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FINAL REPORT

POMPEII SUSTAINABLE PRESERVATION PROJECT

Porta Nocera Necropolis Preliminary Campaign
(22 September to 14 November 2014)

IBAM
INSTITUTE FOR ARCHAEOLOGICAL AND MONUMENTAL HERITAGE OF THE NATIONAL RESEARCH COUNCIL
ITALY

Catania, 22 September - 14 November 2014

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RESEARCH TEAM

Daniele Malfitana	Director of IBAM and Head of research
Giovanni Leucci	Geophysicist
Lara De Giorgi	Geophysicist
Giovanni Fragalà	Photographer
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Antonino Mazzaglia	GIS specialist
Alessio Iabichella	Specialist in information technology applied to archaeology
Salvatore Russo	Mapping/survey technician

Contents

Introduction

DANIELE MALFITANA

The Institute for Archaeological and Monumental Heritage of the National Research Council (IBAM-CNR) is a multidisciplinary scientific structure with highly specialised competences regarding the knowledge, documentation, diagnosis, conservation, enhancement, fruition, and divulgation of the archaeological and monumental patrimony.

It was created in 2001 as part of the reform of the CNR that aimed to incorporate within a single institute various existing research bodies situated throughout southern Italy, in Catania, Lecce, and Potenza. In 2008 a research unit was added in Rome.

From 2011, I have been the director of the IBAM-CNR and in 2013 Catania became the Institute's main structure.

Over the years, the IBAM has worked on themes that regard in particular: the development of methodologies for the analysis of settlement, the territory, the transformation of the environment and the landscape in antiquity and the middle ages; various disciplines in the field of archaeology from the Mediterranean perspective, in particular regarding southern Italy and Sicily; the application of methodologies aimed towards knowledge, diagnosis and subsequent interventions for the conservation, restoration and presentation of the Mediterranean's archaeological (sites and monuments) heritage.

Direct involvement on national and regional territory, together with the participation in archaeological missions and research projects abroad, has provided opportunities for methodological and technological experimentation and for the transfer of knowledge, even beyond the national boundaries. The latter objective, a fundamental part of the Institute's mission has also been pursued through the organisation of thematic Summer Schools, master's degrees, conferences and primarily with the direct involvement of young people in concrete study and research projects, often as part of joint projects involving Italian and foreign universities, territorial bodies and businesses.

On the basis of these considerations and of the Institute's specific competences, together with the high level of its infrastructures and laboratory facilities, IBAM has decided to adhere to the PSPP. This is also justified by the fundamental elements on which its statute is based and by its mission that aims towards greater integration and interaction with other Italian and foreign scientific institutions, as well as with the world of the Superintendencies. Conserve and preserve, also through the study and application of avant-garde technologies and methods in the field of restoration, means working not only for present generations, but also, and primarily, for future generations. IBAM's participation in this project springs from the deep conviction that technologies and a multidisciplinary approach constitute a capital in which to invest in order to create a more responsible and aware society, capable of understanding how much of its future comes from growing up with respect for ones historical roots and own distinctive past.

The offering of capabilities, specialist knowledge, methodologies, and technologies for use within joint projects involving different research teams, also means believing in the importance of comparing and exchanging knowledge. The capacity to think and imagine a research project as a stimulating opportunity for the formation of young researchers, means believing in the importance of training and the transmission of knowledge, without which research itself would lose most of its raison d'être.

In brief, these are the reasons behind IBAM-CNR's participation in the *Pompeii Sustainable Preservation Project*.

In this phase, under the direction of the author, IBAM has decided to become involved in the specific field of documentation, that is in the phase of improving knowledge of the archaeological context in the area of the necropolis at Porta Nocera, identifying two specific possible areas of action. The first foresees the involvement of a team of geophysicists from the Laboratory of Geophysics applied to the cultural and monuments heritage; the second foresees the involvement of teams of specialists from the immersive and multimedia archaeology laboratory.

The team of specialists involved in the *Immersive and Multimedia Archaeology Laboratory* will be coordinated by Antonino Mazzaglia.

Figure 1. Pompeii. Porta Nocera Necropolis. Intro to web immersive gallery.

1. Towards new forms of archaeological data management

ANTONINO MAZZAGLIA

Our knowledge cannot do without spatial-temporal coordinates. Although this statement may seem a philosophical truth, there is no doubt about its usefulness for the purposes of setting up a research project. The *Pompeii Sustainable Preservation Project*, which includes the IBAM-CNR contribution, aims to create new restoration and conservation strategies within the sphere of Cultural Heritage, with particular attention to the problems presented by archaeological structures, in terms of the conservation of materials, analysis of the walls and layers of facings. The necropolis at Porta Nocera has been chosen as the study area thus, in view of future action, it was necessary to gain an accurate picture of the state of preservation of the funerary monuments, go back through all the phases of its discovery and the restoration work that led to its present state. It was necessary to actually place the acquired data in its exact spatial-temporal dimension. Managing time is easier than working with space, in that the analysis of the visible monuments, for example the study of an ancient restoration or the mapping of a lesion, imposes the management of the three dimensions. Modern surveying instruments using laser scanning or high-resolution photogrammetry, produce point clouds from which to construct 3D models, the base for the application of increasingly detailed textures. However, the combined management of all the data, within a three-dimensional space, produced by research in the field, whatever the motivation behind it, documentary, archaeological, or conservative, still presents substantial limitations.

Using modern GIS software it is possible to manage and precisely georeference, on a two-dimensional surface, geospatial data that also contains information about the third dimension, for whose representation however, it is always necessary to use specific external visualization environments.

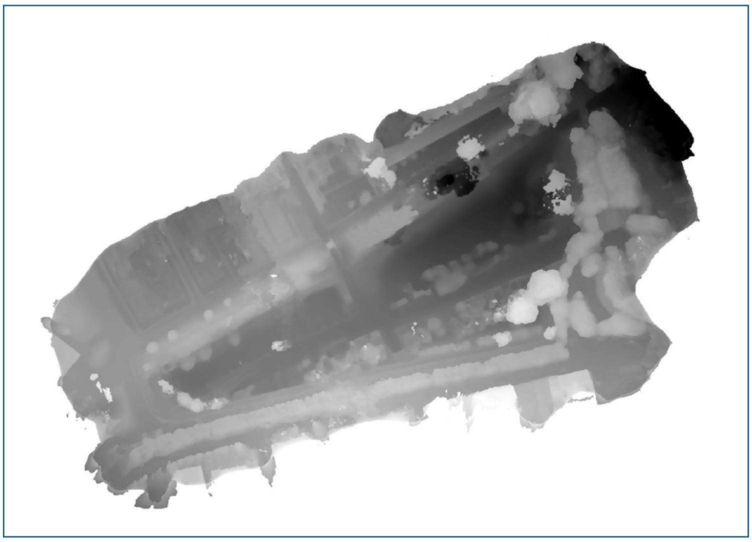

Figure 2. Pompeii. Porta Nocera Necropolis. Grayscale grid of investigated area containing informations about altimetry.

On the contrary, the management of 3D models which, for scientific purposes, requires great precision in the dimensional rendering and high-definition for the graphic textures, at present is possible within specific softwares for three-dimensional processing and visualization, but difficult to combine, with satisfactory results, within a GIS. Various attempts are currently being made, but we are still far from achieving a result that satisfies all.

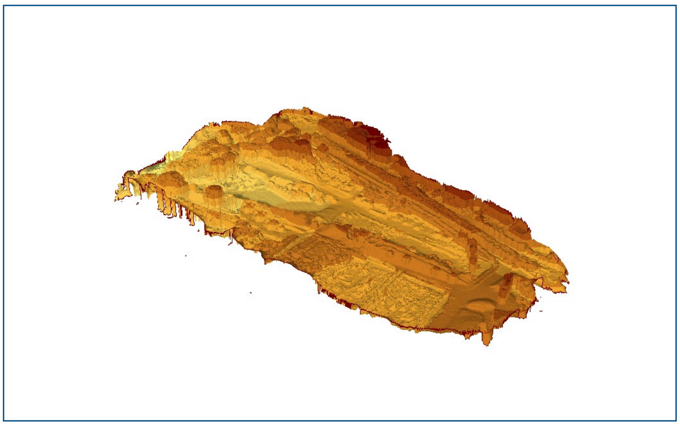

Figure 3. Pompeii. Porta Nocera Necropolis. DEM of the investigated area.

IBAM-CNR's contribution to the *Pompeii Sustainable Preservation Project* falls within this rapidly developing specialist sector. The objective is the creation of a digital model capable of faithfully reproducing in a three-dimensional space, the existing reality that is the subject of the investigation, and rendering the detail to a level that satisfies the requirements of research that needs the utmost precision and realism in the graphics. This is especially true when it is dynamic information that is to be manipulated in relation to the preservation of a monument in its temporal evolution.

The achievement of such an objective required a multidisciplinary approach, involving various disciplines in the field and laboratory: photographers, computer scientists, archaeologists, experts in computer graphics, and geologists, all capable of using the most advance instruments for surveying (laser scanner, high-resolution photographs taken on the ground and from the air using drones, DGPS) and data processing (RDBMS[1], software for graphic and photographic processing, GIS and Web applications). They also had to be capable of developing purposely designed software when none was available that could fulfil specific needs that came to light as the project progressed.

The result is a digital model of the area of the Porta Nocera necropolis, where the space and monumental remains contained within it are reconstructed in their exact physical conformation and volumes, at the same time maintaining the need for maximum detail in the rendering of planes and surfaces. This is a model to be explored and used dynamically for different purposes, which although preserving a high potential in terms of enhancement

1 Relational DataBase Management System.

Figure 4. Pompeii. Porta Nocera Necropolis. Orthophotos of the investigated area placed on the DEM of the previous figure.

and use, is clearly different from "traditional" three-dimensional reconstructions or virtual spaces, whose aim is merely reconstructive.

The digital model created by IBAM-CNR's *Laboratory of Immersive and Multimedia Archaeology* in Catania is a faithful representation of present conditions, which concedes nothing to hypothetical reconstructions. It offers an innovative tool for the storage and manipulation, on a graphic basis, of the data and documents produced as the research proceeds[2]. It has been created to form a starting point from which to undertake, through simulation, possible pathways backwards through time or leaps towards future perspectives, necessary for reconstructing the evolution of the material condition of a monument, from its discovery to the present day, or for testing the effect of future restoration.

We are aware that our digital model presents various difficulties and can certainly be perfected. That is the price to be paid if one wishes to attempt original approaches to present problems, which only progress in the research, with the widening of the documentary base, will resolve. Two problems clearly emerged in the product's development and testing phase. One regards the manipulation, storage, and selection of the textual information produced to annotate the analyses on the state of preservation or restoration undertaken on the monument or parts of it. As it is not structured, it requires the use of strategies purposely put into place prior to operations of information analysis and research[3].

These are problems that will be resolved in the future through consultation between all parties involved in the research project.

The second problem relates to the high degree of precision required, in the graphic rendering, in the spatial positioning and in the measurability of the model, by extremely detailed analyses, such as the need to map the fissures in a wall or structure. The specific solutions created and experimented by our research team will be described in a paragraph within this report.

2 Of course this includes the results from the campaigns of geophysical analysis carried out by Dr. G. Leucci and Dr. L. De Giorgi, in various sectors of the Porta Nocera necropolis. For the results, see infra, pp.

3 A report on the state of preservation or restoration is by its nature a descriptive document, full of tecnical terms, referring to materials and procedures, and above all of a researcher or restorer's personal impressions, difficult to put into the narrow confines of the fields in a database. Thus, it is necessary to create appropriate strategies for storage and management of such a documentary base, which given the specific aims of the *Pompeii Sustainable Preservation Project* is certainly a priority. A solution based on the use of tags and markers typical of XML language and widely used by the textual analysts at the web's most common search engines is proposed in D'ANDREA-NICOLUCCI 2002, pp. 121-132, for similar problems (fresco restoration). Such a solution could be developed and easily integrated into our model, which from the start was designed for web use.

After having illustrated the objectives, this document will look at the results produced by the geophysical investigation carried out by the IBAM-CNR *Laboratory of Geophysics applied to the archaeological and cultural heritage*. This will be followed by an account of the stages that from a campaign of ground based and aerial photogrammetry, and the digital elaboration of the 3D models, led to the creation of the digital model of the necropolis at Porta Nocera. The report will conclude with a few paragraphs about the IBAM-CNR Laboratory of Immersive and Multimedia Archaeology in Catania's ongoing activities, stimulated by the experience gained during the fieldwork undertaken as part of the project in question.

Work continues on the creation of a software application for the management of the metadata in the files produced and of new surveying tools that use a laser scanner, which could be used during future research activities. The report concludes, in the guise of a case study, a gallery of photographs showing a funerary monument at Porta Nocera mapped in its entirety.

2. Objectives

GIOVANNI FRAGALÀ

The main aim of the activities undertaken by the IBAM-CNR *Laboratory of Immersive and Multimedia Archaeology* was the creation of an innovative system for representing reality, combining the scientific rigour and precision of traditional instrumental mapping, with the use of new technologies capable of rendering high-definition photographs able to communicate, used both in ground based[1] and low altitude aerial photogrammetric surveying, and with the computational and processing power of modern 3D graphic software.

The final product takes the form of a digital model of the entire necropolis area, perfectly recreated and explorable in three dimensions, from the macro area of the entire complex, to the details of the single walls inside a funerary structure, all in the highest detail.

Figure 5. Pompeii. Digital model of the Porta Nocera Necropolis. Exterior of the 3 ES tomb.

1 There is a close and in some ways interesting link between photographic documentation and scientific research at Pompeii. In an article written in 1853, published in the *Bullettino Archeologico Napolitano*, entitled *Fotografia in Pompei*, the archaeologist Giulio Minervini wrote that the director of the Reale Museo e Soprintendente degli Scavi di antichità, principe di S. Giorgio, had had "*the happy idea of using photography to reproduce with the utmost speed the antiquities of the buried Pompeii, which show themselves daily in the light of the sun*". Minervini held that "*We are certain that the use of photography will save for study by erudite men some of those particularities, which sometimes disappear a few hours after being uncovered. The use of photography on the excavations at Pompeii ought to be considered an interesting innovation, that should please all lovers of archaeology. When it is used to take a view of a number of buildings, it is of no use to study; but now that the process is used for reproducing all details worthy of being studied in every part of a building, its usefulness cannot be denied*".

The advantages produced by this tool, in terms of the enhancement and divulgation of archaeological and monumental evidence to the wider public, are clear in that they offer the possibility of immerging oneself in a virtual gallery. In this virtual gallery, it is possible to explore the entire necropolis, pausing to take in an overall view or entering into each individual funerary structure to have a close look at the wall decoration.

Despite this, the principal aim of the digital model remains purely scientific and documentary. Obtained by beginning with the faithful recording of the existing reality, the model in fact intends to stand as a container capable of storing all types of information independently of its different multimedia format: photographs, texts, audio-visual resources, surveys, drawings, sketches, can all come together within this digital space and be linked, through following the same topological rules of real space, to its exact context of reference.

In this way the model takes the form of an actual work and research environment with many uses, that expresses all of its potential in the measure in which it allows us to achieve a perfect combination of the various lines of research present within the *Pompeii Sustainable Preservation Project*. The documentary material and photographic archive collected by Pia Kastenmeier[2] can be archived, managed and visualized within a digital space obtaining a tool capable of passing from the present state, to the visualization of a monument's condition at the time of its discovery, to perhaps looking at its appearance after restoration work undertaken in a more or less remote past. In this way it is possible to associate the visualization of the details, for example, of a layer of facing, with the information relating to the materials used in antiquity, to the modern restoration techniques or to problems that now threaten its preservation[3]. If the examples given so far always go from present to past, it is of course possible to look towards the future and use the digital environment as a decisional tool with a view to carrying out restoration work or new musealizations simulating, for example, the impact of different roofing structures to protect the funerary monuments.

2 See *Pompeii Sustainable Preservation Project. Final Report on research history and archive research on earlier restorations.*

3 In this way, all the information collected during the *Conservation survey of the Porta Nocera* carried out by Monica Martelli Castaldi as part of the *Pompeii Sustainable Preservation Project* can be combined within our model.

