Innovative technologies for restoration in Pompeii. The 3D morphometric survey in *via dell’Abbondanza*

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ABSTRACT: The project had as primary objectives the safeguarding of architectural remains and the experimentation with restoration methodologies and materials. The restoration works addressed a number of façades along the stretch of the Decumanus Maximus known today as via dell’Abbondanza. After the collection of numerous notes from previous archaeological investigations and from visual inspections about architectural morphology, materials and state of conservation, surveys of ancient façades were carried out and measurement data were collected. The survey by means of 3D laser scanner of the varied and complex architectures have been characterized by an attempt to focus efforts on contributing representational knowledge of the existing site elements.

1 INTRODUCTION

The project titled From *Asellina* to *Verecundus*: research, restoration, and monitoring addressing painting on certain famous Pompeian *botteghe* in Via *dell’Abbondanza* (Regio IX, Insulae 7 and 11) was characterised by close collaboration between the Soprintendenza Archeologica di Pompei, the “Valle Giulia” School of Architecture at the University of Rome “La Sapienza”, the School of Architecture and the DIAPReM Centre of the University of Ferrara, and the School of Engineering II of the University of Bologna (Forlì campus). Its primary objectives were the safeguarding of famous architectural remains and experimentation with restoration methodologies and materials.

The restoration work addressed a number of façades along the stretch of the Decumanus Maxiumus between the Forum and the Sarnus Gate (a stretch known today as via dell’Abbondanza). The façades were unearthed in 1912 during excavation work under the direction of Spinazzola. Specifically, they comprise:

- The Coactiliaria workshop or Verecundus’s felt shop (Regio IX, VII, 7-5), with the painting of the Pompeian Venus in a chariot pulled by elephants. She was the protectress of the felt workers, who are portrayed at work in their workshop, while the owner, Verecundus, displays a finished piece of wool cloth;
- A private dwelling (Regio IX, VII, 3), whose columned entrance is characterised by a pair of interesting stone capitals;
- The Infectoria workshop or dye works with furnace (Regio IX, VII, 2), with a lead boiler in the entryway incorporated into a larger structure decorated on the outside with apotropaic phalli made of plaster;
- The Coactiliaria workshop or felt shop (Regio IX, VII,1). The faces of tutelary deities are painted on the architrave over the broad entry: Sol, Jupiter, Mercury, and Diana. On the column to the left, the Pompeian Venus is depicted with Cupids. To the right, we see an augural procession in honour of Cybele;

- The Compitum with fountain, dedicated to the Olympian deities (Regio IX, XI, 1). On the façade we find portrayed twelve divinities and ministers before the sacred altar fire in a well preserved scene where the serpent receives the offerings (a pine cone and two eggs);
- The Thermopolium of Asellina, where hot beverages were sold (Regio IX, XI, 2), bearing the famous election inscriptions and the shop sign with painted images of utensils;

These façades are all recognised for their invaluable paintings and election inscriptions, which are among the most famous and representative in Pompeii.

1.1 *Research and experimentation at Pompeii: the restoration project along via dell'Abbondanza*

The particular conditions in the immediate environment around the façades, which stand against the retaining wall for the non-excavated area subjects their structures and paintings to constant deteriorative effects caused mainly by the moisture released by the non-excavated mass of earth, which is composed of layers of volcanic ash and pumice.

The paintings and electoral inscriptions on the façades as well as the decorative stuccowork around the boiler in the *Infectoria* workshop represent the most precious aspects of the façades.

The campaign of monitoring and measurements added a significant amount of data over time and encompassed variations in environmental conditions. These data have aided researchers in their assessment of the state of conservation of the surfaces, providing a much more realistic and dynamic understanding of the deteriorative phenomena, including the rate at which these phenomena act.

The document research conducted at the library, archives, and photography archives of the Soprintendenza Archeologica di Pompei and other institutes was a fundamentally important part of the project. The information gathered during the document search and review, supplemented with survey and visual inspection data were incorporated into an updated overview of work conducted to date within the overall Pompeii project.

The studies focused on research of historical archaeological documents, knowledge and interpretation of the Pompeii national heritage site, an assessment of the state of its conservation, and mapping of the deterioration of architectural and painted surfaces.

After a painstaking assessment of the different structural characteristics, surveys of the ancient façades in via dell'Abbondanza were carried out and measurement data were collected. Numerous notes from visual inspections were collected as well as an equal number of geometrical sketches and diagrams.

Particular care was dedicated to the production of the final documents regarding the façades. In practical terms, traditional and digital graphic documentation was produced to facilitate design work prior to implementing action on the façades themselves.

