Archeologia e Calcolatori
33.2, 2022, 197-214
doi 10.19282/ac.33.2.2022.11

FROM SURFACES TO VOLUME: TOWARDS A VOLUMETRIC RECONSTRUCTION OF THE ARCHAEOLOGICAL DEPOSIT

1. Introduction

Over the last ten years, digital documentation by means of image-based modelling techniques (from now on referred as digital photogrammetry) has rapidly established as a reliable documentation method for archaeological excavations (Katsianis *et al.* 2008; Forte *et al*. 2012; De Reu *et al.* 2014). Recent advances in data acquisition have meanwhile highlighted the necessity to develop new management and analysis workflows for 3D data. These new workflows should comprise a multitude of parameters and allow a balance between expected geometric resolution, acquisition and processing time and the needs of the archaeological practice, which also include the management of the personnel on the field and of the equipment (Roosevelt *et al.* 2015; Sapirstein, Murray 2017). Another equally important aspect, which also affects how fieldwork practice is conducted, is planning in advance what characteristics the 3D data should have to enable further post-processing analysis. It still appears that there is a gap between those works interested in developing methods feasible and sustainable for the digital documentation of the archaeological excavation and those focused on the post-processing analysis on 3D data, often based on small test-sample contexts (Orengo 2013; Dell'Unto *et al.* 2017; Gavryushkina 2021).

This article presents a protocol developed for a systematic application of digital photogrammetric recording to the documentation of an extensive archaeological excavation, in which all the steps are optimized to obtain a 3D volumetric reconstruction of the archaeological deposit. This is achieved by generating 3D data with the purpose of reconstructing the enclosed physical space occupied by each Stratigraphic Unit (SU), representing the smallest volumetric entity in which the stratigraphic deposit is subdivided. This fine subdivision of the stratigraphy enables a better representation of the complexity of the stratigraphic and spatial relationships, keeping at the same time unaltered the topological relations among the units. The protocol enables an entirely new volumetric approach of recording, visualizing, and analysing the stratigraphic space, moving forward from a representation of the stratigraphic deposit based on interfaces and empty spaces to a new one based on solid geometric models. The procedures were developed and successfully applied during four archaeological excavation seasons at the medieval site of Vetricella, in central Italy.

This article is divided into two main sections: in the first part, we discuss operational steps in fieldwork activities, defined in order to make the documentation feasible and compatible with the needs of the archaeological practice. We aimed at presenting how difficulties and issues are tackled to successfully apply this protocol to a wide range of archaeological contexts, not limited only to small trenches and test pits. In the second part, we describe the procedure adopted for processing 2.5D surfaces into solid 3D geometries, which can be used for visualization and for analytical quantitative approach. Lastly, we provide some useful insights on how 3D geometries of the volume can be applied to support the archaeological interpretation of the site, with some practical examples drawn from the site of Vetricella.

2. Background

2.1 *Digital documentation at Vetricella*

Vetricella (Scarlino, GR) medieval site is located in Southern Tuscany, in central Italy, and it was detected for the first time in 2006 during an aerial photographic campaign (Fig. 1). After a few years of minor investigations made largely by archaeological test-pits, in 2016 the project nEU-Med and the project Lok-Med[1] started a series of new extensive excavation campaigns. In order to keep up with the new workload, a digital recording protocol based on digital photogrammetry was developed, allowing to document more than a thousand SUs over the course of four excavation seasons to date (2016-2019) (Marasco, Briano 2020).

Vetricella was an early medieval fortified site made of perishable material features, dated to between the mid-8th and 12th centuries AD. Excavations have detected evidence of a central rectangular tower-shaped building enclosed by a defensive system made of three concentric circular ditches. Moreover, the presence of a burial ground, productive structures and a huge amount of findings (pottery, coins, metals, animal bones, seeds and glass shards) suggests that the site might be identified with the centre of the *curtis regia* of Valli (Bianchi, Hodges 2020).

The area covered by the archaeological activities measures about 60×50 m and covers approximately 3000 m^2, including most of the space delimited by the second ditch. The area was then subdivided into four sectors arranged in a radial pattern from the central place, which overlaps with the centre of

[1] 'nEu-Med. Origins of a new economic union (7th-12th centuries): resources, landscapes, and political strategies in a Mediterranean region' (2015-2021) is an ERC Advanced project (grant agreement No. 670792). 'Lok-Med. The Lands of Kings and Emperors in a Mediterranean region (9th-11th centuries). Fiscal estates and economic growth' (2017-2022) is funded by MIUR, FARE, SH section (2017, D.D. n. 2811). The projects (see respectively https://www.neu-med.unisi.it/it/progetto-neu-med/ and https://www.neu-med.unisi.it/it/lok-med/) are led by the Dipartimento di Scienze storiche e dei Beni Culturali of the Università degli Studi di Siena by Prof. Richard Hodges and Prof. Giovanna Bianchi.

