The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLVIII-M-2-2023
29th CIPA Symposium "Documenting, Understanding, Preserving Cultural Heritage:
Humanities and Digital Technologies for Shaping the Future", 25–30 June 2023, Florence, Italy

DOCUMENTATION OF ARCHAEOLOGICAL STRATIGRAPHIC UNITS. NEW DIGITAL TECHNOLOGIES APPLIED TO THE BURIALS IN SANT'ANDREA IN MOMBASIGLIO

G. Bruschi[1*], D. Amadio[2]

[1] Independent researcher, Turin, Italy – gbruschi@ymail.com
[2] Independent researcher, Rome, Italy –arch.danieleamadio@gmail.com

KEY WORDS: archaeological excavation, digital photogrammetry, 4D model, indirect documentation, heritage survey, site evolution, Sant'Andrea in Mombasiglio.

ABSTRACT:

Archaeological site activities are extremely destructive. To understand how civilizations have developed, archaeologists have to remove layers and layers of land to find evidences of their theories. An important task for researchers is to accurately document every single detail of the site before the definitive removal of precious information. Position, orientation and the context where findings are located could represent important data to be stored and compared many months after excavation process. Survey operations during site activities has to be considered extremely important, since they have to immortalize a particular moment of past human activities before its destruction. Despite this, most of the time archaeological records consist of two-dimensional representation of three-dimensional subjects. In recent years, the spreading of techniques to digitally document heritage assets have allowed to tested new approaches also in archaeological fields. Using digital cameras, drones and laser scanners it is possible to collect a multitude of details, such as textures, materials, decay phenomena, and to collect all these data inside 3D models. Digital techniques for documenting archaeological site has been tested during excavation campaigns in Sant'Andrea in Mombasiglio church, in the northern of Italy. The site has been documented along many years and in different excavation progresses, to be able to digitally recreate multiple stages of site evolution. 4D stored information can be used by archaeologist for scientific purpose, as in the museums through VR and AR applications.

1. INTRODUCTION

Digital technologies applied for documenting extant buildings is a practice in use for many years now, and they concern both engineering works and heritage. The spreading in last years of instruments capable to represent the reality from many points of view has been certainly a stimulus for copious applications in many scientific and professional fields. The big amount of data collected during a digital survey campaign provides 3D models containing information about geometries, materials and decay phenomena. This approach is suitable for many different kinds of heritage, such as historical buildings, ruins, decorative apparatus, findings and archaeological sites, and it does not require a big amount of time acquisition and, sometimes, an elevate financial effort.

This research paper illustrates the application of digital survey for documenting archaeological excavations progress lasted several years. In particular, the research will point out how to use photogrammetry to easily and rapidly document findings before their removal during excavation operations. The case study is represented by three burials rediscovered in 2018 and 2021 campaigns inside the ruins of Sant'Andrea church located in Mombasiglio, Piedmont region in Italy.

After a short report about digital survey applied to the archaeological filed, sect. 1.1, the case study is presented in sect. 2.1, followed by: sect. 2.2 methodology and workflow overview; sect. 3 results; sect. 4 discussion and conclusions.

1.1 Archaeology and digital documentation

Digital technologies applied to survey operations have been increasing in last few years, and they have strongly changed many consolidated habits in documentation fields. At the beginning of last decade, in many architectural courses in Italy, hand drawn surveys were still the main way to investigate buildings, while nowadays laser scanners and photogrammetry have replaced pencils and sheets. These changes have involved quite rapidly architectural and engineering fields, while it has taken more time to spread in the archaeological one. Although a digital approach allows to easy collecting new type of archaeological document, it is not still widely used in the current practice of archaeology (Knyaz et al., 2017). The reasons could be: "historical traditions" of archaeological documenting, initial costs of producing 3D data (Chibunichev et al., 2018) and the "difficulty to integrate 3D world with other more standard 2D material" (Remondino et al. 2010). Furthermore, the big amount of data collected by digital instruments forces the researches to change their approaches and their methods for new kind of data processing (Wagtendonk et al., 2009), (Eppich et al., 2013), (Pollefeys et al., 2001), (Berndt et al., 2010). In spite of these initial set of problems, typical of any fields, the use of three-dimensional recording techniques provides many advantages in archaeology studies. These methods of gathering data from archaeological sites is more efficient, precise and accurate than traditional ones (Howland et al., 2014) and they produce 3D data of different scale and resolution along with high-quality images for photorealistic texturing (Knyaz et al., 2017). This kind of outputs could be use in wide variety of applications, involving

