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Photogrammetric documentation of archaeological artefacts: The current state of the art and future prospects

Abstract

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Photogrammetry has been a part of the curriculum of archaeologists since the early days of photography. This method of obtaining reliable information from non-contact imaging for the purpose of recording, measuring, analyzing and representation of archaeological artefacts is, due to recent advances in imaging techniques and computer technology, going through a renaissance. The history of the method in general terms is discussed in this paper. The authors present new perspectives on current areas of research, including workflows, the use of different hardware and software, and "guerrilla photogrammetry". Furthermore, the authors propose future directions for the development of the field, like using Smartphones, immersive images, truly virtual museums, and public engagement.

Keywords: Photogrammetry, Photography, 3D Documentation, 3D Model

▪ Introduction

Photogrammetry as a whole is the art, science and technology of obtaining reliable information from non-contact imaging and other sensor systems about the Earth and its environment, and other physical objects and processes through recording, measuring, analyzing and representation (ISPRS Statute II). This new method of "obtaining reliable information from non-contact imaging" for the purpose of "recording, measuring, analyzing and representation" of archaeological artefacts is, due to recent advances in imaging techniques and computer technology going through something of a renaissance. It is the authors' aim to present in this short study some aspects of the different faces of archaeological photogrammetric documentation of artefacts, with emphasis on future prospects of the technique drawn from the direction of current publications and recent developments in imaging and computer science.

Photogrammetry has been a part of archaeologists' curriculum since the early days of photography. The first experiments with stereovision actually predate photography itself (Wheatstone 1838; see also Brewster 1856). Stereo photography was used to document major archaeological/architectural wonders of the ancient world (Haaften 1980; Nickel 2004) and present them in a manner that allowed for representation of the depth in the image(s). Stereo photography lost its relative popularity in the early 20th century with the advent of the first mass produced single lens cameras designed for inexperienced users particularly the Kodak Brownie which was marketed as "the only camera that abybody can use without instructions" (Darrah 1977, Lux 2001, Hannavy 2008). Stereo photography did not vanish entirely, but rather remained a specific technique used rarely by individual specialists.

The next approach to metric archaeological documentation was photogrammetry conducted using metric cameras. This technique, which for decades was the basic tool for professional photogrammeters in archaeology, was usually used for architectural studies (see Cummer 1974). It continued to be used until the end of the 20th century but never became a basic archaeological

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tool due to the costly and arduous work regime required to achieve presentable results.

It is worth to note that these phases overlap significantly. There are no points in history of the photogrammetry that would define an absolute end of one approach and sudden emergence of another. Even if one attempts to mark such a point, one has to remember that not all practitioners were or are eager to abandon their established workflows to embrace new approaches no matter how brilliant.

In that regard one could now, or at any moment in 150 years history of the discipline, present tools, workflows, theoretical models, subjects etc. in a manner somewhat similar to a Gaussian curve with the left side of equation dedicated to 'things that were', centre to 'things that are' and right to 'some things that have not yet come to pass'. It is an important parallel for the rest of the discussion since we will attempt to present trends and predictions in such manner.

▪ Things that were

It is difficult to assess the total number of publications regarding photogrammetry in archaeology but certain trends are visible. We can attempt to express general trends using the CAA as an example. The Computer Applications and Quantitive methods in Archaeology Annual Conference is possibly the largest and most up to date venue regarding newest methods in archaeology. It is interesting to see how different are the subjects discussed by archaeologist during different conferences; when did photogrammetry appear in the archaeological discussion and in what form. One has to bear in mind that CAA was established much later than first experiments with photogrammetry conducted by archaeologist.

