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PRACTICAL EXPERIENCE WITH THE 3D PHOTOGRAMMETRIC METHODS USED AT THE EXCAVATION OF CSÓKAKŐ CASTLE

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The use of digital methods in archaeological research and documentation has seen a large increase in recent years, thanks to the growing power and availability of computer technology. While these methods make it possible to record much more detailed and accurate datasets than ever before, they also impose new challenges in data management and capture, which for a long time limited their use mostly to the post-excavation data processing. With the advent of new technologies and the development of mobile devices, however, we can see them being used more and more even during the excavations themselves. A very good example of this is the prevalence of 3D photogrammetry, the impact of which on excavation documentation we aim to demonstrate in this paper.

One of the most challenging aspects of on-site documentation is the accurate capture of the spatial features of an excavation. For a long time, the most widespread method to achieve this was through handmade, paper-based orthogonal and profile drawings. While advances in CAD-based digitization and geodetic localization made these methods somewhat accurate and suitable for GIS databases, they were still limited to a subjectively simplified two-dimensional representation of a site. Due to these limitations, a lot of spatial detail (especially of the third dimension) was irrecoverably lost. While a need to create 3D datasets was undoubtedly recognized, the ineffective field data capturing and heavy computational needs limited their use for a long time.

Recent developments in 3D data capturing and modelling techniques, however, have a potential to remedy some of the issues mentioned above. By using these methods, it is now possible to create objective, photorealistic 3D models not only of small objects, but of complex dig sites as well.

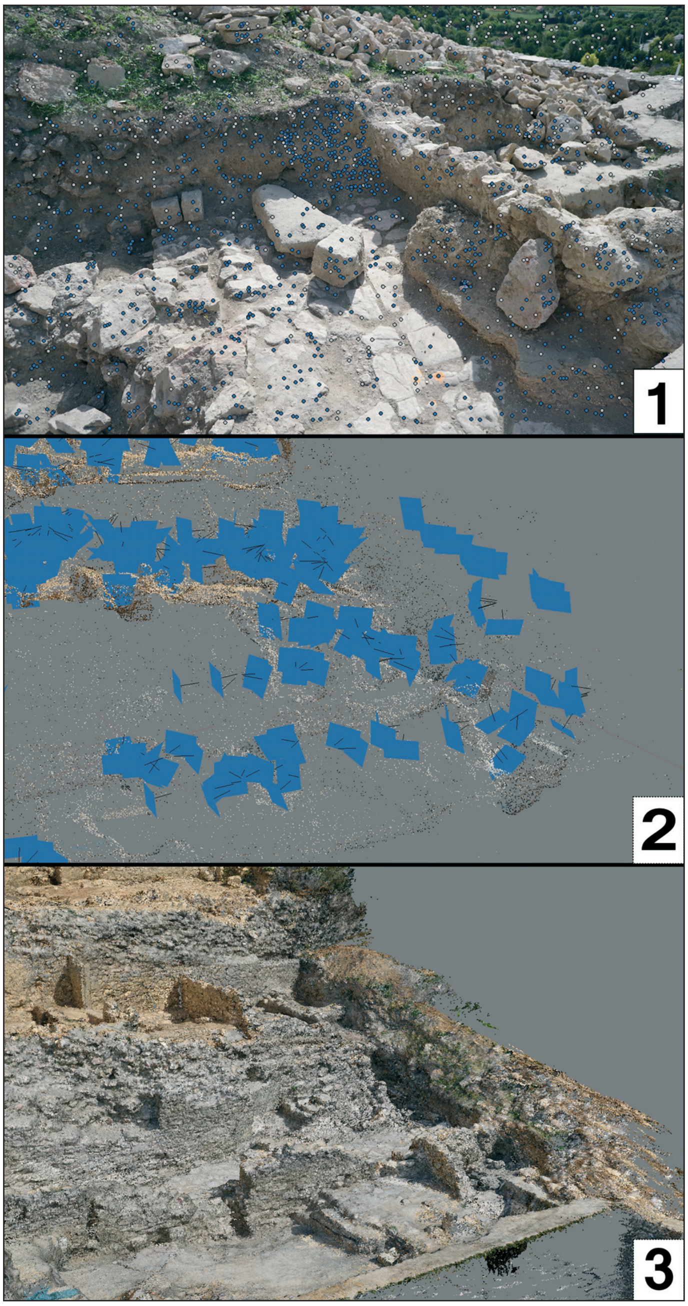

Fig. 1: The 3 main phases of 3D photogrammetric processing:
1.: Fig analysis, mapping of overlapping features.
2.: Mapping of picture locations compared to each other.
3.: Dense point cloud generation

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They also work quickly and effectively in the field, while also making it possible to place their results in a GIS context. While a number of different such methods are available, we chose 3D photogrammetry to help in the documentation of our research at the castle of Csókakő.

