center (RangeVision)	1
RiSCAN Pro (RIEGL – Laser Measurement Systems)	1
Robot Structural Analysis (Autodesk)	1
Scanstudio (NextEngine)	1
SketchUp (Trimble Navigation Ltd)	1
Unity3D (Unity Technologies)	1
V-Ray (Chaos Group)	1
ZBrush (Pixologic)	1

formats (Fig. 11.7). OBJ, JPEG and GeoTIFF were among the top-three formats, while a total of 20 different formats were mentioned. Of these, only OBJ can be considered a 'true' 3D file format. There seem to be hardly any differences between research institutions, state monument offices and freelancers.

11.2.4 Modalities of Archiving

The fourth section of the questionnaire focused on data management strategies and archiving practices. In order to assess this, it was asked whether guidelines were followed in the respective institutions or working environments. Participants were also asked about data formats for archiving, on the grounds that this might provide information about the awareness of challenges for long-term storage and interoperability. About half of the participants stated that there were institutional guidelines

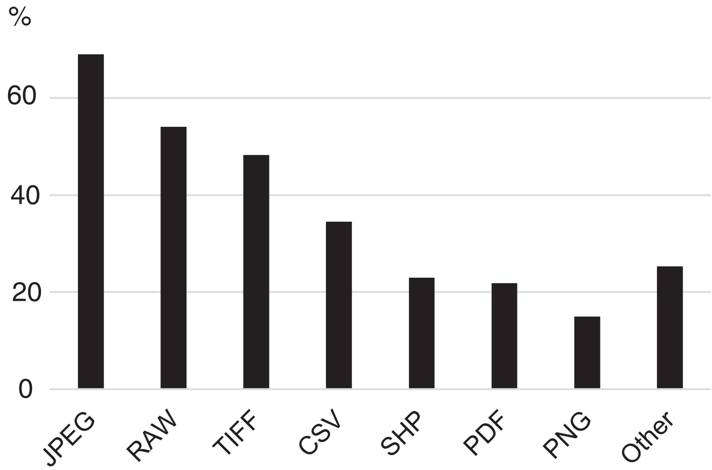

Fig. 11.6 Input data: share of participants who used a specific format. Multiple answers were possible; 100% = 87

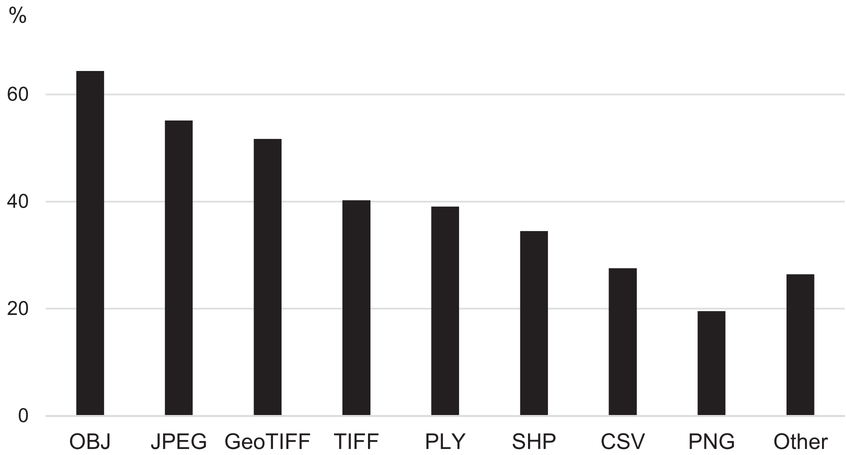

Fig. 11.7 Output data: share of the participants who use a specific format. Multiple answers were possible; 100% = 87

for archiving. From this, we can deduce that, in most cases, their approaches had been tested and validated, but that these approaches are presumably only rarely written down in the form of an established standard. Likewise, only about a quarter of the respondents had a data management plan or a comparable (recorded) strategy (Fig. 11.8). When broken down by fields of work, it was found that participants working in state monument offices and research institutes tended to have more formalised strategies than freelancers.

