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TOPOGRAPHICAL SURVEY AND DIGITAL MODELS

1. From traditional survey to new technologies applied to the excavations of Marzabotto

At the beginning of the excavations of the urban peripteral Temple, in 1999, the Etruscology Chair of the University of Bologna flanked the more traditional direct method of survey with electronic and photogrammetric instruments as the Total Station and the CAD drawing of rectificated images (Sassatelli, Govi 2005, 13-30; Sacchetti 2005). Over the years, as new survey techniques were developed (and tested by surveyors of the Archaeology Department, e.g. Bogdani *et al.* 2007; De Donatis *et al.* 2012), they have been applied to the excavations at Marzabotto. However, we never completely abandon the traditional direct method, especially taking into account that ours is one of the main archeological teaching sites of the University of Bologna. This didactic purpose has always been kept in mind, both during excavation and surveying.

In recent years, the attention of the survey group (represented by the authors) has been focused on two other purposes (which will be better defined in the next sections): on the one hand, to provide excavation documentation as complete and integrated as possible and on the other, to produce graphic models for 3D processing, providing data for the Virtual Reality reconstructions of the FIR Project here presented (A. Gaucci in this volume).

Regarding the first point, about which E. Zampieri will deal in the next section, we developed a workflow (Fig. 1) that allows us to manage the entire digging documentation with a single database (integrating the Geographic Information System with the open source PostgreSQL software): from all Stratigraphic Units (SUs) and findings files, to any type of graphic and photographic printout. The fact that this entire mass of information is integrated and statistically queryable on various levels offers a great tool in the study and interpretation stage with the aim of the complete edition of the excavations. This experimental pipeline, built by adapting to the needs of archeology (and particularly to our excavation) software often conceived for other areas, choosing open source and multiuser versions, satisfy the need to engage and work simultaneously both coworkers and students, who can interface with this framework also using other and more common databases.

Regarding the second goal, more interesting for this Conference and which will be detailed in the second section by B. Gruška, we have to add some brief preliminary remarks on the choices made to improve the topographic survey and obtain in the meantime a 3D product. In 2013/2014 we had the opportunity to simultaneously apply and compare three survey instruments:

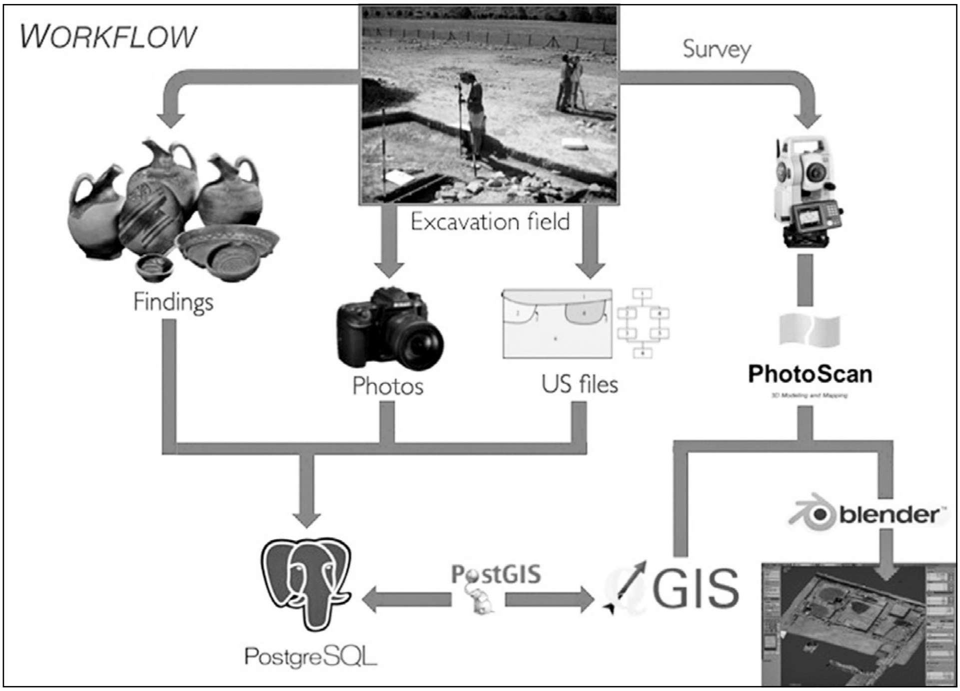

Fig. 1 – Operative workflow of the topographical survey of Marzabotto (BO).