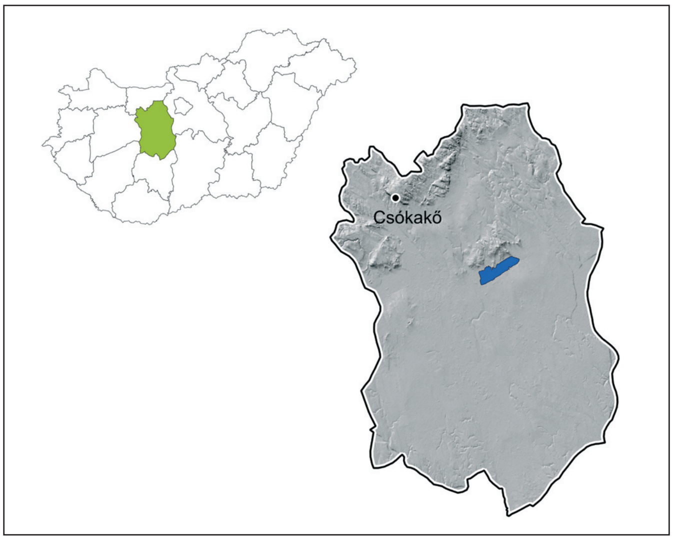

Fig. 2: Location of Csókakő within Hungary

What makes 3D photogrammetry really effective for fieldwork is the fact that the method only requires the modelled object to be photographed from several different angles, with a relatively large overlap between the images.[4] The specialized software then compares the images, recognizing features mutually present in different pictures *(Fig. 1)*. Combined with the metadata[5] embedded in the image files, this feature recognition allows for their occurrences to be mapped, and also for the calculation of the location each picture was taken from.[6] Once this phase is complete, a very detailed point cloud and a textured triangulated 3D mesh (TIN[7]) can be created, which accurately[8] depicts the shape and view of the actual physical surface of the object, essentially a photorealistic digital copy of any item or even excavation surface, viewable from any angle. It is important to note that these models can also be georeferenced by placing and geodetically locating at least four markers on the surface to be modelled that are divergent enough from the background to be easily recognizable on the pictures, where they serve as GCPs[9] during the georeferencing process. This means that the datasets thus created can be placed and used in a GIS environment, where they can be used alongside other datasets, or as the backbone of new databases and spatial analyses.

Furthermore, this data can also be utilized in a number of different aspects of archaeological work outside of a GIS environment. They can help to describe and interpret the spatial properties of a site. When used actively during an excavation, they can help to make the on-site documentation not only more accurate, but also effective[10] by not requiring any specialized equipment for data capture aside from the digital cameras that are already routinely in use at excavation. And, while the hardware and software required for the data processing can be expensive, these costs can be somewhat alleviated by using free and open-source solutions that are also available.[11]

Realizing the potential and the aforementioned benefits of 3D photogrammetry, we started to experiment with it during the last couple of years at the excavations of the castle of Csókakő, gradually implementing it more and more into our workflow. During these experiments, we gained valuable experience in the uses,

4 The number of photographs required can be quite large depending on the size and characteristics of the object in question.

5 It is important to note that the requirement for metadata means that the software only accepts pictures taken digitally. Scanned paper-based photographs cannot be processed.

6 For a detailed explanation of the process, see Westoby, M. J. et. al.: Structure from motion photogrammetry: A low-cost, effective tool for geoscience applications. *Geomorphology* 179 (2012), 302–306.

7 TIN = Triangulated Irregular Network, a vector-based surface model most commonly used in a GIS context.

8 For the accuracy of such models see: Koutsoudis, Anestis et al.: Multi-image 3D reconstruction data evaluation. *Journal of Cultural Heritage* 15 (2014), 73–79.

9 GCP = Ground Control Point. Generally used in a GIS context as points located on the surface to be georeferenced that also have real-world (projected) coordinates.

10 For the use of photogrammetry in site documentation, see Doriana, Mariana: Fieldwork 3D interpretation – Integrating established methods and emerging technologies in a medieval context. In: *Proceedings of the 18th International Conference on Cultural Heritage and New Technologies, Vienna, November 11–13*, 2013, Vienna, 2013.