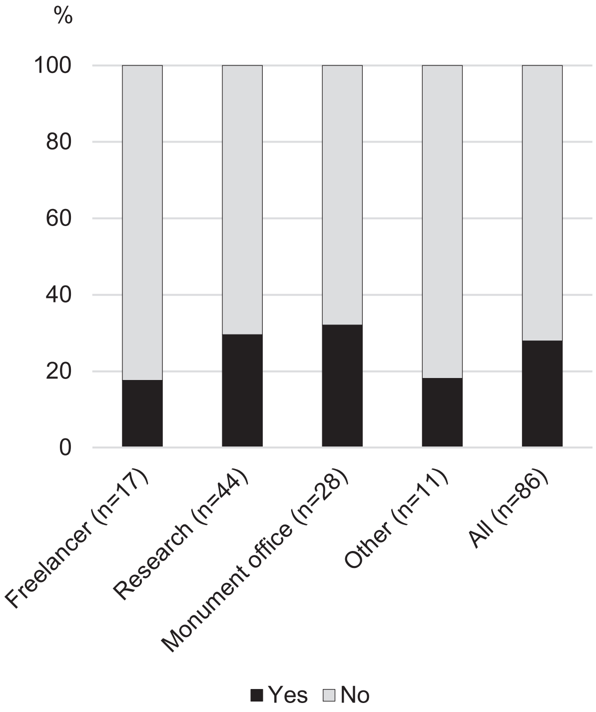

Fig. 11.8 Share of participants with or without a data management plan, broken down according to fields of work

Despite the paucity of fixed guidelines, respondents stated that they archived output data more often than input data (Fig. 11.9), with only slightly more than 20% of cases converting data (both input and output) into a specific archiving format. Only rarely was it stated that the associated software was archived as well.

The answers given concerning the file formats used for archiving input data revealed a preference for JPEG (around 60%) followed by RAW formats (55%) and TIFF (around 50%; multiple responses possible). When it came to archiving the output data, OBJ (55%), GeoTIFF (around 50%) and JPEG (around 40%; multiple answers) were listed most frequently. The available data storage capacity for archiving was mostly identified as lying beyond 1 TB, as in most cases this was identified as the required storage capacity. Here, the questionnaire was unable to solicit meaningful answers, as the question was too narrowly formulated. In addition to the input and output data, most participants stated that they stored the accompanying metadata, which is automatically generated, as well as additional metadata about the actual capturing process, such as the camera lenses and software packages used, and so on. However, multiple answers were not possible, obscuring the relationship between the answers. Most participants stated that the archiving method did not differ in virtue of the subsequent intended use of the datasets.

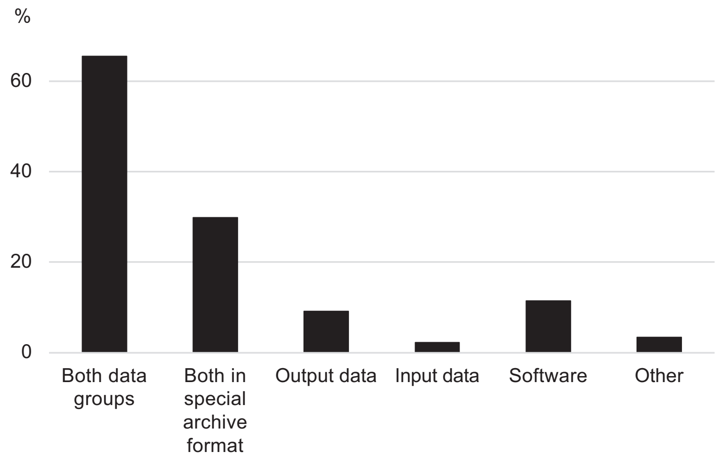

Fig. 11.9 Share of the participants who archived specific data formats. Multiple answers possible; 100% = 87

A lack of long-term experience with archiving digital data was repeatedly thematised in the responses. Nevertheless, confidence in the possibilities given was expressed by about 75% of the respondents.

With regard to the requirements for the archiving of 3D data, the participants most frequently identified the importance of the availability of sufficient storage capacities, high data security and secure protection. These answers were followed in frequency by the requirement of easy access and easy handling of the archives, as well as the ability to store the data on servers located in their own country with a long archiving timespan. The requirements that were accorded the least importance in the answers were the availability of support, public accessibility of the archives and version-dependent archiving (Fig. 11.10).

11.2.5 Accessibility of Data

Another important question concerned the accessibility of the data within the participants' working environment, which could provide information about who is authorised to access the data in a specific working environment. This might provide information about present risks and challenges. In the options given in the questionnaire, a distinction was made between an archive, where the data is stored and durably preserved without constant access, and a database, where the data is stored temporarily before or parallel to archiving but with constant access.