* Corresponding author

new approaches for archaeological data analysis (Chibunichev et al., 2018), allowing for new approaches to presentation of archaeology to the public (Howland et al., 2014) and providing virtual and augmented reality systems (Bianchini et al., 2014), (Botrugno et al., 2017), (Garstki, 2017) for studying (Schöning et al., 2015), (Barceló, 2010), (Kadar et al., 2014) and visualization of findings (Tsipidis et al., 2011).
An interesting use of digital documentation in archaeology is to document excavation phases to recreate a 3D model of every stage of in situ operations. Archaeological activities in the excavations site are often very destructive and dynamic Olson et al., 2013). Soil is removed and mixed little by little to individuate U.S. (stratigraphic unit), while findings and burials are often documented by photographs (with some scale objects) before to be removed from their contexts (Chibunichev et al., 2018). Furthermore, excavations activities could last many campaigns along different years, and sometimes portion of the same age are excavated in different periods. In this context, the holistic picture of a site often escapes from researchers (Knyaz et al., 2017), and many potentially sources of data are annihilated by surveyors and are either too expensive, impractical or impossible to study (Howland et al., 2014). The big challenge of archaeologists is to gather as many data as possible to reconstruct the appearance of findings and the relations between them (Knyaz et al., 2017), because only these data will contain the potential research value (Howland et al., 2014). Documenting the evolving state of an archaeological site through digital technologies allow to collect many information about finding geometries and locations, and about the context where they were excavated. These precious data can provide more concrete evidence for archaeologist assertions and can be stored also for future interpretations and studies. In this way, once site operations ended, later scholars can digitally navigate the model to have a similar experience to that one of archaeologists on the field.

2. THE CASE STUDY

2.1 Sant’Andrea in Mombsasiglio

Sant’Andrea’s church is located along a rural road crossing a hill on the northwest of the ancient village of Mombasiglio. The ruins of the church are isolated from the old medieval village and from the newest one, which have developed at the bottom of the hills (Figure 1). It was almost certainly the parish church of the first settlement of Mombasiglio. The oldest attestation dates back to 1246, when Pope Innocenzo IV emanated a bull to confirm the jurisdiction of «Sancti Andreae de Montebaxilio» to San Dalmazzo di Pedona (today called Borgo San Dalmazzo) abbey (Bonina et al., 2018). Other written sources report about the presence, before outside and then inside the church, of a cemetery. This function has been kept until XIX century, when the church has not more been officiated because of its intense decay phenomena (Bonina et al., 2018).
Unfortunately, in 1923 a private demolished most of the portion of the church, including the bell tower, without any authorization from the Italian authorities (Errani, 2010).
Archaeological activities started in 2003; they concerned all the interiors of the church. During this campaign the basement of the tower was unearth and portions of decorated plaster were founded in the apse area (Errani, 2010). From the entire site, accumulation soil was removed and the completeness of the ruins were finally displayed. The church site is 17,5 meters long (3,9 meters is the apse) and 6,4 meters width. The apse wall is still in place: it is 9 meters long 2 meters high. The façade is also well preserved, reaching the high of 4 meters on the right side. The other boundaries are recognizable but emerging few centimetres from the soil. On the left side of the ruins, close to the façade, there is the basement of the bell tower (1,0 x 1,2 meters). (Figure 2)
Since 2015, the Postgraduate School of Architectural and Landscape Heritage of Politecnico di Torino has been investigating the site of Sant’Andrea in Mombasiglio. In the first years, academic studies have concerned the survey of existing structures, before to make archaeological investigations in the surroundings of the apse and of the entrance. These areas were the same investigated in 2018 and 2021 campaigns.