11 For a comparison of different software solutions, see Kersten, Thomas P. – Lindstaedt, Maren: Image-Based Low-Cost Systems for Automatic 3D Recording and Modelling of Archaeological Finds and Objects. In: *Progress in Cultural Heritage Preservation. 4th International Conference, EuroMed 2012, Limassol, Cyprus, October 29 – November 3, 2012*, ed. Ioannides, Marinos et al. (Berlin Heidelberg: Springer, 2012), 1–10.

limitations, and possibilities of these methods: these observations form the backbone of our study.

APPLICATIONS OF 3D PHOTOGRAMMETRY DURING THE EXCAVATIONS AT THE CASTLE OF CSÓKAKŐ

The Castle of Csókakő is Fejér county's only medieval castle located on a high rock that was not only in use between the late Arpadian period until the end of the 17th century, but is still standing (*Fig. 2*). Research on the castle (led by the King St. Stephen Museum) began in the 1960s by Jenő Fitz and Alán Kralovánszky, and then was continued between 1996 and 2008 by Gábor Hatházi, Gyöngyi Kovács, and Mihály Kulcsár.[12] The latest, ongoing excavations (financed by the Hungarian National Asset Management Inc. and led by Gyöngyi Kovács and Gábor Hatházi) began in 2014 as part of the National Castle Initiative, focusing on the so far unexcavated lower parts of the castle.[13]

Fig. 3: Ortophoto of the site with a vectorised map of the same area (credit: Zoltán Tóth, Krisztián Pokrovenszki)

GIS methods were already employed during the excavations between 1997 and 2008, implemented by Balázs Holl. They conducted a systematic geodesic survey of the whole site, and then printed out the resulting spatial dataset of sequentially numbered points. These printouts then served as the basis of the handmade drawings that were made on the site during the excavation, further enhanced by photographs of the surveyed marker points, which helped the researchers identify areas of the site. After 2000, the aforementioned early GIS methods were complemented by stone-by-stone photogrammetric surveys of wall textures conducted by József Vajda and Ilona Győrfi.

While the documentation of the most recent excavations (started in 2014) was still mostly paper-based, new methods were also implemented. Close-range aerial photographs of the site were taken both during and at the end of the excavation using a quadcopter drone. These pictures were then used not only for illustrations, but also for the mapping of the site with photogrammetry, carried out by Geomontan Ltd. using Agisoft Photoscan. In order to be able to georeference our model, we used unique markers for GCPs that the software could automatically detect on the images. During the photoshoot itself, several hundred pictures of the site were taken from different angles, making it possible not only to generate a very dense point cloud and a textured mesh that depicts the entire excavated surface, but an ortophoto[14] as well. This ortophoto was then used for the 2D vector-based mapping of the site in CAD software (*Fig. 3*). During this mapping process, however, some problem arose whereby several features and details could not be precisely delineated from the ortophoto alone. While we managed to solve this problem by using the handmade drawings for

12 See Hatházi, Gábor: Csókakő vára az írott és régészeti források tükrében (The castle of Csókakő in the light of written and archaeological sources). In: *Csókakő a harmadik évezred küszöbén*, ed. Béni, Kornél (Csókakő, 2010), 15–151.

13 See Hatházi, Gábor – Kovács, Gyöngyi: Újabb kutatások a csókakői várban. Az alsóvár régészeti kutatása (2014–2015) (New research in the Castle of Csókakő. Archaeological investigations in the lower castle), *Castrum* 19 (2016), 111–130.

14 An orthophoto is a picture (or several ones stitched together) taken from an exactly perpendicular angle and then corrected for the distortion caused by the camera lenses. They are generally used for mapping purposes.