When asked about access authorisation, participants stated in most cases that the database was accessible only to team members. This was followed by in-house availability (Fig. 11.11). Public accessibility and restriction of access to individuals

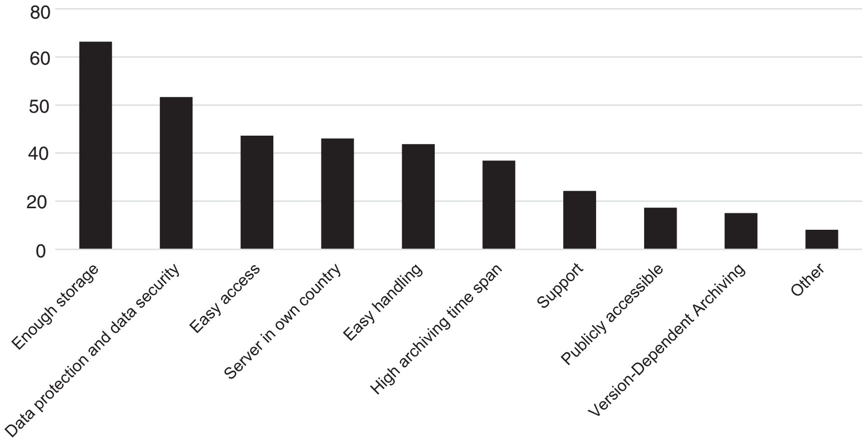

Fig. 11.10 Requirements for a digital archive for 3D data. Percent of participants for every answer

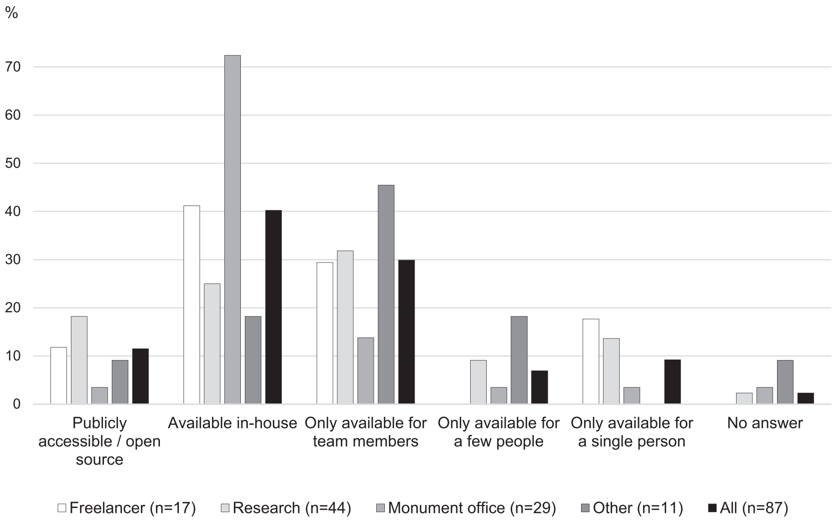

Fig. 11.11 Accessibility of the database containing 3D data

were only seldom mentioned. Public accessibility was mostly listed by participants working in (academic) research contexts.

The archives, by contrast, were mostly said to be accessible within the institutions. This was followed by being restricted to team members. It was relatively rarely claimed that access was restricted to specific individuals. Public access to archived data was also rarely listed, and when it was mentioned, it was mostly by participants working at research institutions (Fig. 11.12).

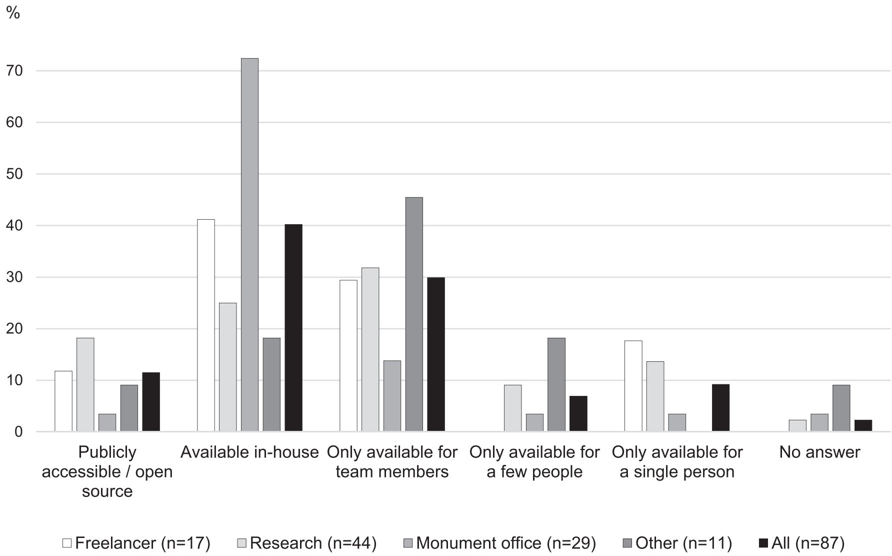

Fig. 11.12 Accessibility of the archive

11.2.6 Project Duration and Archiving Timeframe

For successful data management (independent of specifications or guidelines), both the project duration and the planned duration of archiving are important parameters. Both of these parameters were surveyed in the questionnaire, with predefined time ranges being given.

