Pompeii Revived: Scanning Mission - Insula V 1

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Abstract:
The Swedish Pompeii Project started in 2000 as a fieldwork initiated from the Swedish Institute in Rome. The aim was to record and analyze a full Pompeian city-block, Insula V 1. This paper presents the initial results of one of the actions in the context of this project. In October 2011, two houses were acquired using 3D scanning and 3d-from-photos techniques, and the data was processed to obtain an accurate and complete model. Through the use of Virtual Reality Techniques, it will be possible to visit the Pompeian houses of Casa del Torello and Casa di Cecilio Giocondo understanding the relation between the actual archaeological context and their original outfit. The collected data will be used also to design and test a web-based access system, where the entire dataset will be available for browsing, measurement and data extraction. The features of HTML5, in particular WebGL, will be used to deliver realtime 3D content and interaction.

Keywords:
Field Recording, 3D Scanning, Pompeii

1. Introduction

Three-dimensional digital surveys have become, in the last few years, a standard tool for cultural heritage studies. The advancements in both the scanning devices and the computers used in data processing and visualization have enabled the cultural heritage operators to carry out large-scale surveys and data gathering campaigns.

This technological advancement, however, cannot, by itself be a game-changer in the field of cultural heritage studies.

In order to effectively use all the data produced by these technologies, it is necessary to carefully consider all the aspects of the digitization campaign and the available tools for the processing of the data, and to have a clear idea of the possible uses of the generated dataset.

While in recent literature it is easy to find examples of quite extensive 3D scanning and data gathering campaigns, what is still, in most cases, missing is a plan to effectively manage and use all the gathered data.

2. The Swedish Pompeii Project

During autumn 2000 the Swedish Institute in Rome started a campaign of field documentation of the Insula V, 1 in Pompeii with the aim of recording and analyzing a full Pompeian city-block. From the very beginning, different types of documentation techniques and technologies were tested; this multiple approach of methods was realized in order to provide an accurate, conjoint description of as many different aspects of the ancient buildings as possible. The possibility to develop a project for the documentation of an entire insula allowed the researchers to consider its different constituents (houses), not as separate entities but as part of a total (Fig. 1). This approach underscored the importance of the relation between the different kinds of entities that characterize Pompeian domestic architecture in order to comprehend the development of Pompeian building and social history (Leander Touati 2010; Staub 2009).

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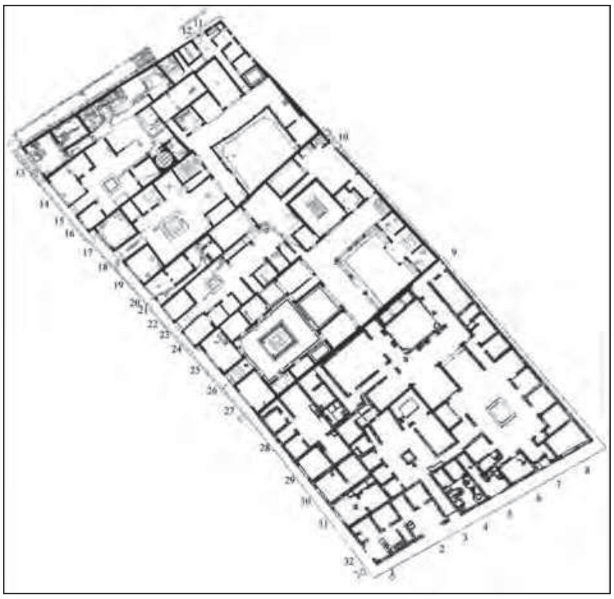

***Figure 1**. map of the insula V 1 compiled by the Swedish Pompeii Project.*

During spring 2011, a collaboration between the National Research Council of Italy (Institute of information Technology and science "A.Faedo") and Lund University (Institute of Archaeology and Ancient History together with the Humanistic Laboratory), allowed to start testing the use of integrated methods of 3D data recording. The integration of acquisition techniques like 3D Scanning or Dense Stereo reconstruction will increase the knowledge of the relations between the technological infrastructures of the *insula* i.e. water pipes system, illumination etc. and the distribution of the public and private spaces.

The goal of this ongoing sub-project is the documentation of the entire insula in three dimensions. The result of this work will be mainly used as a platform to visualize and highlight with accuracy the research so far developed by the Swedish Pompeii Project team.

To reach such result, a two-steps process have to be carried out: data acquisition of structures and data post-processing. Acquisition technologies, i.e. phase shift laser scanners and 3D from images techniques, and partial post-processing have already been successfully performed. The remaining work consists of an intense work of virtual interpretation of the buildings before the eruption that destroyed Pompeii. In particular, the documentation produced in the last two centuries will be used to reconstruct part of the architecture and the decoration, today not anymore available *in situ*.