In the publication from the XXX conferences, Wilcock (1973) refers to touch scanners also known as profilers but he does not name them as such but rather as a "pencil follower". In 1977 an essentially photogrammetric method of aerial photography analysis and plotting of archaeological features on a map was proposed (Scollar *et al.* 1977). At the conference in 1982 we find an important turning point in that regard, firstly because a computerised method for producing 3-dimensional views of artefacts (pottery) from their profile's drawings is proposed (Angell, Main 1982), but also because archaeologists notice the advantages of now miniaturised and suddenly accessible computers for more effective photogrammetric workflows (Chamberlain, High 1982). This, however still refers to aerial imaging. In 1984 the use of CAD – Computer Aided Design software was proposed for documentation of pottery with the use of computers without the proxy of hand drawing (Hall, Laflin 1984) but this advanced technique, which still is not used as standard in many regions did not utilise photographs.

During the 1985 CAA conference L. Biek (1986) proposed 3D presentation of archaeological objects and excavation via digital stereo images. We might reasonably see in this a starting point where archaeological 3D Photogrammetry of artefacts starts its digital career. The paper mentioned above together with another (Wilcock, Coombes 1986) also mark the beginning of archaeologist's interest in work on digitally stored visual data. During 1986 conference the ARCOS system was presented, and with it working station and workflow not very dissimilar to the ones used today (Kampffmeyer 1986).

The word ‚Photogrammetry' first appears in a CAA conference paper title in 1998 (Astorqui 1999) but it relates to large scale research conducted with the method.

During the 2001 conference practical photogrammetry emerged (Shinoto *et al.* 2002; Pomaska 2002; Boochs *et al.* 2002; Velios, Harrison 2002) and since that time photogrammetric documentation of artefacts has had a constant presence (Tsioukas *et al.* 2010; Karasik *et al.* 2007; Kampel *et al.* 2006; Lambers, Remondino 2008; Hörr *et al.* 2011). In that regard it is clearly visible that progress in archaeological photogrammetry and exposure of archaeological community to this method has always been tied to wider progress in camera, computer and software technologies.

▪ Current research

Photogrammetry has seen some rapid and powerful developments over the past decade due to developments in computer software, computer power and digital camera technology. This general trend has also spread to archaeology, however today the vast majority of publications that explore the use of the method use the popular SfM approach during the excavation process or site documentation (Ioannidis *et al.* 2003; Sapirstein 2016). Photogrammetry in archaeology is enjoying a third major period of popularity. For many it is being discovered anew.

Currently photogrammetry competes with many other methods both traditional drawings (axonometric) as well as digital three-dimensional acquisition systems for object measurement using non-contact methods based on light waves (compare Remondino, El-Hakim 2006, fig. 1). It is beyond the scope of this article to discuss these but wide literature of the subject exists (see Crutchley, Crow 2009; Kamermans *et al.* 2014; Cowley,

Opitz 2012; Gojda, Kol 2013; Barber, Mills 2011; Remondino 2011).

It is accepted that photogrammetry in archaeology is, or should be, a tool not an end objective in itself (Remondino *et al.* 2008; Molloy 2015; Campana 2014). As a tool used in a discipline, which is devoted to asking and answering archaeology related questions, photogrammetry should be treated in a very utilitarian fashion. For many reasons this may not be the case. Different methodologies of 3D documentation (compare Remondino, El-Hakim 2006, fig. 1) require the archaeologist conducting them to stretch their most valuable commodity – time, to the limit just to become proficient in use of such auxiliary tool as photogrammetry or laser scanning or Rti etc. One has also to consider the cost of equipment and software. Very often when 3D documentation of an artefact or assemblage is to be conducted, the choice of method is biased by the fact that only one or two methods are truly mastered by the researcher.

Campana stated "...technological and methodological research in archaeology, and in heritage management generally, should be initiated or at least guided by the desire to answer essentially historical questions" (Campana 2014). But authors would argue that when genuine knowledge is obtained the exercise is still worth the effort, especially in case of non contact method like photogrammetry.