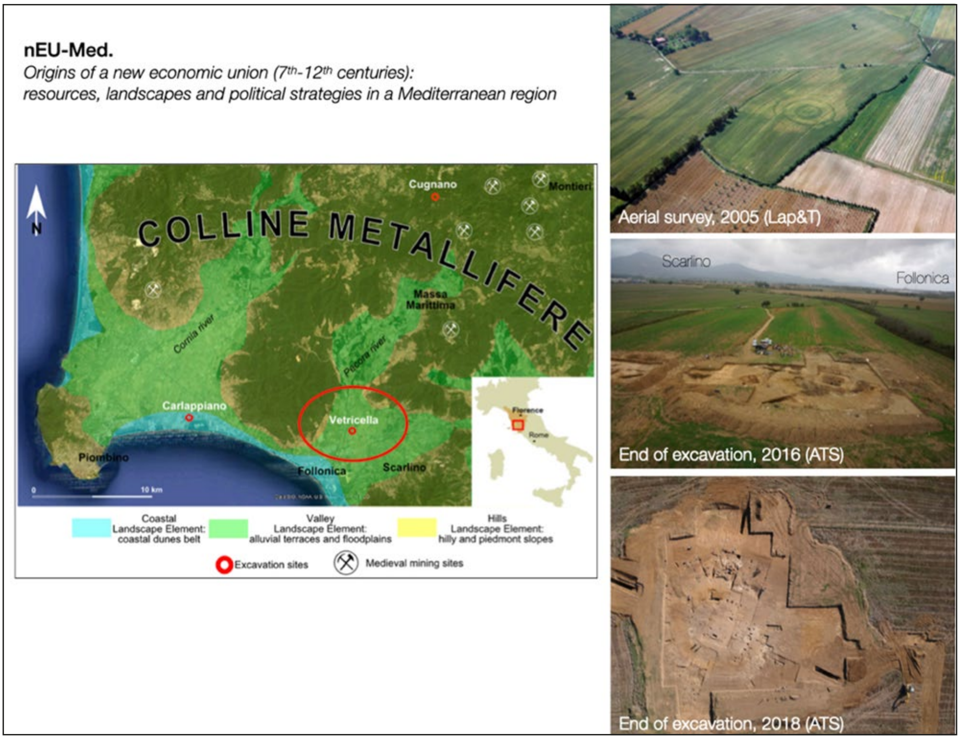

Fig. 1 – The area investigated by the ERC Advanced nEU-Med project. On the right, aerial views of one of the key sites of the project, the medieval site of Vetricella (Scarlino, Grosseto, Italy) (http://www.neu-med.unisi.it/).

the settlement. Within each sector, several minor excavation areas have been opened to better investigate some important contexts. Moreover, in selected parts of the site, especially along the path of the ditches, some trenches and test pits were simultaneously opened, leading to a deeper comprehension of the stratigraphic relationships (Fig. 1).

2.2 *The volumetric approach*

The stratigraphic deposit can be represented as a continuous physical space in which archaeologists identify spatial discontinuities among separate depositional processes, interpreted as unitary natural or anthropogenic events (Barceló 2000). Discontinuities are recognized principally for changes in colour, shape and texture, thus leading to the identification of the boundaries of the SUs. The physical space occupied by a SU is therefore enclosed between two adjacent discontinuities, namely the upper and the lower surfaces, shared with contiguous contexts (Nobles, Roosevelt 2021). Archaeological documentation with digital photogrammetry is generally carried out by recording surfaces at various stages of the excavation. Surfaces are arbitrarily selected by archaeologists after the identification of SUs and for each SU generally only its upper face is recorded before its removal.

The aggregation of all the surfaces recorded in the whole archaeological deposit returns, however, just the false impression of a reconstructed 3D space, because each SU is modelled through a single surface and its actual physical space remains empty. The volume of the SU is intangible and it can be only visually reconstructed by interpreting a series of surfaces and empty spaces.

To overcome these issues, we propose a method to fill the empty space within the surfaces by reconstructing the volume occupied by each element of the stratigraphy, obtaining a 3D model that encompasses the volume of the SU. The real effort is trying to integrate the processing of 2.5D raw surfaces into volumetric 3D models within the documentation procedure, trying to keep compatibility with timings and needs of the archaeological fieldwork practice. This aspect is particularly important in order to provide ready to use data for enabling post excavation analysis.

3. Digital photogrammetric survey at Vetricella

In this section, we are going to uncover some of the most important steps of the protocol, underlying some main aspects such as: SUs recording, organization of the fieldwork activities and logistical issues. The volumetric approach aimed at reconstructing the 3D solid geometries of each SU has required the definition of new procedures that enable the exploitation of the potential of 3D data in post excavation analysis. All these operations must be integrated into the fieldwork activities without overlooking other important archaeological aspects and consolidated practices, by carefully balancing data accuracy, processing time and amount of data produced. We divided the main fieldwork activities into two main blocks: the first block of operations takes place before the removal of each SU, whereas most of the processing steps in digital photogrammetry can be performed later.

In order to create 3D solid geometries, it is necessary to record the top and the bottom surface of each SU. During the excavation, the top surface of each SU is recorded, framing the condition of the unit before its removal, while the top surface of the context underneath serves as the bottom surface. This simple pattern works flawlessly in case of two perfectly overlapping SUs, although it becomes more complicated for a SU with multiple physical relationships with several SUs underneath. In this case, the bottom surface would be made by the combination of the upper surface of all the underlying units. To keep the data management simple and to adapt the method to all the possible stratigraphic relationships, photogrammetric acquisition is carried out with particular attention to the extension of the area recorded.

For each SU, the extension of the photo survey should include the actual boundaries of the SU and the extension of the last overlying SU previously removed, for which this model serves as a bottom surface. With this data structure, the displacement of 3D models in chronological order would result in an accurate reconstruction of the evolution of the excavation activity, where SUs are encompassed completely by two consequent surfaces. This method has proven to be particularly effective for reducing data production and to limit the targeted area of the photogrammetric processing. In fact, only one model is recorded for each SU and the area modelled with digital photogrammetry is limited to the merged extension of two consequential units.

Coded targets are usually placed outside each spatial context's extent and measured with total station in local coordinates system. We experienced that the management of 3D models georeferenced in local coordinates reduces the incompatibility encountered in some software at handling large geographic coordinates. After the procedure of elaboration is completed, the models can be translated to geographic coordinates by applying a fixed translation matrix.

The delineation of the boundaries of a SU is an important step of the archaeological excavation and it is based on the evaluation of some parameters of the dirt, such as colour, texture and composition. On a 3D model, the same process of delineation is less accurate, since the archaeologist must rely mostly on colour information. In developing the procedure, we dedicated particular attention on how to report on the 3D models these evaluations, keeping the relationship with the relevant on-field interpretation phase. This task is done onsite by measuring with a total station a trail of points tracing the unit's boundary and the relevant archaeological features. At a second stage, in post-processing analysis, points can be used as guidelines to perform the cutting of the models and for interpreting the most relevant features. Even though the programmatic acquisition of several surfaces enables the automatic delineation of the extension of each SU (see § 4), these points constitute the only reference to delineate the boundaries of negative SUs because of the absence of a tangible volume.