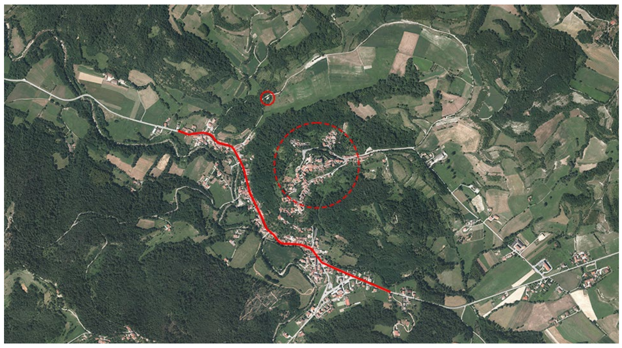

Figure 1. Location of: Sant’Andrea’s church (red ring), the medieval village (dashed red ring) and the road along which the newest village have developed (red line)

Figure 2. 3D dense point cloud elaborated after 2019 survey campaign. a) apse; b) the façade; c) burial number 2; d) bell tower basement

2.2 Methodology

2.2.1 An integrated methodology of techniques: has been used to carry out the survey. In detail, a photogrammetric survey using manual photographic equipment and a series of scans using LiDAR technology (Gomarasca, 2004).
The need to integrate the two techniques has been due both to the availability of the equipment on the excavation site and to a precise operational choice. The goal was to produce three-dimensional photogrammetric models of the burials (the main subject of the study in this case). The burials and the structures in their immediate vicinity have been documented with photogrammetric methodology, while the LiDAR technology has been employed in order to obtain a point cloud of the entire church of Sant’Andrea. This kind of survey was indispensable to obtain a general survey and contextualization with the surrounding landscape (Bryan P. et al., 2009).
The survey has been divided chronologically into three phases.

2.2.2 In phase 1, 2018: the photogrammetric survey of the excavation of burial number 2 (Figure 3) was carried out with the human remains present.

Since the use of GPS or Total Station instrumentation has not been envisaged, due to excavation organizational conditions, no physical targets were used for georeferencing or for the alignment of the survey phases.

As a metric reference, a graduated metric pole was inserted near the human remains, so as to be included in the survey and to be used later as a dimensional reference of the 3D model.

The operation was carried out with particular attention on burial 2, where the lower part of a human skeleton was found. Due to site layout and excavation needs, it was not possible to investigate the portion of the church where it was supposed to be the top of the skeleton (Figure 4). Excavation supervisor decided to study that portion during next campaigns.

Figure 3. Burial number 2, excavated in 2018 campaign

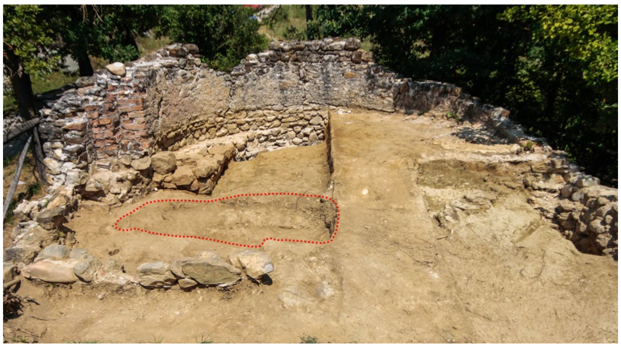

Figure 4. The north portion of the church after the end of 2018 campaign. With dashed red line is burial number 2

2.2.3 Phase 2, 2019: After the photogrammetric survey and the further cleaning of the entire excavation area, was carried out an entire LiDAR survey of the structure of the church.

Before this activity, human remains present in burial number 2 were already been removed, thus obtaining an excavation situation completely free from finds of any kind.

Multiple scans were carried out inside and outside the perimeter of the structure, in order to detect the main shapes and the surrounding terrain, since the entire excavation area was located on a small hill.

Even for these operations, as for the entire survey process, no targets have been positioned for alignment and georeferencing. (Figure 5).

At the end of these operations, the excavation was covered with suitable material and was subsequently officially closed. An UAV has been used for an aerial photogrammetric survey to obtain a texturized model of the ruins. Excavation operations of other portions of the site were scheduled for the next campaign.

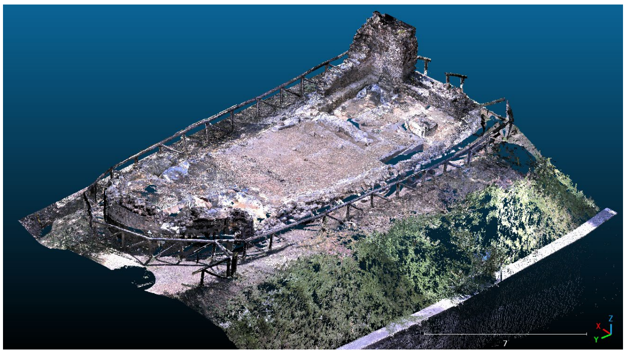

Figure 5. Lidar dense cloud (Phase 2)

2.2.4 Phase 3, 2021: In 2021, a new archaeological excavation activity was carried out (Demeglio et al., 2022), (Demeglio et al., 2022a) to continue the remaining areas to unravel. During these operations, which involved uncovering the upper part of the skeleton of burial 2, a second burial was found, numbered as 5 (Figure 6). The progress of excavation has revealed another burial (number 6) which lied on the bottom of the number 5, with a different orientation (Figure 7). The prediction of being able to reunite the upper and lower part of the skeleton of burial 2 could not be prosecuted.

