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The archaeological excavation of the Early Neolithic site of Portonovo as a case study for testing a 3D documentation pipeline

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Abstract
An archaeological investigation carried out by INRAP (Institut national de recherches archéologiques préventives) rThe paper outlines how different state-of-the-art survey workflows can be applied to map the Early Neolithic site of Portonovo - Fosso Fontanaccia (Ancona, Italy), establishing a straightforward, fast and often low-cost workflow for excavation recording. Different survey experiences are carried out to map the five domed ovens (VI millennium BC) excavated during the 2013 field campaign, ranging from digital photogrammetric to terrestrial laser scanner data acquisition and from open source to commercial processing. The option of quick, well-tested and often low cost/open source survey pipelines makes the research experience a case-study highlighting new approaches that can be integrated in the general excavation methodology and additional interesting features such as model/data reusability. The produced photorealistic 3D models together with all the other digital data are integrated inside a GIS environment satisfying the need to manage on situ the documentation of on going excavations.

Keywords: archaeological excavation, Portonovo, 3D documentation, GIS

1. Introduction
Stratigraphic archaeological excavations demand high-resolution documentation techniques for 3D single-surface documentation because only within a destructive process each single deposit can be uncovered, identified, documented and interpreted. Documentation must be systematic, objective and independent from the given interpretation and should permit the re-examination of the work even after a long span of time. This 3D recording is typically accomplished using total stations but other techniques such as photogrammetry and 3D scanning are nowadays standing out because of their performance and affordable deliverables. These 3D methodologies for Cultural Heritage 3D techniques should be taken into consideration because overcoming previous constraints in terms of processing time and cost (Cowley, 2011). Moreover it is documented how they can be really affordable establishing a straightforward, fast and often low-cost workflow for excavation recording and Cultural Heritage in general (d’Annibale, 2014). More important they allow the generation of very realistic 3D results (in terms of geometric and radiometric accuracy) that can be used for many other purposes: digital preservation and conservation, cross-comparisons, monitoring of shape and colours, simulation of aging and deterioration, virtual reality/computer graphics applications (Bruno et al., 2010), 3D repositories and catalogues (Fangi et al., 2013), web-based geographic systems (Manferdini et al., 2010), computer-aided restoration, multimedia museum exhibitions and so on (Barcelo et al., 2000, Cowley, 2011).

Figure 1: The position of the archaeological area in Portonovo.
2. Excavated Area

The site of Portonovo dates back to the ancient Neolithic of the middle-Adriatic Italian peninsula (Fig. 1), and the structures that have been found represent a unique evidence in Italy and in the Mediterranean area. The archaeological site is located on a south-facing slope (Fig. 2), along the right bank of the river Fontanaccia, at an altitude of about 120 m asl.

Soundings were conducted in 2006 by the Soprintendenza per i Beni Archeologici delle Marche (a peripheral organ of the Ministry of Culture with the institutional task of protecting, conserving and valorising the architectural and landscape heritage in the Marche Region). Since September 2011 systematic excavation campaigns has been undertaken by the Sapienza University of Rome (2011, 2012 and 2013) over an area of about 300 m² (Conati Barbaro 2013).
These investigations revealed 18 domed ovens dug in the ground along the hill slope and dated at the half of the VI millennium BC cal. The ovens were aligned at different heights along the hillside overlooking shallow and irregular pits, which were dug to facilitate the excavation of the ovens and provide their access for use (Fig.3).

The downslope ovens are well preserved because they were protected by a thicker surface deposit, while the upper slope ovens are badly damaged by erosion and ploughing.

Six ovens are entirely preserved, while the others were cut by erosion and ploughing: these appeared as circular structures lined with clay. The ovens have circular and smoothed bases with diameters ranging from 1.80 to 2.00 m and an average height of 0.50 m. The inner lining is partly made by firing of the natural sediment and partly by addition of a clay paste.

Three badly preserved burials were found within two ovens: oven 1 contains the remains of two individuals while oven 5 contains one adult male of more than 55 years.

The PXRD analysis (X-ray powder diffraction) of hardened sediment samples of the inner walls of the ovens showed that the sediments were affected by exposure to very low temperatures not exceeding 500°C (Muntoni, Ruggiero 2013). This low value does rule out the possibility of using the ovens for firing pottery, but is compatible with other uses such as cooking and food processing.

Moreover, during the 2013 campaign dozens of charred barley caryopses were found inside three well-preserved ovens, thus confirming the hypothesis of use of the ovens for roasting cereals. Three radiocarbon dates were obtained so far:

- $6555 \pm 45$ BP - 5620-5460 BC cal $\sigma$ 2, on a barley caryopses, found at the entrance of oven 14;
- $6500 \pm 50$ BP - 5560-5350 BC cal $\sigma$ 2, on a charcoal from the base of oven 5, under the male burial;
- $6418 \pm 50$ BP - 5480-5310 BC cal $\sigma$ 2, on a bone of the male burial in oven 5.