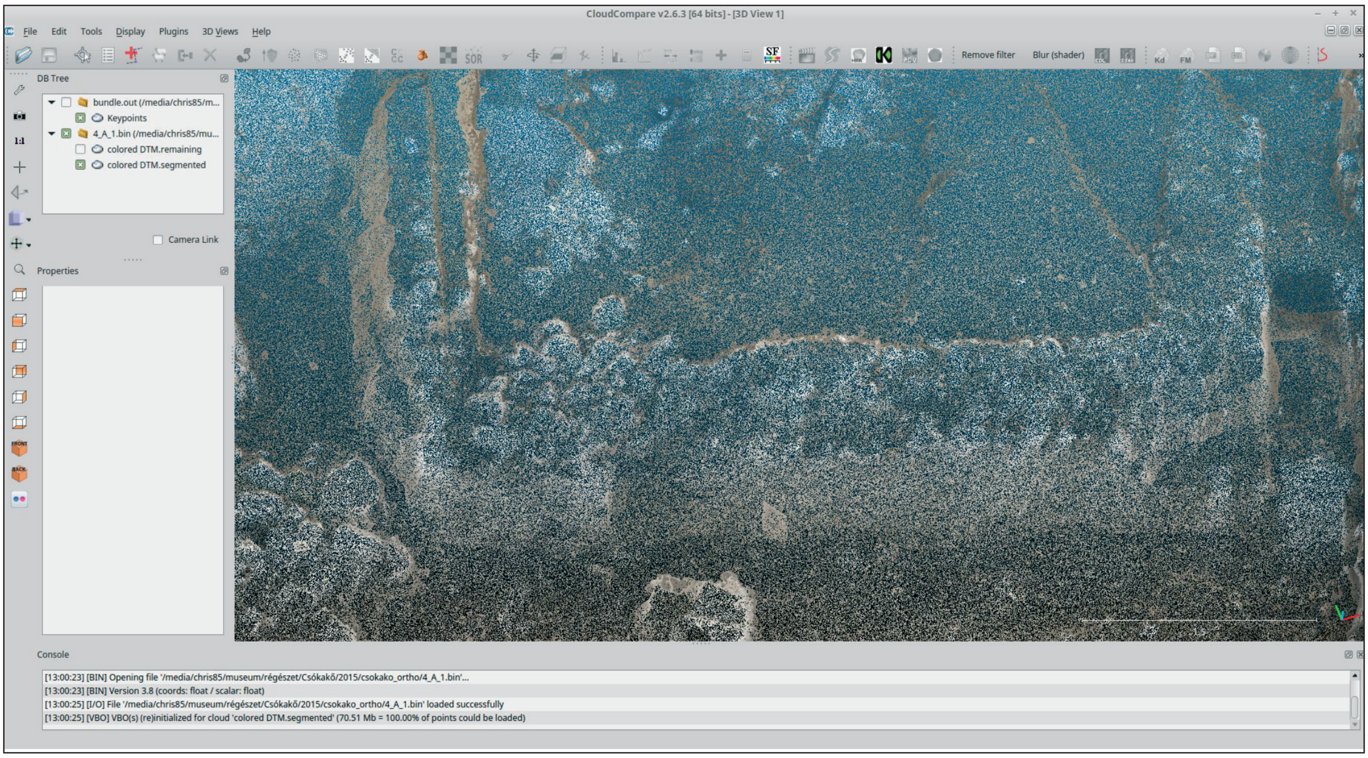

Fig. 4: Dense point cloud displayed in CloudCompare

additional spatial information, this shows that in many cases orthophoto-based documentations still need to be combined with other sources.[15]

During the 2015 season, we had a number of new challenges in documentation to overcome. Due to the increasingly complex features and stratigraphic structure of the site, and the almost 10-meter fall within it, we decided against the use of handmade drawings as the main method of documentation, because it would have been not only extremely time-consuming, but also very inaccurate. Instead, we used photogrammetry as the primary method, which we always optimized for the task at hand. Every feature was photographed separately with a handheld camera, sometimes utilizing a monopod, aiming to make as many perpendicular-angled photographs as possible. Every photoset consisted of 50–150 pictures (depending on the feature), which we processed with free photogrammetric software, of which there are several alternatives to choose from. While we previously had some success with Autodesk's cloud-based 123D Catch, its limitation of only 70 pictures per model was deemed too low for our purposes. What we used instead was OpenDroneMap, which we could utilize to generate very dense point clouds and models either overnight, or even out in the field on a laptop if needed. While the use of the datasets from a vertical viewpoint was relatively difficult, they worked very well for georeferenced orthographic images. As usual, georeferencing was done through markers placed on the specific surfaces, and then picked out on the finished point cloud (instead of the photos) in CloudCompare (*Fig. 4)* after processing the images in OpenDroneMap. It has to be noted that most of the time the dense point cloud generated by the above methods proved to be so dense, that it appears to be a complete surface from a viewpoint distant enough. Therefore, for most of our on-site documentation it was enough to create orthogonal images only from the point clouds. These could then be printed out in a number of different scales (1:20, 1:40, etc.) and brought out to the field, where we could manually draw and mark the features and details on them that previously proved to be problematic to identify from ortophotos alone (*Fig. 5*). By doing so, we managed to merge the advantages of direct on-site observations with the accuracy and detail of 3D photogrammetry, and thus we had detailed, continuously up-to-date maps of

15 During our experiments, the drawing of small-scale sketches in the field depicting areas that could be possibly problematic proved to be very helpful.

the site that proved to be very useful in directing the excavation.