Another important issue is how to incorporate a highly specialized form of documentation in a working environment composed of students and researchers, often unaccustomed to handling such technologies. The complexity of the protocol requires the presence of qualified staff who supervise all the processing steps, ensuring data standard quality and homogeneity. Operations of planning, management and processing of the digital data are conducted by archaeologists specialized in digital photogrammetry, while other collateral activities can be supported also by non-trained archaeologists. At Vetricella, two to three specialized archaeologists rotated across the excavation to supervise the documentation of all the areas.

Lastly, the protocol should consider the possibility to handle the documentation directly on-site at the 'trowel's edge', a recommended condition widely supported by many authors (Berggren *et al.* 2015; Dell'Unto *et al.* 2017; Taylor, Dell'Unto 2021). Ready-to-use documentation requires that the photogrammetric processing is completed directly on the field in order to create a synergy with the archaeological excavation practice. After the image acquisition, data is immediately processed on-site with notebooks powered by an electric generator. Photogrammetric elaboration is generally launched before the removal of each SU. Archaeologists who work in the corresponding area are often challenged to evaluate the preliminary results of the 'image alignment' step in terms of visual quality and spatial coverage, while point density and camera optimization are inspected by the staff. If the model complies with the requirements, the excavation can continue with the removal of the SU, otherwise it is possible to integrate the photo dataset taking additional pictures of the context.

The last steps of the processing, which include georeferentiation and dense point cloud reconstruction, are often completed after the reprise of the digging activities. Having the models ready to consult on the field has proven to be of great benefit for the archaeological practice, influencing fieldwork strategies and the interpretation of contexts.

4. From surfaces to volumes

The aim of the workflow described in this section is to elaborate point clouds into solid 3D geometries, enabling the reconstruction of the volumes encompassed within overlapping surfaces (Fig. 2). The workflow is composed, at the moment, of a series of manual and software driven operations, while the development of the method aims at gradually introducing a higher level of automation. Programmatic procedures will enable faster processing, therefore producing ready-to-use documentation for a wider range of contexts. Moreover, the intervention of the archaeologist will be rerouted to less technical but not least important operations, such as quality control and interpretation of the outcome.

From the photogrammetric software (in this case Agisoft Metashape: https://www.agisoft.com/), georeferenced point clouds with associated RGB colour information are exported as .ply file (Polygon File Format) in binary format, a standard particularly suitable for large sets of point cloud data. Point cloud names are reported in a scheme diagram designed on top of the Harris matrix of the excavation, beside the name of each SU. Point clouds of the upper and lower surfaces are stored in dedicated folders named after the code of each SU, according to the scheme diagram structure. This scheme monitors the storage of the data and allows to quickly recall each point cloud needed for the elaboration of the volumetric 3D point cloud.

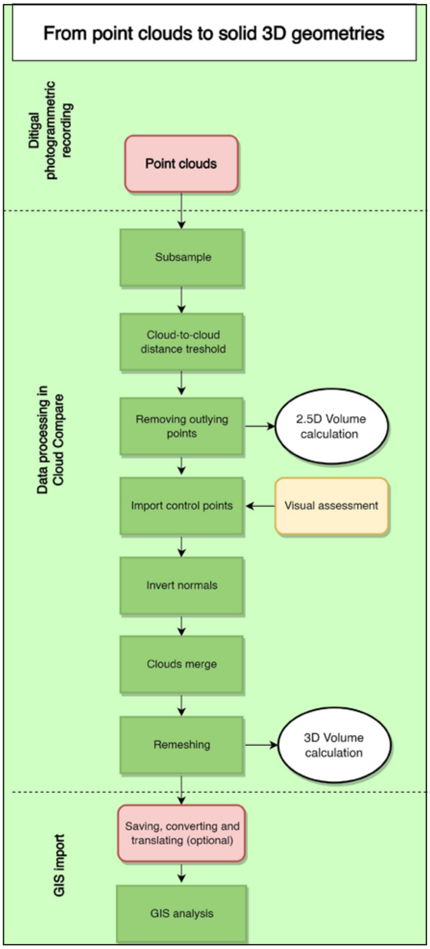

Fig. 2 – Schematic workflow for the processing of point clouds into solid 3D geometries.

For each SU, the two point clouds that form the top and bottom of the spatial context are imported into CloudCompare (CC), a 3D point cloud and mesh processing open source software (https://www.danielgm.net/cc/) (Fig. 3a). CC can handle extremely dense point clouds and geographic coordinates associated with 3D models. Anyway, as already mentioned, in our case we preferred to work in local coordinates and then translating to geographic coordinates only at the end of the processing, just before exporting to a GIS software. Point clouds are initially subsampled to reduce the workload of