2.1 The archaeological materials

Archaeological materials are quite scanty suggesting that this area was devoted to “specialized” activities related to food processing, which were performed outside or near to a village, although any evidence of houses or domestic structures so far were found.

Typical central Adriatic Impressa pottery, groundstones (mainly fragmented grinding slabs and grinders) and chipped stone artifacts were found in the pits in front of the ovens (Fig.6).

Flint cores, blades and blade lets, some of which showing thermal alteration, were found both outside and inside the ovens. These data allows us to hypothesize that ovens...
could also have been used to heat flint in order to facilitate the knapping operations.

According to the radiometric dates, the site of Portonovo-Fosso Fontanaccia represents a good evidence of the process of Neolithization of the middle-Adriatic Italian peninsula, standing out for the pottery and lithic production. This particular characteristics is widely spread from Abruzzo to Romagna regions.

3. Previous Documentation

2013 fieldwork recording strategies have so far been distinguished from the rest of the excavation documentation, which has largely remained on paper.

During 2006-2013 field campaigns covered around 300 square meters and recorded the archaeological excavations mainly by hand drawn documents. The main working tool was the daily field report, used to register all the relevant observations and data interpretation during the workday.

Mapping draws were done manually using optical levels to record the height of each SU and the total stations to georeference grid points in a topographic reference system.

A grid system of 4mx4m was set up in 2006, using the X axis as main reference system. This grid gradually enlarged over the years, according to the expansion of the excavation area. A Archaeological materials (lithics, pottery, faunal and botanical remains) were recorded together with their position, depth, Stratigraphic Unit. Artefacts were removed and stored in numbered collections, marking them in detailed plans (scale 1:10), in order to help the identification of possible associations and refittings during post-dig study.

Each structure was recorded by field finds labels, detailed plans (1:10) and sections (scale 1:20) to study morphology and depth articulation (Fig.7, left). General sections were also drawn in a smaller scale (1:50), in order to relate the structures along the hillside. All the recorded structures were placed in a general plan (scale 1:50). Each SU was documented by taking photographs at various stages of excavation: at the beginning, when the SU is recognized, while being excavated and finally when it is completely dug up. Moreover the wide shot and aerial photos allowed to record the excavation area as a whole.

SU Sheets were filled during the fieldwork, according to a widely shared form (Parise Bodoni, Ruggeri Giove 1984), storing all the SU information together with all the observed stratigraphic links, in order to recreate the stratigraphic sequence of the entire site.

After the excavation the work went on creating computerized database for the stratigraphic units, digitalizing the Italian context sheets (SU reports) and rebuilding stratigraphic sequences (Fig.7, right). Part of the post-excavation study.

![Figure 7: Previous documentation: Hand drawn plan (left) and SU reports (right).](image)
Consisted in the digital reworking of hand drawn plans and sections and in the analysis of the archaeological materials.

The SU form uses as a starting base the Italian Archaeological Find Sheet (Fresina 2006), with some modifications such as new categories and types.

A filemaker database was developed for pottery study, focusing on qualitative and quantitative analysis, technological and typological aspects.

Finally, graphic and photographic reproduction of artefacts is important both for documentation and scientific publication and allows to compare archaeological remains with those of other contemporary sites.

Previous fieldwork seasons revealed detailed stratigraphic sequences requiring a complex documentation, highlighting the need for managing data in a GIS platform, able to collect all the stratigraphic, topographic and cartographic data.

For this reason in 2013 first, new recording techniques (Photogrammetry and Laser-scanner) were tested. Second, a dedicated GIS has been developed and closely linked to the digital recording and data processing of archaeological excavation context.

4. Research Issues

The research approach tries to test a 3D documentation and GIS management pipeline for the archaeological site of Portonovo bringing in a systematic way 3D digital field recording procedures and combining them in a GIS environment with previous integrated data storage mechanisms.

In this context, different data are collected during last excavation (September and October 2013) by means of terrestrial laser scanner and photogrammetry and different deliverables are produced (photorealistic 3D surface models, orthophotos, 3D sections etc.). 2D and 3D representations of all excavated features are then linked together with other digital data taking full advantage of recent open source GIS functionality in data management and supporting the archaeological knowledge production process.

Moreover the creation of photorealistic 3D models giving realistic representation of excavation features in digital 3D space will help to make visible and accessible this unique site in the panorama of Italian prehistory. This result gains in importance because the ovens of Portonovo are very fragile and prone to rapid deterioration. Therefore, the idea of an open-air musealization of these structures is not feasible.