The photographic documentation process involved a parallel procedure whereby documentary-quality images were obtained along with a series of working photos to aid project staff in developing the proper restoration measures.

Once the graphic and photographic survey of all surfaces had been completed, thematic plates on photographic supports were drawn up for all painted surfaces in order to assemble a complete and efficacious mapping of the site, encompassing the walls and the stone, wood and metal elements present on the façades.

In addition to the documentation produced for all painted surfaces, stuccowork, and architectural structures, project staff produced 1:1-scale acetates of the paintings in the Thermopolium of Asellina.

These greatly facilitated the assessment of the extent of degradation, the condition of the intonaco, and the cracking of the paint. Tests and experiments were carried out in the site regarding the various operations planned for the subsequent restoration work, such as cleaning, biocide treatments, the consolidation of surfaces and loose stucco and intonaco layers, and tests of mortar to be used for patching and filling work.

The objective of these experiments was to identify the most suitable materials and products to be used in the project.

The choice of products was made by comparing the results of field tests with the results of laboratory analyses of mortar and intonaco samples collected from points in the surfaces where restoration work had been performed in the past.

2 THE MORPHOMETRIC SURVEY IN ARCHAEOLOGICAL FIELD

2.1 *Introduction to three-dimensional laser scanner survey*

The speed of the digital image process tends to obscure its associated purpose when confronted with a comprehensible and equally alluring action intended enhance and promote (as opposed to consuming) cultural heritage. While difficult to bring into focus because of the greatly stimulating effect of technological innovation, this phenomenon threatens to generate substantial disaffection among specialists and technicians who seek to give some useful validity to their subject matter through description. In the case of the Pompeii archaeological site, the issue appears all the more relevant and begging of detailed explanation because the comparison between Pompeii as it once was and Pompeii as it now is and observations of how it changes, decays, and mutates day by day offer an extraordinary arena for experimentation and research. Having said this, and seeking to avoid getting embroiled in past or present disputes, the nearly ten years of research and experimentation at Pompeii have been characterised by an attempt to focus efforts on contributing representational knowledge of existing site elements. The chosen research field, which nevertheless remains open to interdisciplinary approaches, is archaeological excavation and restoration and problems of conserving our cultural heritage. The newly developed technologies for the automatic acquisition of geometrical data are innovative elements that allow us to create databases of high definition, three-dimensional morphometric data. These archives of architectural and archaeological data are a valuable research tool for archaeologists, architects, and historians of art and architecture, but also, and above all, they serve the purpose of protecting and conserving cultural heritage sites and provide support to restoration processes and training programmes. The first three-dimensional data acquisition operations using 3D laser scanning instruments began in the *Insula* of the Casti Amanti in 1998* as a collaborative scientific project involving organisations, universities, foundations, Italian and international research centres, and leading companies in various market sectors. The project's ambitious objective has been to develop criteria for the multilevel organisation of a database oriented principally to conservation and restoration work, but also supporting the enhancement, promotion, management, and enjoyment of cultural heritage sites. The database contains 3D models obtained by use of the laser scanner and all the topographical, photographic, diagnostic, and structural data associated with them. The database allows users to consult and update all data. This provides an important foundation for the management, conservation, maintenance, and enhancement of Pompeii's extensive, complex, and diversified urban, architectural, and monumental legacy.

2.2 *The purposes of three-dimensional survey*

Distances and directions have always been the quantities we seek to determine. The difference between them regards the time (little or very little) needed to take the measurements and the amount of data collected (at a level of precision sufficient for archaeological or architectural purposes). Speed of measurement (a non-trivial characteristic in archaeological studies of stratigraphic phases and processes) and quantity of data collected are the fundamental advancements that qualify 3D laser scanning as a valuable technology for obtaining a description of the morphology and dimensional aspects of archaeological sites, architectural works, and monumental complexes. Experimentation carried out since the mid 1990s has established the validity of a new technology and a new role for it alongside and integrated with established and proven survey and measurement methods and techniques. The complex variety of Pompeian architecture on its different scales (territorial, urban, architectural, and detailed) has steered the research approach towards the synergic integration of different measurement methods:

Three-dimensional laser scanning used to obtain a three-dimensional scale model;

Topographical and GPS surveys, used to record the various scans and to determine an overall reference framework;

Photography paired with topographical surveys to create an archive of reference images that can be used to monitor the condition of relics and decorations;

Direct measurements, used for verification purposes and applicable to areas that are inaccessible to other methods.