Like in the previous year, the final, complete map of the site was also completed by using aerial photography and photogrammetry. While theoretically, the more detailed models depicting smaller areas (each georeferenced to a different set of GCPs) could have been stitched together, our experience has shown that, in this particular location, GPS data had so much inaccuracy that the models could not be fitted together with tolerable accuracy. Therefore, we needed one complete photogrammetric map of the final state of the excavation. Theoretically, this is also achievable by handheld photography, but the higher viewpoint and the overview of aerial photography (especially considering the agility of a drone) allows for producing a higher number of images with more overlap and higher coverage per picture much faster, resulting in less data capture work in the field, and faster model generation. The only drawback is that the overall resolution of such a model is relatively smaller than that of a model made from pictures taken by a handheld camera.[16]

Fig. 5: 1.: Printable ortophoto made from a dense point cloud. 2.: Printed version drawn over with details recorded on-site (model: Krisztián Pokrovenszki, drawing: Gábor Hatházi)

While 3D photogrammetry proved to be a useful tool for our everyday workflow, it was also of much help through the post-excavation phase. A good example of this is the creation of cross-section drawings of certain aspects of the site, such as the stairs in the northwest corner of the area (*Fig. 6*). Using the models we created, this task could be done with a few clicks, not only sparing us a lot of time-consuming manual measurements, but it also meant that we could create cross-sections of anything, any time after the end of fieldwork. The data also proved to be useful in the identification of the stratigraphic units, which could be directly recorded on the orthophotos, and then could be identified much easier than with previous, more abstract drawings. Furthermore, aside from the aforementioned improvements in documentation, conservation efforts also benefited from the information generated by 3D photogrammetry, as it gave valuable spatial data to the engineers designing the special protective roof (*Fig. 7*) over the walls and surfaces uncovered by the excavation.

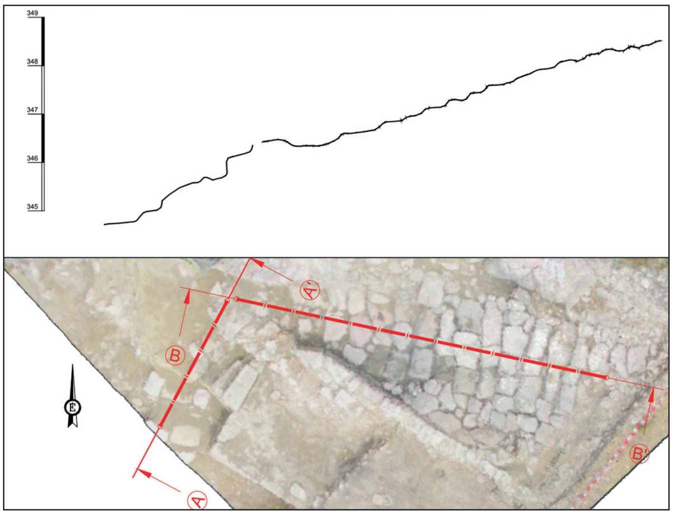

Fig. 6: Cross-section of the stairs leading to level "A"

[16] A good example of this is the model made of the same area, but with a handheld camera. While the resolution of this was much higher (due to each pixel representing a smaller area), the complex nature of the site made it much more difficult to photograph the whole site from this low angle. A total of 446 images were thus required to make a complete model, the shooting of which took significantly longer than in the case of the drone-based imaging, making this method less practical for documentation at this scale.