The excavation phases documented with the photogrammetric method on this occasion are two, identified in the following images as phase 3.1 and 3.2.

On this occasion, a further photogrammetric survey of the investigated areas was therefore completed with the same methods previously described for phase 1.

Even in this case no targets have been inserted, and no metric bars has been inserted as a dimensional reference.

Figure 6. Burial number 5, excavated in 2021 campaign, on the left is burial number 2 (image used for 3D reconstruction)

Figure 7. Burial number 6, excavated in 2021 campaign (image used for 3D reconstruction)

2.3 Data processing

All the data collected were also processed in phases. First of all, in phase 1, a 3D model was developed from the photos taken using photogrammetric processing software. In detail, a dense point cloud and a textured mesh were created (Figures 8 to 10).
The processing of the second phase took place with automated alignment processes of the LiDAR point clouds without the use of targets or reference points. The LiDAR point cloud was the only cloud to be directly dimensionally correct.
For the elaboration of the phases 3.1 and 3.2 was adopted the same process of phase 1 but without targets and dimensional references. In this case, the only way to scale the 3D model was a reference process "cloud on cloud" between the phase 2 and phase 3 point clouds.

Figure 8. Burial number 2, photogrammetric dense cloud

Figure 9. Burial number 2 (on the right) without human remains and burial number 5 founded in 2021 campaign (on the left), point cloud (Phase 3.1)

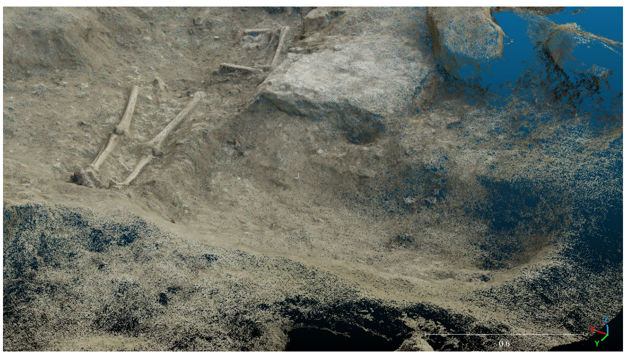

Figure 10. Burial number 2 and 5 (on the right and in the centre) without human remains and burial number 6 (on the left), point cloud (Phase 3.2)

2.4 Data produced

These elaboration phases have produced these outputs:

- 1 dense point cloud of phase 1, 2018;
- 1 texturized mesh of phase 1, 2018;
- 1 LiDAR cloud of phase 2, 2018;
- 1 dense point cloud of phase 3.1, 2021;
- 1 texturized mesh of phase 3.1, 2021;
- 1 dense point cloud of phase 3.2, 2021;
- 1 texturized mesh of phase 3.2, 2021;

3. RESULTS

At the end of the post-processing, it was possible to compare and relate the various phases of the excavation. To carry out this operation it was necessary to align the various point clouds with each other.
The main problem with this operation is that the individual surveys were not intended for an operation of this type and therefore in each of them there are no specific targets or alignment points.
The individual point clouds have a metric correctness given by the tool used (for the LiDAR methodology) and by the references introduced (for the photogrammetric processes) and it was necessary to align them each other with "cloud on cloud" processes.
This type of procedure consists in setting one of the point clouds as the main reference system (in this case the one deriving from the LiDAR survey) and aligning the subsequent ones on it. This operation is possible by identifying points in common between the reference clouds and those to be aligned, initially manually to create a general alignment and subsequently through automated procedures.
After this operation, which in this case was repeated three times (phase 1, phase 3.1 and phase 3.2), the overlap of the excavation phases was obtained in a 3D environment system thanks to which it was possible to analyse the relationships between the excavations of 2018 and 2021.
Once point clouds were aligned with each other, they were saved and exported with their respective new coordinates.
In this way, with any point cloud visualization software, it is possible to load and compare the new files (Figures 11 to 14).