Regarding the differences among the methods, one aspect that merits emphasis is that they may constitute an initial means of differentiation among methodologies and procedures in the acquisition and compilation of 'measurement data assets' that are more universally accessible. The 3D survey and measurement process is organised in such a way that the steps remain clear and all data acquisition and fusion processes can be retraced and reconstructed.

The three-dimension scale model that is produced, certified to a specific degree of accuracy and precision depending on the performance specifications of the instruments and the complexity of the data acquisition process, is represented by a set of x,y,z coordinates that can be retrieved and examined by anyone at any time.

The degree of flexibility offered by this system allows researchers to transfer organisational and interpretive work into the laboratory, decoupling the data acquisition process from the exclusive purpose of producing a measurement, and making the collection of measurement data exportable, updatable, and implementable.

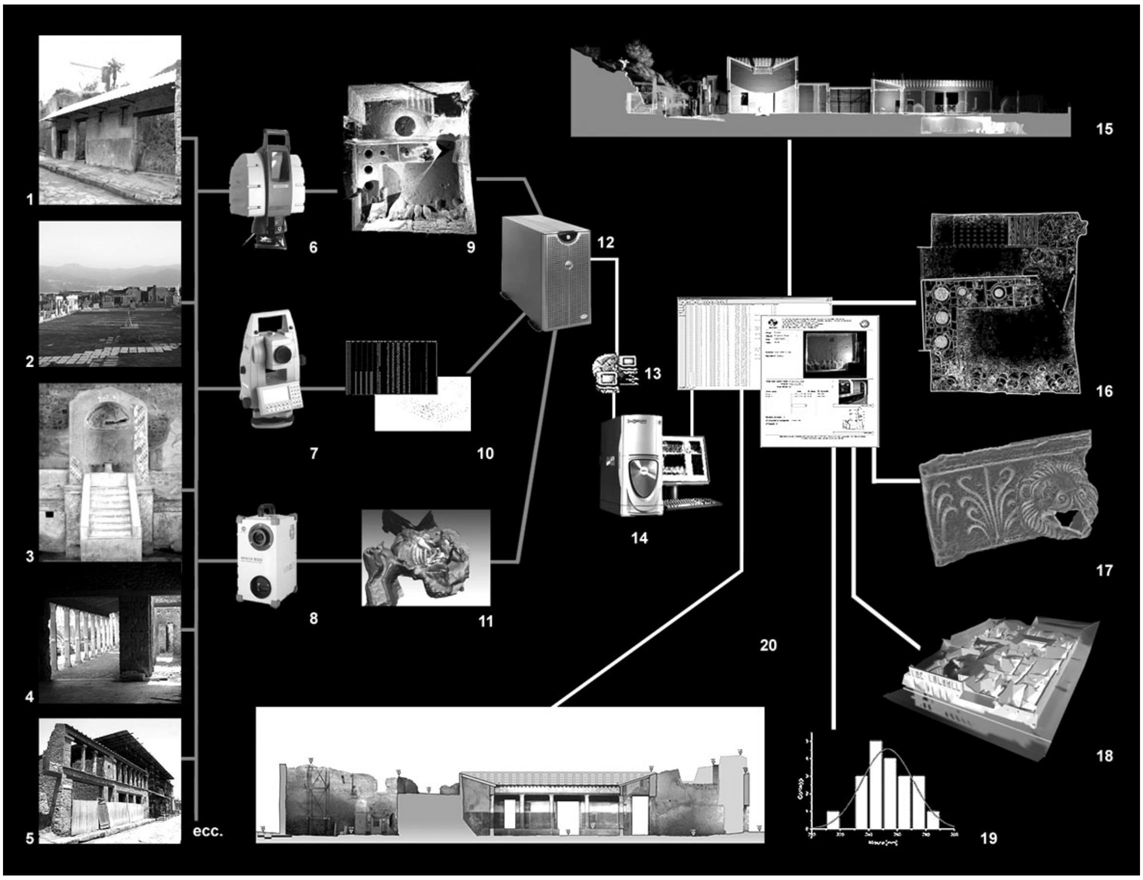

Figure 1. Scheme of the methodology of data acquisition and management. The steps to implement the server data-base follow three different integrated methodologies: 3D time of flight laser scanner survey (point clouds digital models and scan-registration by the support of a total station); 3D optical triangulation laser scanner to survey details with a high accuracy. By web or local network it is possible to explore the data-base also for: checking measurements and morphological data, creating CAD drawings and 3D simplified models also to be printed in solid models, useful for monitoring and restoration simulations, connecting and linking the surveyed data with, historical notes, surface specifications, chromatic descriptions, material and morphological aspects.