The most frequently stated project duration was five years (18%), followed by ‘less than six months’ (17%). Projects with a duration of three years came third (14%).

Freelancers stated that they worked mostly on short-term projects (less than one year, 43%) and on five-year projects (27%). Participants from research institutions mainly stated that they worked on projects with a duration of three or five years (20% and 24%), although projects with a duration of ten years also accounted for a significant share (16%). For participants working in state monument offices, a plurality of projects had a duration of less than one year (38%), while projects with a timeframe of more than 50 years were frequently listed as well (at a rate of 25%, as compared with about 11–13% for research institutions and freelancers).

The queried time horizons for archiving reveal two focal points, one at 10 years (28%) and the other at more than 50 years (33%). When these were sorted by field of work, it was revealed that freelancers and participants from research institutions, in particular, identified an archiving timeframe of 10 years or less (42% and 38%), while participants working in state monument offices stated that the archiving timeframe was generally more than 50 years (82%).

11.2.7 Guidelines?

The last section of the questionnaire asked whether guidelines would be supported, and solicited individual comments. The question of whether broad-based guidelines would receive support was largely answered in the affirmative (74%). The comments were diverse, but they all pointed in a similar direction: basic guidelines for the use of 3D technologies in archaeology could provide guidance, especially for less experienced colleagues. A second important point mentioned was the comparability and interoperability of the results that guidelines should aim to achieve. Reservations were expressed because many projects tend to have their own specific needs. It was therefore claimed that guidelines should be formulated in a sufficiently open manner, but without sacrificing their applicability.

11.3 Discussion

11.3.1 Demographic Data

The demographic questions were mainly asked in order to make it possible to group the participants in the evaluation of the survey. The focus lay mainly on determining the participant's broad field of work (i.e. academic context, state monument office or freelancer). Nevertheless, some other interesting observations could be made, giving potential insights into the structure of the field of archaeology.

For instance, the survey had a relatively low return rate from people over 60 years. This could be a sign of a generational shift in archaeology, as despite early pioneering applications of 3D technologies, the relevant techniques have only recently been used more widely. As the survey data indicates, 3D technologies seem to be more readily adopted by people aged 30–39 years, some of whom have been accustomed to the presence of digital technologies in their daily activities since childhood.

At the same time, a gender imbalance among the survey participants can be observed, with significantly more male respondents than female ones. Does this reflect an actual gender imbalance with regard to 3D technology or could other explanations be given? However that may be, it is important to keep in mind that the survey is not representative. One hint that the prejudice that it is mainly men who are interested in technology might not be correct is the large proportion of female authors in this book. As awareness about gender discrimination in archaeology is also currently increasing, this may deserve its own study.

11.3.2 Importance and Objectives of Use

A large proportion of the respondents viewed their use of 3D technologies as a means to an end, with high importance being assigned to the use of 3D technologies even in their daily work: 3D technologies are used in both the field and the laboratory for documentation purposes (means to an end), as well as for the study of specific questions (central role). For the respondents, 3D technologies are thus an important tool that is used routinely. However, this does not necessarily reflect the situation in the field of archaeology as a whole, since the survey explicitly targeted people with some sort of relationship to 3D technologies, with the result that it is unsurprising that 3D technology has significant importance for most of the participants.

More interesting is the relatively high percentage of participants who claimed to use 3D technologies in a testing phase (20%). Although the same limitation applies here, it nevertheless shows that the percentage of people entering the field may be rather large. This fits with the common picture of a growing interest in these technologies in recent years. Furthermore, it can be assumed that at least some of the respondents will soon integrate the technologies that are currently being tested into their regular practice. Accordingly, we can deduce the existence of a tendency towards further consolidation of 3D technologies in archaeological practice. The answers given to the question “Who in your team works with 3D technologies?” clearly show that tasks involving 3D techniques in archaeology are mostly carried out by specialised team members. This may be due to the fact that, until recently, academic training did not include the use of such techniques. The relevance of specialised team members for 3D documentation may also pose a risk in the context of fieldwork, as it is unclear whether other team members would be able to replace the specialist if needed. Giving a higher percentage of archaeologists training in 3D techniques as part of their basic education seems desirable.