the monoscopic photogrammetric survey (which had in the meantime become a "traditional" practice), the three-dimensional survey using laser scanner, and its cheaper alternative of stereoscopic photogrammetry using the PhotoScan Structure from Motion software (see e.g. Paris 2012; Campana, Remondino 2014). While the survey with laser scanner was tested by engineers and surveyors of the Department, and at that time considered not useful to document the particularities of our excavation, the survey team was able to verify on the field, throughout the campaign, the other two systems.

We were thus able to compare surveys obtained via the traditional image rectification and CAD drawing with the new processing system of 3D models of archaeological structures obtained with the PhotoScan photomodelling, from which it is easily possible to cut sections and obtain two-dimensional plans and prospect views. These outputs were then processed with the open source software QGIS to get geo-referenced plans and sections on a low scale. Then they were compared with drawings processed in CAD and some direct manual measurements and we found that the margin of error was restricted and tolerable (Bianchini 2008, 65). Since 2014/2015, for the excavation of the new Tuscanic Temple of *Uni*, we decided therefore to proceed only with the direct survey (for the educational purposes mentioned above and because in some special cases it is still one of the most effective ways to survey) and with the PhotoScan photogrammetry. We considered that the greater margin of metric error (still acceptable) compared to the laser scanner, is amply compensated by the inexpensiveness (in terms of costs and execution time, see Kersten, Lindstaedt 2012; Sfacteria 2016) and that, always thinking to educational purposes, it is an employable tool also for students (especially in data acquisition, but also in their processing), as well as for their professional training. We thus obtained the double advantage of processing the survey in a geo-referenced GIS environment, adding it directly (avoiding the expensive transition through CAD) to the general digging database, and also to get a useful product for the digital 3D modeling. Finally, 3D photomodelling (unlike monoscopic photogrammetry) offers the further advantage of being able to draw up plans and sections also when the excavation is closed and under study and publication. In this way we will recover a greater interpretative reflection, one of the principal merits of the direct method.

For the topographic survey of the Tuscanic Temple of *Uni* we developed a workflow that we applied also to the documentation of the years 1999-2012. We thus proceeded to the digitization and input into the GIS system of all the digging documentation of the peripteral Temple of *Tinia* and the area N of it. This was done for the double purpose of getting a GIS of the entire Etruscan town of Kainua-Marzabotto and for the more immediate goal of publishing the 1999-2012 excavations (forthcoming), which will include a large detailed documentation, freely consultable online by an open access platform such as WebGIS.

The photogrammetry Agisoft PhotoScan software has thus proved to be a satisfying tool also for the two-dimensional survey of the archaeological excavation. With a system of Ground Control Points near the excavation limits and fixed to the traverse (geo-referenced via GPS), we obtain both general excavation plans and detailed plans and sections in a lower scale. In an urban excavation as that of Marzabotto there are generally no high level gaps, mainly because the structures are preserved only at the level of the foundation walls. Since these are often built in the virgin soil and therefore dug for limited trenches, the 3D point cloud system has proved to be very useful. Furthermore, the fact of having three-dimensional surveys of the structures is essential to understand the construction techniques and stratigraphic relationships between these. Finally, having 3D models of excavated structures or single objects and architectural materials was crucial to the FIR Project (Gruška, Mancuso, Zampieri in this volume) and more generally to have fruitful products for the dissemination to a wider audience of the archaeological activities in Marzabotto.