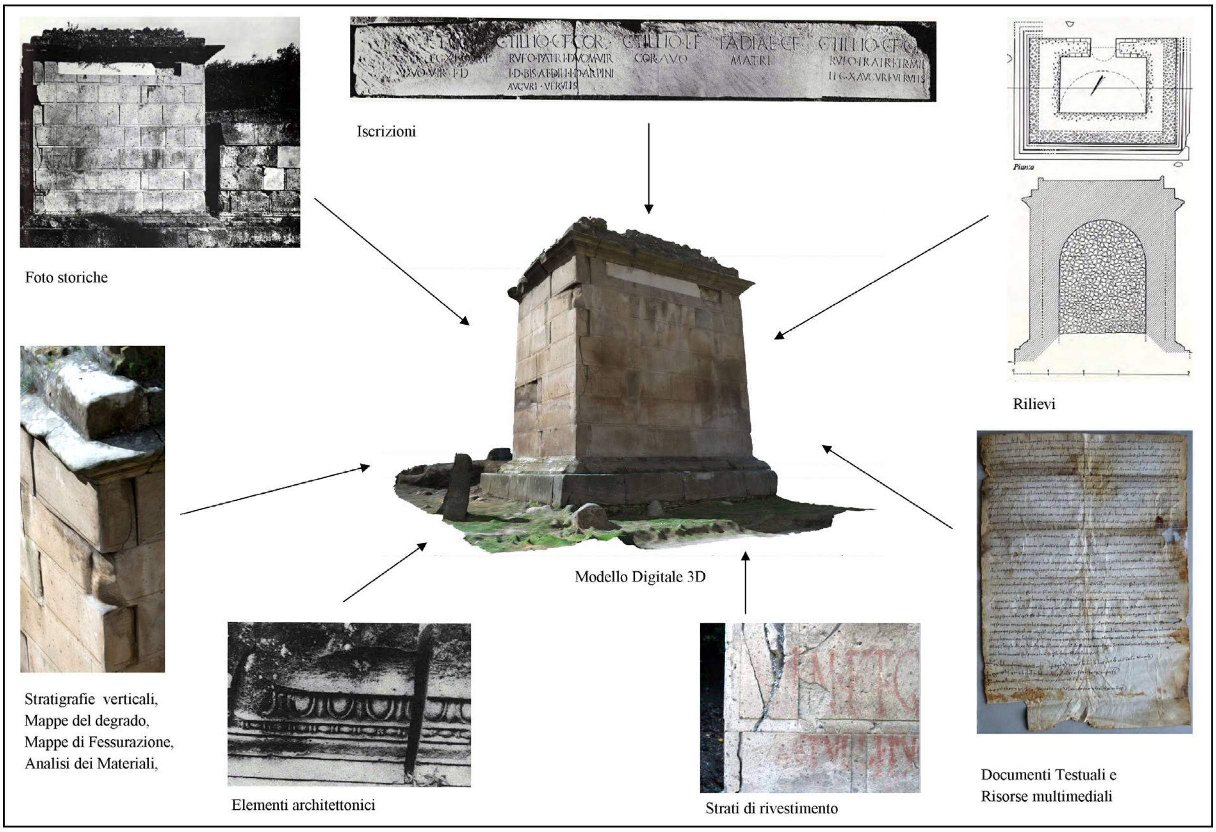

Figure 6. Types of data stored into the digital model of the Porta Nocera Necropolis.

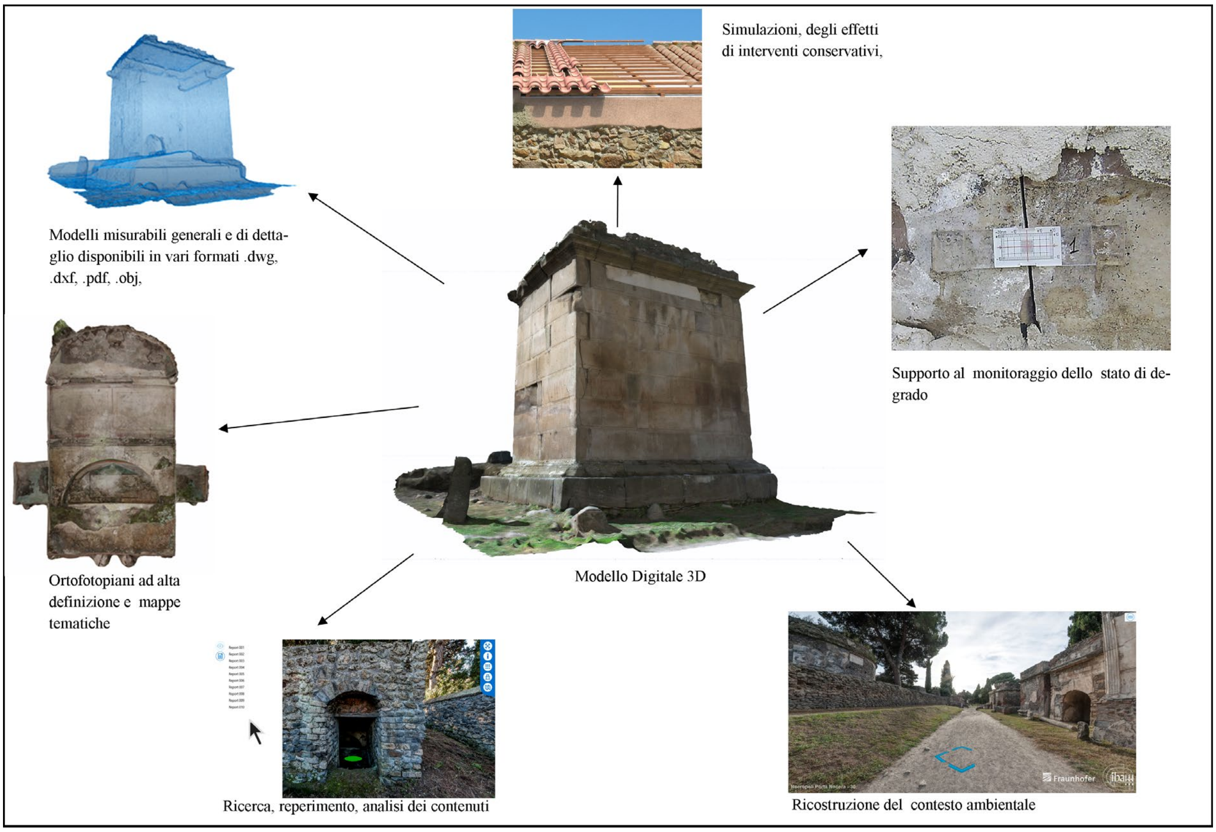

Figure 7. Types of data accessible through the digital model of the Porta Nocera Necropolis.

From what has been discussed so far it appears clear that the model created by the *Laboratory of Immersive and Multimedia Archaeology* for the Porta Nocera necropolis, in making information useful for diagnostics, design, and the checking of preservative and restorative hypotheses available to the user, particularly archaeologists and restorers, can only be defined as "virtual" if this adjective is given a weighty value[4].

4 For an example of this way of seeing virtual reality C.F. GIORDA 2000, p. 25: "*The distinction between material space and virtual space and their representation as reciprocally indispensible to the existence of real space lived by man makes it possible to place the products of new digital technologies among the elements of the real*".

3. Analyzing the invisible: the Necropolis of “Porta Nocera” seen through Geophysical prospection

GIOVANNI LEUCCI, LARA DE GIORGI

Geophysics is the science that deals, in the physical aspect, the Earth and the space that surrounds it. The Applied Geophysics, also called exploration, is aimed only at the most superficial part of the earth’s crust, to search for minerals, geological structures, groundwater, etc.

Geophysical methods are used in the indirect investigation in order to evidence the presence of bodies and/or structures in the subsurface by measuring, in surface, the variations of some physical parameters into the ground. The physical properties of earth materials (bulk density, bulk elasticity, magnetization, dielectric, electrical resistivity, etc.) can be esteemed from measurements of the corresponding physical fields (gravity, seismic waves, magnetic fields, and various kinds of electrical fields).

Each geophysical method has its own characteristics and can help to solve specific problems. The choice of method and the design of the related campaign operations for the execution of a survey are operations that are generally planned in the preliminary stage, sometimes even by the aid of theoretical models. The geophysical, employing methods of nondestructive testing, allow to investigate rapidly vast areas of land without having to intervene, at least in the preliminary stages of research, directly in the ground.

Also the remote sensing are now familiar to many people and it could be related to the concept of the geophysical survey. Remote sensing include the aerial photo and satellite imagery.

The term “Archaeo - Geophysics“ refers to the set of methodologies of Applied Geophysics addressed in the resolution of archaeological al problems.

The contributions of Geophysics for archaeological research are in fact many and range from the management to the protection of the archaeological structures, both in the design and evaluation of archaeological excavation area extension, both in the discovery of important buried archaeological features or high urban archaeological risk.

Consider, for example, studies on the archaeological urban sites, where it is necessary to pay particular attention to the near surface anthropization (cables, water network, etc.). The resolution of cases related to the presence of water as a cause of instability in the ground where important historical monuments and archaeological site are located (it is important to know the main routes of water flow in the subsurface, to assess the volumetric water content of the soil which, together with estimates of other factors, contribute, for example, the construction of flood risk maps and subsidence risk maps) .

Furthermore, the information obtained from geophysical surveys often provide effective tools for the development of intervention strategies both in terms of both the archaeological impact study and the the restoration of degraded archaeological areas and monitoring situations with a high environmental risk (i.e. Pompei, etc.).

In the case of archaeology, the application of geophysical methods provides indirect information on the presence and state of preservation of buried structures and contribute to design the archaeological excavation. In practice we suppose to achieve on the surface of a specific archaeological area or a monument area, some measures of a given physical field, i.e. gravimetric, magnetic or electromagnetic. If the ground is perfectly homogeneous the measurements of physical parameters done the same value without variations. Assuming, however, that in a certain zones of the subsoil is present a body with different physical properties than the surrounding material, when the measuring instrument passes in correspondence of the body, the measured value tends to be different from the unperturbed value and the observed physical field assumes a value defined anomalous, i.e. a variation with respect to the value of reference relative to a homogeneous situation (anomaly).

Applied geophysics define, on the basis of these changes and the observation of the anomaly, the nature and the geometry of the buried bodies. Furthermore it propose as objectives the definition of:

1. methods and tools for the measurement of physical parameters;
2. mathematical procedures to derive the characteristics of the subsurface structures (the so-called model) based on the observations.

One of the fundamental problems is to understand, for a particular studied problem, what parameter to measure and to study in order to optimize the characterization of buried structures. Each physical parameter is linked to a geophysical method and each method has its own characteristics and can help to solve specific problems.

The geophysical methods can then be classified, according to the physical quantities involved in the measurement, and the most used are the gravimetric, magnetometric, electrical, electromagnetic, including the georadar or Ground Penetrating Radar (GPR), seismic (such as refraction, reflection, tomography). Each of them uses measures of particular physical quantities (acceleration of gravity, magnetic field, intensity of current and potential difference, way times and amplitude of the electromagnetic and seismic waves, etc.).

Since each geophysical method is sensitive to the contrast of particular physical parameters (density, magnetic susceptibility, resistivity, dielectric constant, elastic constants, etc.) of the object to be investigated with respect to the surrounding environment, it is guessed that the greater or lesser effectiveness of one method respect to the another method depends on the extent of the contrast of the corresponding physical parameters.

Therefore, the choice of methods and techniques of geophysical prospecting most suitable for a particular problem is highly dependent on the target and it is essentially guided by the identification of the physical parameters of the object to determine which have the greatest contrast to the host environment, and then allow the greater ease of detection, as well as economic and logistics considerations.

The characteristics of some geophysical methods and their main applications in archaeology was provided in Table 1. Classically, the most commonly used geophysical methods in archaeological research are magnetometric and resistivity methods: under favorable conditions (i.e. in the case of strong contrasts of susceptibility and/or resistivity) these methods can generate maps, whose interpretation provides guidance on the planimetric position of possible archaeological structures.

Methods	Measurable physical parameters	Esteemed physical parameters
Gravimetric	Gravity acceleration, g (mGal o μGal)	Bulk Density, δ (g/cm3)
Magnetometric	Magnetic Induction, B (nT)	Magnetic Suscectivity , χ
Geoelettrical	Active Electrical Current, I (mA), Electrical Potential , V (mV) Passive Self Potential , V (mV)	Resistivity, ρ (Ω m), Induced Polarization, IP (mV/V) Self Potential , V (mV)
Ground Penetrating . Radar (GPR)	The electromagnetic (EM) two way time t (ns), Electromagnetic wave attenuation, A (dB), Frequency, f (MHz)	EM wave propagation velocity. v(ε, σ, μ); The attenuation coefficient α(ε, σ, μ, f)
Sismic	The seismic way time t (ms), Seismic wave attenuation, A (dB)	Seismic wave velocity of propagation VP(λ, μ, δ) and VS(μ, δ); The attenuation coefficient, α

Table 1: Main characteristics of geophysical methods most frequently used in archaeology and cultural heritage.

The map representation as well as facilitating the correlation with the results of the excavation also allows the integration and comparison with other types of data such as aerial photographs and satellite images. These methods, however, generally do not allow to obtain direct information on the depth of the structures.

For this reason recently is gaining increasing interest in archaeology the GPR, a method with high resolution that, using appropriate techniques of acquisition, processing and visualization of data, it is able to provide detailed information on both the planimetric and depth position of possible archaeological remains.

Working at different scales, geophysics can be applied to a wide range of investigations.

It ranging from the study of the entire Earth (depth geophysics) to the exploration of localized regions of the crust surface (surface geophysics) to the application to structures such as buildings, monumental heritage (micro-geophysics).

In the exploration geophysics methods, the measures within areas "geographically restricted" are used to determine the distribution of the physical properties at depths that reflect local subsurface geology. An alternative method of investigation of the subsoil is of course the direct exploration through drilling, but these are very expensive and give information regarding only the points investigated (points information).

The geophysical surveys, although sometimes limited by greater ambiguity or uncertainty in the interpretation, offer a relatively rapid means to derive information on a large areas. They offer also an excellent cost-benefit ratio.

In the exploration of underground resources geophysical methods are able to identify features of potential interest that may not be detected by simple coring. The geophysical methods clearly not exempt from the necessity of realization of coring; they can optimize the programs of exploration maximizing the speed of coverage and minimizing the number of coring. The importance of exploration geophysics as a means to get information about the subsoil is so great that the basic principles, the purpose of the methods and their main applications should be appreciated by every scientist practitioner of the earth.

3.1. THE GEOPHYSICAL METHODS USED IN POMPEII

In the archaeological site of Pompeii Integrated active electrical resistivity tomography (ERT), passive (Self Potential- SP) and Ground – Penetrating radar (GPR), geophysical methods were used.

Electrical Resistivity Tomography

The degree to which a material restricts the passage of an electric current is known as electrical resistance. There is only one way to directly esteem electrical resistance: pass a current through the material, measure voltage with a voltmeter and esteem electrical resistance using the Ohm's law. It is measured in Ohms. Electrical resistance is related to the electrical resistivity by a simple relationship that taken into account the geometrical characteristics of the materials.

Variations in electrical resistance and therefore in the electrical resistivity are related to the amount of moisture in the soil. Coarse grained, well-drained soils (gravels, sands) exhibit a relatively high resistance, whereas fine grained soils (clays, silts) that hold more moisture exhibit lower resistance. Compared to soil, rocks and bricks are typically characterized by very high resistance. Electrical resistance is useful on archaeological sites because cultural features represent localized disturbances to natural soil strata, and often include concentrations of organic materials, rocks, and other artifacts. These disruptions to the natural soils are associated with a localized contrast in moisture retention and therefore electrical resistance. A wall made of rock or brick, for example, is typically much more resistive than surrounding soils.

Resistivities vary tremendously from one material to another. For example, the resistivity of a good conductor such as copper is on the order of 10 -8 ohm m, the resistivity of an intermediate conductor such as wet topsoil is ~10 ohm m, and the resistivity of poor conductors such as sandstone is 108 ohm m.

The measured resistivity is a weighted average of the resistivities of the various materials that the current encounters. When the current electrodes are placed very close together some small amount of the current still penetrates to the deep layer. Thus, the measured resistivity will not be exactly that of the upper material. Similarly, when the electrodes are spaced very far apart, some of the current still traverses the upper layer. The overall resistivity measured at the surface will then only asymptotically approach that of the lower material as the electrodes are moved toward infinite separation. True resistivity values and actual depths may be obtained from data acquired at the surface through various ''inversion methods'' in which information obtained at the surface is used to extract information about the subsurface.

Figure 8 shows a general linear electrode configuration for a typical resistivity survey. All four electrodes are chosen to be in a straight line in the present work for simplicity. In general, the electrodes are not restricted to being collinear, although solving the electromagnetic field equations that accompany such arrays becomes more difficult. The current I going into the ground through the electrodes at points A and B: A voltmeter attached to the two electrodes at points M and N measures the potential difference V between these points. The ratio (V/I) obtained is the apparent resistance for the entire subsurface.

There are several ways in which the electrodes in figure 8 may be arranged, with the spacings chosen to match the needs; of a particular survey site. The electrical resistivity has the longest association with archaeological investigation.

Resistivity surveys were carried out in a new way. A constant spacing perpendicular traverse, i.e. electrical profiling, measures lateral variations in subsoil resistivity. These lines can generate a 3D image of the subsurface using a particular inversion algorithm.

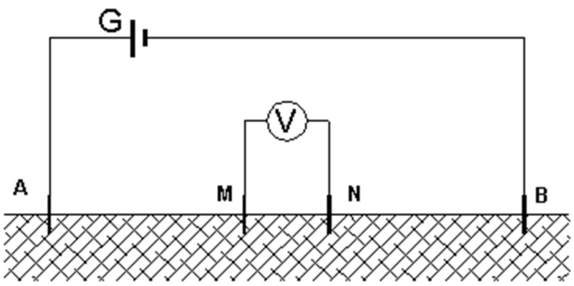

Figure 8. General configuration of the four surface electrodes in linear resistivity surveys.Current is delivered through the electrodes A and B, and voltage readings are made with electrodes M and N.

Self Potential

The Self Potential (SP) survey is one of the oldest methods in geophysical exploration, and it is still used for solving many problems in applied geophysics. It is very rarely used in archaeological prospection because the related phenomena are not very well known. The application of SP to archeology aims to discuss the different SP phenomena responsible for anomalies on archaeological sites, such as electrokinetic, electrochemical and other SP effects. The SP measures the natural or spontaneous potential difference that exists in the subsoil in the absence of any artificially applied current. They map buried structures and altered soil related to physical variations caused by temperature, pressure gradient, porosity, fluid migration, resistivity variation and moisture content of soil. SP measurements are widely used thanks to the relative simplicity and to the low cost of the required equipment. In fact, field measurements are made between two non-polarizing electrodes connected to a suitable high impedance voltmeter. In this research, the SP data were collected in the total field measurement technique. For this acquisition technique, one measurement electrode is fixed at the base station, and the other electrode is moved along the survey line. SP data are also related to the fluid flow in the subsoil and therefore can be used also in subsoil stability stdies.

The Self Potential signals were measured at the ground surface in a set of 864 measured points located along the same lines used for ERT measurements. All the electrodes were scanned during a period of 30 s.