11.3.3 Software and Data Formats

The evaluation of the questionnaire showed that there exist myriad different software applications and file formats. However, despite this large number of different options, only a few are used by a significant percentage of respondents. Although the survey is not representative, we assume that this observation (i.e. a few with high usage frequencies vs. a vast majority with low usage frequencies) may also be valid for the broader field.

When it comes to the choice to use a specific software application, it is probable that the decision is heavily influenced by the user-friendliness of the application, its flexibility in relation to different scenarios, and – in the context of archaeological documentation – the possibility of georeferencing the output. In our experience, Agisoft’s Metashape meets all these criteria, which could be one of the reasons for its popularity. Another argument in favour of a certain product is its pricing. Autodesk ReCap Pro costs about €420 per year with a subscription and the permanent version of CapturingReality's Reality Capture costs regularly €15,000 (comparison of company websites). The 'Professional Edition' of AgisoftMetashape costs about $3500/€3000, while the 'educational license' for non-commercial purposes is priced at about $550/€470 (comparison of company websites). Archaeology and heritage management are usually not added-value-generating fields. The single-fee-based software applications seem preferable, as their cost is comparably lower. It can also be observed that commercial applications are mostly preferred over open-source solutions. From the perspective of open science and reproducibility, it would be preferable to have a broader application of open-source software in this field as well. However, this might change in the future, if open-source solutions are able to match the quality of their commercial competitors. The possibility of georeferencing, in particular, could potentially be a crucial development enabling open-source applications to become more useful for archaeological purposes.

Of all file formats, TIFF and JPEG are the most commonly used for 2D images. They have complementary characteristics, which makes them suitable for different purposes, and they have been in use for several decades, which probably gives them the best interoperability at present. In the case of RAW formats, which were often referenced as well, respondents retain the greatest-possible flexibility for recalculating images and thus accept a larger storage volume. However, RAW formats are mostly proprietary, which means that they cannot be considered an interoperable solution and face relatively early obsolescence.

OBJ and PLY are the most widely used 3D formats. Both enable the display of point clouds and polygon-based meshes. Aside from the possibility of calculating textures on the mesh and the linkage with other information, OBJ and PLY are accepted for import and export by most common software applications (Jones and Church 2020). Although GeoTIFF is a 2D raster, it can still be used as a digital elevation model (DEM) for three-dimensional research questions. In particular, the analysis and manipulation of extracted surface or terrain models within a Geographical Information System (GIS) is probably common practice.

Answers explicitly mentioning GIS or 3D GIS as tools were infrequent. However, this may be due to the fact that the questionnaire focused more on the acquisition of 3D data than on evaluation and post-acquisition use. At least one mention of ArcGIS was recorded, possibly indicating the use of 3D data in a GIS context. In the context of this survey, it remains unclear how extensively 3D GIS is used, as the questionnaire did not query the further examination and use of 3D outputs. However, in the past decade, the application of 3D GIS has been significantly developed (cf. Katsianis et al. 2008). Recently, a comprehensive overview of 3D GIS was published (Dell'Unto and Landeschi 2022). Dell'Unto and Landeschi bring together several concise chapters covering the application of GIS and 3D technologies in archaeology, both on their own and in combination. They provide a basic overview of the methods and a comprehensive history of development, enriched with case studies and detailed descriptions of the respective methodologies. In their view, the main applications of 3D GIS include documentation and excavation evaluations, surface and subsurface analysis, visibility analysis (on both small and large scales) and volumetric analyses. Future developments are seen, for instance, in sensory analyses, such as movement or perception analysis. The latter uses the 3D GIS environment of a reconstructed house for VR applications and viewpoint analysis, which might advance our understanding of architectural perception using modern audiences. This example shows the enormous possibilities that 3D GIS can open up in the future.

Another emerging subfield, which was not covered by the survey, is the application of HBIM (Heritage Building Information Modelling) on the basis of 3D modelling (cf. Bagnolo et al. 2019; Banfi 2020). None of the answers in the survey hinted at the use of such approaches, although, as with GIS, the focus of the survey did not lie on the further use and evaluation of the 3D objects acquired.