In conclusion, we will approach a possible future development of stereophotogrammetry, about which G. Mancuso will deal in the last section. The goal is to go beyond the two-dimensional survey and make the most of the possibilities offered by stereoscopic photogrammetry. Thanks to the integration between the survey with Agisoft PhotoScan and the 3D modeling software Blender, we are developing an experimental workflow that allows to produce a three-dimensional, geo-referenced survey of the excavation by means of which we can move beyond the two-dimensionality and fully reap the advantages offered by a graphical representation of the vertical sequence of the stratigraphy of an archaeological excavation.

S.S.G.

2. Integrated systems for excavation data management

The use of GIS as the main tool for managing topographic data in the excavations of the University of Bologna in Marzabotto has greatly improved the survey methods. At the same time, we needed a system which could manage all the data generated by the excavations: the topographic survey, the general graphic documentation, and all the information on the SUs and related materials. Our goal was to build a structure exclusively based on Free Open Source Software (FOSS) considering the variety of operating systems used within the Research Unit.

We did it moving from CAD to GIS, when we adopted QGIS software. On the other hand, excavation documentation has been collected in the last years through FileMaker, a cross-platform proprietary software with a user-friendly interface. Using FileMaker makes the alignment between alphanumeric data and GIS geometries particularly time-consuming. The use of shapefiles and DBF tables proves to be equally time-consuming. We therefore decided to adopt a spatial database such as PostgreSQL, implemented with PostGIS: a plugin that allows, among other things, to convert GIS shapefiles into tables containing geometries.

This software has already been tested in another research project directed by Chair of Etruscology, the ongoing study of Valle Trebba necropolis in Spina. In this case, it was necessary to have an overall view of the graves and vessels they contained. The implementation of a PostgreSQL/PostGIS database in the GIS allowed to create a dynamic and promptly available archive, and above all a tool to analyse the ways of deposition and distribution of objects using SQL queries, in a diachronic and spatial perspective.

The excellent result achieved with the study of a context that was excavated a long time ago led us to apply the same method to the ongoing excavation at Marzabotto. The experimentation is at present restricted to the area surveyed with electronic devices like the Temple of *Tinia*, its northern area, and the Temple of *Uni*. The spatial database PostgreSQL/PostGIS allows to collect in a single platform alphanumerical data from different tables and the geometric and georeferenced data of shapefiles obtained in vectorizing orthophotos. The first non-negligible advantage of this data centralization is the constant preservation of their integrity. Through the configuration of a server or a simple local network, PostgreSQL allows multiple users to work on the data at the same time. It also ensures the alignment of the data, which would otherwise require much time and energy implying high probability of error, especially during an excavation campaign. This feature is essential in an excavation like Marzabotto, where many researchers and students are working on the materials, managing the topographic survey and all the documentation at the same time. It is thus increasingly important to provide dynamic tools for the simplification of a complex workflow.

The QGIS-PostgreSQL/PostGIS structure allows to establish a spatial and dynamic relationship between the shapefiles and the database of SUs and materials. Its creation is suitable for users with average informatics skills. Its fruition can be eased by using a common database software (such as MS Access or FileMaker) as front-end. Nowadays, almost all archaeologists are familiar with them (Bogdani 2009, 439-449).

This platform can be also a useful tool for processing data in the study phase. Much is being done to overcome the limits of a two-dimensional approach to the analysis of stratigraphic succession (Mandolesi, Cocca 2013). At present, however, QGIS offers some simple tools like the DB Manager plugin, which allows to run SQL queries with alphanumeric tables and tables containing geometries, and loads the results as a new layer into QGIS. It is also possible to reach higher levels of complexity through a system integration software that connects the system with a statistical software.

Anyone who uses PostgreSQL can interact with the database in the way most suitable to his skills and needs, without affecting the integrity of the data, which is the most valuable resource in the destructive operations of archaeological excavations. This system, based on the dynamic relationship between QGIS and PostgreSQL, facilitates the dialog between the topographical survey and the data collected in the field. It can also support the interpretation of contexts during and after archaeological campaigns.

E.Z.