Aim of this work is assessing if, and eventually how, the use of 3D models affects the interpretation of the Pompeian domestic architecture.

During the progression of the archaeological data collecting in the field, the Swedish Pompeii project developed a digital research platform characterized by its unique transparency. The data elaborated during the field campaigns are published online. The archaeological results are organized into a website (www.pompejiprojektet.se/insula.php) that allows rapid access to different kinds of information, advancing from general information towards detailed data, presented both in text, graphic and photograph. It includes high-resolution ortho-mosaics of the ancient structures, plans, elevation and reports (Fig. 1).

For the reason that the maximum transparency should include also the 3D-datawe experimented the use of WebGL, to visualize the gathered three-dimensional data directly through web browsers, in order to connect this new experimental approach with the classic documentation disseminated during these years through the Internet.

The development of such web access for the visualization of the 3D data would provide the opportunity to anyone interested in studying the insula V,1 to access directly the information elaborated by the project team.

3. Previous Work

Three-dimensional digital surveys have become, in the last few years, an important part of the documentation and communication process of archaeological sites; the examples presented in literature show how acquisition techniques and methods have been successfully used so far in similar case studies. An overview of all the most successful 3D scanning campaigns goes well beyond the scope of this paper, but we can cite two examples where 3D Scanning was used as a valuable support to provide data for reconstruction projects.

The first one, *Rome reborn*, dealt with the case where the original structures have been partially destroyed (Dylla et al. 2009). The second one, *The Parthenon*, took into account a monument which fragments are now scattered in different parts of the world (Stumpfel et al. 2003).

Another example is provided by the Flaminia project (http://www.vhlab.itabc.cnr.it/flaminia/), which describes the development of a workflow for the three dimensional documentation and the communication of several archaeological sites, through the combination of different acquisition techniques such as Laser scanner and photogrammetry.

The result of such projects can be easily employed to build visual infrastructures of cultural communication such as Virtual museums or museum installations. Among a number of possible examples, The Virtual Museum of the Western Han Dynasty (Forte et al. 2010) uses several acquired structures and objects to build a virtual museum.

Pompeii and, more in general, the entire area affected by the eruption of 79 AD has been subject of study and mapping way before the actual birth of modern archeology. A great deal of maps and technical surveys are available for this area, with quite various levels of accuracy and detail. Recently, many different survey actions have been carried out using modern, dense-sampling devices like laser 3D scanners. This has been done, for example, in Herculaneum (Brizzi et al. 2006) to increase spatial resolution in surveys and provide effective geometric data for conservation purposes. In other cases, like (Hori et al. 2007), the aim was to validate (and possibly correct) older surveys. Other surveys covered specific areas of the Pompeii area (Poehler and Ellis, 2012) (Balzani at al, 2004) for specific conservative actions.

4. Data Acquisition

The acquisition campaign took place during the first week of October 2011; a team of six people (three from Pisa –CNR- and three from Sweden -Institute of Archaeology and Ancient History-) started the acquisition campaign of the insula through the employment of two different phase shift laser scanners: a Faro Focus 3D and a Faro

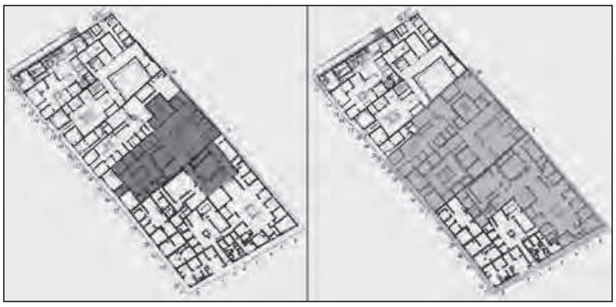

***Figure 2**. This image shows the extension of the area acquired at the end of the campaign and the extension of the area expected before the beginning of the campaign.*

PHOTON 120. Despite these two instruments have similar characteristics in terms of acquired data quality, their different sizes and weight affect their use in different situations; Faro focus 3D is more light and easy to use in fragile and unstable areas, Faro PHOTON 120 is more sturdy and stable, thus more suited for the acquisition of higher structures from scaffoldings. Moreover, the employment of two scanners allowed also a more efficient data acquisition process, since two teams could work at the same time in different areas of the insula.

Before starting the campaign, several acquisition strategies were discussed in order to optimize the process in the limited amount of time available, and to be able to highlight parts of the archaeological features considered more challenging for the instruments. As a consequence, markers were excluded from the process due to the complexity of the houses geometrical features, and a manual alignment of the point clouds was performed instead.