5. 3D documentation

Different survey experiences are carried out to map the five ovens excavated during the 2013 field campaign, ranging from close-range Photogrammetric to Terrestrial Laser Scanner data acquisition and from open source to commercial processing. In particular, three surveys are carried out to map different excavation stages and the overall archaeological site:

- At excavation beginning (September 19), Photogrammetric survey (PHMY)
- During the excavation (September 27), Photogrammetric and Terrestrial Laser Scanning survey (PHMY and TLS)
- At excavation closing (October 10), Photogrammetric and Terrestrial Laser Scanning survey (PHMY and TLS)
Ground control points are acquired with a total station to geo-reference the 2013 surveys, bring the two models (PHMY and TLS) into a common reference system set them in the existing dig working grid and link in with archival data from previous excavations (Fig. 8).

Several recent publications compare the two mentioned technologies based on factors such as accuracy and resolution. Even if both technologies are nowadays capable of providing similar accuracy and resolution when supported by a well-designed digitization plan, their combination and integration remains the ideal solution to survey large and complex sites and improve the extraction of features with different geometric level of details. In particular laser scanning data is used as reference for a comparison with photogrammetric data and as documentation for the creation of high precision DSM and 2D metric deliverables (archaeological sections and orthoimage of the site). On the other hand, textured photogrammetric 3D models are used for visualization purposes of the entire site and assist archaeologists in interpretations of past uses of space. The collected images and range data are processed independently as described below.

5.1 Laser Scanner survey

Acquiring large number of precise 3D data points, Laser scanners are effective tools to measure the topography of the 3D data gathered so far (point clouds, triangulated meshes, orthophotos etc.) document with high quality the excavated surfaces but need to be archaeologically interpreted. These data formats have the potential to replace the traditional analogue excavation maps and drawings and to increase the scientific value and extend the application of the recorded archaeological data. During the process of interpretation, these collected documents have to be combined with all the other excavation data, especially with finds and samples. This is best done using GIS.

Figure 10: 2D orthoimage.

Figure 11: DEM (GSD of 2cm) and 5 cm contour lines.

Figure 12: Georeferenced textured 3D model.

Figure 13: Sections by photogrammetric surveying and open source ParaView.
the site as well as of the surface single archaeological units. Additionally they become invaluable when upstanding features like walls or cross sections make the recording process by total station time consuming and complicated or where, as happens to our case-study, the excavated surface is too vulnerable to be walked on (e.g. waterlogged environment, mosaics, organic material) (Doneus et al., 2005).

In total eight scans are performed by a CAM2 Focus3D laser scanner in two surveys carried out to map different campaign steps (September 27 and October 10). collecting data with a good average sampling distance of 3.1 mm and resulting in a dataset of ca. 45 million points acquired. Acquisition parameters are chosen as an acceptable compromise between level of detail of the final 3D model and computing resources needed for data processing. The number of the range acquisitions and stations for each temple depends on the dimensions and on the complexity of the monument. The positions of the different acquisitions have been organized to cover the entire volume of the monument, taking account of shadows, obstacles and undercut.

The laser scanner data are used as metric reference to scale the image data, for a geometric comparison with the photogrammetric data and for the creation of archaeological sections and plans of the site.

Range data are cleaned and aligned with the specific brand Faro SCENE software, then meshed, georeferenced (Fig.9) and edited using different software tools (Cyclone, Pointools, ParaView) as each of them has limitations in some processing functions.

Other bottlenecks, typical of the laser scanning processing are:
• long editing / working time to generate a suitable polygonal model
• heavy 3D models not suitable to manage by a computer/laptop with medium characteristics (even after a decimation of the triangles)
• good texture normally missing and so requiring texture mapping procedures to map high resolution images onto the range-based 3D geometry

Nevertheless a 3D data from laser scanner data are easy to be acquired, accurate and different analyses and studies can be performed. Figures 10 and 11 show some processing steps and examples of final deliverables: 2D orthoimage, DEM (GSD of 2cm) and 5 cm contour lines.

This documentation helps in analysing the differences in shape and height of the different structures and in creating layout digitisations in Autocad and/or QGis, useful later to identify US and populate the PostgreSQL implemented database.

5.2 Close Range Photogrammetry survey

Over the last years, close-range photogrammetry methodology is showing promising characteristics for 3D spatial-data acquisition. Several photogrammetric approaches have already been used in archaeology and often dedicated to field archaeology, thanks to 3D restitutions of excavation units meeting archaeological accuracy requirements (Daniel et al., 2008).

Approximately 300 images are acquired in three different surveys (September 19 and 27 and October 10) keeping the camera at the minimum focal length while the image resolution is set at the highest level in order to acquire good quality textures. Two different camera and settings are simultaneously used in order to speed up the survey: a Canon PowerShot SX30 IS (12mm, 4320 x 3240 pixels) and a SONY SLT-A65V (18 mm, 6000 x 4000 pixels). The distance to which the images are taken is quite constant due to the limited articulation of the archaeological site.