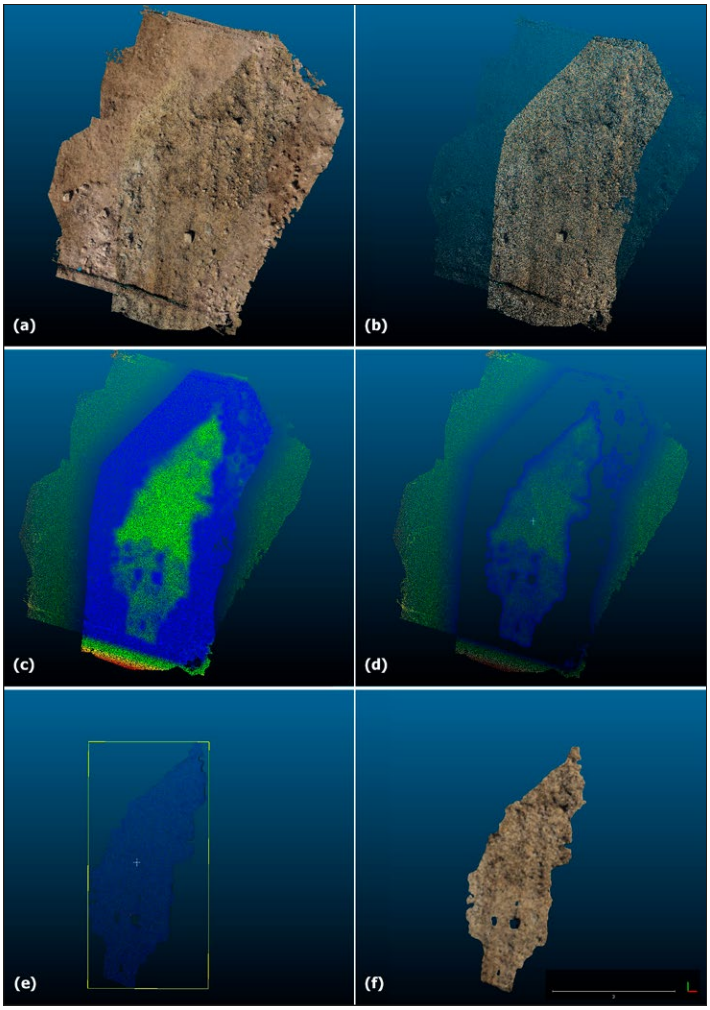

Fig. 3 – Main phases of the processing steps in CloudCompare: a) import of points clouds; b) subsampling; c) cloud-to-cloud distance calculation; d) distance threshold; e) cleaning and merging; f) remeshing.

subsequent elaboration steps, by setting a minimum space between points of 0.02m (Fig. 3b). This threshold has been set arbitrarily according to the needs of our research, whereas some small adjustment in point density can be done for contexts with particular characteristics.

The next step is aimed at detecting and cutting the portions of the surfaces that encompass the volume of the SU and delimitate its physical space. Firstly,

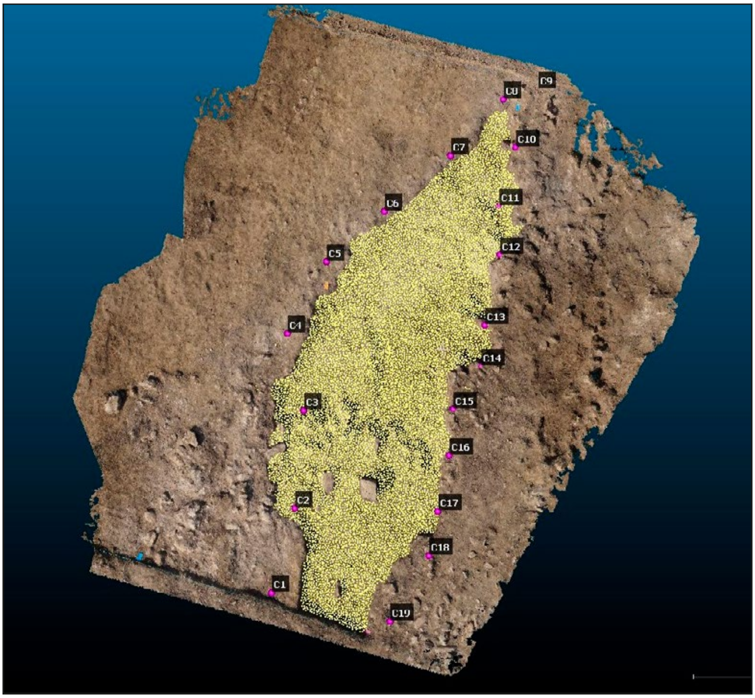

Fig. 4 – Control points measured on-site to check the reliability of the process.

a cloud-to-cloud distance is calculated between the two clouds, returning for each point the minimum distance measured from any point of the other point cloud (Fig. 3c). Then a distance threshold is set to clean out all the points that indicate perfectly overlapping between the point clouds. This operation removes all those points that show a limited oscillation between the point clouds, and that consequently are not directly pertaining to the SU itself, but likely belong to those parts of the stratigraphy that remained unaltered during the course of the removal of the SU (Fig. 3d). In this case, we chose a 0.03m threshold for most of the contexts, a value just enough larger than the sampled point resolution of the clouds. Isolated points or groups of points can be then deleted by computing the 'Segmentation - connected components' tool, setting a rather high octree level.

Further manual cleaning and visual assessment of the data is highly recommended at this stage of the process to ensure the consistency with the archaeological interpretation of the SU. This evaluation can be assisted by importing onto the point clouds the associated reference points that were previously recorded on-site along the boundary of the unit and on the most relevant features (see § 3). Reference points can be used to verify the extension of the boundaries of processed point clouds, especially in the case of very thin SUs, where the result of the cloud-to-cloud distance algorithm may not be able to clearly distinguish overlapping points from non-overlapping ones (Fig. 4).

After completing the check, the normals of the points of the lower surface are inverted and the two point clouds are merged to create the 3D point cloud of the volumetric space of the spatial context (Fig. 3e). Subsequently, the point cloud is interpolated into a solid geometry mesh using the Poisson Surface Reconstruction method and volume can be calculated (Fig. 3f). Alternatively, merged point cloud can be imported back again for remeshing into Agisoft Metahsape, which offers a different remeshing algorithm that in our experience had provided generally better performance. By importing the new solid geometry mesh into the same Metashape project of the upper point cloud, it is possible to generate a texture of the upper surface of the mesh, improving display quality of the data. Models are then saved as COLLADA file (.dae) for ESRI ArcGIS interoperability and imported into a geodatabase.