Are we (the practitioners of archaeological photogrammetry. Not we – the archaeologist. To some extent it is the case of multiple identity) artisans or craftsmen? This is a valid question regarding the ISPRS definition of photogrammetry. Authors would argue that if one is to treat photogrammetry as secondary to his research question, then one has to treat his role in the process as that of a craftsmen, hence this approach allows for one of main pillars of scientific method to be present – repeatability, where artistry produces unique results. Perhaps it is one of the reasons for so many of archaeological practitioners in photogrammetry to seek and reevaluate their photogrammetric workflow. One would even think that the technical details of photogrammetric process are questioned and presented more often than reasons that led to photogrammetric documentation of an artefact or assemblage in the first place.

Interesting workflows are presented by Pamart (Pamart *et al.* 2017, fig. 8) for multispectral photogrammetric studies of wall paintings and by Rizzi (Rizzi *et al.* 2007) specifically for the purpose of infrared documentation of murals; Simon (Simon *et al.* 2012) discusses precise positioning method and proposed workflow; Alsadik (Alsadik *et al.* 2015) discusses the efficient use of video for 3D modelling and proposes workflow. Zhou (Zhou *et al.* 2009) explores possibilities of virtual pottery reconstruction and proposes workflow, similarly to Hermon (Hermon *et al.* 2011) but both present different approach. Carboni (Carboni *et al.* 2016) proposes specific workflow aimed to ensure data provenance retrievability. Adami (Adami *et al.* 2015) present detailed description of sculpture documentation. A good summary of a traditional workflows is given by Schenk (Schenk 2005), while Remondino, El-Hakim, Gruen and Zhang (Remondino *et al.* 2008, fig. 2) proposed interesting

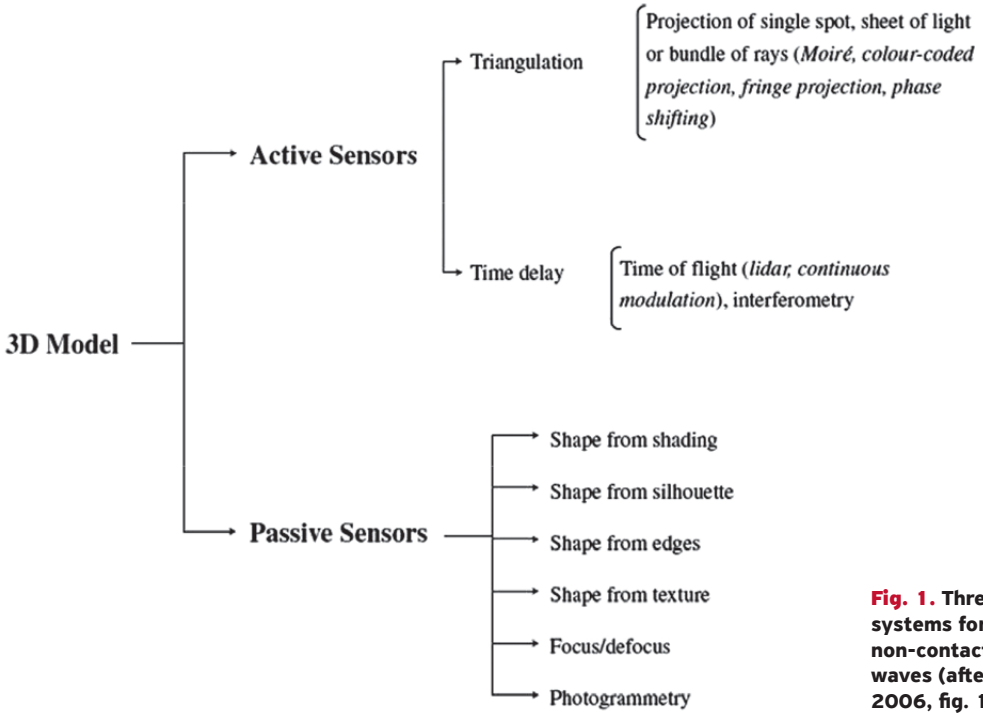

Fig. 1. Three-dimensional acquisition systems for object measurement using non-contact methods based on light waves (after, Remondino, El-Hakim 2006, fig. 1)