3. 3D field recording and data processing

Currently, the digital detection techniques and three-dimensional modeling are the best tools to document the archaeological evidence, in terms of accuracy, precision and detail of the data obtained. The experimentation and use of 3D digital acquisition techniques in the field of archaeological survey have now become an established practice, as confirmed by the widespread use of systems based on active sensors (range-based methods), such as laser scanners and total stations, whose methodology of acquisition and data processing is well known and standardized (Böhler, Marbs 2004). In recent years, also systems based on passive sensors (image-based methods), such as digital photogrammetry and computer vision algorithms, were progressively optimized: the former, today widely used in archaeology, has the metric documentation of objects as a purpose; the latter, more recent, is focused on the automatic 3D modeling (Hartley, Zisserman 2004; Remondino, El-Hakim 2006; Buscemi *et al.* 2014). From the combination of digital photogrammetry and computer vision techniques, algorithms like "Structure from Motion" (SfM) were implemented into software like Agisoft PhotoScan, which allow to reconstruct 3D models from photographs using a typical automated process, as experimented in this research work.

During the excavations at Marzabotto in 2014, it was decided to take advantage of these methodologies using PhotoScan combined to total station's data acquisitions in the field: the aim was the production of three-dimensional models related to the various digging stages, useful not only as accurate representations of the detected areas but also, at a later time, as a metric database to study and interpretate archaeological data. Therefore in the last few years of investigation it was possible to test a new survey method, establishing a workflow which greatly implemented the speed and quality of obtained documentation.

Obviously, on the field we focus on the topographic approach using total station and georeferenced ground control points that allow us to keep controlled faults and distortions of the model. The second issue of paramount importance during the fieldwork is the acquisition of digital images, in order to obtain reliable results. Both these operations, when compared to a traditional survey, are considerably shorter, thus overcoming problems related to the continuation of archaeological research activities.

For the data processing we have chosen Agisoft PhotoScan Pro, a SfM software, able through an algorithm to identify some points associated with descriptions in each image; these descriptions are used to identify the correspondences between the photos required to create the model.

During the stage of data processing it is essential to proceed while maintaining a good level of accuracy in order to produce a reliable documentation, in which the spatial relationships between the different layers are expressed in the correct manner, and to allow the subsequent integration of different diachronic models (Sordini, Brogi, Campana 2015, 386). Just for the latter purpose, it is necessary to pay particular attention to the cleanliness of point clouds generated in order to obtain polygonal meshes that best represent the individual SU.

The last phase of the workflow on PhotoScan is the texture mapping on the polygon meshes, after which it is possible to export high quality