11.3.4 Archiving

The survey revealed a potential lack of institutional guidelines in relation to archiving. Data management plans (DMP) appear to be rarely elaborated or adopted, at least from the perspective of the respondents. This contrasts with the fact that most scientific funding institutions explicitly require DMPs, for instance the Swiss National Science Foundation (SNSF, http://www.snf.ch/de/derSnf/forschungspolitische_positionen/open_research_data/Seiten/data-management-plan-dmp-leitlinien-fuer-forschende.aspx, accessed 17 Jan 2021), the Deutsche Forschungsgemeinschaft in Germany (DFG, https://www.dfg.de/foerderung/antrag_gutachter_gremien/antragstellende/nachnutzung_forschungsdaten/, accessed 17 Jan 2021) and the European Research Council (ERC, https://erc.europa.eu/sites/default/files/document/file/ERC_info_document-Open_Research_Data_and_Data_Management_Plans.pdf, accessed 17 Jan 2021).

We assume that orally transmitted and only lightly formalised 'best practice' guidelines play an important role in archaeology. These are likely to exist and be implemented in the majority of institutions and working environments. If such 'best practices' are in place, there is usually no need for formalised DMPs, unless a specific funding scheme requires one. This entails a large variety of different solutions for archiving and data management that take into account local specificities. A set of overarching guidelines seems to be a widespread desideratum among the respondents. Should such guidelines be developed in the future, they must take this diversity into account. One of the major challenges in elaborating such guidelines is likely to be the need to offer sufficient flexibility, whilst covering diverse application scenarios.

A second challenge revealed by the survey concerns the different needs of the specialists working in different fields. One important issue is that project duration can differ significantly depending on the working environment. Freelancers, research institutions and heritage-protection authorities deal with different project durations in their routines. Heritage-protection authorities, for instance, have much longer timeframes in which to plan and operate, as opposed to freelancers who mostly work on short-term projects. Short-term projects place other demands on data management systems than long-term projects do. The exact differences between the needs of different kinds of institutions and professional contexts in archaeology must be examined more closely and better understood if future guidelines are to be adequate and effective. Most respondents were aware of this difficulty, as it was often cited in the survey as a probable reason for potential non-compliance with guidelines.

Furthermore, the interoperability of the data and outputs that are compiled, produced and processed must be seen as a third challenge. The high level of trust in the existing archiving solutions that was recorded probably ought to be critically interrogated. As the survey shows, in addition to JPEG and TIFF formats, RAW formats are also often archived. Due to their manufacturer-specific peculiarity and diversity, however, long-term interoperability is doubtful. It is striking that sustainable long-term solutions are only seldom put in place in data management. Here, it will be of the utmost importance to find simple solutions that can be implemented in 'daily' working conditions and workflows. In our opinion, the long-term archiving of 3D data (including derivatives) is one of the most important challenges raised by the digitalisation of the archaeological professions.

Topics that have, until recently, only seldom gained attention when discussing 3D data in archaeology are data security and protection, the resilience of the digital infrastructure and its environmental footprint (for a broader discussion, see, e.g., Bridle 2018; for a focus on archaeological data, see, e.g., Huggett et al. 2018). Awareness about these topics is reflected in the oft-stated requirements for the archiving of 3D data. In addition to data security, easy access and handling of the data is also perceived as a requirement, as is the server infrastructure being located in one's own country, which is once again connected to data security and legal issues.

Not considered a requirement by the respondents, the public accessibility of data seems to be significantly less important than data security. This circumspection towards publicly accessible data can mainly be seen in the questions concerning the accessibility of the database and archive. Most participants stated that access is restricted to the institution or even to smaller circles of people. Public access is mainly provided by research institutions, but even there, it is rather unusual, a situation that is at odds with various initiatives that have been working intensively to promote the more open handling of research data for several years, such as the FAIR principles (Wilkinson et al. 2016).

At present, increased efforts are being made at various political levels to tackle the challenge of long-term archiving. This is accompanied by efforts to develop a common baseline upon which guidelines could be developed. As such, the European Union recently implemented a new, comprehensive approach to digitalisation. Within this framework, several projects have been launched in the last two years that explicitly deal with 3D data and cultural heritage (EU ERA Chair in Digital Cultural Heritage: Mnemosyne: DOI: 10.3030/810857, accessed 17 Jan 2021; study on quality in 3D digitisation of tangible cultural heritage: https://ec.europa.eu/digital-single-market/en/news/study-quality-3d-digitisation-tangible-cultural-heritage, accessed 17 Jan 2021). Furthermore, since 2019 there has been a declaration of intent from 27 European states to cooperate more closely in the digitisation of cultural heritage (https://ec.europa.eu/digital-single-market/en/news/eu-member-states-sign-cooperate-digitising-cultural-heritage, accessed 17 Jan 2021). In August 2020, 10 basic principles and tips concerning digitisation and cultural heritage were published by a task force (https://digital-strategy.ec.europa.eu/en/library/basic-principles-and-tips-3d-digitisation-cultural-heritage, accessed 16 Aug 2022):