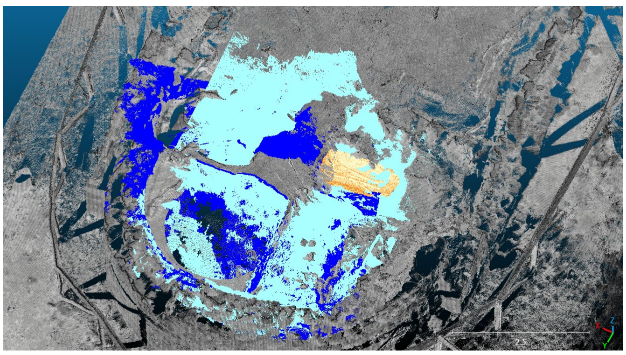

Figure 11. Three-dimensional representation of the 4 point clouds produced and overlapped with different colours (orange: phase 1, grey: phase 2, blue: phase 3.1, cyan: phase 3.2)

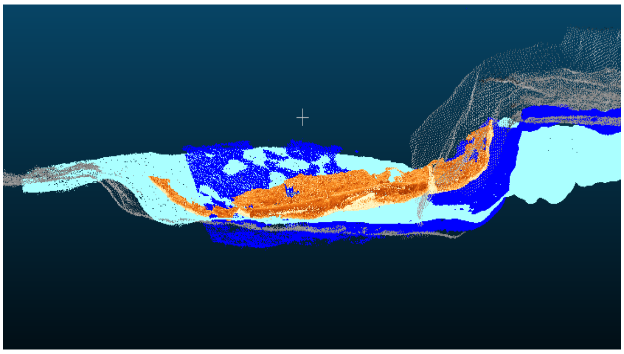

Figure 12. Section of the 4 point clouds produced and overlapped with different colours (orange: phase 1, grey: phase 2, blue: phase 3.1, cyan: phase 3.2)

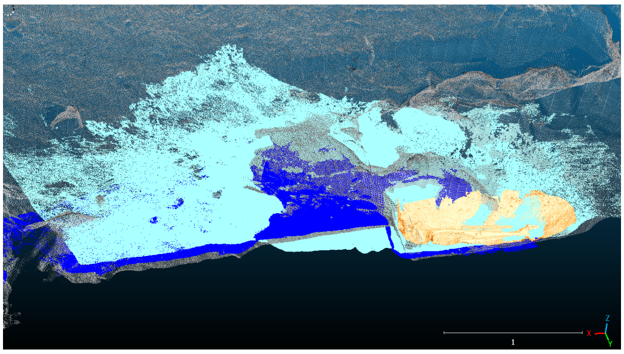

Figure 13. Detail of the overlapping of all the phases, point cloud section (orange: phase 1, gray: phase 2, blue: phase 3.1, cyan: phase 3.2)

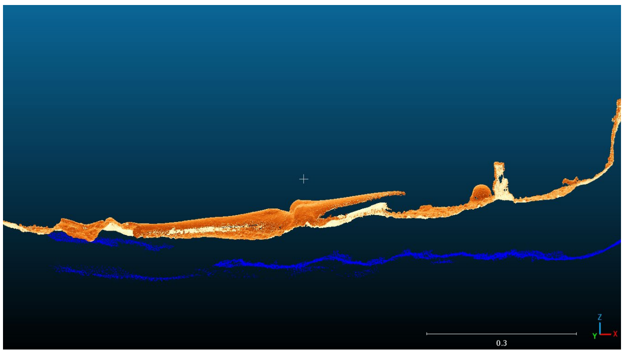

Figure 14. Detail of the overlapping of phase 1 (orange) and phase 3.1 (blue), point clouds

4. DISCUSSION AND CONCLUSIONS

4.1 Discussion

Digital photogrammetry has allowed to easily and quickly document excavation phases without hinder archaeological activities. Surveys have required a digital camera, a metric reference (in this case the laser scanner cloud), and few minutes of suspension of excavation operations. The data acquired during the archaeological campaigns have been related to each other even if they have been collected years apart. Postproduction phase have not required a big amount of time due the low number of pictures needed to document the findings, which were localized in a small portion of the site. In this particular case study was not necessary, but it would have been possible to provide to archaeologist the point clouds of the US few hours after the burial removal.