SP data were filtered with a low pass filter in the frequency domain in order to avoid edge effects of space domain filters, so that high frequencies were eliminated and low frequencies were preserved. A least-squares analysis method to estimate not only the depth and shape but also to determine the horizontal position of a buried structure from the SP anomaly profile was used. The method is based on normalizing the residual SP anomaly using three characteristic points and their corresponding distances on the anomaly profile; then the depth for each horizontal position of the buried structure is determined using the least-squares method. The computed depths are plotted against the assumed horizontal positions on a graph. The solution for the depth and the horizontal position of the buried structure is read at the common intersection of the curves. Knowing the depth and the horizontal position and applying the least-squares method, the shape factor is determined using a simple linear equation. Procedures are also formulated to estimate the polarization angle and the electric dipole moment. The method is semi-automatic, and it can be applied to short or long residual SP anomaly profiles. These processed data are used to build the 3D Self Potential maps.

Ground-penetrating radar

Ground-penetrating radar (GPR) has recently gained a wide acceptance in the archaeological community as a method that can quickly and accurately locate buried archaeological features, artifacts, and important cultural strata in the near-surface. The GPR method has been especially effective in certain sediments and soils between about 20 cm and 10 m below the ground surface, where the targets to be imaged are fairly large, hollow, or linear or have significant physical and chemical properties that contrast with the surrounding medium. Ground-penetrating radar has a reputation as one of the more complex of archaeological geophysical methods because it collects large amounts of reflection data from numerous transects within grids, oftentimes producing massive three-dimensional databases. The ability to detect multiple interfaces at different depths below the surface, the interpretation of these numerous reflections, and the difficulty in correlating the abundance of reflections between many profiles within a grid can make GPR data collection and processing a somewhat intimidating venture for the uninitiated. However, with modern data acquisition and processing and a knowledge of how radar energy travels and reflects from interfaces in the ground, GPR mapping in archaeology need not be as daunting as its reputation suggests.

Some of the earliest model GPR systems recorded raw subsurface reflection data on paper printouts that allowed little postacquisition processing. Although these radar systems, a few of which are still in use, can many times yield valuable subsurface information, modern digital systems record reflection data on a computer hard drive for later filtering, processing, and sophisticated data analysis. Most important, when the data are digital, a computer can process, filter, and enhance raw field data almost immediately after they are collected. Computer manipulation of the digital data, which removes unwanted noise and enhances the portions of the signal that are important, allows for rapid data processing and dramatically increases subsurface resolution and interpretation of complex data sets. Accompanied by a trend in equipment miniaturization, computer processing of the acquired GPR data can now occur immediately after they are acquired and interpretation can often begin while the operators are still in the field. The recently acquired speed at which data can be filtered, processed, and interpreted can often allow archaeologists to produce three-dimensional images of buried features just hours after data are acquired. When this is done, further data acquisition or the planning of excavations to confirm features of interest that have been discovered can begin almost immediately, making geophysical data collection, interpretation, and excavation an iterative process.

GPR is a geophysical method that can accurately map the spatial extent of near surface objects and archaeological features or changes in soil media and ultimately produce images of those materials. Radar waves are propagated in distinct pulses from a surface antenna, reflected off buried objects, features, bedding contacts, or soil units, and detected back at the source by a receiving antenna. As radar pulses are transmitted through various materials on their way to the buried targets, their velocity changes depending on the physical and chemical properties of the material through which they travel. The greater the contrast in electrical and to some extent magnetic properties between two materials at a subsurface interface, the greater the strength of the reflected signal and therefore the greater the amplitude of the reflected waves. When the travel times of energy pulses are measured and their velocity through the ground is known, distance (or depth in the ground) can be accurately measured to produce a three-dimensional data set. Each time a radar pulse traverses a material with a different composition or water saturation, the velocity changes and a portion of the radar energy is reflected back to the surface to be recorded at the receiving antenna. The remaining energy continues to pass into the ground to be further reflected, until it finally spreads and dissipates with depth.

The success of GPR surveys is to a great extent dependent on soil and sediment mineralogy, clay content, ground moisture, depth of burial, surface topography, and vegetation. It is not a geophysical method that can be immediately applied to any subsurface problem, although with thoughtful modifications in acquisition and data processing methodology, GPR can be adapted to many differing site conditions. Although radar-wave penetration and the ability to reflect energy back to the surface are enhanced in a dry environment, moist soils can still transmit and reflect radar energy and GPR surveys in these conditions can yield meaningful data.

The depth to which radar energy can penetrate and the amount of definition that can be expected in the subsurface is partially controlled by the frequency of the radar energy transmitted. The frequency controls both the wavelength of the propagating wave and the amount of spreading and attenuation of the energy in the ground. One of the most important variables in GPR surveys is the selection of an antenna with the correct operating frequency for the desired depth and resolution of target features. Commercial GPR antennas range from about 10 to 2000 megahertz (MHz) center frequency.

Proper antenna frequency selection can in most cases make the difference between success and failure in a GPR survey and must be planned for in advance. In general, the greater the necessary depth of investigation, the lower the antenna frequency that should be used. Lower frequency antennas (below 100 MHz) are large, heavy, and difficult to transport to and within the field. They must be either towed behind a vehicle on a trailer or sled or carried manually. In contrast, a 900-MHz antenna or other higher frequency antennas are quite small and can easily fit into a suitcase. Subsurface feature resolution varies with radar energy frequency. Low-frequency antennas (10–120 MHz) generate energy with wavelengths of many meters that can penetrate up to 50 m in certain conditions but are capable of resolving only very large subsurface features. In contrast, the maximum depth of penetration of a 900-MHz antenna is about 1 m or less in typical soils, but its generated reflections can resolve features down to a few centimeters. A tradeoff therefore exists between depth of penetration and subsurface resolution. These factors are highly variable, depending on many site-specific factors such as overburden composition and porosity and the amount of moisture retained in the soil. The standard image for most GPR reflection data is a two-dimensional profile, with depth on the x-axis and distance along the ground on the y-axis. Profiles are constructed by stacking together many reflection traces, obtained as the antennas are moved along a transect. Reflection profiles are most often displayed in gray scale, with variations in the reflection amplitudes measured by the depth of the shade of gray. Color palettes can also be applied to amplitudes in this format, but it is usually easier for the human brain to process gray-scale changes than color differences. Often two-dimensional profiles must be corrected to reflect changes in ground elevation. Only after this is done will images correctly represent the real world when the ground surface is irregular. This process, which is usually only important when topographic changes are great, requires detailed surface mapping of each transect within the data grid and then reprocessing the data from each transect by adjusting all reflection traces for surface elevation changes. Standard two-dimensional images can be used for most basic reflection data interpretation, but analysis of tens or hundreds of images within a grid can be tedious. In addition, the origins of each reflection in each profile must sometimes be determined before accurate and meaningful subsurface maps can be produced. Detailed and accurate profile interpretation comes only with a good deal of experience. A more sophisticated and faster type of GPR data manipulation of large data sets is amplitude slice-mapping, which creates images of the spatial distribution of reflected wave amplitude differences within a grid. The result can be a series of maps that illustrate the three-dimensional location of reflection anomalies derived from a computer analysis of many two-dimensional profiles. This method of data processing can only be accomplished with a computer using GPR data that are stored digitally. Raw reflection data are nothing more than a collection of many individual traces along two-dimensional transects, each of which contains a series of waves that vary in amplitude depending on the amount and intensity of energy reflection that occurred at buried interfaces. An analysis of the spatial distribution of reflected wave amplitudes is important because it is an indicator of potentially meaningful subsurface changes in lithology or other physical properties of materials in the ground. If amplitude changes can be related to the presence of important buried features, the location of those changes can be used to reconstruct the subsurface in three dimensions. Areas of low-amplitude waves usually indicate uniform matrix material or soils while those of high amplitude denote areas of high subsurface contrast such as buried archaeological features, voids, or important stratigraphic changes. In order to be interpreted, amplitude differences must be analyzed in slices that examine only changes within specified depths in the ground. Each amplitude slice consists of the spatial distribution of all reflected wave amplitudes, which are indicative of these changes in sediments, soils, and buried materials. Amplitude slices need not be constructed horizontally or even in equal depth intervals. They can vary in thickness and orientation, depending on the questions being asked. To produce horizontal amplitude slice-maps the computer compares amplitude variations within traces that were recorded within a defined time window. For instance, if data were recorded to a maximum of 30 nanoseconds in the ground, six slices of 5 nanoseconds in thickness would be analyzed and the spatial distribution of amplitudes in each slice would be produced. When this is done both positive and negative amplitudes of reflections are compared to the norm of all amplitudes within that window. No differentiation is usually made between positive or negative amplitudes in these analyses; only the magnitude of amplitude deviation from the norm is expressed. An abrupt change between an area of low and high amplitude can be very significant and may indicate the presence of a major buried interface between two media. Degrees of amplitude variation in each slice can be assigned arbitrary colors or shades of gray along a nominal scale. Usually there are no specific amplitude units assigned to these color or tonal changes. Slices that are produced in thicknesses based on radar travel time can readily be converted to depth slices, if the velocity of energy movement through the material (or its relative dielectric constant) is calculated. This is the preferred format for most archaeological applications. There are a number of computer programs available that can estimate velocity of radar travel times from individual reflection profiles; alternatively, direct measurements can be made in the field if open excavations are present.

3.1. THE RESULTS

Integrated Ground – Penetrating radar (GPR), passive (Self Potential- SP) and active electrical resistivity tomography (ERT) surveys at three different areas of the Necropolis of “Porta Nocera” were performed (Fig. 9). Geophysical survey was conducted by the Geophysical Laboratory for Archaeology and Monumental Heritage (IBAM – CNR) under the scientific supervision of Dr Giovanni Leucci and collaboration of Dr. Lara De Giorgi and Dr Maria Sileo.

Figure 9. Areas of interest.

GPR data were collected along parallel profiles 0,5 m spaced using the Ris Hi Mod georadar system with the 200MHz and 600MHz antennae. GPR data were processed in a 3D mode. SP and ERT data were collected in a 3D mode along non-conventional profiles using Dipole-Dipole array and variable electrode spacing using a modified Syscal Kid with 24 active channels. A two-dimensional least squares algorithm based on the smoothness-constrained technique, implemented in Res2Dinv software, was used in order to inverted the 2D apparent resistivity data; while the ErtLab software add to an algorithm written by Leucci in MATLAB-environment was used for 3D total volume data distribution in the subsurface.In the area 1 the slices ranging from 2.0 to 2.5m depth, relatively high-amplitude alignments (dashed dark line in Fig. 10) is clearly visible. This correspond to prolongation of the orthostate city wall south of the Amphitheatre.

The results of the electrical data set, given as 3D volume (parallel to the surface) through the ground, are shown below (Fig. 11). It is possible to note (Fig. 11a) a relatively high resistivity (700 ohm m) zone at variable depth ranging from 0.5 m (SW side) to 2.5m (NE side). This correspond to prolongation of the orthostate city wall south of the Amphitheatre. The result of self-potential values (Fig. 10b) vary between -100 to 100 mV. This result can be interpreted that there is a movement of ground due to the water flow from the ground surface into the subsoil. This gives rise to an area of instability (see the red arrow).

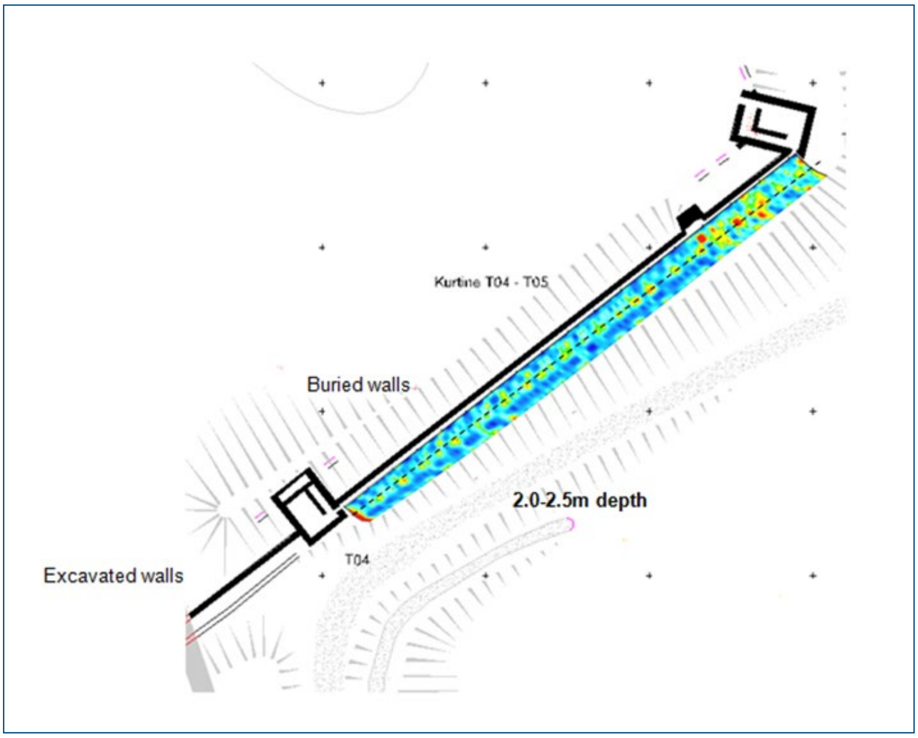

Figure 10. Area 1: the "georadar" depth slices at 2.0-2.5m in depth.

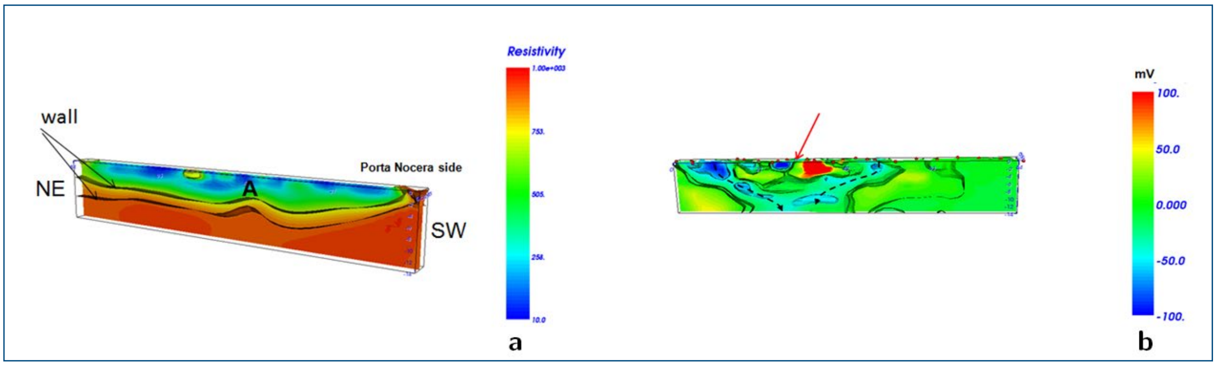

Figure 11. Area 1: the "electrical" 3D visualization: a) resistivity; b) self potential.

In the areas 2 and 3 The results allowed to evidenced different structures of archaeological interest (tombs, road, walls and ducts). In addition to the archaeological structures, the acquisition of more physical parameters and the use of data analysis procedures implemented in IBAM showed:

1. In the necropolis named "small" (area 2 in Fig. 9) the presence of archaeological structures were found and a prolongation of the street (Fig. 12a) in front of Porta Nocera – in that case there would be a fork in the road under the not excavated part between the two sections of the necropolis: one part of the street leading northeast around the city direction porta Sarno, while the other one leads towards Nocera. North and east of the tombs at the eastern section of the Necropolis were found indication for building structures. It is not clear if those are other monuments or the upper parts of the today visible monuments that collapsed in an earthquake. Other archaeological structures are visible at depth slice between 6.5 and 7.0m (Fig. 12b);

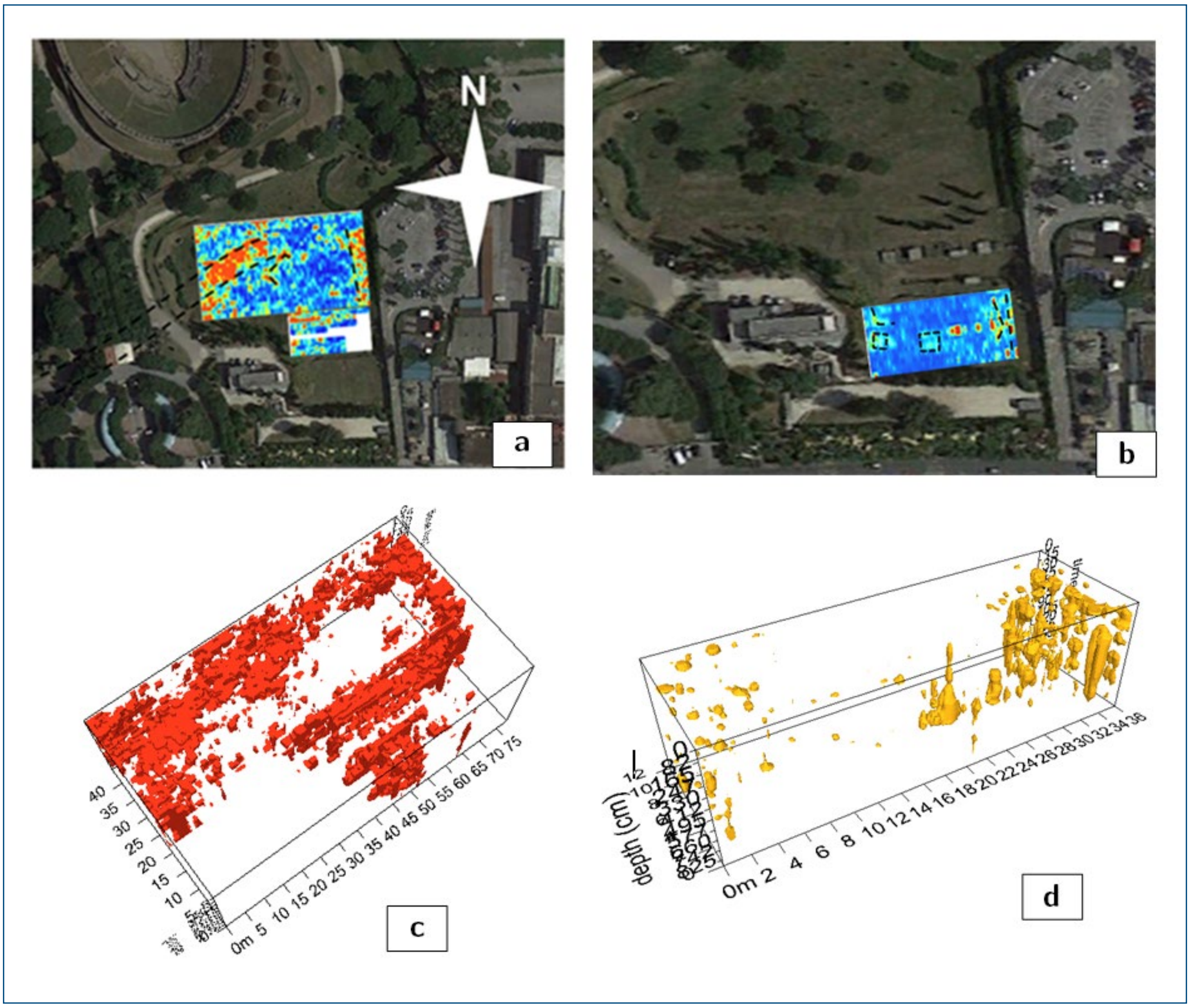

Figure 12. Area 2: The "georadar" depth slices a) 1.0-1.5m in depth; b) 6.5-7.0m in depth; c) and d) 3D iso-surface visualization.