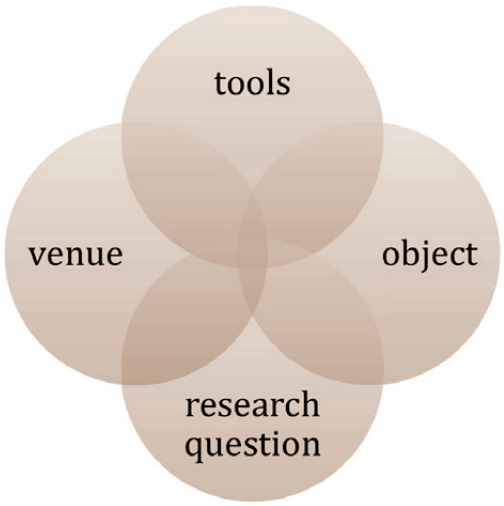

Fig. 2. Components of data acquisition process in artefact 3d photogrammetric documentation

workflow, that predates the very popular AgiSoft PhotoScan, yet is strikingly similar. It therefore shows that some ideas were present in the community for quite some time.

Most discuss anatomy of the first stage of the process – the data acquisition. Authors would like to think of it as four components: tools, venue, object and question interlinked in a coherent whole.

Tools used for photogrammetry can be understood as hardware (equipment), software tools, the know-how and light.

Currently popular software solutions have one major feature in common – some form of automatic photo orientation. Also workflows are increasingly more unified. Academic community is visibly pushing for open source solutions, due to their transparency and reliable results (Remondino, Del Pizzo, Kersten, Troisi: *in press*), but rulers of the market are AgiSoft PhotoScan and PhotoScan Professional software packages. And it is use in archaeology that helped AgiSoft products become so popular. The company hosts a website, where large selection of academic articles, citing PhotScan, are presented, and most of these are dedicated to either Archaeology or Cultural Heritage.

It is relatively easy to follow the evolution of this programs via AgiSoft website, which provides full change log since December 2010 and version 0.7 of the software (http://www.agisoft.com/pdf/photoscan_changelog.pdf). Currently this document is 25 pages long. PhotoScan is being criticized for being a "black box" type solution and prized for everything else. Together with Meshlab (Cignoni *et al.* 2008) and Cloud Compare PhotoScan creates a very comprehensive photogrammetric suite used probably by most archaeological practitioners in photogrammetry.

▪ Future of Photogrammetry in Archaeology

Future photogrammetric software solutions are already heralded. Firstly, we see very promising idea of high quality single view modelling provided by photometric stereo approach (Hameeuw 2015). On-line services providing remote model computations become increasingly more popular.

In that regard archaeologists are passive users waiting for mainstream computer developers to act (Archaeologists do not create popular computer solutions, but are consumers in this area). We have to accept the fact that most likely computer operating system created or customized by archaeologists would not become a mainstream 'hit', but we are able to utilize existing solutions. Last but not least one of examples of this approach is to use game engines to present and disseminate 3D archaeological data (models).

Possibly a novel approach would make it plausible. A multi method software platform allowing to seamlessly combine results of photogrammetry with data from other methods. Photogrammetry has its shortcomings but different scanning technologies are better in some aspects, while lagging behind in other. It has been noted that in many cases photogrammetry is best used in conjunction with other 3D documentation methods for best results (Molloy *et al.* 2016) This is possible today, but learning curve is quite steep. Software that would allow one to complete whole documentation process in one GUI (Graphic User Interface) would greatly improve experience and speed up the process, and that is necessary if we want to use such combined methods for standard documentation of hundreds or thousands of artefacts during one research project.