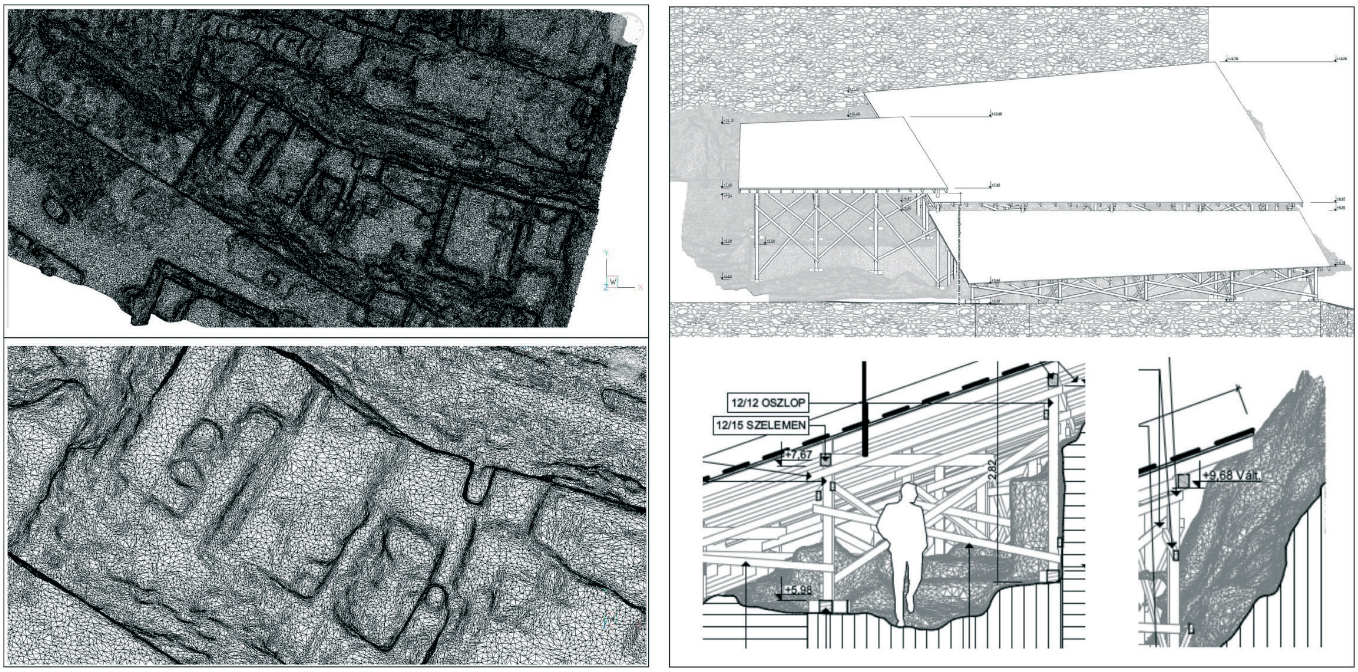

Fig. 7: TIN model generated from the dense point cloud (left, credit: Zoltán Tóth) with the design of the protective roof (right, engineer: Tibor Gál [GLG Engineering Ltd.])

SUMMARY

The above-mentioned examples of the 3D photogrammetric methods used at the excavation of the castle of Csókakő present a significant improvement both in the efficiency and the accuracy of on-site and post-excavation documentation. The orthophotos generated by this method made allowed for making even the 2D drawings of the site more accurate, while the georeferenced 3D data helped not only to analyze the spatial characteristics of the site, but also to protect it.

All of these advances are the results of a continuous development process, improving our workflow step by step. It is important to note, however, that this process is far from being over: there are a number of ways in which our current methods can be further developed, while there are also several new ways in which photogrammetry can be utilized. One of these aspects is the further digitization of our on-site documentation, much of which is still at least partially paper-based. While these are already big improvements over older methods, natively digital datasets made on-site with GIS principles in mind could be even more accurate and detailed, thanks, in part, to the continuously improving documentation capabilities of handheld devices such as tablets and smartphones. These devices could not only bring 2D vector-based mapping to the field, but in due time even the on-site manipulation and processing and drawing of 3D datasets generated by photogrammetry.

The more widespread use of 3D methods also has huge potential for the post-excavation processing of a site. The high-detail textured models generated during field work give researchers a chance to examine every feature from any angle and context long after the excavation ended. These features can also be combined into GIS databases, replacing and vastly improving our current 2D polygon-based databases.[17] Together, these datasets provide an excellent visual tool not only for future scientific examination of a site,[18] but also for its presentation to the public, and long-term preservation[19] as part of our cultural heritage.

17 Roosevelt, Christopher H. – Cobb, Peter et al.: Excavation is ~~Destruction~~Digitization: Advances in Archaeological Practice. *Journal of Field Archaeology* 40/3 (2015), 337–339.

18 De Reu, Jeroen – Plets, Gertjan et al.: Towards a three-dimensional cost-effective registration of the archaeological heritage. *Journal of Archaeological Science* 40 (2013), 1108–1121.

19 For the principals of heritage management in the digital age, see the London Charter (Downloaded on 2016.09.14.).

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