2. in the necropolis named "big" (area 3 in Fig. 9) the causes of the static instability that affected some tombs in the area. These cases are due both to the presence of very degraded foundation materials and to a slow movement of the soil estimated at 0.1 cm/year.

Furthermore, from the geological point of view, the results show a sub-horizontal stratification of the subsoil, with electrical resistivity values that indicate the presence of a number of electrical layers ranging from 8 to 11 and probably related to different periods of volcanic deposit.

The resistivity depth slice (1m depth) showed in the figure 13 evidences high resistivity anomalies (red) related to archaeological structures (tombs).

In the necropolis named "big" GPR results shows (slices ranging from 1.5 to 1.8m depth), relatively high-amplitude alignments (red). These correspond to archaeological structures (roads and walls) (Fig. 14).

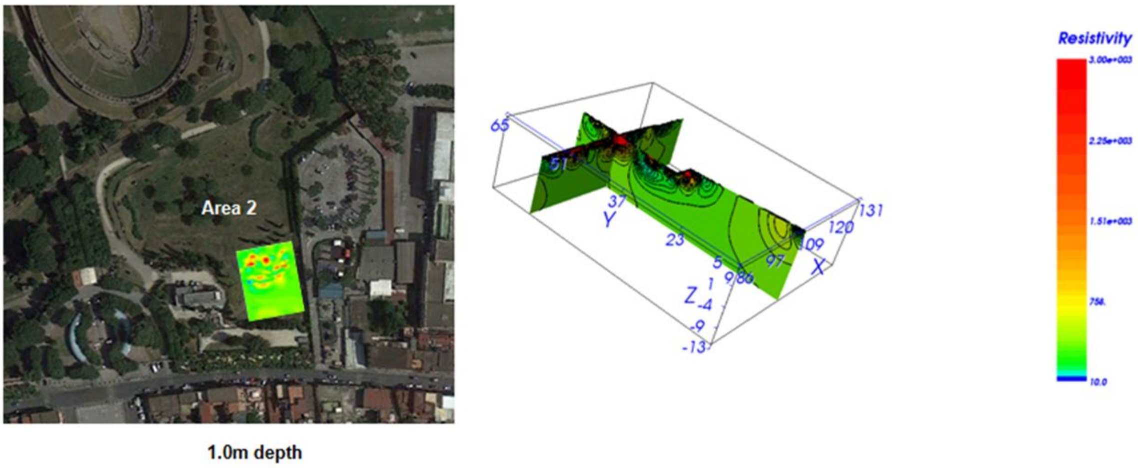

Figure 13. Area 2: The “resistivity depth slices 1.0m in depth.

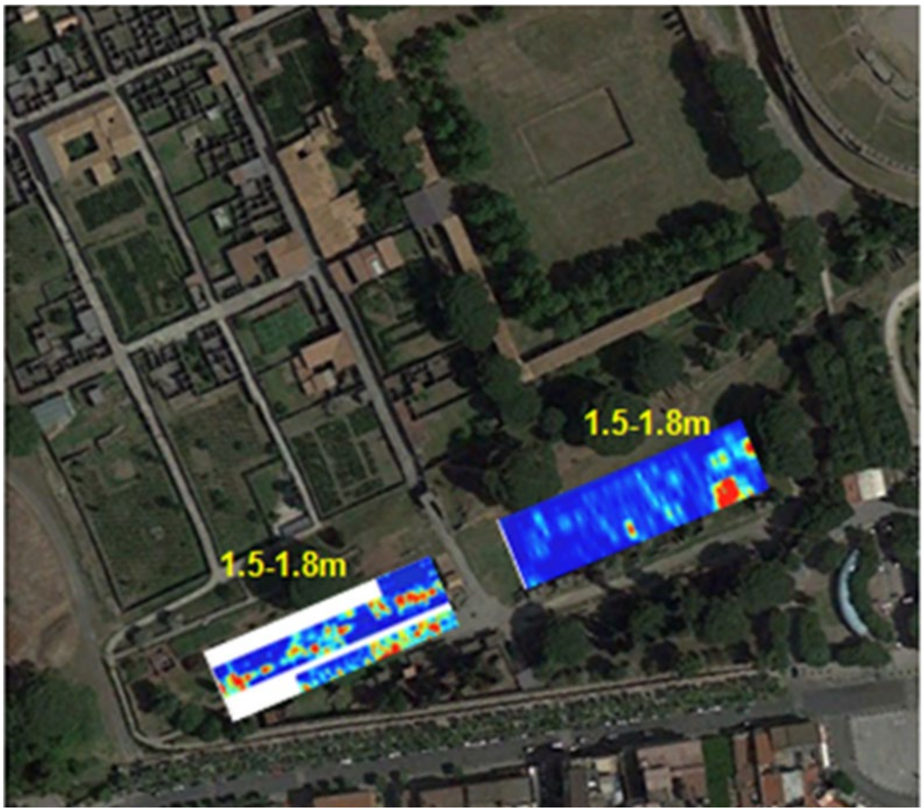

Figure 14. Area 3: The “georadar” depth slices 1.5-1.8m in depth.

In the Porta Nocera east area, relatively high-amplitude alignments (dashed dark line) are clearly visible. These correspond to the bedrock (4m depth). In the 3D representation a channel (about 3m depth) is visible. It diameter was about 1.5m (Fig. 15).

Furthermore in the area 3 is possible to note an intense sub horizontal stratification related to a volcanic deposit. Furthermore the tombs foundations are clearly visibly at 3-4m depth. In the eastern part of the necropolis the foundation laid on degraded materials (circled by the dashed black line) (Fig. 16).

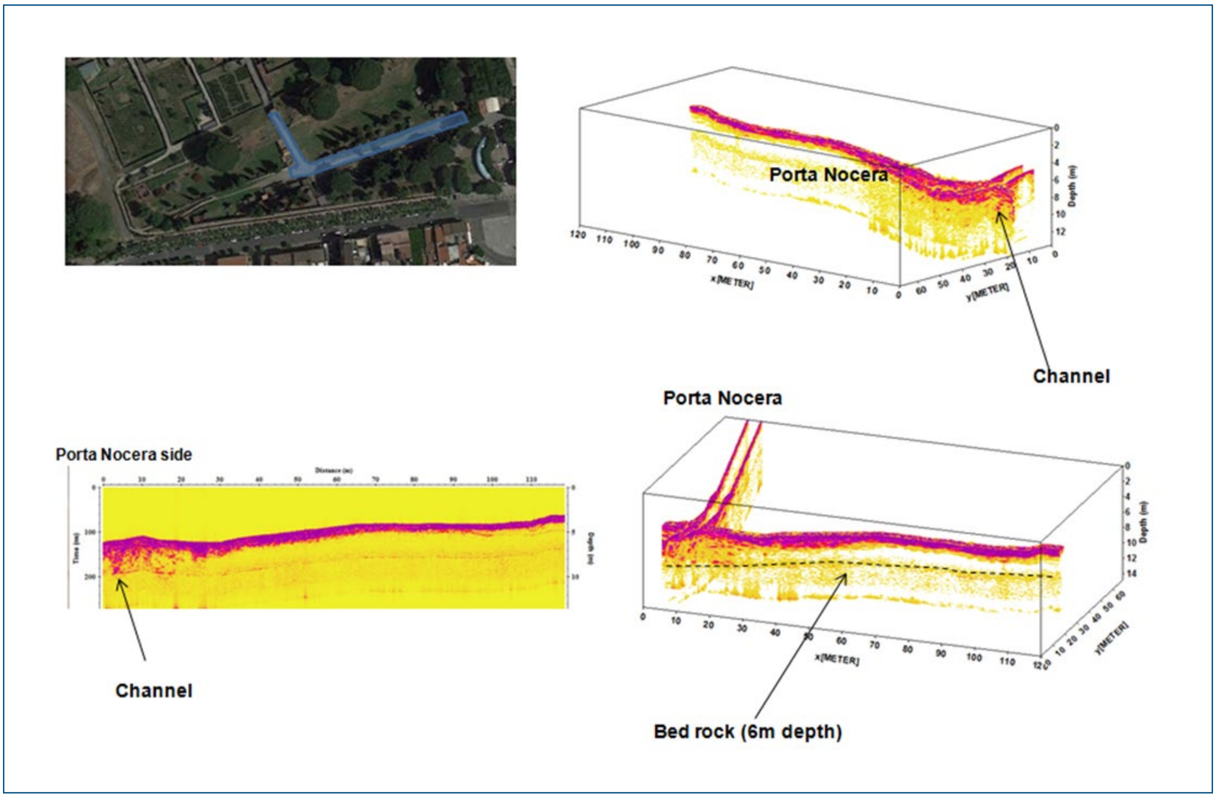

Figure 15: Area 3: The "georadar" results

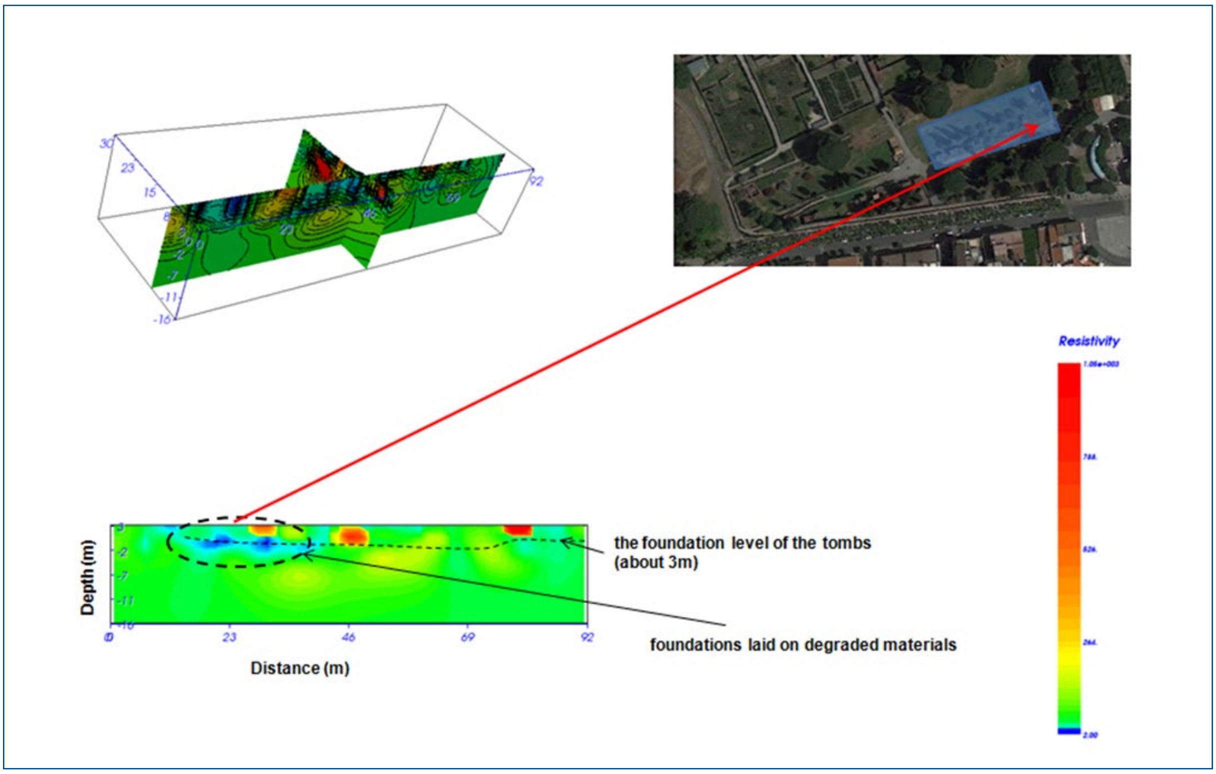

Figure 16: The "electrical" 3D visualization.

4. Ortophoto mapping and DEM of the Porta Nocera

SAMUELE BARONE, GIOVANNI FRAGALÀ

The high level of detail required of the digital model of the entire area of the Porta Nocera necropolis, presupposed the availability of an aerial orthophoto taken at low altitude, which was at the same time able to assume the form of a base linking all the monumental evidence present in the area.

This could not be achieved with high altitude aerial photographs or satellite images. Therefore, a special campaign of aerial photogrammetric mapping was undertaken using an APR (Remote piloted aircraft) or UAV (Unmanned Aerial Vehicle), commonly known as a drone, equipped with a GoPro Hero 3 Black Edition camera. For the APR, a multirotor quadcopter with overlapping counter-rotating propellers was used which, as well as increasing the payload capacity, guaranteed greater stability during flight even in difficult conditions.

Figure 17. Pompeii. Programming steps of drone aerial photography of the Porta Nocera Necropolis.

Figure 18. Pompeii. Porta Nocera Necropolis. A phase of the pre-flight check for the realization of the drone aerial photography.

Figure 19. Pompeii. Porta Nocera Necropolis. Programming phases of the flight plan with waypoints.

Figure 20. Pompeii. Programming steps of the drone aerial photography of Porta Nocera Necropolis.

The flight plan was set using Waypoints fixed at a height of circa 40 metres above ground and foresaw the coverage of the entire area in three main strips, obtained in a single flying session. This was made possible thanks to the choice of the GoPro Hero 3 Black Edition camera, which being extremely light, just 73 gr., saved on the consumption of the drone's battery.

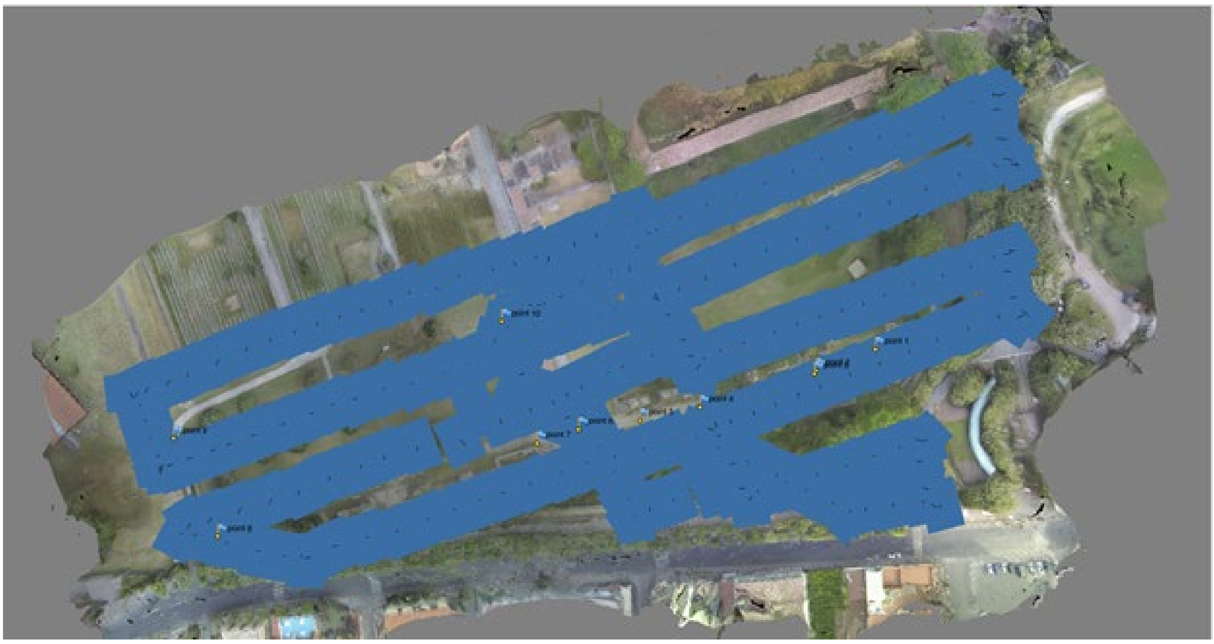

Figure 21. Pompeii. Porta Nocera Necropolis. Graphic rendering of aerial photography plan.