The principles and tips cover the decision-making process, from whether or not to digitise an object to the definition of the audience and whether or not the digitisation process should take place in-house (principles 1–3). The user is encouraged to critically rethink whether digitisation is needed and for what purpose. However, the principles fail to consider data-security issues or the environmental impact of an ever-expanding digital archive. Here, a broader discussion on digitisation and its societal and environmental impacts is needed.

Among other things, the principles also explicitly identify the need to clarify the licencing beforehand and to ensure the use of open data formats and the inclusion of machine-readable metadata, thereby encouraging broad and open access (principle 4).

Data formats and archiving data are tightly connected to the quality and resolution of the models that are targeted by the project. Moreover, the required data formats may differ according to the use case. Principles 5 and 6 recommend defining the minimum quality needed, but aiming for the highest affordable quality and offering access with at least one open data format. As the survey showed, it is important to deal with these issues, as the open-access policy does not seem to be widely applied in relation to 3D outputs in archaeology and cultural heritage. At the same time, the evaluation of our survey showed that, of the recommended open data formats, such as glTF, X3D, STL, OBJ, DAE, PLY, WRL, DICOM or IFC, at least two are widely used (i.e. OBJ and PLY).

Principles 7, 8 and 9 focus on the long-term preservation of the outputs, the adequacy of techniques and workflows, as well as the protection of the originals during the process. While principles 8 and 9 align with what should be expected by experts from the field of archaeology/cultural heritage, principle 7 refers to a much less clear issue. The document states that researchers should be encouraged to store everything, even the software used to open the stored files. As the survey showed, this is still where most challenges connected to the 3D digitisation of cultural heritage lie. Among other issues, such as the question of the durability of software and hardware, the apparent lack of use of open software applications seems striking. The principles, at least, explicitly call for as much use of open solutions as possible.

Finally, principle 10 encourages the reader to invest in acquiring knowledge about and conducting further research into 3D technologies. The importance of this point cannot be overstated.

The Cyprus University of Technology started coordinating a consortium to study the relevant elements of the 3D digitisation of cultural heritage. In order to do so, an online survey to determine the relevant parameters for quality within the complex digitisation process was conducted between the summer and winter of 2020. The entire study included the definition of different degrees of complexity concerning the digitisation of Cultural Heritage, the identification of the technical and non-technical parameters defining the quality of 3D objects, the identification and analysis of existing formats, standards, methodologies and guidelines, the analysis of past or ongoing 3D digitisation projects with a benchmark character and, finally, linking the results of these sub-studies. The aim in the long run seems to be the establishment of applicable guidelines serving the standardisation of the digitisation of tangible cultural heritage (http://ec.europa.eu/newsroom/dae/document.cfm?doc_id=69940, accessed 17 Jan 2021).

Europeana, a Europe-wide museum platform, provides access to millions of digital assets from European museums, galleries, libraries, archives and research institutions. For several years, Europeana has been stepping up its efforts to achieve interoperability and find ways of making 3D data available (Fernie et al. 2019). In this context, they have been able to acquire extensive experience in the merging of heterogeneous 3D data. Problems such as low standardisation, high complexity, large amounts of data, low interoperability and a lack of metadata became apparent, and finding a solution for these problems was identified as an objective. The current work of the IIIF 3D Group, which cooperates with Europeana, seems promising in this matter. The International Image Interoperability Framework IIIF was developed in 2011 and proved to be a highly successful interoperability environment for digital two-dimensional images. The aim is now to develop similar solutions for 3D data (Haynes 2020). Other technological developments are also currently underway, which could enable not only better interoperability and archiving, but also the easier handling of 3D assets in the future. A team led by Touradj Ebrahimi from the EPFL in Switzerland is working on machine-learning-based algorithms to compress 3D data. The neuronal networks are trained both in the compression of joint and separate geometric and textural information from point cloud contents. The approach is promising, demonstrating better performance in certain aspects than the MPEG anchor used as a comparison. The novelty of the approach lies above all in the combined compression of geometry and texture (Alexiou et al. 2020). New impulses and solutions for archiving, exchanging and operability may also be expected to emerge from this research.