The most important challenge has been to align and to georeferencing the point clouds to each other. During excavation phases, a referred system has not been placed, so the clouds have been aligned through manual process. The right workflow should have been to set up a referred system before the beginning of excavation operations, so to link all the surveys to it. Obviously, the referred system has to remain the same during the site changings and over the years.

4.2 Conclusion

Archaeology is a destructive discipline based on analysis, connections and interpretations of data collected during excavation process. The main task of archaeologists on site is to record as many information as possible before removing them from their original context. These data are the knowledge base for interpreting and reconstructing the diachronic evolution of the site during different ages (Dellepiane et al., 2013). To facilitate this process, the quality of acquired data has to be as fine as possible, including also orientation, position in a reference coordinate system and relative position in a group of objects, context, etc. (Knyaz et al., 2017). Due to the obvious evolution typical of an archaeological site, which could last several years, the documentation of its evolution is needed almost every time a new historical feature is detected (Dellepiane at al., 2013): every day or every few hours. Collected data have to contain visual and spatial information able to describe the appearance of findings and the relations between them (Knyaz at al., 2017).

In this context, the use of digital technologies for collecting data during excavation process is particularly recommended. Current techniques allow for the creation of a fully-three-dimensional record of archaeological excavation with high temporal and spatial resolution (Olson et al., 2013). Collected data can be stored and organized in a digital environment containing 4D information about site evolution and findings. In addition to consult information about geometries, textures, locations and materials, it would be possible to visualize site evolution during campaign progress. In addition to the above, digital survey techniques permit a no-contact approach to heritage, which certainly contributes to the conservation of findings.

In Sant'Andrea in Mombasiglio new approaches for archaeological site evolution documentation have been tested. The initial purpose to digitally recreate the entire skeleton of burial number two has been left for pursuing the documentation of site evolution during 2018 and 2021 campaigns. In this case study, digital photogrammetry has confirmed its potentialities to be used in heritage fields. Simply using a reflex camera, archaeological activities have been suspended for few minutes to allow survey operations, which can be easily carried out following photogrammetric rules. Digital photogrammetric surveys can be easily carried out by the same archaeologists, who could in real time make post-processing or send data for let make it to other specialists. It was not the case of Mombasiglio site activities, but it would have been possible to create 3D models while site operations were still ongoing, allowing to speed up excavation activities and to record every information needed. Even if studying a site from real is without any doubts recommended, it could happen not to have enough time. If it happens, it would be possible to visualize a digital reconstruction of a stratigraphic unit removed few hours before to study it more in deep.

Other than as scientific tool 4D models, composed by various 3D models of site evolution, can be used for divulgation purpose. Thanks to AR and VR, models can easily depict archaeological activities and site evolution to people who have never approached this field. This kind of representation let people feel how to be on site and to understand better what archaeology means, in addition to allow specialists to "come back" to every stage of site evolution.

4.3 Acknowledgements

We thank the Graduate School in Architectural and Landscape Heritage of Polytechnic of Turin, especially Professor Paolo Demeglio who introduced us to the fascinating world of archaeology and followed us during excavation campaigns. We credit L.A.R.T.U.lab of Polytechnic of Turin for the TLS survey data.

REFERENCES

Barceló, J. A., 2010. Visual Analysis in Archaeology. An Artificial Intelligence Approach. Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 93–156

Berndt, R., Buchgraber, G., Havemann, S., Settgast, V., Fellner, D. W., 2010. A Publishing Workflow for Cultural Heritage Artifacts from 3D-Reconstruction to Internet Presentation. Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 166–178

Bianchini, C., Borgogni, F., Ippolito, A., Senatore, L. J., 2014. The Surveying and Representation Process Applied to Archaeology: A Quest for Invariants in a Highly Variable Context. Springer International Publishing, Cham, pp. 1–29.

Bonina E. N., Casanova Guindulain B., Demeglio P., Rosati G., Scano G., Summa S., Vagnarelli T., 2018. La Chiesa di Sant'Andrea in Mombasiglio (CN): note sulle fonti scritte e sui sondaggi di scavo. *VIII Congresso nazionale di archeologia medievale*, III-IV, 11-15.