The achievement of the entire aerial coverage in one session ensured uniform light across the area and facilitated the work of photogrammetrical restitution in the post-production phase. The camera has a wide-angle lens capable of reaching a 170 degree field of view, with fixed focus, and able to guarantee, in a reduced number of photographs, the coverage of ample portions of territory. The distortions produced by the sensor's optics were corrected in the post-production phase using tools present within the software applications. The images were acquired in the Continuous Shooting mode, at 3 shots per second. In post-production, this allowed the operators to choose the best shots based on the best overlap between consecutive photographs, which never had less than 60% in common.

The photographs obtained during the flight, the sampling on the ground of various Ground Control Points using GPS coordinates associated with targets clearly visible in the pictures, the creation of a polygon for the georeferencing, made it possible to achieve an orthophoto of the Porta Nocera necropolis, with a resolution on the ground of circa 4 cm per pixel, and as a by-product a DEM (Digital Elevation Model) of the study area.

Figure 22. Pompeii. Porta Nocera Necropolis. Orthophotos of the investigated area.

The orthophoto's extremely high resolution provided a very reliable base for the positioning on the ground of the remains, at the same time providing the possibility of creating a Digital Ground Model in the same detail, which as well as a precise reconstruction of the area's geomorphology, essential for a realistic rendering of the digital model, may reveal itself to be a useful tool for all future operations, in which the exact definition of the ground's slope becomes crucial[1].

1 For example, the enormous importance of a Digital Ground Model within a project to regulate the down flow of rainwater within a particular area.

Figure 23. Pompeii. Porta Nocera Necropolis. Ortophotopiano's detail of the investigated area.

Figure 24. Pompeii. Porta Nocera Necropolis. Ortophotopiano's detail of the investigated area. Visible Ground Control Points for the ground control and georeferencing.

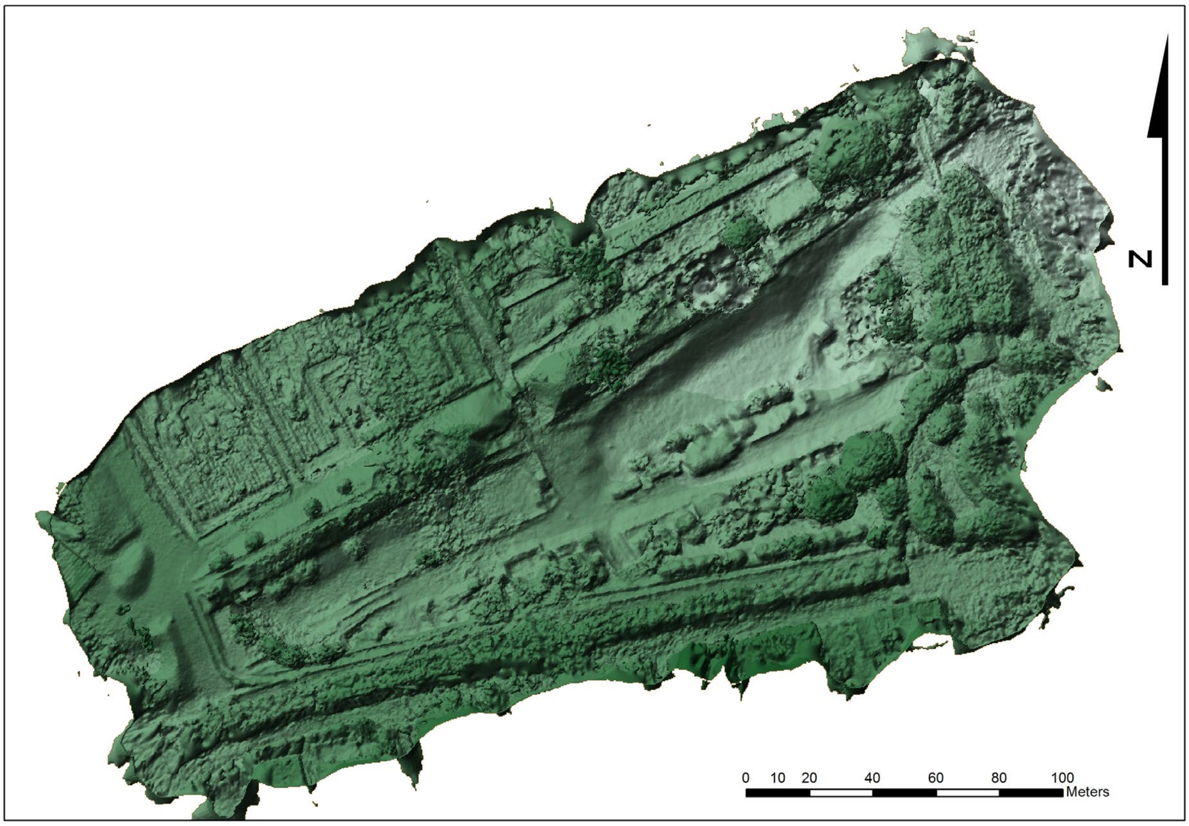

Figure 25. Pompeii. Porta Nocera Necropolis. DEM of the investigated area.

5. Photogrammetric mapping on the ground

SAMUELE BARONE, GIOVANNI FRAGALÀ, DANILO P. PAVONE

The entire area of the Porta Nocera necropolis has been the subject of a campaign of photogrammetric mapping for the creation of a three-dimensional digital model.

This requires not only the precise rendering and positioning of the volumes of each individual monument, but also the exact characterisation of the fabric and decoration of the wall surfaces, from whose exact representation crucial data can be extrapolated. Therefore, alongside traditional perspective photographs taken from points perfectly orthogonal to the plane on which the camera rested, it was necessary to add a complete coverage of the monument taken from all possible angles, including views from above and of the interior.

Particular attention was also focused on the environment in which the evidence is placed, in order to avoid risking the loss of important data, but that is difficult to express in a completed form. This required the creation of an organised plan for the photography, based on an in depth study of the area under investigation and created using a dense network of viewpoints, with reciprocal visibility, covering the entire space in question.

Thus, the photographs can be arranged in different typologies, differentiated on the base of the techniques used and the aims of their use.

5.1. IMMERSIVE PANORAMAS

The campaign of panoramic photography aimed to reproduce all viewpoints, the wide-ranging views, panoramas, which a hypothetical visitor could take during a normal visit to the archaeological area. The pictures were taken using the expedients necessary to obtain equirectangular images, with a resolution of 5000 x 2500 pixels[1]. The entire area of the Porta Nocera Necropolis was divided into various "viewpoints", corresponding with the different and successive photography stations, with a reciprocal distance, between an minimum of 3 to a maximum of 15 metres, based on the amount of detail required by the presence of points of interest (POI) in the immediate vicinity. The network of station points was designed to cover all possible angles and perspectives, always making sure to position the viewpoints for the photographs at a height compatible with that of a hypothetical visitor.

1 An equirectangular photo or better an equirectangular panorama represents a 360° horizontal and 180° vertical view and aims to represent a spherical surface on a flat photograph. As no lenses exist that are able to cover such a wide range, equirectangular photos are obtained through "stitching" and photographic editing.

Figure 26. Pompeii. Porta Nocera Necropolis. Plot points of the photogrammetric station.

The equirectangular images were made for the cubic or spherical rendering of the image.

The shots were taken using the Hing Dynamic Range[2]. This offered the advantage of being able to contain the dynamic gamma of the image within the “visibly appreciable” in order to offer the final user a good quality of detail, both in strong light and in shadow, maintaining the atmosphere of the place, present at the moment the shot was taken, unchanged.

D.P. Pavone

2 HDR is a technique used in computerised graphics and digital photography to obtain an image in which the interval between the light and dark areas is greater than that in usual methods. HDR is based on taking multiple shots of the same subject in order to compensate, with the different exposures in the various images, the loss of detail in the under-exposed and over-exposed zones of each single image. The subsequent processing of the series of images makes it possible to obtain one image with a correct exposure in both the dark and light areas.

Figure 27. Pompeii. Porta Nocera Necropolis. 3 ES tomb. Example of equirectangular photo. Obvious distortions generated by the representation on a flat surface.

5.2. ORTOPHOTOS OF THE ELEVATIONS

Photogrammetric shots were taken of the external and internal elevations for the generation of the 3D models, to be created beginning with photographic datasets. This required the programming of precise shooting schedules, dictated by the need to obtain photographs according to determined models. They were designed to ensure the best possible rendering in the post-production phase, in view of the creation of 3D models of the individual units in the monumental complex, nodal points on which to base the entire digital structure devised by the IBAM-CNR team for the documentation of the Porta Nocera necropolis.

The photographic stations were arranged around each monument in such a way as to guarantee the total coverage of the surfaces, according to the same principle of overlap used in aerial photography, that is with about 60 % in common between one photograph and the next.

The photographs were taken with a 24 megapixel Sony Alpha 6000 digital camera, with a 16 mm lens. A carbon fibre tripod was used in order to guarantee uniformity and stability, avoiding small vibrations that could compromise the results.

The overhead shots, necessary to cover angles and views otherwise unreachable from the ground, nor obtainable with sufficient detail by aerial photographs taken from the APR, were taken using a purposely designed and made telescopic aluminium pole. The roofs of the tombs, for example, were photographed using this technique.

The acquisition of photographs using the telescopic pole was remotely monitored by an application that used the capabilities of the WiFi Direct connection present in the camera and mobile devices with the Android or iOS operative system.

S. Barone, G. Fragalà

Figure 28. Pompeii. Porta Nocera Necropolis.
Positioning of the target for the orthophotographic realization.

Figure 29. Pompeii. Porta Nocera Necropolis.
Positioning of the target for the orthophotographic realization.

Figure 30. Pompeii. Porta Nocera Necropolis. Orthophotogrammetric relief.

Figure 31. Pompeii. Porta Nocera Necropolis. Orthophotogrammetric relief.

5.3 DETAILED PHOTOGRAPHY

The accurate reconstruction of an archaeological monument situated within its specific environment, in this case the funerary buildings at Porta Nocera, through a digital model that aspires to be a tool for scientific knowledge and to incorporate reality. Therefore, it must include all moveable objects, such as furnishings, statues, and herms that if placed or replaced in their context can contribute to the creation of a more complete and accurate picture of the complex together with elements that constitute the reality that is the subject of the representation. The vast informative potential of such a reconstruction is notably increased in all cases where the re-composition "virtually" incorporates moveable elements which, for various reasons, are now de-contextualised[3].

Figure 32. Pompeii. Porta Nocera Necropolis. Detailed Photography.

Such photographs similar, in the techniques used to take them, to those taken for the three-dimensional reconstruction of the funerary buildings, were also taken of some mobile objects, in order to test the time and methods in relation to the results obtained, and possible spin-offs in terms of the documentation and information deducible from them.

Here, we present the results of the photography and subsequent three-dimensional reconstruction of the plaster cast of the body of an individual, who died during the eruption of Vesuvius, found during the excavations in the Porta Nocera area.

D.P. Pavone, S. Barone, G. Fragalà

3 For example, all those finds, such as a sarcophagus, a statue, a particular artefact from among the grave goods, which for motives of conservation are now displayed in museums.

Figure 33. Pompeii. Porta Nocera Necropolis. 3D Reconstruction from photographic survey of a plaster cast of a deceased found during excavations.

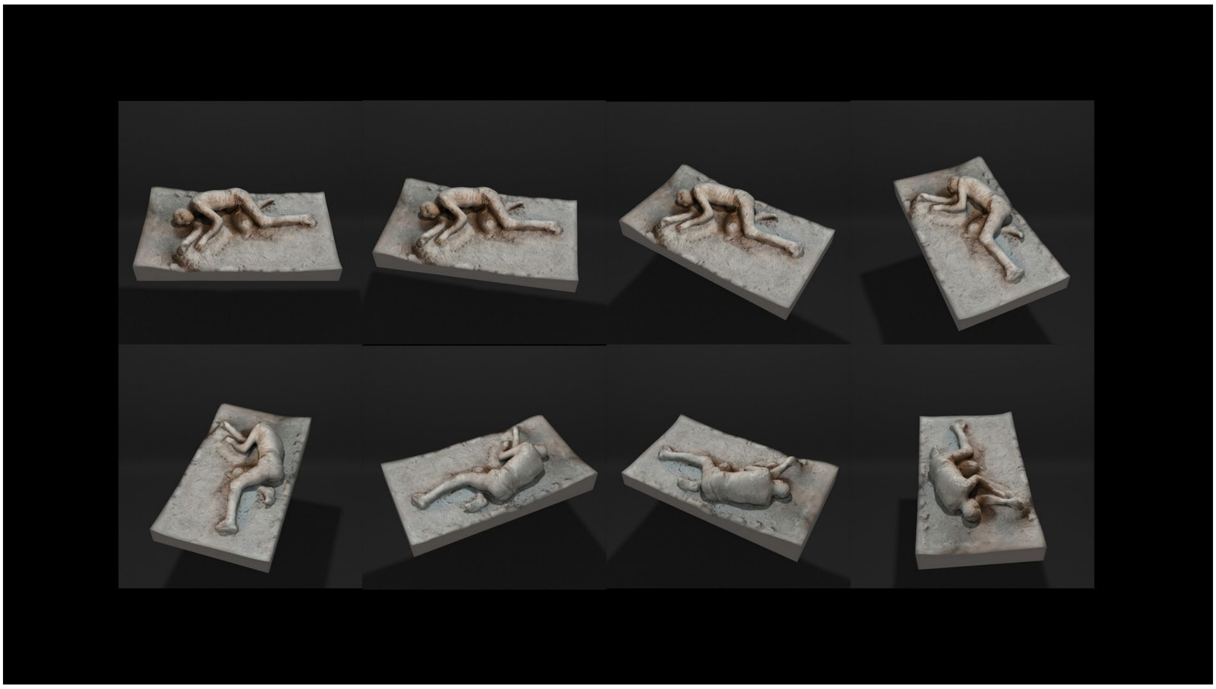

Figure 34. Pompeii. Porta Nocera Necropolis. 3D Reconstruction from photographic survey of a plaster cast of a deceased found during excavations.

6. 3D modelling

SAMUELE BARONE, GIOVANNI FRAGALÀ, DANILO P. PAVONE

6.1 FROM THE PHOTOGRAPHY TO THE DIGITAL MODEL

The photography undertaken during the fieldwork produced an enormous amount of material, which required careful organising in order to ensure efficient management. Therefore, the material was chosen by differentiating the individual photographs on the basis of what they were to be used for, whether the construction of the 3D model, the creation of textures or simply for documentation. However, all the material was archived and given a set of metadata and thus constitutes a documentary base for subsequent research operations[1].

The images used for the 3D model were calibrated starting from the specific characteristics of the camera, which is able to correct the distortion caused by the optic used. This is essential for rendering the photographs uniform, assisting in the alignment and correct putting into scale, facilitating the process of automatic recognition by the software, which recreates the photographic space through the recognition and overlapping of homologous points in different photographs within a determined dataset. The successive application of a specific software algorithm, denominated SFM (Structure From Motion). Through the operator's calibration and manipulation, this permits the reconstruction of the 3D model, from a point cloud generated from the information deducible from the space recreated by the photographic mapping.

The next phase foresees the production of mesh beginning with the point cloud generated by the software and lastly, the application of textures.

The quality and reliability of the final result largely depend on the operator's choices during the various post-production phases briefly described above. The need to guide the software in one of the most critical moments, through the choice of a wide range of options, means the final result, albeit with the use of the same software algorithms, can vary greatly in terms of quality and correctness. Above all, this is due to the heterogeneous, although levelled, photographic material. For example, the different level of illumination of the same object or same surface, which sometimes cannot be eliminated or is impossible to keep within acceptable limits, as in the case of photographs taken outside, where it is impossible to avoid variations in the intensity of sunlight, the angle of the sun's rays, or cloud cover. These changes produce problems, sometimes complex, that can compromise the final result if not identified by careful analysis and manually corrected by the operator.