In addition to the European effort to formulate guidelines and tackling the challenges of digital long-term storage, other political bodies have also recognised the need to improve infrastructure and software. On the national level, for instance, the Deutsche Forschungsgemeinschaft (DFG) in Germany is working on developing national research-data infrastructure (Nationale Forschungsdateninfrastruktur, NFD), while the Consortium NFDI4Objects is attempting to add a section in NFD which explicitly tackles the needs of object-based research (https://www.nfdi4objects.net/, accessed 17 Jan 2021) Meanwhile, in Switzerland, efforts are being made to build a digital archive of cultural assets, which explicitly includes 3D models and other digitised data. A first study evaluated possible risks of digital cultural assets that need to be dealt with, including the resilience of existing electronic infrastructure. In the future course of this project, valuable experience and knowledge should be gained that is relevant to a wider range of applications (Albisettli 2020).

In addition, the association of the archaeological-technical excavation staff of Switzerland (VATG) with a working group (D!G) is working on an intensified exchange to bundle together know-how and experience. They are also attempting to impose a certain standardisation of methods (http://vatg.ch/wp-content/uploads/dig-grobkonzept-1.pdf, accessed 17 Jan 2021). This can be seen as a bottom-up movement, which is trying to self-organise in terms of its resources and possibilities.

11.4 Conclusion

The survey presented here gives an overview of the current significance of image-based 3D technology in archaeology. The most important goals, which are the documentation of excavations and research through 3D data, could be attained by employing the most frequently used software application (Metashape from Agisoft LLC) and data formats for input (JPEG, TIFF and RAW formats) and output (OBJ, PLY and GeoTIFF). The image-based technologies discussed, together with other methods like laser and structured light scanning, already have a place among the many tools used in archaeology. Since the application of these technologies was mostly said to be still at the testing phase, we can expect a continuous increase in their use and integration in the future. Archiving data is one of the major challenges that arises in all the working fields of archaeology. There are no well-established institutional guidelines, and formalised data management plans are also rarely available. In addition, the survey results indicate that the different fields of archaeological work (i.e. freelancers, research institutions and heritage-protection authorities) have different needs. Potential future guidelines must be acceptable to all the different stakeholders. Another unsolved problem concerns the interoperability and long-term storage of the data.

On the international and national levels, efforts are underway to tackle most of the apparent challenges, such as storage infrastructure and long-term archiving. Nevertheless, difficulties remain, such as the still-missing open-source solutions for image-based 3D reconstructions (including georeferencing). At the same time, the impact of already-published tips and principles or other best practices remains unclear. It is often the case that the best-possible solutions cannot be implemented, due to restrictions from funding schemes and the need to work within the (often limited) budgets of the institutions in question. In an utopian view recently taken by Hodel (2020), the entire data acquisition process would be undertaken with high-resolution sensors (image-based 3D modelling could be an example of this) and archaeology could be reinvented without material boundaries by a digital humanist. The additional processed data would then be included in linked-open-data triple stores and be organised using elaborate ontologies. The whole would then be published in open repositories and further enhanced with metadata, which could be blockchain-like, being linked and enriched even further with results, interpretations and critiques. This could, in turn, provide the basis for research projects and/or digital exhibitions.

This survey has shown that archaeology is currently undergoing a process of reinvention with reference to the aspects outlined above. But rather than being reinvented by a digital humanist, this process is taking place bottom-up and on the job – or to put it in the words of Costopoulos (2016): 'We are building a digital archeology by doing archeology digitally [sic]." While this may add to the difficulties in establishing overall standards, it also ensures the application of a diverse range of models and tools. That said, an inherent part of the digitalisation process is the negotiation of standards concerning the classifications and the ontologies behind them. Of importance in this context for the 3D documentation is the epistemological grounding of the capture of documented data (How is it captured? How does the method distort the evidence? Etc.). Its enrichment, analysis, dissemination and storage are further domains in which classifications and standards are applied. This application is mainly shaped by research projects, which produce data, but all the later stages also come into play, leading to the fragmentation and diversity which has been observed. As Hodel (2020) puts it in his conclusion, the digital turn will be less a top-down revolution than an evolution that requires an active contribution from all practitioners. While this latter call can and must be agreed upon, increasing efforts by supranational organisations to increase standardisation must be watched more closely, while archaeologists and other practitioners in cultural heritage and related fields must become more involved. The issues at stake are central for the field as a whole and should not be left to digital specialists or funding bodies alone.

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