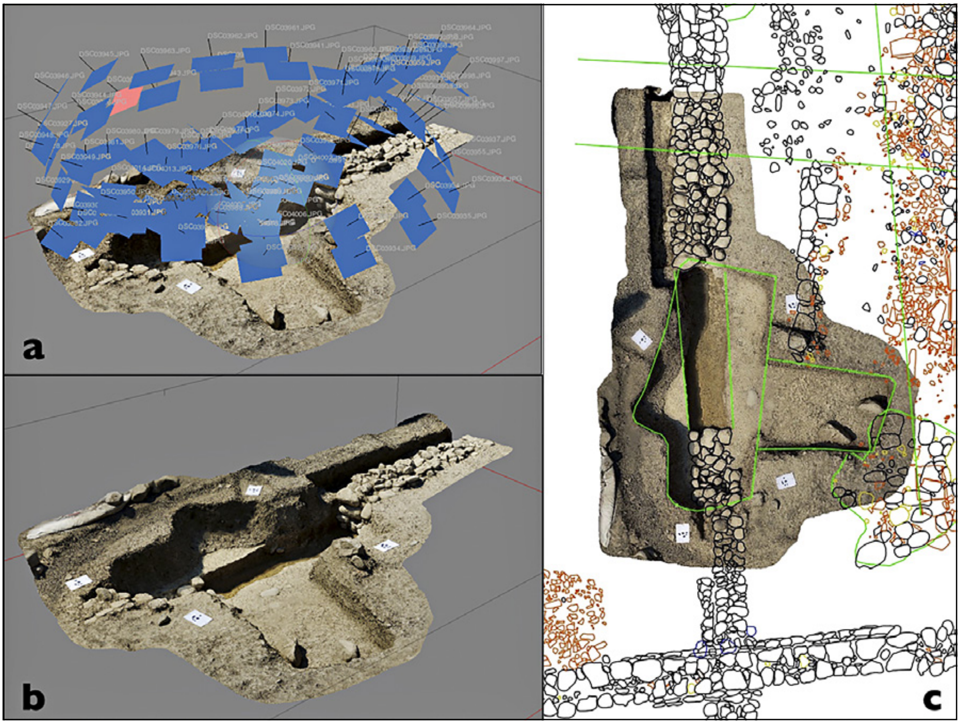

Fig. 2 – a-b) Data processing in Agisoft Photoscan; c) Vector drawing on the orthophoto in QGIS.

orthophotos directly from the program. The color, together with the geometry, constitutes a fundamental characteristic of the archaeological stratigraphy and despite this software uses a color correction algorithm that minimizes the differences in exposure between the source images, it is necessary to choose an adequate resolution of textures to correctly represent the surfaces.

The produced documentation lends itself perfectly to the phase of interpretation and to the excavation processing plants. The orthophotos are imported into a 2D GIS where each layer is drawn through a shapefile (Fig. 2). This activity can be carried out almost simultaneously with the excavation work, giving the opportunity to the archaeologist to review the context in case of doubt and to work faster on the field not having to stop work for long periods as in the traditional survey.

The 3D models are uploaded into Blender from which it is possible to extrapolate sections and overall prospects of investigated areas in different years, because they can be unified within the platform in a single scene. The archaeologist has therefore the possibility to explore the data with a more complete perception compared to the top view of the 2D GIS, achieving more information on overlapping layers such as the thickness and the inclination thanks to the third dimension (Sordini, Brogi, Campana 2015, 387-390).

However, vector drawing activity remains indispensable for integrating archaeological data, as it transposes graphically the process of interpretation of the SUs: only at this stage you have the option to point out some details, or to exclude irrelevant parts of objective documentation produced by digital technologies. Indeed, the end of each archaeological excavation is not only the objective rendering of the SU, but the ability to define and interpret these units.

In conclusion, the 3D photomodeling applied to Marzabotto excavation has brought many benefits to the research: significantly higher accuracy and quality of documentation, greater speed of work on the field, and also, the removed SUs can be "reconstructed" backward and analyzed metrically appreciating the volume and mutual relations in 3D, with considerable advantages both in the interpretation and in the dissemination (Sfacteria 2016, 282). The reversibility of the excavation actions through the overlapping of different 3D models investigated also in different years, allows to evaluate new aspects without the process of abstraction belonging to the traditional documentation. The most time-consuming moment is related to the computer calculation during the alignment stages of images and the generation of point clouds, but it is an avoidable "limit" since, not being required a constant interaction of the user, these operations can be carried out simultaneously with other activities.

B.G.

4. Further development

Notwithstanding the great improvements in terms of accuracy and precision that a regular usage of these survey techniques brought us, a few limitations have emerged.

The first is surely the absence of a platform that allows storage and analysis of all the 3D data acquired on the field. Even if recently GIS programs come with utilities that allow visualization and basic manipulation of 3D models, unfortunately they still lack tools that allow simultaneous visualization and analysis of multiple models that insist on the same area at different height, such as in any archaeological survey (Agugiaro 2014, 108-110).

The most common solution to overcome this problem is to work just with the orthophotos produced by the 3D models; raster images can be easily loaded in GIS and traced with shapefiles in order to recreate a bidimensional layout of every single SU (Sordini, Brogi, Campana 2015).