1 Cf. *infra*. paragraph 9.1

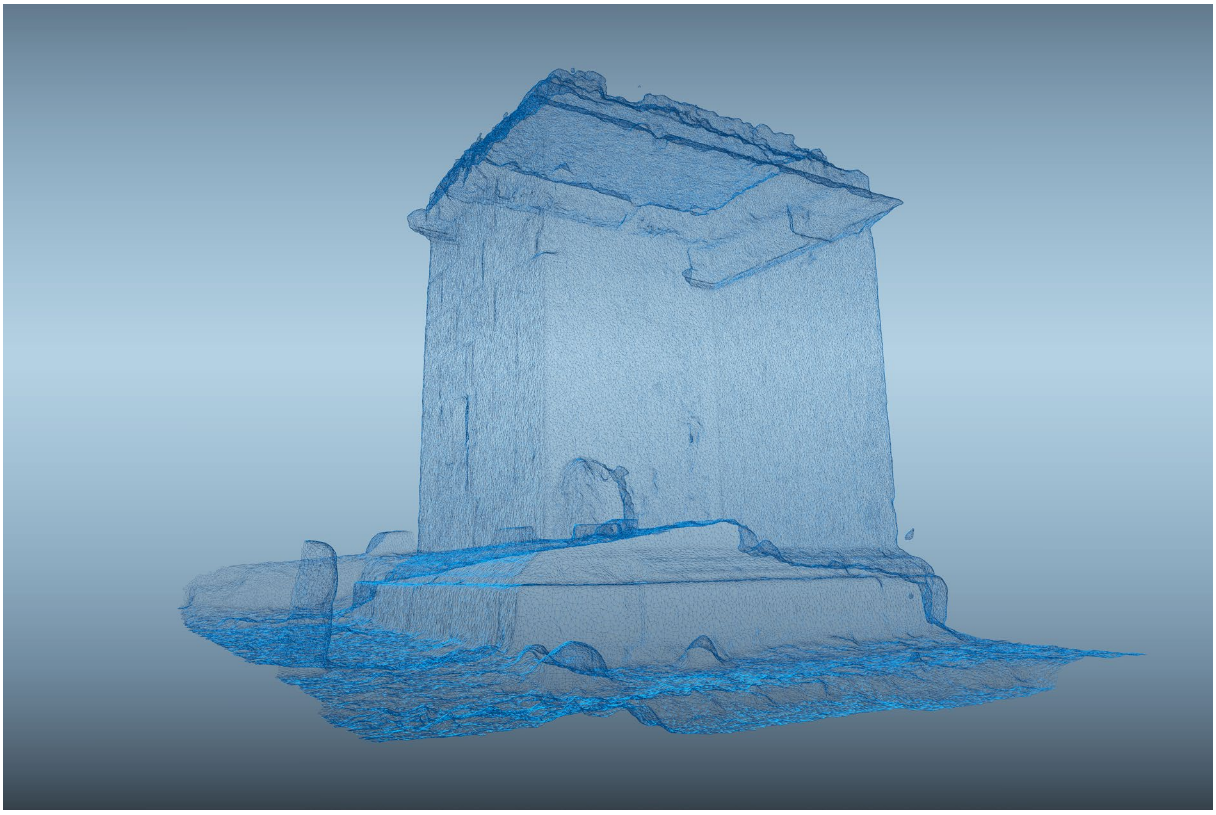

Figure 35. Pompeii. Porta Nocera Necropolis. 17 SO tomb.
Point cloud generated from ortophotogrammetric reliefs.

Figure 36. Pompeii. Porta Nocera Necropolis. 17 SO tomb.
Texturing the 3D model generated from the point cloud.

The entire process, from the recognition of the photographic space to the creation of the model sometimes requires a gradual refining of the digital model, which often involves the repetition of the same phases and the checking of the real data with which the process began.

Thanks to modern software's power to calculate, recognize, and process the images, it is possible to reach a realistic reconstruction of the geometry of the photographed object, with a level of approximation to the real thing that is widely acceptable, also because of the numerous measurements it is possible to make.

The software used for the photographic recognition and creation of the models is Agisoft Photoscan, which at present is the point of reference for this particular sector of applications and permits the exportation of models created in various formats that can be successively processed and manipulated using other applications.

In our case, the final export in .OBJ object file format permits the migration to Blender, an open source software for 3D modelling and rendering.

S. Barone, G. Fragalà

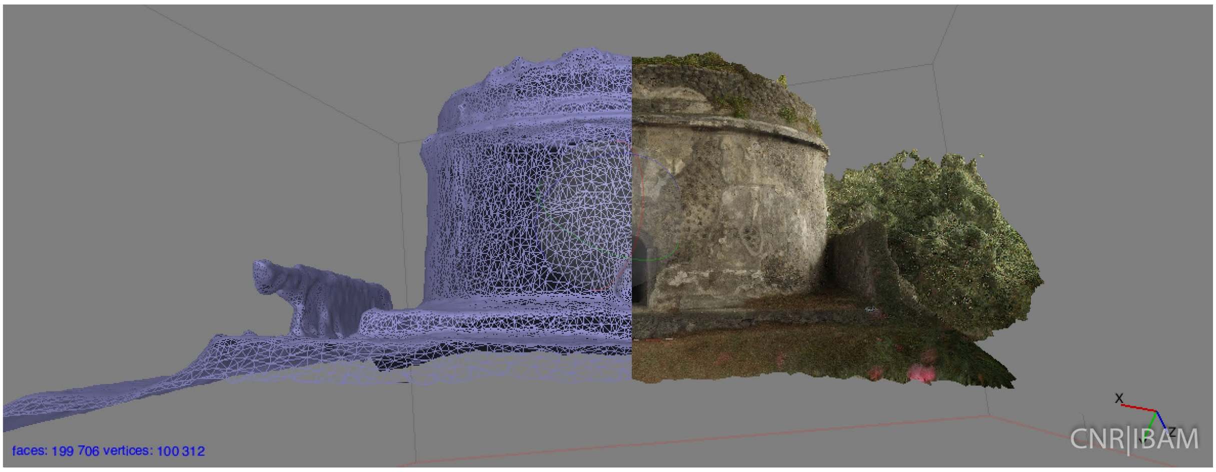

Figure 37. Pompeii. Porta Nocera Necropolis. 3 ES tomb.
Texturing the 3D model generated from the point cloud.

Figure 38. Pompeii. Porta Nocera Necropolis. 3 ES tomb.
3D model of the iscription and architectural relief of the tomb.

6.2. FROM THE MODEL TO THE THREE-DIMENSIONAL SPACE

The single 3D models, which start from the photogrammetric acquisitions, and are characterised by a very high density of points, were simplified using Blender, so as to make them lighter in terms of management resources. This was achieved by first subjecting the .obj models exported from Photoscanner to a topology intervention on the triangular meshes[2] and then by reptologizing[3] the entire object, transferring the texture created during the preceding manipulation of the photographic images onto a new simplified model created on square meshes, via a process known as "baking".

Figure 39. Pompeii. Porta Nocera Necropolis. 17 SO tomb. 3D Model.

The presence of trees close to the funerary monuments and of ample areas of uncultivated vegetation, and also of heaps of detritus, representing elements of interference, badly limited, in a number of points, the ability to create through photogrammetric mapping, accurate 3D models of the structures. In order to avoid this inconvenience it was necessary to intervene manually on the 3D models, redrawing and integrating those parts where the photogrammetric acquisition had not produced an adequate rendering due to the presence of obstacles.

Having obtained simplified models, lighter in terms of management resources, but which succeeded in keeping the very high level of detail in rendering textures and precision in the dimensions and characteristics of the model, the next step was the creation, starting from the panoramic photographs of the entire complex, of a common space delegated to contain them and which would permit at the same time the accurate recreation of the necropolis environment, in which the single monuments stand.

2 The term topology refers to the geometric characteristics of the surface of a 3D object, denominated mesh. An intervention of topology aims to obtain a "clean" surface, which requires an effiecient distribution of polygons, the perfect overlap of contiguous edges and a low number of triangular faces, in favour of square ones.

3 The term retopology indicates the process of simplifying a 3D object's mesh and usually aims to simplify the triangular mesh produced by photographic processing software by making it square. This offers the advantage of a lesser number of edges and easier texture application.

Figure 40. Pompeii. Porta Nocera Necropolis. 17 SO tomb. 3D Model.

Figure 41. Pompeii. Porta Nocera Necropolis. 17 SO tomb. 3D Model.

In view of this, routes divided into successive stages were created that are not bound to each other by a precise order of exploration, so as to recreate various possibilities for a visit. Each stage is associated with a photographic bubble, which constitutes both a dynamic view of the entire surrounding area and at the same time a junction leading to the other available routes.

D.P. Pavone

Figure 42. Pompeii. Porta Nocera Necropolis. 3D recostruction of the investigated area.

Figure 43. Pompeii. Porta Nocera Necropolis. 3D model with the paths structuring for the immersive gallery..

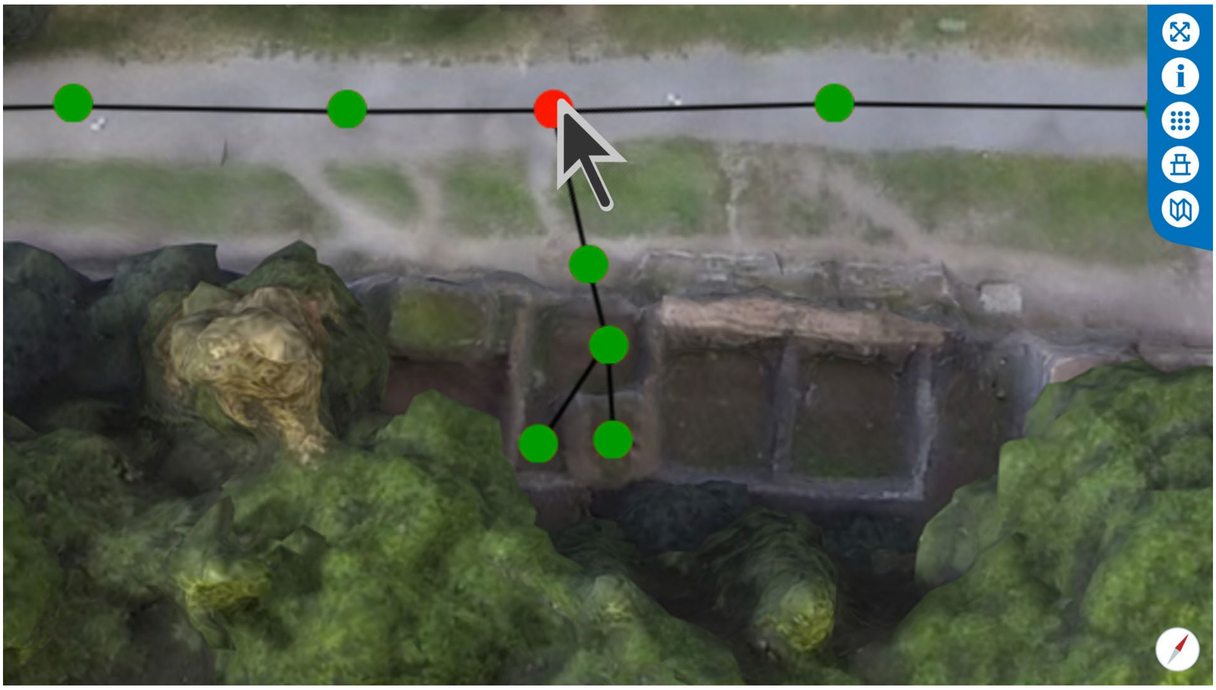

Figure 44. Pompeii. Porta Nocera Necropolis. 3D model's details with the paths structuring for the immersive gallery.

Figure 45. Pompeii. Porta Nocera Necropolis. Panoramic image with overlapping network of paths making possible to navigate within the immersive gallery.

Figure 46. Pompeii. Porta Nocera Necropolis. Panoramic image with overlapping network of paths making possible to navigate within the immersive gallery.

Figure 47. Pompeii. Porta Nocera Necropolis. Web Immersive gallery. Panoramic photo with hotspot for dinamic navigation.

7. Web Immersive gallery

DANILO P. PAVONE

The final product, in which all the processes described above come together, from the orthophotos, to the panoramic photos or the 3D models, is an immersive gallery. A tool capable of standing as a digital copy of the real space freely explorable to 360° by the user and capable of offering a research aid thanks to the possibility of positioning on the topographic base any sort of technological-scientific content.

Only in this perspective is it possible to grasp the project's great novelty, which differs in this way from traditional Virtual Tours that are only capable of offering a visual exploration that is an "end to itself".

The immersive gallery was specifically designed to be used as a web resource via an internet connection. From the start, the various uses the platform lends itself to pushed towards a modular design, which makes it possible to offer different resources based on the various types of use and user.

In this way the gallery can be used as an efficient means of enhancement and communication to the public, perhaps through the creation of specific divulgative contents, while the access and use by research teams remains clearly separated and can, when necessary, be regulated through access requiring a password, allowing the visualization and manipulation of all or part of the content produced.

Figure 48. Pompeii. Porta Nocera Necropolis. Web Immersive gallery.

7.1. GRAPHIC INTERFACE

Particular attention has been dedicated to the creation of a graphic interface that would allow simple and intuitive navigation within the immersive gallery and access to the informative and multimedia contents.

The "real time" navigational mode allows one to move within the model, as if walking through the real physical space, in a series of stages linked by a reciprocal spatial relationship. The direction can be chosen by clicking on special arrows, which lead from the station point towards the four cardinal points.

Figure 49. Pompeii. Porta Nocera Necropolis. Web Immersive gallery. On the foreground directional arrows to navigate in "real time".

Using the mouse it is possible to vary the visual angle and explore the entire space at 360°, both along the azimuthal and zenithal planes, at the same time zooming to explore elements in detail or to get an overall view.

The user can access a side menu at any time, from which it is possible to pass to a full screen visualization, or access different modes of exploring the space. Using a map of the entire necropolis area, one can move from one place to another within the cemetery, using the "POI Monuments" option one can enter the code of any individual funerary structure, with which each burial is indicated in the reference text.

Figure 50. Pompeii. Porta Nocera Necropolis. Web Immersive gallery. Example of mouse navigation.

Figure 51. Pompeii. Porta Nocera Necropolis. Web Immersive gallery.
On the right the menu showing navigation option.

Figure 52. Pompeii. Porta Nocera Necropolis. Web Immersive gallery. On the left the general plan of the Necropolis giving direct access to a monument.

7.2. FROM THE MODEL TO THE CONTENTS

The project's strength and novelty lies in its capacity to associate contents with elements of the digital space.

From the moment that the possibilities of interrelationship between the monumental remains, taken as a whole or individually, and the data correlated with them differ, then the strategies used to represent them within the virtual gallery are also different.

Indeed, there are contents that could be defined as "general level" regarding both an entire sector of the necropolis or a single monument. This type of information can be accessed via the icon "Info Scene", present in the side menu. The content, also in the form of a list divided into various dossiers, varies on the basis of the user's position. In this way, the necropolis can be explored by having direct access to a document, which differs according to the precise context in which the user is positioned. Each one provides general information regarding, for example, the history of the excavations or the discovery of a particular funerary monument, the finds from inside it or the restoration work carried out on it.

There is also information that is directly linked to each individual architectural element. This category of data includes, for example, the information that can be deduced from a layer of painted plaster, from a graffito, or from a particular building technique used in the construction of a wall. This type of information has a direct relationship with a specific

Figure 53. Pompeii. Porta Nocera Necropolis. Web Immersive gallery. On the top left corner, the context menu and access key to display and download textual and multimedia documentation.

Figure 54. Pompeii. Porta Nocera Necropolis. Web Immersive gallery. On the top left corner, the context menu and access key to display and download textual and multimedia documentation.

element of the visualized scene. However, it is possible to further distinguish between data that can be precisely referred to a determinate element in the surrounding space and data that has a more direct link with the spatial element that represents it. A document that offers an aid to the correct interpretation of a message present in a decorative element or the transcription and translation of a graffito can be satisfactorily linked to the graphic element, via a punctual element or any sort of graphic symbol. A piece of restoration work that fills a gap on the crest of a wall or the use a particular type of material, find in the exact delimitation of the area, the best channel of expression. To have neglected this different and particular method of dialogue between data and elements in the context of reference would certainly have had negative effects in terms of the information's comprehensiblity, immediacy, and completeness. Therefore, this second category of information was given a different treatment, through the use of graphic symbols or through the exact delimitation of the occupied spaces, elements which it is possible to directly interact with by using the mouse.

Figure 55. Pompeii. Porta Nocera Necropolis. Web Immersive gallery. Example of access to the available documentation by selection of a symbol into area of interest.

Figure 56. Pompeii. Porta Nocera Necropolis. Web Immersive gallery.
Example of access to the available documentation by selection of an area of interest.

A last type of content relates to all the technical documentation that was produced during the creation of the immersive gallery and forms a valid documentary base for other research activity. It is constituted by the 3D model of each funerary structure and relative plans and elevations. This material can be accessed and downloaded via a specific button in the side menu and can be activated each time such documentary content becomes available in the particular context of reference.

Figure 57. Pompeii. Porta Nocera Necropolis. Web Immersive gallery. On the top left corner, the context menu and access key to the general documentation (Reliefs and 3D models).

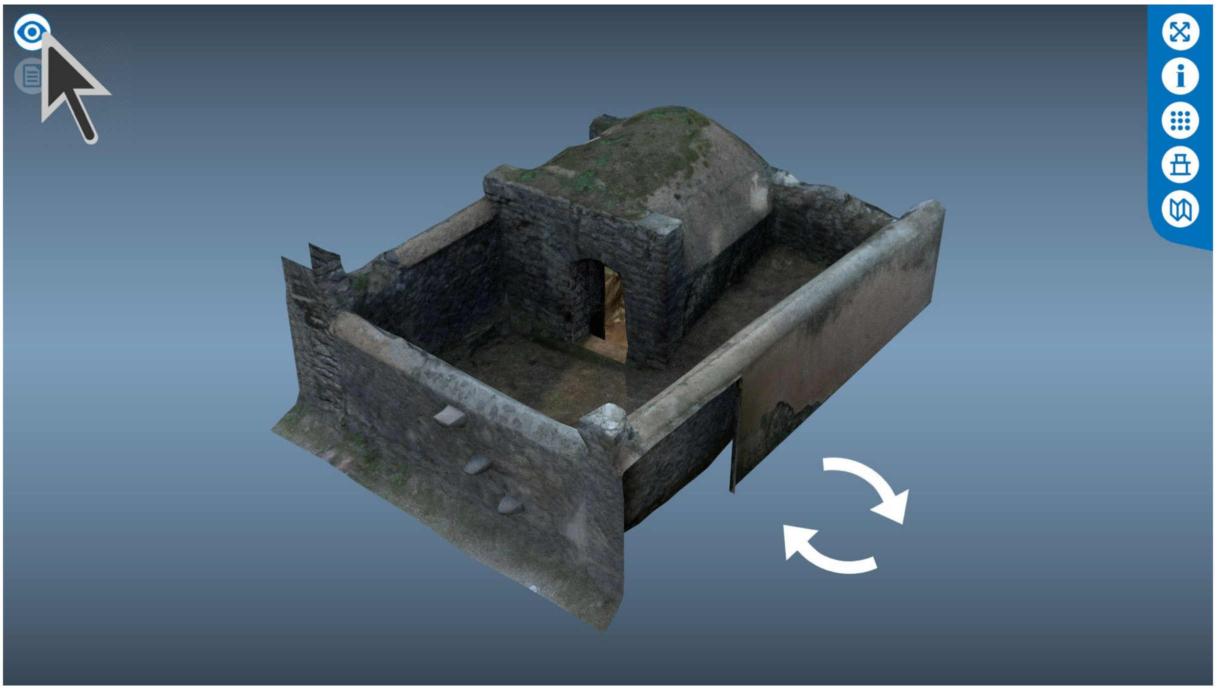

Figure 58. Pompeii. Porta Nocera Necropolis. Web Immersive gallery.
Visualization and download of 3D Models.