The images are taken both convergent and nadir with a good overlap.

Terrestrial photogrammetric data are collected for the entire site because ideally-suited for 3D modelling purposes (confined, standing with no presence of grass etc.).

Both image alignment and 3D model reconstruction are fully automated using Agisoft Photoscan and some small user interaction allowed. Total station’s GCPs and laser scanner data are used to drive the orientation and bundle adjustment and control the right scaling of the mesh. The results are quite dense, complete, with high quality texture and georeferenced (figure 12 & 13).

To improve the final result Photoscan is use to wrap the Photogrammetric textures over the TLS mesh and extract orthoimages (Fig.14)

6. Open Source GIS management

The digital recording solution introduced in this last excavation campaign resulted in a data production booming allowing: a systematic collection of excavation unit and artefact documentation, a fast and detailed production of digital excavation plans and sections and an increase in the photographic documentation of the excavation.

It was argued that in order to achieve a true integration of excavation data recording, management and representation, GIS technology had to be in the core of such attempt. Implementing a Geographical Information System was in fact possible to handle alphanumerical table, vector geometries, topographical and multimedia data within a single solution, keep as much as possible the integrity of the raw data and provide a very fast and robust management tool for daily life of archaeological fieldworks and archaeological site comprehension.

With the idea to test a really affordable working pipeline, it was decided to adopt the open source plug-in pyArchInit, well meeting the requirements of a user-friendly
archaeological FOSS (Free and open-source software). PyArchInit is created by Mandolesi in 2009 (Mandolesi, 2009 and Mandolesi and Cocca 2012) and integrates itself inside the QGIS environment but it can stand alone too. It is pre-prepared, already successfully tested in several context (Gugnali et al., 2011) and perfectly in line with the needs which emerged during the work. Being able to manage excavation data (compatible with Italian ICCD standard record sheets), PyArchInit can support the archaeologist for his daily work in rescue excavations.

The first step of the GIS project was to georeference old and new excavation plans in the same reference system tied to the surveyed GCPs and reference excavation grid. Then all the stratigraphic units (pyarchnit_US) were created in order to manage on situ the documentation of on going excavations. After having digitized the stratigraphic units, it was possible to fill US reports and link to GIS features via US_table (Mandolesi, 2009). Fig. 15 and Fig.16 shows some working steps related to Oven number18, from US digitalization to US_table filling-in by US reports and GUI data entry.

Alphanumeric, topographic and multimedia data coming from the above mentioned sources were stored in PostreSQL thanks to the different GUIs supporting the data entry and the database management. The geoDB allows to manage all the topographical objects: sections, sites, projects, stratigraphic units, small finds, etc. In particular seven management GUIs (Stratigraphic units, Site, Chronology, Infrastructures, Taphonomy, Record Archaeological, Multimedia) comes with the plug-in and allowed to handle and display in a single analysis environment different data (georeferenced plans, orthoimages) simultaneously. After data entry it was possible first to query the database and transform these queries into GIS visualization, then look for US and visualize linked US reports (Fig.17), images and excavation plans to work with.

Fig.18 shows how was possible, by means of the Multi Media manager, to tag images and link to US/artifacts (N:N) too.

A particular issue dealt with old excavation data and databases management. PyArchInit lacks of specific tools to import vector data created by other GIS software or stored in other databases. To use all the produced documentation it was necessary to import it in QGIS and then modify the relative attributes in order to match the pyArchInit PostGIS layer, to which all the vector data were further added. A similar matter was the data migration from Filemaker and access databases (used for US and pottery) to pyArchInit.

7. Conclusions

The entire methodology supports a complete digital excavation recording workflow and facilitates interpretation in a data-led synthetic manner. The produced photorealistic 3D models can be used to extract maps, plans, cross-sections, orthoimages for a technical public or for conservation issues and together with all the other digital data can be integrated inside a GIS environment satisfying the need to manage on situ the documentation of on going excavations.

The option of quick, well-tested and often low cost/open source documentation makes the research experience a case-study highlighting new approaches that can be integrated in the general excavation methodology and additional interesting features such as model/data reusability.

Moreover, the photorealistic 3D models can be refined and drive other cultural heritage experiences such as...
multimedia enjoyment and virtual museums, enhancing the knowledge of the site or helping education and promotion. This communication feature becomes especially important when the archaeological site (as happens to our case-study) must be covered/closed in default of other protecting / museum solution.

On-going research focuses in augmented reality to visualize GIS layers and 3D models and allow the exploration of the archaeological area of Portonovo on situ even post-excavation.

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