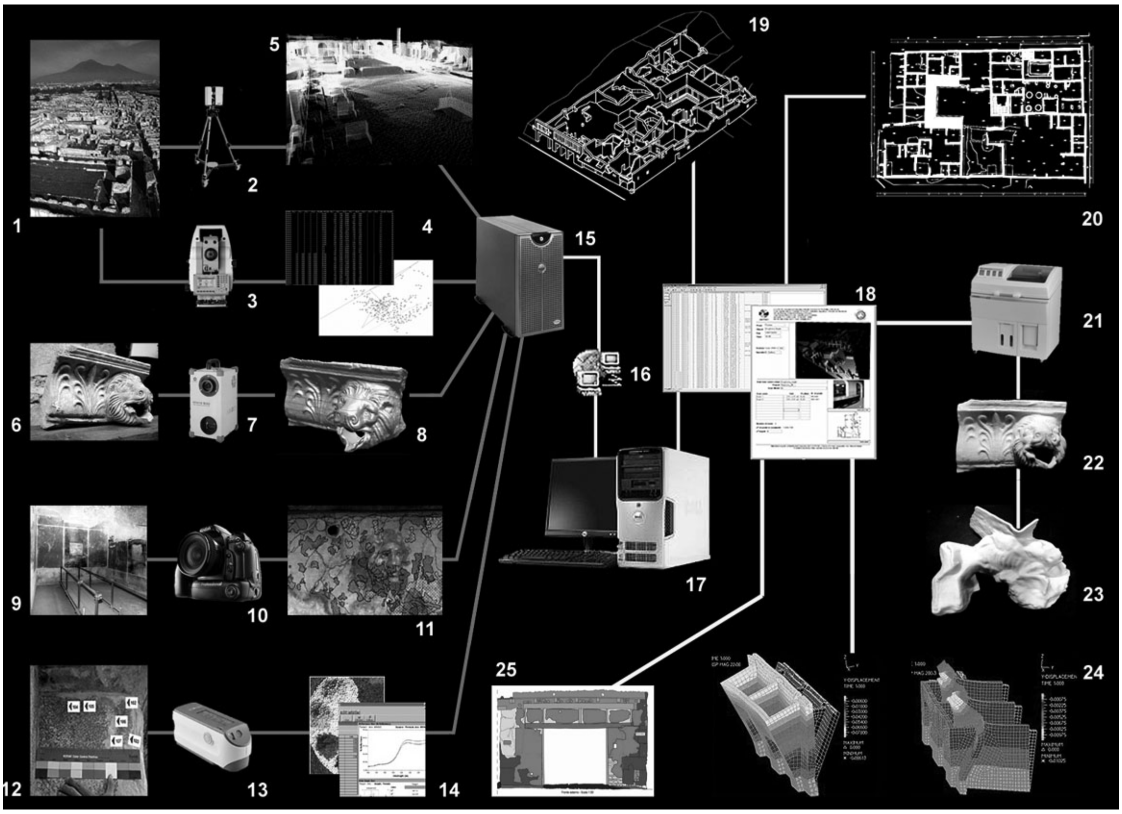

Figure 2. 3D morphometric acquisition methodologies: 3D time of flight laser scanner survey (2), topographic survey (3, 4), 3D optical triangulation laser scanner (7, 8), digital photographic survey (9, 10) for the analysis of the surfaces specifications (11). Analysis of conservative specifications (12) by spectrophotometric survey (13) to study the reflectance data acquired by laser scanner. From the server (15) by means of local network or web (16) it is possible to use the integrated data-base by PC (17) to obtain CAD representation (18), solid model by 3D printer (21) of decorative details (22), up to structural analysis (24) and decay and conservative specifications (25).