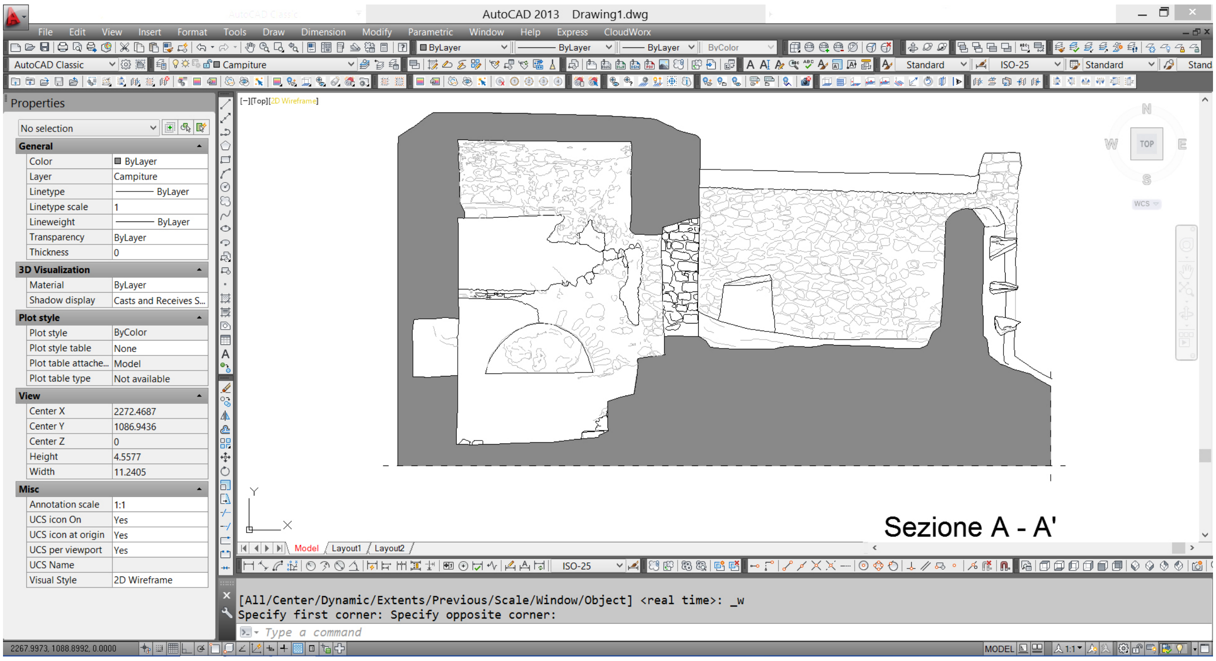

Figure 59. Pompeii. Porta Nocera Necropolis. Web Immersive gallery.
Example of 3D models in .dwg format accessible from the context menu.

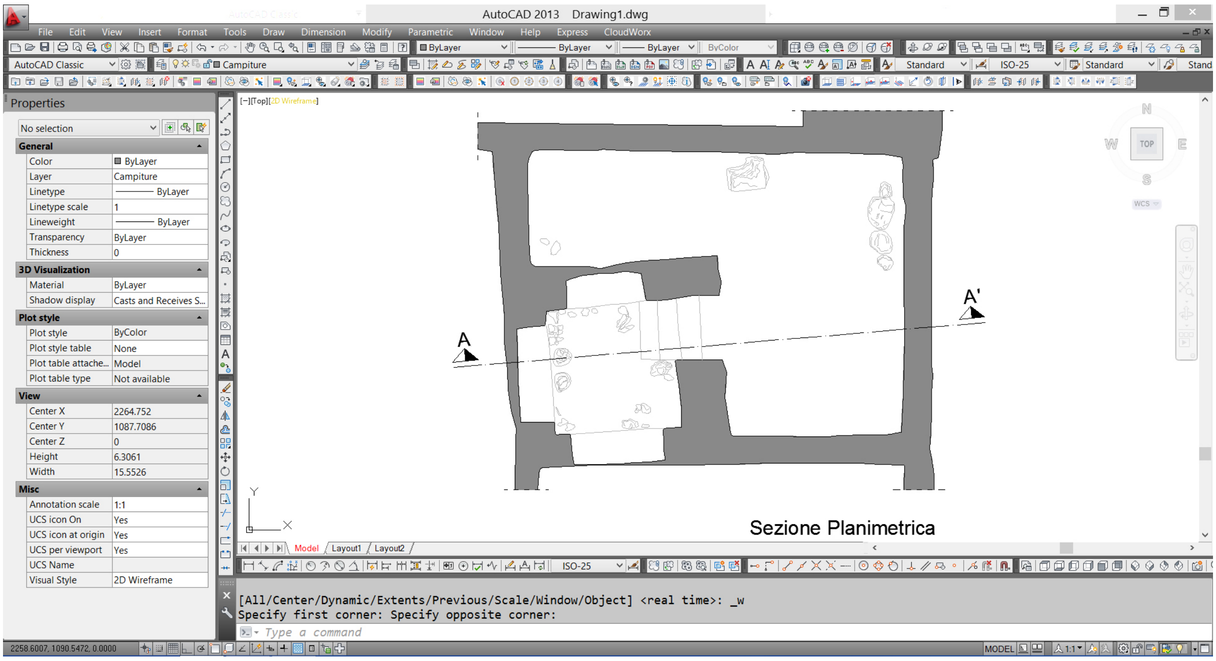

Figure 60. Pompeii. Porta Nocera Necropolis. Web Immersive gallery.
Example of 3D models in .dwg format accessible from the context menu.

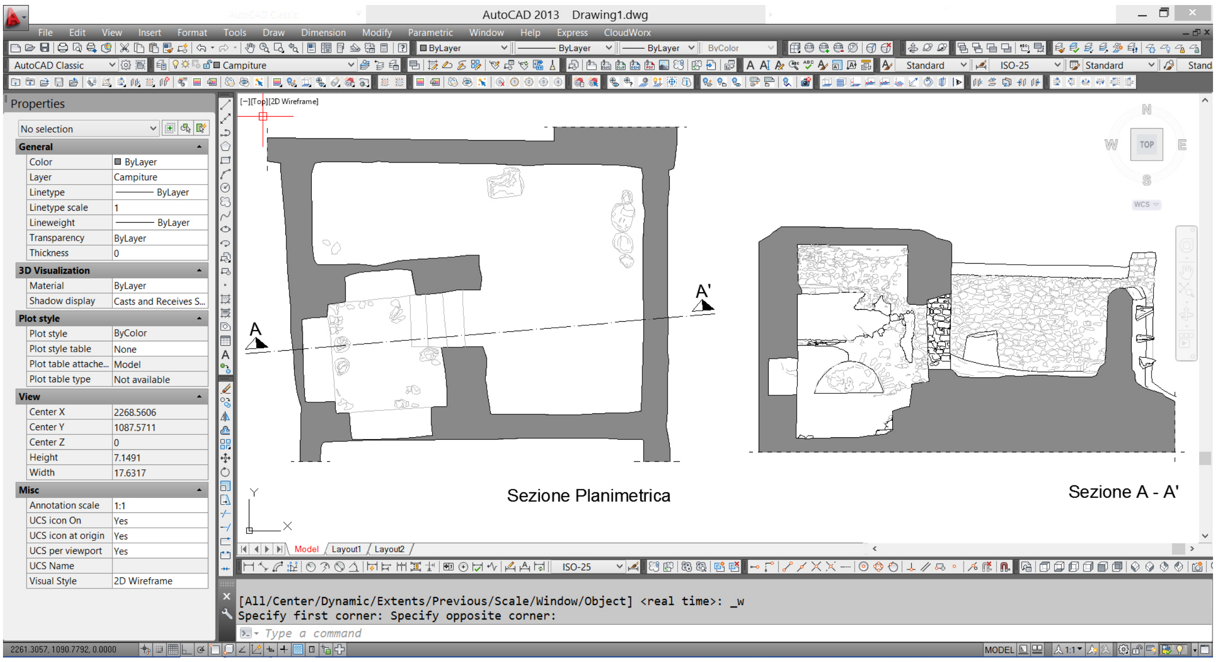

Figure 61. Pompeii. Porta Nocera Necropolis. Web Immersive gallery.
Example of 3D models in .dwg format accessible from the context menu.

At the same time all the documentary material produced by the various research teams involved in the Pompeii Sustainable Preservation Project can be archived and made available using the same strategies analysed above.

Content that can be manipulated within the immersive gallery includes the historical photographs showing the monuments at the time of their discovery or after one of the restoration phases. These are of great documentary value and an evocative resource, especially if placed in relation to the present state of the structures. Of course this is only one example of the immersive gallery's possible applications and of the advantages of its use as a tool that can aid in all phases of this research.

Figure 62. Pompeii. Porta Nocera Necropolis. Web Immersive gallery.
Example of overlapping of the historical photographs on a digital model of the current state.

8. Storage and sharing. The management of the Metadata

ALESSIO IABICHELLA, DANILO P. PAVONE

Most of the material produced by the IBAM-CNR team within the Pompeii Sustainable Preservation Project is constituted by images and to a lesser degree other types of multimedia files. Although created with the principal aim of making 3D models and an immersive gallery, it has substantial documentary value, which goes beyond the project's specific aims and whose informative potential means it must be conserved for future use. The same considerations stand for the results produced by others working on the project. The production of multimedia files, independently of the specific storage format and aims behind their collection, imposes the need for specific strategies to guarantee their future conservation and the possibility of future use.

It is of fundamental importance not only to adopt all the necessary measures for correct conservation, which safeguards against accidental loss of the archives, but it is also vital to preserve a minimal store of information, necessary for a correct process of research and reuse. The totality of the information is commonly known as metadata, "data about data", that is data that serves to give a value to other data.

The importance of metadata is such that in some cases its loss can compromise the correct use of a file, whether an image or any other multimedia resource, even as far as making it useless.

D.P. Pavone, A. Iabichella

8.1. THE IMPORTANCE OF METADATA

The majority of files produced by the research teams involved in the Pompeii Sustainable Preservation Project, are image files mainly containing technical data, already memorised by the camera at the time the photograph was taken, either by the camera's own factory setting or by the setting put in by the user.

Other information can be added to this through key words (tags). When these contain information that is fundamental to the correct storage, cataloguing, and recovery, they can be known as "meta-tags". For example, the date and time of the shot, the type of camera used, and the photographer's name are possible meta-tags.

The creation and conservation of metadata can be achieved in two different ways: the information can be structured within the files themselves or in external files correlated to them. Both solutions have advantages and disadvantages. The archiving in a single file safeguards against the accidental loss of one of the two parts, but presents limitations in terms of compatibility between formats and access to information. Vice versa, the archiving in separate files guarantees better accessibility to the information and compatibility, but the separation increases the risk of the accidental loss of one of the parts.

It is clear that the management of metadata is a question of fundamental importance that involves the work and actions of all the teams involved in the research project. It is a question that touches on the way the research is intended, as a common effort and inter-generational contribution, in that it prepares the correct conservation of both the archives and related metadata. It means not only putting ourselves in the condition to be able to use the data produced, but also whoever may take up our research after us. Thus, it is essential to set up shared norms, which regulate the format and minimum data to store for each different type of multimedia file produced.

The most important question relates to the name assigned to each single file. This is an apparently banal question but one that can have concrete repercussions in the phases of storage and retrieval. To what degree this is a slippery question and not without danger is attested by various opinions on the subject that were recorded among the various individuals involved in the project.

The commonest habit during the designing of one's own archive, particularly photographic, is based on the re-naming of files via "brief" descriptive texts; names which, although simplified, are often too long, thus entering into conflict with the HD, DVD etc. archiving systems. For this reason, we have tried to make the contributors aware of the use of an easy and performant coding system, as shown by its widespread use in professional photography. This method involves the use of an author's identification code, the abbreviation of the year, a project code, and progressive file number.

Nomefile	
Codice identificativo dell'autore	DAN
Abbreviazione dell'anno	15
Codice del progetto	001
Numero progressivo	0001
Es. DAN-15-001-0001.jpg	

The use of an identification code avoids the danger of possible coincidence of names which, in the rare case of two files with corresponding numeration, could lead to the generation of two identical user names with the possible risk of accidental overwriting.

Subsequently, we created a list of common key words (tags) for the drafting of the metadata with the aim of obtaining a list of words subjected to an internal check on their coherence, which avoids ambiguity and semantic overlapping, and is therefore able to ensure a simple and shared use of the adopted lexicon.

In the light of these considerations, we carried out experiments to define the most efficient mode for the input, storage, and manipulation of metadata.

Firstly, the collective use of the Adobe LightRoom[1] platform was proposed, later substituted, in agreement with the other contributors, by XnView, an open source software.

However, the use of this software presented various limitations especially in the input phases, forcing the use of processes that were at times not very intuitive or performant, particularly in cases in which batch processes with multiple images needed to be created. For this reason the IBAM-CNR team is designing and developing a cross-platform desktop application (a software application usable on today's common operative systems) capable of ensuring more efficient input and metadata management processes.

D.P. Pavone

8.2. METADATAMANAGE: TOOLS FOR SHARED STORAGE

The stand-alone tool MetaDataManage, was purposely designed by the research team at IBAM-CNR Catania to offer a concrete answer to the problems of storing and managing the metadata that emerged during the field work and from the comparison of the results of all those involved in the project.

MetaDataManage makes it possible to visualize a preview of the selected image, to extract, via an automatic function, the list of related metadata, edit the tags present, add new ones and rewrite information contained in the same file or in correlated XML files. In this way, any input, manipulation and updating of the metadata can be carried out in a single solution, and it also becomes possible to choose between various strategies for archiving the information, on a single file or separate files.

The tool also aims to manage and process any type of digital file, beyond the specific archiving format, through a simple access to the local folder or network folder in which it is stored[2].

The user will be offered a semantic research function based on meta-tag within the same environment and through a graphic interface[3].

1 This software, unfortunately branded, was developed to manage large quantities of data, tags and automatic imput procedures and permits the creation of filters and personalized visualizations.

2 The latter case is a characteristic rarely present in the software on the market, which only in rare cases allows the management of metadata in different file formats.

3 Semantic research simplifies the management of unstructured information, that is information not immediately accessible or manageable by the user and contained in books, documents, and various types of

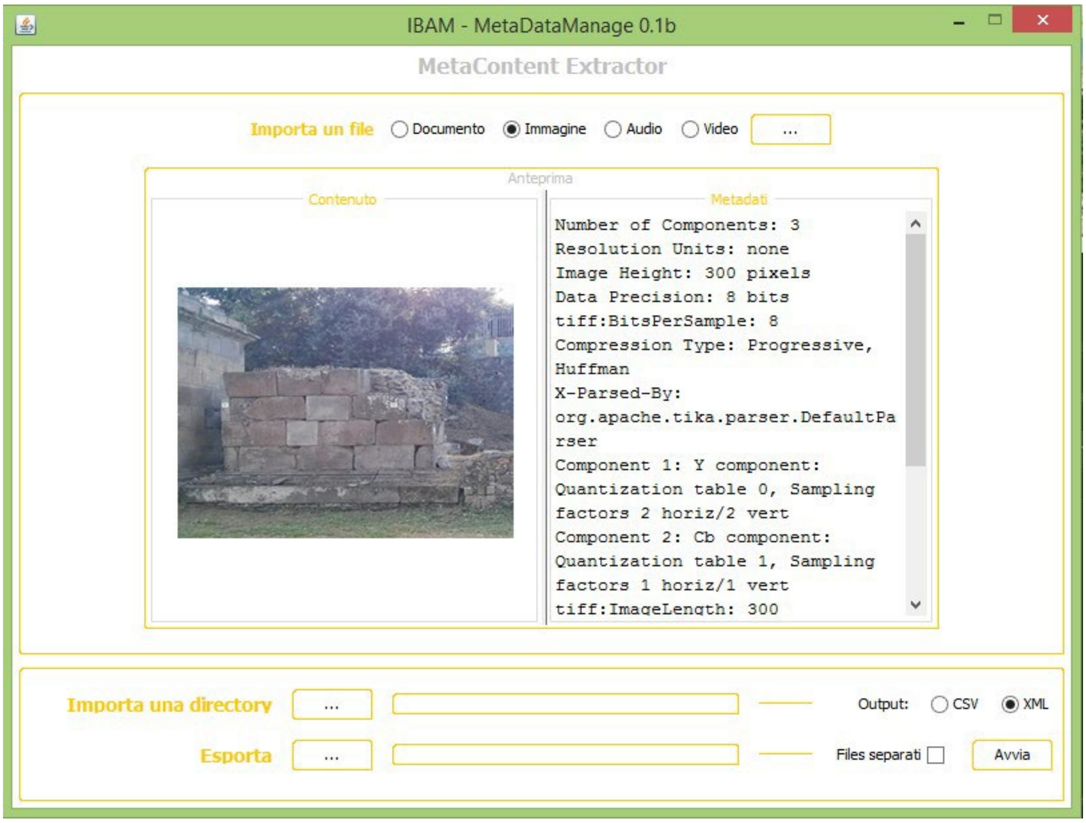

Figure 63. MetaDataManage v.0.1b. GUI for metadata management.