This workflow, inspired by direct survey techniques, is yet the best solution possible to produce maps and to run every kind of spatial analysis on

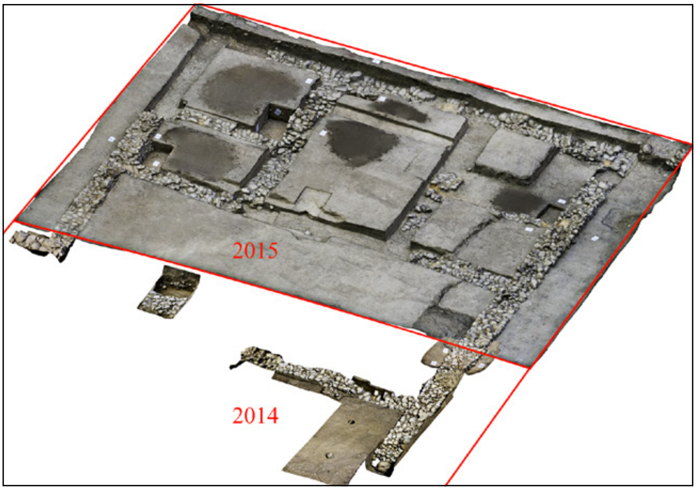

Fig. 3 – 3D models of the temple of *Uni* acquired over different years and rendered together within Blender.

archaeological and topographical data, but it does not enhance enough the stratigraphic sequence of the archaeological context.

For this reason, mainly, we decided to try a different technique (to be used alongside with the GIS) in order to manage altogether the 3D data surveyed, creating a new platform to store and visualize simultaneously every digital model acquired. Since our problem was strictly connected with the very essence of every GIS program, we decided to direct our efforts to other kind of software, such as 3D modeling ones, and specifically Blender (https://www.blender.org/). Our choice was driven to this program because it is open source and it is the only 3D modeling software where georeferenced files can be loaded (thanks to the add-on named Blender-GIS: https://github.com/domlysz/BlenderGIS/). This specific utility allows us to directly import into the scene the same georeferenced models elaborated in Agisoft Photoscan, always preserving their positioning, fundamental to the correct superimposition of multiple models.

The first results of this experiment, initially conducted during the 2015 excavations, were extremely promising. This system has given us the chance to visualize and understand in a much more immediate and comprehensible way some complex stratigraphic sequences.

It has proven itself extremely useful also to associate together different models of the same SUs (especially foundation walls), that, due to various management needs, have been excavated over different years. An example consists in the eastern wall of the Temple of *Uni*, whose southern portion was excavated in 2014, and the northern in 2015. In this specific case it has been possible to easily associate together not only the structural evidence of the foundation wall itself, but also all the other related layers, coming to an easier interpretation of the stratigraphic sequence and the archaeological context itself (Fig. 3).

This first promising result has encouraged us to move further and to enhance this new 3D visualization system. So during the 2016 excavation we developed a new workflow to take the most out of it. Every point cloud has been fully processed in Agisoft Photoscan in order to gain a full orthophoto to be loaded in QGIS and, after that, every SU have been extracted and individually processed as a different chunk, in order to elaborate a 3D model of the superficial layout of the unit itself to be loaded into Blender.

A Blender scene, so configured, literally allows the user to "peel of" every single layer, taking maximum advantage of the 3D model acquired on the field. Of course this solution is yet to be definitive and cannot be considered a valid substitute of GIS, mainly because it lacks of almost every kind of analysis tool. It is in fact yet impossible to join 3D models with any kind of database, giving the impossibility to make any kind of spatial analysis based on external data. It is also impossible to filter data with query based on groups of action or phases, restricting every analysis to a simple, but yet effective, selecting view.

In spite of this heavy restriction we believe that this system can represent the first step towards a new way to manage all together the topographical data acquired on the field, and we hope that in the future the usage of an open source software can easily facilitate the process of integration between databases and 3D models enhancing the analysis tools, as in every GIS software.

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ABSTRACT

In this paper we will briefly discuss the evolution of the solutions that the Chair of Etruscology of the Bologna University applied to the topographic survey of the archaeological excavation in the Etruscan city of Marzabotto (BO). The operational choices, the instruments and the software used in the latest excavation fields will be presented here. We will then illustrate the applied experimental workflow and its possible further development in order to take full advantage of the possibilities and benefits offered by the 3D survey techniques.