Alongside the elaboration of solid geometries for visualization purposes, models can be measured to obtain the volume in cubic units for quantitative

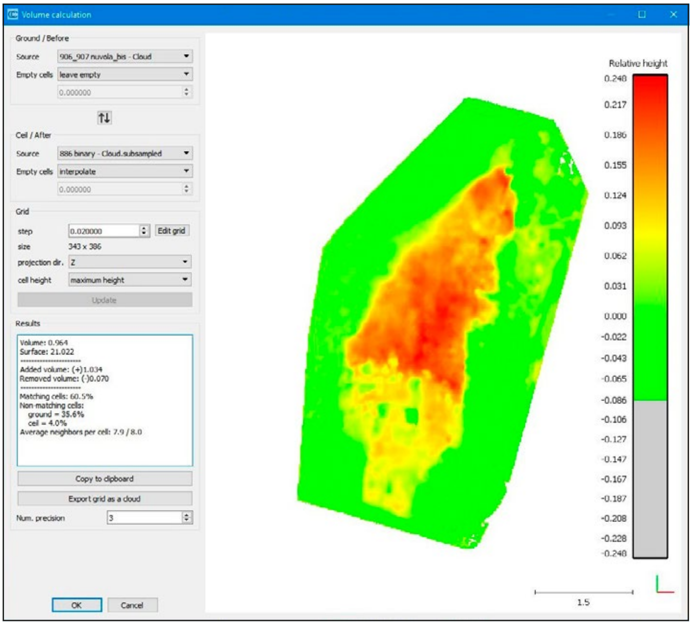

Fig. 5 – Volume calculation with '2.5D Volume' tool. The red colour corresponds to the greater distance between the surfaces. The total volume is returned in cubic meters.

analysis. At Vetricella we experienced that both visual entities and quantitative volumetric data provide valuable support for the archaeological interpretation of the site (see § 5). However, specific research questions that may be addressed exclusively to quantitative data require the implementation of more immediate methods for volume calculation. In CC, the rasterization process of the point clouds operates without the need of creating a solid geometry. The tool, called 2.5D volumetric calculation, at first sets a grid of arbitrary resolution and for each cell constructs an elementary parallelepiped. The process uses the cell footprint multiplied by the difference in height between the points of the two clouds, namely the upper and the lower surface of the units. The total volume of the model is then computed as the sums of the contribution of each cell. By using a dense resolution grid (i.e. <0.05m), volume calculation obtained with this method has returned negligible difference in result to that obtained with solid geometry calculation (Fig. 5).

5. Discussion

5.1 *Management and visualization of volumetric models*

Models created with this procedure can then be managed and visualized in different ways, according to the need of the project and to the preference of the user in terms of software and display types. In this case study, we opted for a geodatabase GIS management system for three reasons: i) models can be matched with attributes for queries and thematic displaying; ii) models are interfaced with all the other spatial and alphanumeric data obtained from the excavation; iii) geodatabase storage system helps in keeping tidy a great amount of data. ESRI ArcGIS was chosen for its good 3D visualization performance and the capabilities of importing georeferenced 3D models in various formats (Campanaro *et al.* 2016; Gavryushkina 2021; Katsianis, Kotsakis, Stefanou 2021).

The layered structure of the GIS system allows to reconstruct the entire stratigraphic deposit through solid 3D geometries, with the intent to favour a better understanding of the physical relationships between those elements by representing the complexity of the archaeological record. Imported models result in a succession of interconnected objects, organized along both the vertical and horizontal axis. By displaying all excavation models together, the upper layers result in covering the lower ones, making it difficult, if not impossible, to read the relationships among the inner units. The solution to this problem was to put each 3D model into a separate feature class. This data structure returns a succession of autonomous layers, one for each 3D model, that can be turned on or off depending on the specific need, enabling the comprehension of the stratigraphic relationships among all the units of the deposit (Fig. 6). It is possible, for example, to turn off the layers closest to

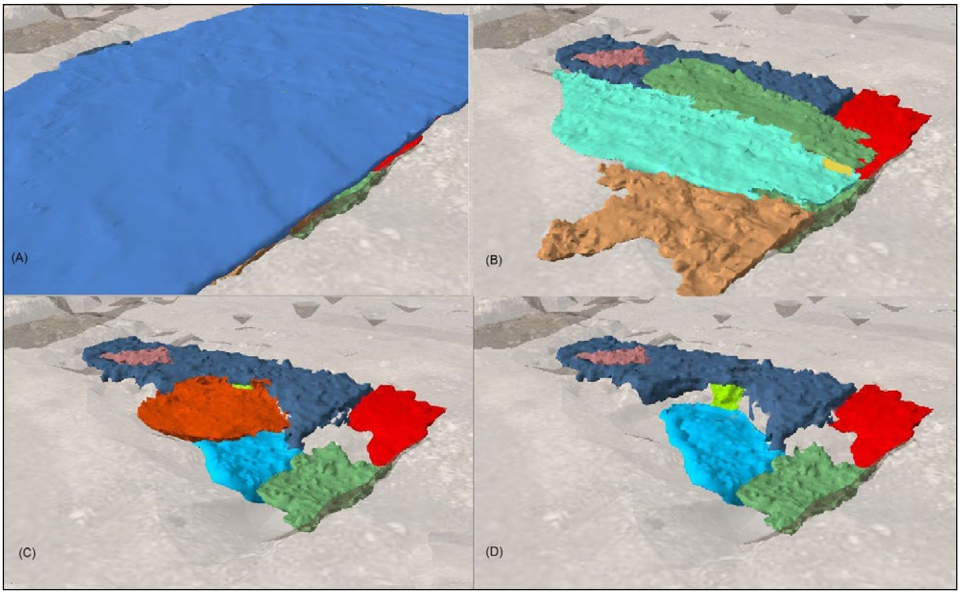

Fig. 6 – Reconstruction of the archaeological deposit of Vetricella with solid 3D geometries. The stratigraphic sequence is unveiled by gradually removing overlapping layers, reproducing the events of the excavation.

the camera view, unveiling gradually the immediately lower layers, or to turn on only some distinctive elements for studying specific contexts. 3D models retain information colour from the photogrammetric recording, but we have experienced that those relationships are better emphasized with contrasting false colours. A unique colour can be assigned to each individual element to facilitate its identification within the deposit.