2.3 *Survey purpose and scale in relation to the archaeological relic*

One variable in the data acquisition process that gives it a specific representational function is grid density, i.e., the possibility to select the intervals between measurement points in direct proportion to the scanning distance. On the one hand, as in a traditional survey, there is the option of accentuating the importance of the detail within the general setting. On the other, the acquired data are not integrated into a generic or difficult-to-define system of spatial references (oftentimes the survey of a detail is a completely self-referenced collection of data), but are located within an overall georeferenced three-dimensional grid or reference frame. Thus, within a predetermined set of items of interest and according to a specific 'syntax' of the archaeological research process, it is possible to select, even during the measurement acquisition phase, an array of morphologies representing two levels of investigation. The first level is associated with the general archaeological and architectonic model of the context. The second can be extracted directly as morphometric data (of graffiti, decorative components, mosaics, capitals, cornices, basements, etc.) via visual, geometrical, or structural comparison criteria in which the measurements make it possible to investigate the dimensions and positions (orientation, inclination) of worked stone, overhangs, etc. in relation to the form and state of conservation of the relic. The measurements of the detail as expressed within the archaeological survey thus maintain both a level of precision correlated to the overall organisation of the database for the entire complex, and to its own singular content as read in the data extracted from the single scan or scans of that detail. This is perhaps one of the most interesting factors, but it produces a complexity of investigation that obliges researchers to establish extremely precise and verifiable data extraction procedures. A database containing three-dimensional reconstructions of settings, archaeological sites, and architectonic complexes that are as varied and complex as those in Pompeii will often contain close to a billion pieces of data. It can be thought of as a galaxy of points organised into solar systems (external and internal hulls, areas below ground level, roofs, etc.) and single planets (entries, rooms, porticoes, decorations, etc.) in their actual size, i.e., in a scale of 1:1. Navigating this universe is not a simple matter. An insufficiently specified reference frame or an inexact axis of symmetry is often all it takes to end up with a tangle of apparently incongruous relations. This is why a high density, three-dimensional survey is always doubly linked to its reference setting. This setting is composed of many aspects of structural position and conservation (influenced by structural collapse, settling and subsidence, maintenance operations, and restoration work) that specify a morphological model that is only useful if it is always critically interpretable in its entirety.

A subsequent step that increases the accuracy and quality of reconstructions of certain important relics involves the use of 3D surveying instruments of greater precision that can be integrated with time-of-flight and phase difference laser scanners. In the botteghe in via dell'Abbondanza, for example, many decorative relics and stuccoed supports were surveyed with an optical triangulation laser, a technology that offers precision to a tenth of a millimetre and thus offers a much greater potential to provide a faithful and detailed description of the real article. But while the potential for data gathering is far higher, the time required for data acquisition and elaboration remains a daunting obstacle for its use on large, complex surfaces, such as those that we seek to detail in archaeology. Additionally, the acquisition method obliges operators to determine the distance ratio between the instrument and the surface it is measuring which is correlated with the precision of the measurements. This imposes a need to provide costly logistical support during the measurement phases which cannot be accomplished except during restoration work where there is stable and protective scaffolding.

3 DATA MANAGEMENT

3.1 *Displaying morphometric data*

Accepted scientific practice places a sharp distinction between the survey phase and the reconstruction phase. It also requires that a relationship of purpose be established between these two fundamental moments in the process of acquiring knowledge of the real. In the everyday practice of work, the raw survey datum may be considered to be a quantitative geometric element (spatial coordinates) that has to be qualitatively interpreted (within a relationship of contiguity, consecution, displacement, etc.) to offer the possibility to extrapolate (we could also say statistically mediate or extend the degrees of correlation) the true character of the real object. In other words, if one does not know the 'rule' (i.e., the qualitative causality relation) that associate two coordinates in space (and not others), one cannot choose to unite them to determine the length (or average) of measured quantities that may represent a profile, a segment, or something else. This process is complex and exhausting especially in archaeological sites where the ruggedness of the surfaces is not immediately visible to the naked eye. It places an initial constraint on the determination of a useful and necessary reference frame so that the survey will give us a correct and coherent reconstruction that responds to specific relations of scale and descriptive quality necessary to meet most of our objectives. If we view one isolated survey element we find a limited cloud of nearly meaningless spatial geometric data which in most cases would be of ambiguous or doubtful relation. This is why the accepted scientific practice in this discipline demands that a direct relationship of purpose be established between the survey phase and the reconstruction phase. The latter, via the production of topographical sketches, incorporates into the 'survey project' the representational model that serves the purposes of morphometric data acquisition (scales, precision, instrumentation, etc.). The relationship constitutes a continuous and close qualitative link between the measurements of the real and the possibilities of describing it, as if the surveyor (with his or her instruments) continuously verified the degree of representational quality of each act of measurement performed in an apparently immediate process of self-checking. There is an 'extractive', synthetic, and motivational factor in the reconstruction phase that makes the survey drawing a bona fide project in its own right, with notable critical