Specifically, the semantic search engine implemented in the MetaDataManage tool will be based on Information Retrieval and Representation (IRR) and techniques for the manipulation of ontological information. The first permits the extraction of terms or keywords from documents through processes of indexation, categorization, and text transformations, involving the elimination of the stopwords (articles and conjunctions) and noun groups (adjectives, adverbs and verbs), and the use of stemming (reducing words to their grammatical root).

The second technique used in the search engine will aim to describe a group of concepts and the specific semantic relationships present between them, purposely thought of for the Cultural Heritage dominion. Its creation foresees the use of word-sense disambiguation techniques, obtainable through the implementation of a lexical semantic database, and of MultiWordNet query expansions by using similar terms in the initial enquiry.

files. It allows not only an immediate interaction with unstructured contents in a database, exploiting the natural language, but also makes it possible to obtain “richer” results compared to those obtained using the syntactic approaches at the bases of traditional search engines. This can be achieved by the implementation of statistical approaches to the search and retrival of information based on the techniques of machine learning.

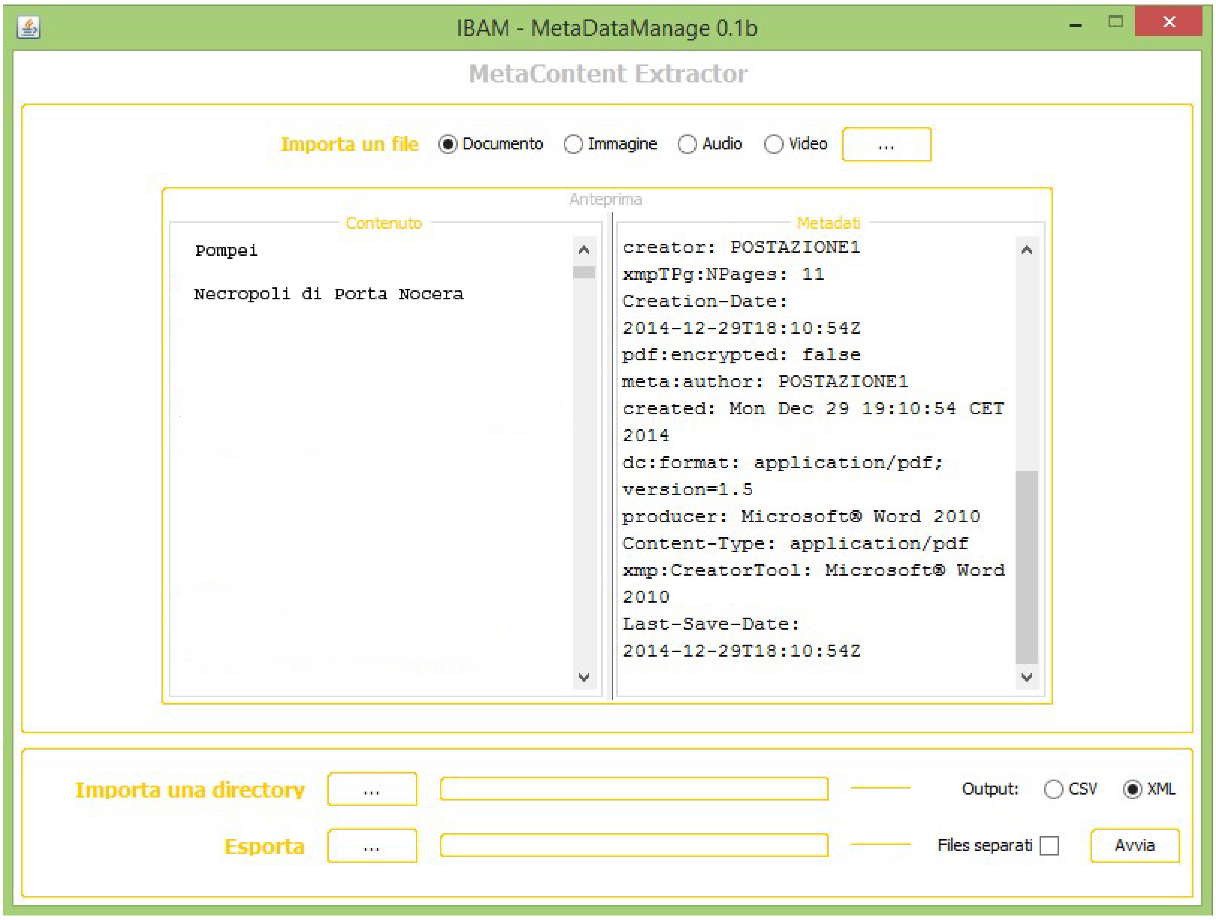

Figure 64. MetaDataManage v.0.1b. GUI for metadata management.

There will be numerous advantages to using such a tool, and its future use in the various research sectors in which IBAM-CNR is involved is already a possibility. From the point of view of increasing the tool's efficiency, it is important to undertake tests involving all the research groups in the Pompeii Sustainable Preservation Project.

Indeed, an ad hoc design, purposely modelled on the particular needs that arose during the field work and capable of responding in a precise manner to the problems that appeared, represents the tools main point of strength, together with the possibility of managing in a single environment files in different formats and using different strategies for the conserving the metadata.

Moreover, the possibility should not be neglected of structuring and managing archives standardized on shared norms, that permit the implementation of various forms of access and sharing of the data produced, ranging from the free circulation of files and relative metadata, to the exportation of just the document containing the metadata. In the latter case, this will permit the stakeholders to check the existence of a specific image or set of images in the archives of their project partners.

Ultimately, this tool would lend itself to an on-demand functionality, guaranteeing the conservation of the original files and foreseeing specific politics of privacy-policy or of Open data for access and sharing.

A. Iabichella

9. Limitations and future prospects: a combined approach

SALVATORE RUSSO

Technological development in the field of survey and mapping has made tools available that are capable of ensuring precise measurements, speed, and a quantity of data that was unimaginable only a few years ago.

However, although the aim of all survey activity is the faithful reproduction of the object in question with the lowest margin of error possible, today different tools, technologies, and methodologies are available that offer various solutions in terms of precision in the details and in costs of use.

However, despite technological developments, one fundamental assumption remains valid in any survey operation: there is no survey method that is better than another; different methods exist in view of different objectives. That is, a complete and exhaustive survey will always be achieved through the combination of different strategies and technologies.

Our priority in this first phase of activity within the Pompeii Sustainable Preservation Project was to create a digital model of the entire Porta Nocera necropolis, completely navigable in its three dimensions and with a very high resolution in the rendering of planes and surfaces. In order to do this it was decided to undertake campaigns of photogrammetric mapping, combining different methods of photography, which provided the base both for the creation of three-dimensional models of the monuments and surrounding physical space, and for the textures to apply to the generated models. From the outset, this strategy appeared capable of ensuring that the desired objectives would be reached in the available time.

The model generated in this way, although capable of fulfilling many of the expectations it was designed to meet (a comprehensive and unitary model of the entire Porta Nocera necropolis, reliable rendering of the volumes, very high rendering of detail, complete navigability, capacity to archive contents). However, we were aware that it had limitations inherent to the type of mapping undertaken, that does not permit the rendering of detail and a capacity to manage measurements with margins of error within an acceptable range in the millimetric analysis, required, for example in the mapping of cracks, for monitor ongoing phenomena of deterioration.

This can be achieved, by combining photogrammetric mapping of the individual monuments, with measurements taken using a 3D laser scanner, which with a field of acquisition equal to 360° on the horizontal plane and 300° on the vertical plane, makes it possible to obtain point clouds of the entire area in question, with a mesh no smaller than 5 x 5 mm and a precision of $\pm$ 2 mm on each point recorded. This would permit the creation of high quality mesh starting from the point clouds obtained, on which it would be possible to overlay textures extrapolated from the photographs.

From the data obtained by the laser scanner it will also be possible to render in DWG, DXF or similar formats, the point clouds as lines, joined by adequate drawing software, using digital inking, that permits the creation of important plans, profiles and sections, with an exact planimetric and altimetrical dimensioning.

This will permit an extremely detailed representation of the visible fabric of the walls, as well as the rendering of moulding, cornices, and friezes, the indication of the wall masses, the real dimensions of the interiors and the thickness of existing walls. The scale will of course be programmed during the planning phase of the mapping.

The graphic rendering could also be completed by:

- Mapping the deterioration. Instruments necessary for monitoring degenerative phenomena present on the surfaces of the structures being investigated;

- Mapping the cracks. To establish the level of deterioration of a structural element or for evaluating the static condition and the seismic vulnerability of a monument from the length and width of the main lesions.

- Stratigraphic study of the walls: For determining the absolute chronology of the layers present in a wall.

Lastly, the final step could be to aim at the creation of a virtual visualizer designed to respond to the specific final objectives of the research and capable of generating a multimedia file for interactive navigation within the single point clouds, in photographic quality (Real Texture Maps). The software, to combine inside the virtual gallery created, would permit the reading of a multimedia file, where it will be possible to directly interact with the single scans made and, from the point of view of the station, measure and identify the coordinates of every single scanned point.

10. Tomb 7 ES of the Porta Nocera necropolis

SAMUELE BARONE, GIOVANNI FRAGALÀ, DANILO P. PAVONE

What follows is an example of a digital model created for the Porta Nocera necropolis, a photographic gallery of tomb 7ES, obtained through a series of screenshots directly extrapolated from the immersive gallery together with a number of axonometric views and sections, relating to the 3D model of the structure.

Tomb 7 ES is a funerary monument in an enclosure with a semi-underground chamber in its interior. It does not have a monumental façade like the majority of the other funerary buildings, but was simply separated from the via Nucerina by the north wall of its enclosure. Today, the wall is bare, but in antiquity it was faced with white plaster, still partially visible at the time of its discovery. Indeed, it presented two legible inscriptions, one mentioning a Primigenia and a greeting for Martialis from one Soter[1].

The enclosure was accessed from the via Nucerina via three steps formed by three stone slabs projecting from the north wall on the exterior and interior. The funerary structure only occupied the south-eastern corner of the internal courtyard and is constituted by a single sunken floor chamber with a semi-quadrangular plan. The interior space, entered via three steps from a north-facing opening, was covered by a barrel vault and lit by a narrow skylight. The burials were situated inside three arcosolia in three of the walls. The back wall of the arcosolium in the south wall, was painted with an aedicule with a triangular tympanum.

In the south-west corner of the courtyard a structure for funerary banquets was situated immediately up against the funerary structure. It is formed by a masonry-built table with a podium surrounded on three sides by a low bench. Lastly, an altar stood up against the courtyard's west wall.

The tomb had already been disturbed when it was discovered. It dates to between the late 1st century B.C. and the first half of the 1st century A.D.

1 Della Corte 1958, p.155.

Figure 65. Pompeii. Porta Nocera Necropolis. Web Immersive gallery.
7 ES tomb. 3D model. Burial chamber, from north-west.

Figure 66. Pompeii. Porta Nocera Necropolis. Web Immersive gallery.
7 ES tomb. 3D model. Burial chamber, from north-east.

Figure 67. Pompeii. Porta Nocera Necropolis. Web Immersive gallery.
7 ES tomb. 3D model. Burial chamber, from north-west.

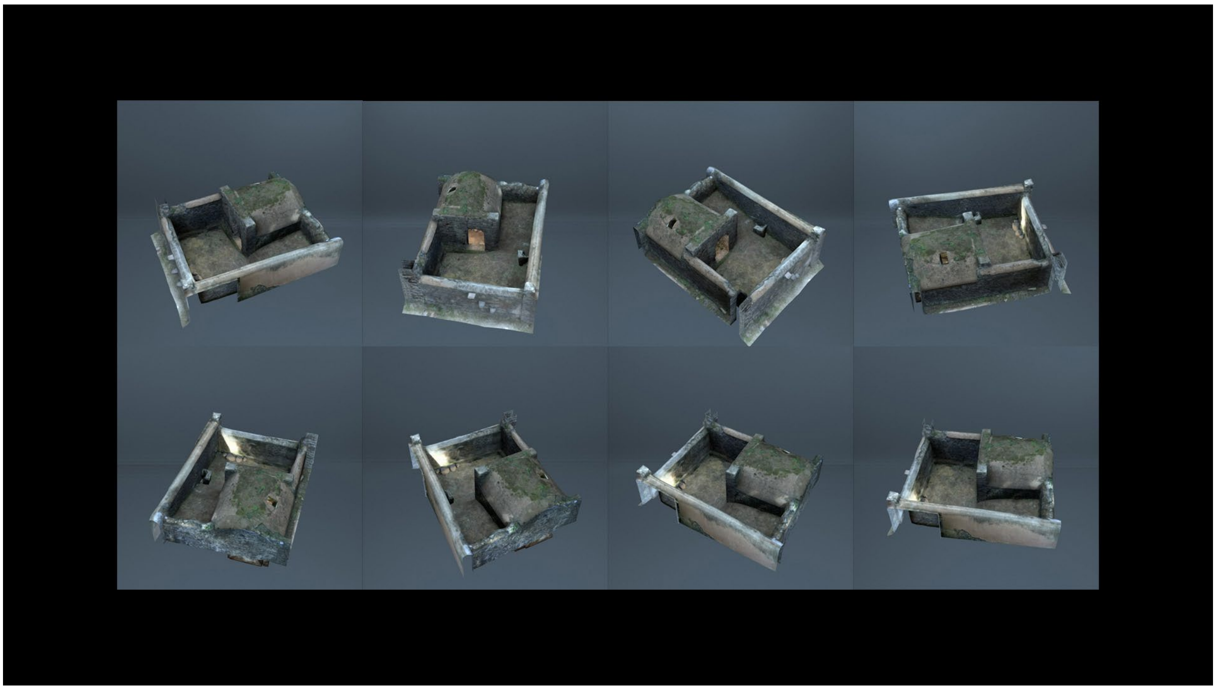

Figure 68. Pompeii. Porta Nocera Necropolis. Web Immersive gallery. 7 ES tomb. 3D model.

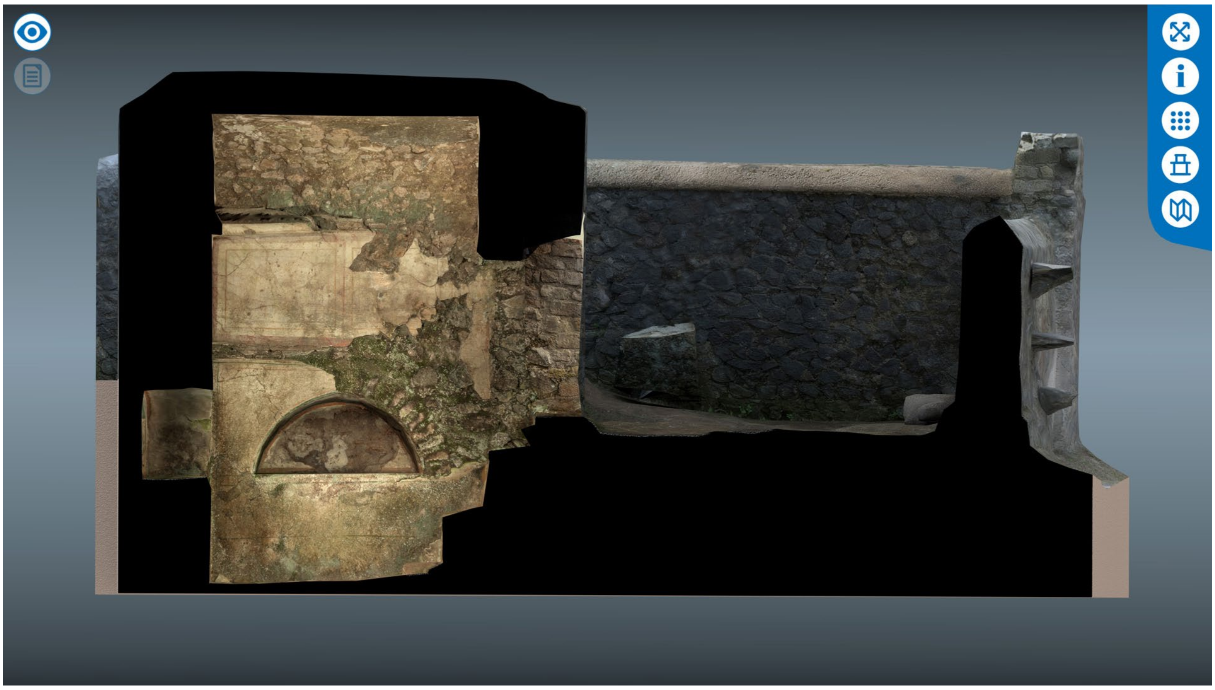

Figure 69. Pompeii. Porta Nocera Necropolis. Web Immersive gallery.
7 ES tomb. 3D model. North-South Section.

Figure 70. Pompeii. Porta Nocera Necropolis. Web Immersive gallery.
7 ES tomb. 3D model. East-West Section.

Figure 71.Pompeii. Porta Nocera Necropolis. Web Immersive gallery.
7 ES tomb. 3D model. Funerary chamber, overall view.

Figure 72. Pompeii. Porta Nocera Necropolis. Web Immersive gallery.
7 ES tomb. 3D model. Funerary chamber, from east.

Figure 73. Pompeii. Porta Nocera Necropolis. Web Immersive gallery.
7 ES tomb. 3D model. Funerary chamber, from north.

Figure 74. Pompeii. Porta Nocera Necropolis. Web Immersive gallery.
7 ES tomb. 3D model. Funerary chamber, from south.

Figure 75. Pompeii. Porta Nocera Necropolis. Web Immersive gallery.
7 ES tomb. 3D model. Funerary chamber, from west.

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