Among the most useful features offered by the geodatabase management system, there is the capability to correlate 3D models with other spatial datasets and attributes elaborated during specialized studies or post-excavation analysis of the stratigraphy. This feature enables both spatial and attribute-based queries providing a more comprehensive way of exploring the 3D dataset. It will also be possible to isolate a specific group of SUs according to common characteristics, thus simplifying the study of specific sections of the deposit. Moreover, attributes can be used for thematic displaying of the models, by assigning graduated colours according to the value of certain parameters. In the examples we are going to propose, thematic displaying has been associated with the use of the volumetric data, showing how solid 3D geometries can be employed for both their visual and quantitative properties in the aid of the archaeological interpretation of the site.

5.2 *Case-study: from volume to material's standardization*

We are going to present some practical examples drawn from the site of Vetricella, in which data produced with the above protocol have been used in support of the interpretation of the stratigraphic deposit and of its depositional processes. Besides the aid in the visualization of the stratigraphic and spatial relationships, the protocol returns accurate quantitative volumetric data for all the SU of the excavation. Our goal is to test how this new variable can assist the archaeological analysis of the site.

One of the main challenges in the comparison of different contexts is that they may differ significantly in spatial extension (including the z-dimension). Different extensions indirectly influence the number of the finds retrieved during the excavation, making the comparisons based on quantities almost unreliable. Volumetric data can be used to normalize the quantity of finds of each SU, relating them to a minimum common unit of volume, obtaining a density value. Density is generally calculated as the ratio between weight of the finds and the volume of dirt of the deposit of origin (Ceci, Santangeli Valenzani 2016), but more in general it can be used to normalize every numeric/quantitative variable.

In this study we used the volumetric data to normalize the attributes of pottery weight, that is the sum of the weight of the pottery shards, and of the minimum number of vessels (MNV), that is the minimum number of whole finds identified by the shard's reassembly. Pottery was chosen among all the

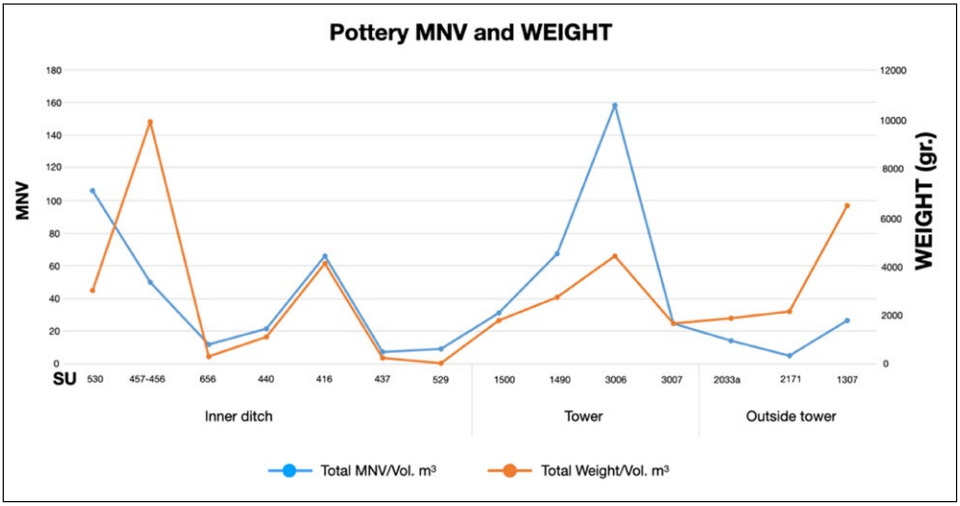

Fig. 7 – The graph shows the comparison between two trends of normalized values: orange line represents the total weight of ceramic sherds per cubic meters, while light blue indicates the total minimum number of vessels (MNV) per cubic meters.

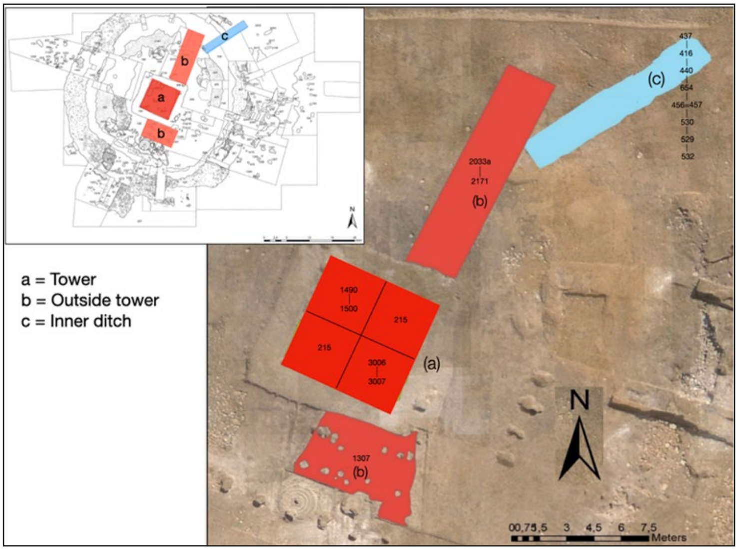

Fig. 8 – Localization of the contexts analysed with the method of standardization of the volume with respect to the values of weight and number of minimum vessels.