What has not yet come to pass but is the dissemination of virtual objects in museums (Ioannidis, Verykokou 2014) and the idea of truly virtual, on-line museums has not yet fully materialized, although it is discussed for a long time now (Payne *et al.* 2010; Walczak *et al.* 2011; Abate, David 2015; Mostern, Arknsey 2015; Guidi *et al.* 2015). Drawings on 3D models are already possible (Kimbal 2016) but this feature is, as of yet, complicated and rarely utilized, and interactive hot spots are used by some researchers in on-line services like Sketchfab (see BreakingTheMould project). Ability to draw on the virtual object will probably improve soon.

The idea of 3D photogrammetric modelling with the use of historical photos as a source has been entertained by some (Kozan, Kozan 2007; Wiśniewski 2014; Resco *et al.* 2014) but considering immense amount of photographic records created during last 150 years of

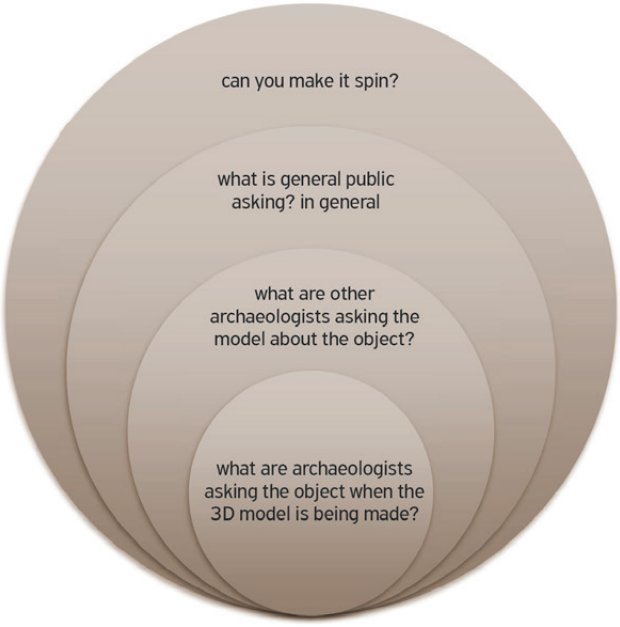

Fig. 3. Levels of engagement represented by questions asked

archaeological research it is an area where a lot of work may be done and probably will be conducted fairly soon.

Another part of the puzzle is to pose the right question. There is a place for "essentially historical" questions as defined by Campana (Campana 2014), which is the starting point of the research process and possibly can be answered with help of photogrammetry or 3D models of artefacts, created by all means. Yet, there is also place for other types of questions especially once one starts to disseminate his or her work results. Traditionally understood scientific method obliges us to form a hypothesis, design experiment, conduct the experiment, confront results with the hypothesis and draw conclusions. Some research methods create results that may help to answer the original question, but can also start a life of their own as separate (in case of modern 3D models - digital) entities.

These induce new discussion, generate new ideas, change perspective on original problem, sometimes overshadowing it completely. In the case of 3D models – either those created photogrammetrically, or those created with other methods, we may create a illustrative tool that sparks discussion un-related to the original research question. From authors perspective it is important that it draws attention and conveys ideas, but it is understandable that it may be difficult to face the fact that means change the goal.

Authors propose to structure questions that refer to, or circulate around 3D models from the most basic to most detailed according to fig. 3.

Still today, practitioners of archaeological photogrammetry rely on the "wow effect" their work provides. This eye-catching capability of interactive 3D modelling helps promote archaeology, archaeologist and artefacts to general public and to other specialist completely new to these solutions. Can you make it spin (?) may sound trivial but it is the most important question one can answer. In modern world, where getting attention is increasingly more difficult, this phrase symbolizes somebody's interest and engagement and the answer will create first mental note that will be assigned to the discipline as a whole. From here one can follow the more and more specialized aspects of photogrammetry/archaeology/art history/augmented reality and myriad other related disciplines.

Questions asked also evolve and different topics can be viewed as trends in short history of artefact 3D photogrammetry. Also there is a distinctive difference between what are we (practitioners in archaeological photogrammetry) asking? What we think we should be asking? What will we be eventually asking?