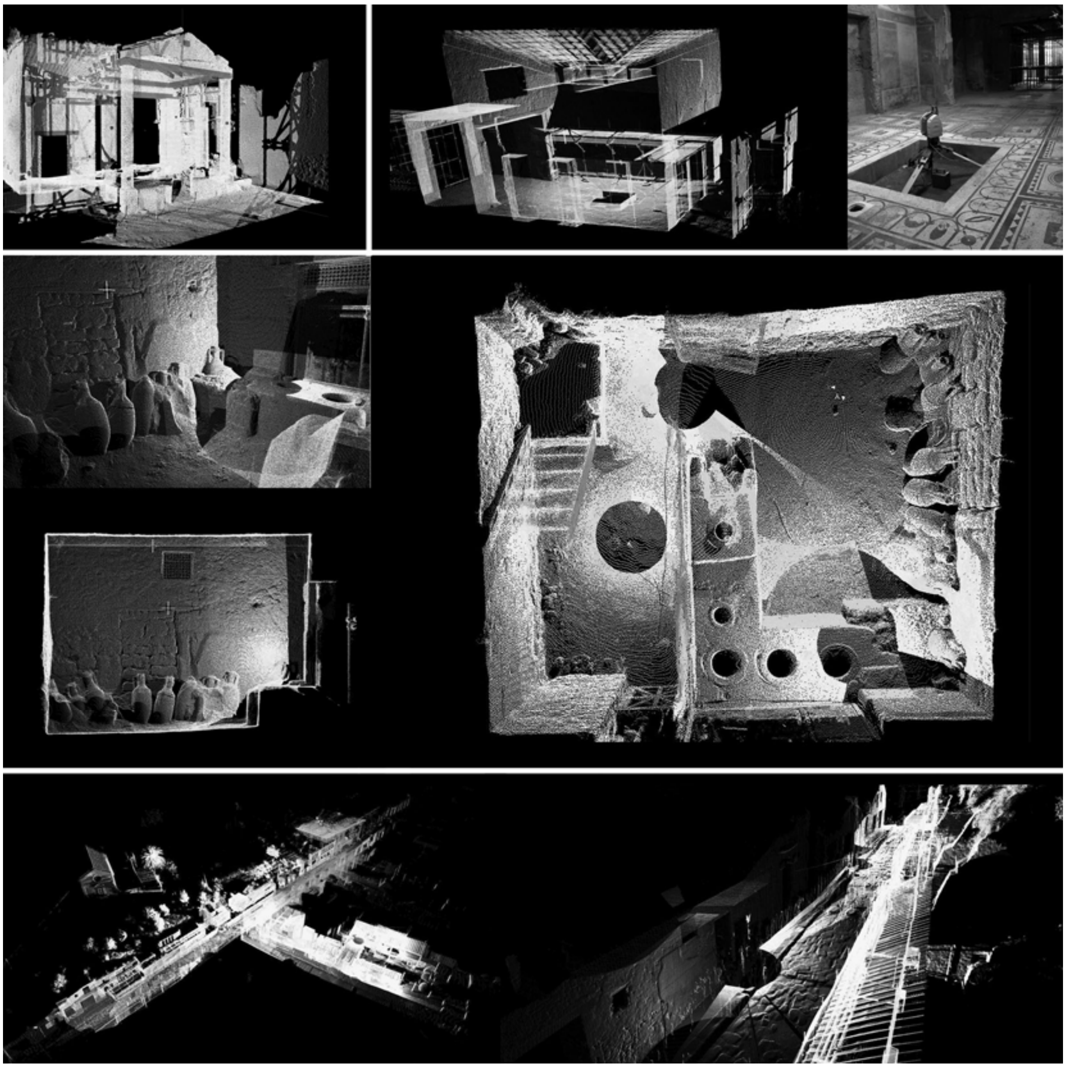

Figure 3. Acquisition and modeling phases of some archaeological context surveyed along via dell'Abbondanza. The survey of the entire exteriors and interiors has been performed mainly with Leica 2400, HDS 2500 and HDS 3000 3D laser scanners using time-of-flight technology. These scanners are able to rapidly acquire a high definition 3D point cloud (accurate to 5-6 mm) and are highly reliable instruments on the monumental and urban scale. Data were supplemented by the use of interferometers (HDS 4500 series), GPS stations, and total stations. In situations with decorations or particular details (graffiti, terra cotta moulds, stucco supports, etc.) Konica-Minolta Vivid optical triangulation laser technology with sub-millimetric precision was used. The high definition surveys of the morphometric characteristics of sculptures or architecture were performed with a Minolta VI-910 laser scanner. This is an ultraportable optical triangulation range finder with a range of 7 x 7 cm to 110 x 110 cm. The data are available as 3D point clouds, 3D triangle meshes, and gouraud-shading.