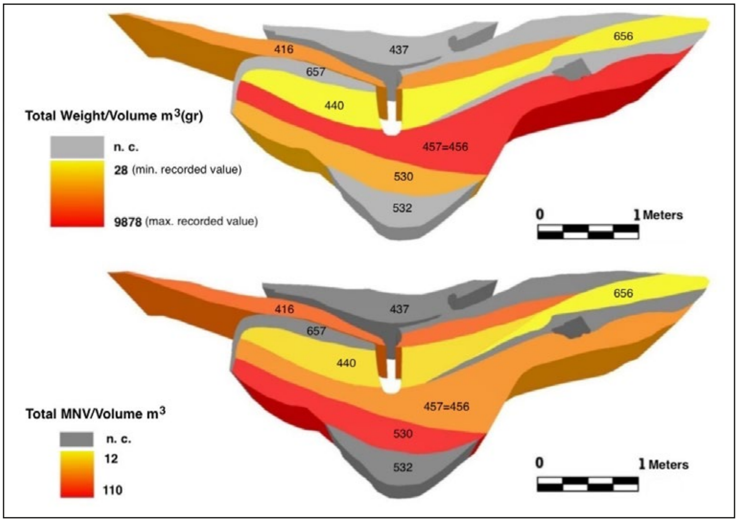

Fig. 9 – 3D reconstruction of the ditch fillings. The different colour gradient, from lighter to darker, corresponds to the ratio of a certain variable to the volume of the unit. In the upper case (minimum weight value = light yellow; maximum weight value = red), and in the lower case (minimum number of MVN = yellow; maximum number of MVN = red).

find's categories because of its high frequency distribution which makes it more suitable for analytical approaches. The results of the calculations are summarized in the chart (Fig. 7). We focused on two important contexts of the central part of the site: the filling of the most inner ditch, which was interpreted as an intentional backfilling of the unused defensive structure, and the stratigraphy of the tower and the adjacent areas, most likely formed by the sedimentation of the occupation floor. All these contexts were drawn from the same chronological phase of occupation, dating to the first half of the IX century AD (Fig. 8).

In the first case, the different spatial extensions of the units of the filling inside the trench is emphasized by the display of solid geometries (Fig. 9). Thematic displaying based on normalized values highlights the difference in finds density, greatly helping in distinguishing units with a greater anthropic impact from the others. The values of MNV and of weight appear to vary accordingly and clearly point out the different characteristics of the SUs 440 and 656. These units were probably subjected to depositional processes with a greater impact of natural factors.

In the second case, it is possible to spot some differences across the occupation floor (Fig. 10). The contexts placed on the southern side of the tower (SU 1307) show a higher pottery density than the contexts of the

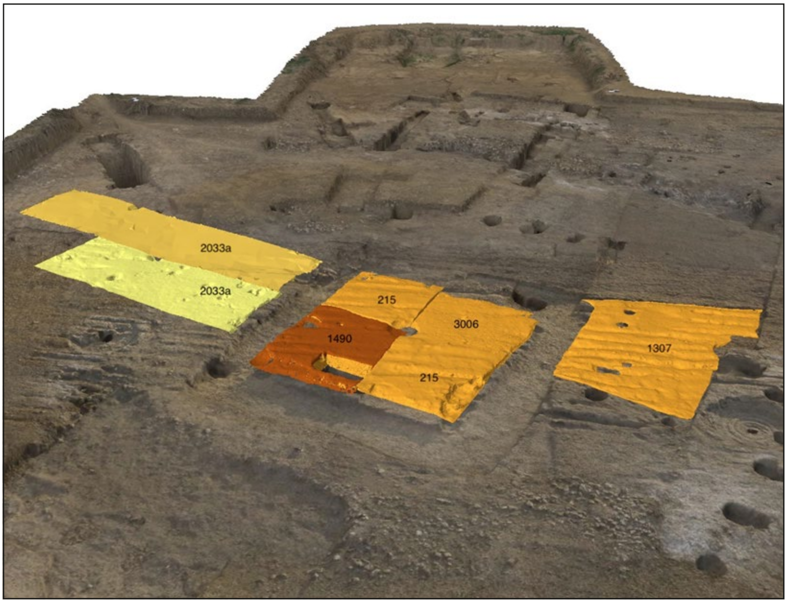

Fig. 10 – Floors inside and outside the central tower. Different colours refer to the different concentration of MVN with respect to the volume of the units.

northern side (SU 2033a). At the same time, within the rectangular perimeter of the tower, the NW sector (SU 1490) shows an unusually high MNV number. Differences in density may indicate a differentiation of the use of the spaces which need to be further investigated with the aid of other tools and information.

6. Conclusion

This contribution has demonstrated that a volumetric way of recording, visualizing, and analysing the archaeological stratigraphy can be implemented in compatibility with the timing and the needs of an extensive archaeological excavation. The volumetric approach developed for the site of Vetricella introduces a little extra workload to the conventional 3D recording procedure, however greatly expanding the potential of the use of 3D data for post-excavation analysis.

The representation of the 3D volumetric space of the archaeological deposit with solid 3D geometries enabled a better visualization of the stratigraphic and physical relationships than just the use of raw surfaces. Despite the lack of a real 3D topological implementation for spatial queries, a GIS management solution offers some useful visualization methods by adding further levels of information to the models, allowing us to display and query the data on attribute values and spatial position. Volume quantitative information constitutes an important additional variable to standardize the number of finds and other units' properties, which results in great help in determining the depositional processes of formation of the contexts and in evaluating a differentiation in the use of the space for wide occupation floors.

Future developments in the protocol include the gradual switching towards a programmatic approach in order to reduce the intervention of the archaeologist during the post-processing phase and to speed up the delivering of a ready-to-use documentation.