Guidi (Guidi 2014) evaluates if photogrammetry is a viable tool to check the quality of a 3D structured light scan of historical object and provides a positive answer. Also is photogrammetry a reliable tool to document museum collection of bronze and gold artefacts? Yes (Nicolae *et al.* 2014). Is photogrammetry a reliable tool for creating 3D models of obsidian artefacts? Yes (Porter *et al.* 2016). Is it possible to setup "A Simple Photogrammetry Rig for the Reliable Creation of 3D Artefact Models in the Field"? Yes (Wiśniewski 2013; Porter *et al.* Soressi 2016). Can one use photogrammetry to document other small museum objects i.e. fossils? Yes (Falkingham 2012). Is it a tool for an Osteologist? Yes (Hasset, Lewis-Bale 2017). Is it applicable to Zooarchaeology? Yes (Evin *et al.* 2016). Is it good for documenting very large and fragile objects like a shipwreck? Yes (Costa *et al.* 2016). Is it a viable method for documentation of pottery? Yes (Gianolio, Mermati, Genovese 2014). Is photogrammetry practical for documenting and possibly reconstructing cuneiform tablets? Possibly quite soon (Lewis, Ch'ng 2012). How few photographs are enough for a good 3D model? Fewer than one might think and it will reduce the computing time by 60% if method is applied rigorously (Alsadik et. al 2014). These are only examples of topics that are popular and important for archaeologist today.

▪ In what direction is photogrammetry leading?

Traditionally purely photographic techniques used by specialists like focus stacking may be used more often and in conjunction with existing workflows. It is

important to note here that focus-stacking method is used in electronic microscopy but in macro photography the process is significantly different and not yet explored in conjunction with 3D photogrammetry of archaeological artefacts.

Archaeologist will venture into merging photogrammetry with other methods for seamless models and animations.

Databases of 3D model are being built, however they are scattered and sometimes inaccessible for the "outsiders". Since creators of 3D models always prised the ability to study the artefacts remotely via a proxy in shape of an interactive, digital entity that is the model, it is only natural that in time such work will be conducted and existing repositories of 3D data will have to open and merge. For that one will have to be able to query data and search models with browser like tools. The measure of true success would be to create the ability for a photogrammetry non-practitioner to find, analyse and compare 3D models online for his/her research using standard computer tools and then publish the results of his/her research.

We may also expect emergence of new services providing ways to publish the results of the academic projects retaining their interactive appeal but gaining academic recognition?

Panoramic and immersive images are likely to play more important part in the data acquisition process in archaeological photogrammetry, just as augmented reality solution in disseminating the results of 3D work.

Archaeologists like all other practitioners are likely to pursue technical aspects of the photogrammetric process. Very important subject in that matter are camera self-calibration, model automatic scaling, placing RTK (millimetre level) GPS on a camera for perfect geo-positioning, or equipping camera with professional rangefinder for of-camera precise calibration.

What is important with photogrammetry is the flexibility of the method to suit specific needs of an archaeologist. There are many ways to conduct 3D photogrammetric documentation of an artefact and it is impossible to list all examples. In general there are two major variables to consider: public engagement and control (of workflow, data, tools and procedures), which compete constantly and are directly in contrast to each other.

After eleven years one has still to agree with Remondino and El-Hakim (Remondino, El-Hakim 2006) „...for all types of objects and sites, there is no single modelling technique able to satisfy all requirements of high geometric accuracy, portability, full automation, photorealism and low cost as well as flexibility and efficiency", but out of today available 3D documentation methods close range photogrammetry is possibly the easiest to grasp, most flexible and affordable solution which also makes time of data acquisition manageable and sustainable (Guidi *et al.* 2015). There exist a whole spectrum of potential pitfalls for archaeologists using this method, but advantages by far exceed the disadvantages.

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