and cognitive implications. It seeks to accomplish a purpose that is not merely a question of geometrical accuracy but, especially in architecture, also of the conceptual representation and visualisation of the real. The limits to the cognitive data and the representational models trace out the confines of any possible aspiration. The Pompeii surveys, together with other experience gained by DIAPReM in recent years, have also imposed a new need: that of building a methodology for the comprehension of the quantitative survey data that will permit a simulation of the traditional architectural reconstruction while at the same time providing the basis for investigative processes into the volumetric structure of the spaces. In other words, there is the need to *visualise the survey*. The investigative process that leads to the discovery of form through the information generated by the high definition three-dimensional survey may be described as two basic operational areas:

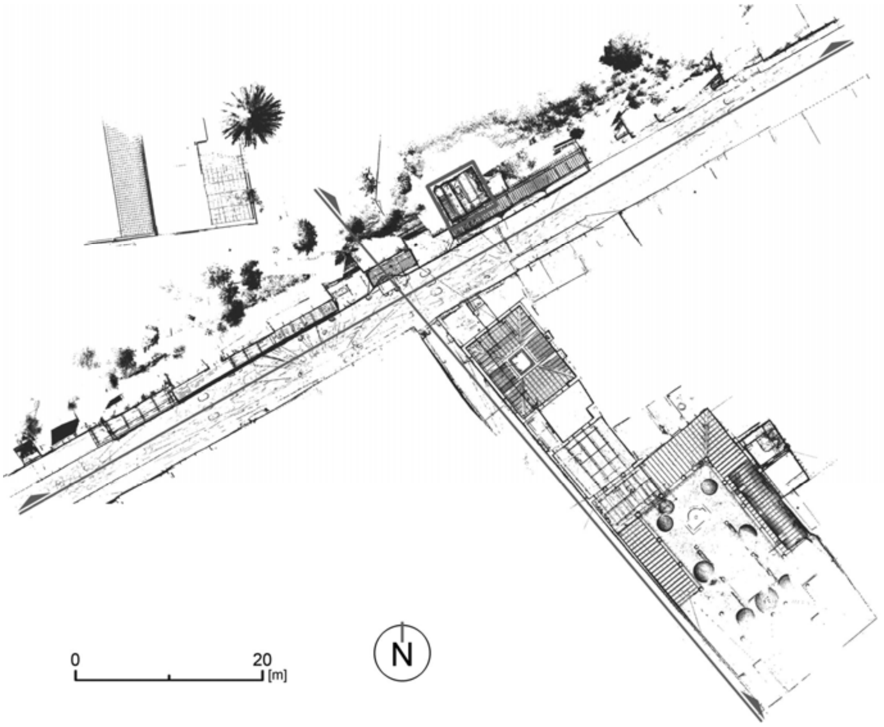

Figure 4. Planimetric scheme obtained by the 3D database. The context involves via dell'Abbondanza and the house of Paquius Proculus, on the opposite side of the restoration project context.

Figure 5. Restoration project context along via dell'Abbondanza in an elevation view obtained by the 3D survey.

The first seeks to extract coordinates, lines, or surfaces from the 3D data to reconstruct, as if retracing the steps backwards, the descriptive synthesis normally obtained through a discrete survey designed to produce a predefined reconstruction. It is a selective process that aims to systematically reduce the geometrical data through a mathematically or critically derived screening process.

The second addresses the question of visual interrogation of the scale measurement datum to simulate traditional views (plans, sections, elevations) or to construct completely new navigation processes into the volumetric relationships.

The possibility of volumetrically correlating the main architectural spaces of any environment, archaeological excavation or architectural setting, independently of any predetermined sections or plans, opens up very broad investigative opportunities exploiting the morphometric potentials of the 3D coordinate database both in the overall view and in the progressive zooming in on details. A transparent silhouette makes it possible to simultaneously view, for example, the intrados of an arch from an external perspective, the correspondences between the sides of a nave, and between the overhangs of cornices and the structural confines of the walls. The database of three-dimensional coordinates presents itself as a 'body of substance', of which we may decide to amputate parts (to better view others), filter the data (which may be stratified and more or less dense), and free the observer from the constraints of altitude or elevation. As opposed to a traditional graphic representation on an orthogonal support of the survey datum, which places a descriptive constraint on the elevation, the transcribed measurement and its possible role as a proportion-dictating element within a context of hundreds of millions of organised three-dimensional coordinates allow for a *transparent* reading of the volumetric correspondences of every situation within the urban fabric, archaeological dig, or architectural complex and all their various possible combinations.