Giulio Poggi, Fabrizio Falchi,
Luisa Russo, Mirko Buono
Dipartimento di Scienze Storiche e dei Beni Culturali
Università degli Studi di Siena
giulio.poggi@unisi.it, ffalchi20@gmail.com
luisarus87@gmail.com, mbuono92@gmail.com

REFERENCES

Barceló J. 2000, *Visualizing what might be. An introduction to Virtual Reality in archaeology*, in J.A. Barcelo, M. Forte, D. Sanders (eds.), *Virtual Reality in Archaeology*, British Archaeological Reports 843, Oxford, Archaeopress, 9-36.

Berggren Å., Dell'Unto N., Forte M., Haddow S., Hodder I., Issavi J., Taylor J.S. 2015, *Revisiting reflexive archaeology at Çatalhöyük: Integrating digital and 3D technologies at the trowel's edge*, «Antiquity», 89, 344, 433-448 (https://doi.org/10.15184/aqy.2014.43).

Bianchi G., Hodges R. 2020, *The nEU-Med Project: Vetricella, an Early Medieval Royal Property on Tuscany's Mediterranean*, Firenze, All'Insegna del Giglio.

Campanaro D.M., Landeschi G., Dell'Unto N., Leander Touati A.M. 2016, *3D GIS for cultural heritage restoration: A 'white box' workflow,* «Journal of Cultural Heritage», 18, 321-332 (https://doi.org/10.1016/j.culher.2015.09.006).

Ceci M., Santangeli Valenzani R. 2016, *La ceramica nello scavo archeologico. Analisi, quantificazione e interpretazione*, Roma, Carocci Editore.

Dell'Unto N., Landeschi G., Apel J., Poggi G. 2017, *4D recording at the trowel's edge: Using three-dimensional simulation platforms to support field interpretation*, «Journal of Archaeological Science: Reports», 12 (https://doi.org/10.1016/j.jasrep.2017.03.011).

De Reu J., De Smedt P., Herremans D., Van Meirvenne M., Laloo P., De Clercq W. 2014, *On introducing an image-based 3D reconstruction method in archaeological excavation practice*, «Journal of Archaeological Science», 41, 251-262 (https://doi.org/10.1016/j.jas.2013.08.020).

Forte M., Dell'Unto N., Issavi J., Onsurez L., Lercari N. 2012, *3D Archaeology at Çatalhöyük,* «International Journal of Heritage in the Digital Era», 1, 3, 351-378 (https://doi.org/10.1260/2047-4970.1.3.351).

Gavryushkina M. 2021, *The potential and problems of volumetric 3D modeling in archaeological stratigraphic analysis: A case study from Chlorakas-Palloures, Cyprus*, «Digital Applications in Archaeology and Cultural Heritage», 21, March, e00184 (https://doi.org/10.1016/j.daach.2021.e00184).

Katsianis M., Kotsakis K., Stefanou F. 2021, *Reconfiguring the 3D excavation archive. Technological shift and data remix in the archaeological project of Paliambela Kolindros, Greece,* «Journal of Archaeological Science: Reports», 36, March, 102857 (https://doi.org/10.1016/j.jasrep.2021.102857).

Katsianis M., Tsipidis S., Kotsakis, K., Koussoulakou A. 2008, *A 3D digital workflow for archaeological intra-site research using GIS*, «Journal of Archaeological Science», 35, 3, 655-667 (https://doi.org/10.1016/j.jas.2007.06.002).

Marasco L., Briano A. 2020, *The stratigraphic sequence at the site of Vetricella (Scarlino, Grosseto). A revised interpretation (8th-13th centuries)*, in Bianchi, Hodges 2020, 9-22.

Nobles G.R., Roosevelt C.H. 2021, *Filling the void in archaeological excavations: 2D point clouds to 3D volumes*, «Open Archaeology», 7, 1, 589-614 (https://doi.org/10.1515/opar-2020-0149).

Orengo H.A. 2013, *Combining terrestrial stereophotogrammetry, DGPS and GIS-based 3D voxel modelling in the volumetric recording of archaeological features*, «ISPRS Journal of Photogrammetry and Remote Sensing», 76, 49-55 (https://doi.org/10.1016/j.isprsjprs.2012.07.005).

Roosevelt C.H., Cobb P., Moss E., Olson B.R., Ünlüsoy S. 2015, *Excavation is destruction digitization: Advances in archaeological practice*, «Journal of Field Archaeology», 40, 3, 325-346 (https://doi.org/10.1179/2042458215Y.0000000004).

Sapirstein P., Murray S. 2017, *Establishing best practices for photogrammetric recording during archaeological fieldwork*, «Journal of Field Archaeology», 42, 4, 337-350 (https://doi.org/10.1080/00934690.2017.1338513).

Taylor J., Dell'Unto N. 2021, *Skeuomorphism in digital archeological practice: A barrier to progress, or a vital cog in the wheels of change?*, «Open Archaeology», 7, 1, 482-498 (https://doi.org/10.1515/opar-2020-0145).

ABSTRACT

3D recording methodologies have been successfully integrated into the archaeological fieldwork practice, resulting in a widely accepted series of advantages for the documentation of the excavation. However, post-processing analysis is often neglected and recording protocols do not consider possible developments for exploiting the potential of 3D data. At the excavation of Vetricella, in Italy, the ERC nEU-Med project developed a digital documentation protocol aimed at reconstructing the volumetric physical space occupied by each stratigraphic unit, generating more than a thousand contexts over the course of four archaeological seasons. In this contribution we are going to present how the volumetric approach has influenced the whole methodology of documentation since the recording stage, introducing a standardized workflow aimed at reconstructing solid geometries from 3D surfaces. In this protocol a great attention is paid to the strategies, timings and needs of the fieldwork practice, without overlooking important archaeological aspects such as data accuracy and the chance to generate data for more quick on-field interpretation. The final outcome is a new visualization and analysis of the space with the use of volumetric models, which results in greater accuracy in displaying physical and stratigraphic relationships, as well as generating volumetric quantitative data. In the end, some examples drawn from Vetricella will be employed to show how solid 3D geometries and volumetric quantities can be used in support of the archaeological interpretation of the site.