Botrugno, M. C., D'Errico, G., De Paolis, L. T., 2017. Augmented Reality and UAVs in Archaeology: Development of a Location-Based AR Application. Springer International Publishing, Cham, pp. 261–270

Bryan, P., Blake, B., Belford J., 2009. *Metric Survey Specifications for Cultural Heritage*, 2nd edition, English Heritage.

Chibunichev, A., Knyaz, V., Zhuravlev, D., Kurkov, V., 2018. Photogrammetry for archaeology: collecting pieces together. *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLII–2, 235–240. doi.org/10.5194/isprs-archives-XLII-2-235-2018

Dellepiane, M., Dell'Unto, N., Callieri, M., Lindgren, S., Scopigno, R., 2013. Archeological excavation monitoring using dense stereo matching techniques. *Journal of Cultural Heritage*, 14(3), 201–210. https://doi.org/10.1016/j.culher.2012.01.011

Demeglio P., Finco L., Gomez Serito M., Lerma S. G., Rosati G., 2022. La Chiesa di Sant'Andrea in Mombasiglio (CN): prime riflessioni sulle indagini 2018-2021. *IX Congresso nazionale di archeologia medievale*, I-III, 196-201.

Demeglio P., Occelli F., Uggé S., Lerma S. G., Serito Gomez M., 2022. Mombasiglio. Chiesa di S. Andrea. Attività formativa della Scuola di Specializzazione in Beni Architettonici e del Paesaggio del Politecnico di Torino (2015-2021): analisi degli elevati e indagini archeologiche. *Quaderni di archeologia del Piemonte 6,* 271-274.

Eppich, R. and Almagro Vidal, A., 2013. Challenges, strategies and techniques for international training in technology for cultural heritage conservation. *ISPRS Annals of Photogrammetry, Remote Sensing and Spatial Information Sciences* II-5/W1, pp. 109–114.

Errani, E., 2010: *Gli statuti di Mombasiglio. Carte di franchigia e appunti storici.* Mondovì.

Garstki, K., 2017. Virtual representation: the production of 3D digital artifacts. *Journal of Archaeological Method and Theory* 24(3), pp. 726–750

Gomarasca, M. A., 2004. *Basics of Geomatics,* Milan, Springer.

Howland, M. D., Kuester, F., Levy, T. E., 2014. Photogrammetry in the field: Documenting, recording, and presenting archaeology. *Journal Mediterranean Archaeology and Archaeometry,* 14(4), 101–108. escholarship.org/uc/item/5ps0z7pf

Kadar, M., Muntean, M., 2014. A Collaborative Environment for E-training in Archaeology. Springer International Publishing, Cham, pp. 303–312

Knyaz, V., Chibunichev, A., Zhuravlev, D., 2017. Multisource data fusion for documenting archaeological sites, Proc. SPIE 10427, *Image and Signal Processing for Remote Sensing,* XXIII, 104271V. doi.org/10.1117/12.2278736

Murgatroyd, P., 2013. Visualising Large-Scale Behaviours: Presenting 4D Data in Archaeology. Springer London, London, pp. 259–274

Olson, B.R., Placchetti, R., Quartermaine, J., Killebrew, A.E., 2013. The Tel Akko To-tal Archaeology Project (Akko, Israel): Assessing the suitability of multi-scale 3D field recording in archaeology. *Journal of Field Archaeology*, vol. 38, 244–262.

Pollefeys, M., Van Gool, L., Vergauwen, M., Cornelis, K., Verbiest, F., Tops, J., 2001. Image-based 3D acquisition of archaeological heritage and applications. *Proceedings of the 2001 Conference on Virtual Reality, Archeology, and Cultural Heritage*, VAST '01, ACM, New York, NY, USA, pp. 255–262.

Remondino, F. and Rizzi, A., 2010. Reality-based 3D documentation of natural and cultural heritage sites—techniques, problems, and examples. *Applied Geomatics* 2(3), pp. 85–100

Schöning, J., Heidemann, G., 2015. Evaluation of Multi-view3D Reconstruction Software. Springer International Publishing, Cham, pp. 450–461

Tsipidis, S., Koussoulakou, A., Kotsakis, K., 2011. Geovisualization and Archaeology: supporting Excavation Site Research. Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 85–107

Wagtendonk, A. J., Verhagen, P., Soetens, S., Jeneson, K. and de Kleijn, M., 2009. Past in Place: The Role of Geo-ICT in Present-day Archaeology. Springer Netherlands, Dordrecht, pp. 59–86.