3.2 *Database browsing and multi-resolution models*

The need to be able in the future to use such a broad and descriptive source of measurement data demands new software applications that facilitate access to the information on Pompeian architecture and urban design contained in the three-dimensional coordinate database without compromising the quality and amount of information contained in the survey. If it is true that entering into the structure of the elements and parts that make up each individual survey via a complex logically organised series of data tables allows users to understand how each phase was carried out (scans, topographic support, data acquisition, etc.) and thus to obtain the maximum possible amount of morphological information, it is equally true that this means being able to work with complex interfaces that are based on the programming languages of the software used to complete the survey itself. If this is the case, then the database will always have to be managed and mediated by skilled operators who are trained and kept up-to-date on the organisational content and data extraction procedures. Currently, efforts in developing the user interface are concentrated on providing direct or partially controlled access to the large three-dimensional scale models. In a reasonably near future, immersional navigation will be possible. This is the true technical and logical answer (also in conceptual terms) to the creation of large digital spaces that are properly set up in terms of both form and *dimensions*, where it will possible to navigate, enter, come into contact with the ‘geometrical substance’, and extract its qualities and specifications (measurements, colours, materials, historical documentation, conservation records) in real time. However, the user’s curiosity and desire for knowledge might be somewhat stymied by such complicated interfaces that do little to facilitate the understanding (or recognition) that he or she is in front of or inside a three-dimensional space. While we wait to be able to put on digital gloves and glasses and ‘physically’ enter the geometrical and volumetric richness of today’s Pompeii, current efforts are focused on creating visualisations that can be accessed and interrogated via the Web. This phase in the research foreshadows a future ‘immersive development’ and involves our seeking to understand and resolve a host of technical problems. The experience acquired in recent years with the Visual Computing Laboratory of the Information Science and Technology Institute of the Italian National Research Centre of Pisa (ISTI-CNR) is heading precisely down this road**. The field of experimentation underlying the integrated, interdisciplinary research effort shares many aspects (dimension and complexity of the data) with the Pompeian surveys, and the results obtained so far give us reason to hope that these optimisation processes can be exported. In the multi-resolution visualisation mode, the entire model is never downloaded from the server memory, but only the areas adjusted to the point of view and degree of detail (broad or close-up view) applicable to ‘normal’ PCs with 3D graphics cards. New simplified navigation interfaces are also being developed for users with lower levels of expertise to facilitate access to and navigation of the three-dimensional models.

It is thus clear that new visualisation and communication modes for the geometrical and measurement information have to be conceived and developed in step with the development and application of three-dimensional surveys.

3.3 *Conclusions*

This paper presents just a summary of an interdisciplinary research project into method to studying and conserving the architectures and the ancient painted surfaces along via dell’Abbondanza in Pompeii. The experimentation addressed critical historical aspects, restoration methods and materials, and the protection and maintenance of painted and architectural surfaces. It’s our opinion that the critically study of Pompeii still shows in a manner that is in some ways unique the history of the methods of archaeology and restoration, up to the use of the most modern technologies that in certain case are truly transforming it in a kind of advanced laboratory. The research project about the innovative technologies for studies and restoration in Pompeii involved: historical studies, analyses of materials and states of conservations, architectural studies relating to the various expression and characters that can be investigated during the entire develop of Pompeii; structural investigations regarding the study of the static tests on the buildings of two thousand years ago; technological researches regarding the organisation of the building site or the study of how, in ancient times, the techniques of the various systems of production evolved; restoration, architectures and environment.

3.4 *Notes*

*The first experiments conducted in this area by the Ferrara School of Architecture under the direction of Nicola Santopuoli and Marcello Balzani were part of a framework agreement between the Architecture Department of the University of Ferrara and the Soprintendenza Archeologica di Pompei, which began working with the *Nub Lab* (three-dimensional survey and modelling laboratory) in 1998 and later with DIAPReM as qualified facilities offering integrated tecnological innovation support. The collaborative relationships continued through the years (with projects in the Insula dei Casti Amanti, the Forum, and other houses and settings) through agreements also with Consorzio Ferrara Ricerche and the Kacyra Family Foundation.

**In this regard, the ISTI-CNR of Pisa has developed and tested the Virtual Inspector system. Conceived for museum arts exhibition design (sculpture, sculptural groups, etc.), it is an interactive navigation guide that reduces the risk of losing one's bearings. It makes it possible to observe even the finest details and enrich the surfaces of the 3D model with links to html descriptions.

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