We decided to start our work from *Casa di Cecilio Giocondo* and document its structures. Once completed the acquisition of this part, we planned to start acquiring a small portion of *Casa del Torello di Bronzo (ninfeum)*. In particular, the structures that we experienced being troublesome in terms of acquisition were the *cubicula* of *Casa di Cecilio Giocondo* and some of the corridors that connect the public with the private areas of the house; the small size of these rooms was almost at the limit of the acquisition range of the instruments and we were not sure if it would have been possible to use the laser to acquire such environments. At the end of the week, the campaign resulted extremely successful: after only three days we were able to acquire the two houses entirely (*Casa del Torello di Bronzo and Casa di Cecilio Giocondo*) plus the streets that surround the structures (Fig. 2)

The final laser scanner dataset covered around 1330 (620 + 710) square meters, acquired using 110 scan positions, each one with a 360 degree coverage, with a quite dense sampling rate (1cm at 10 metes). The size of this three-dimensional dataset is more than 200 GB of raw data. The quality of the acquired data is visually very good. Having a precise measurement of the precision and accuracy of the sampling (beside accepting the declared specifications of the devices) would require a ground truth geometry, which is unavailable. On the other hand, since the scanning has been carried out using two different devices of the same class, by comparing the data coming from the two devices in overlapping areas, it is possible to evaluate the coherence of the two samplings (like if we were using the data from scanner #1 as the ground truth to evaluate scanner #2 and vice-versa): the value of this incoherence will be an upper bound of the sampling error. In this dataset, we obtained very low values: 90% of the measured overlapped areas had a disparity below 2.5mm and 50% below 1.5mm. This low error level may be due to the nature of surfaces (mostly non-reflective and optically cooperative) and the closeness of the sampled surfaces to the scanner.

Despite the efficiency of the Laser scanner in acquiring the main structures of the insula, several important features such as the water pipe system of the Casa del Torello di Bronzo, turned to be extremely complicated to document with the Laser scanner. In fact, the location of this structure, which was used to regulate the distribution of the water inside the house, and the complexity and size of its geometry, would have required a quite different kind of scanner (possibly, a triangulation one).

Therefore, we decided instead to use Computer Vision techniques to generate resolute 3D models to align afterwards with the laser scanner model of the house (Fig. 3a-b).

This technique combines algorithms of structure from motion and dense stereo matching in order to build a 3D model of a scene starting from an uncalibrated set of images.

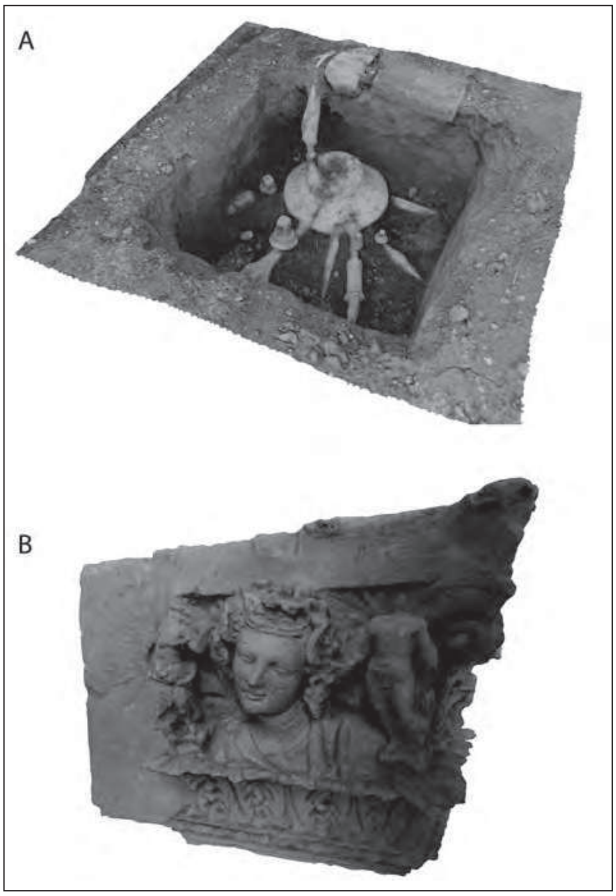

***Figure 3**. 3D models created using Computer Vision techniques: A water pipe device of the fountain of the Casa del Torello Di Bronzo, B architectonical decoration found during the archaeological investigation of the Casa del Torello Di Bronzo.*

This technique was also tested to acquire architectonical materials found inside the houses and stored in a different area of Pompeii. Due to their fragility and the considerable size, architectonical decorations are often very difficult to transport and therefore not so easily acquired. In fact, the narrow space of the storage rooms does not allow the use of any kind of Laser scanner or calibrated camera. On the contrary, the possibility to use uncalibrated pictures to get 3D information, allowed the elaboration of a resolute three-dimensional model to be transferred inside the house and simulate the relationship between environment and decorative elements characterizing the structures.

We have, in a previously published work (Callieri et al. 2011), carried out tests on 3D-from-images technologies, assessing their practical use on the field and the processing of the recovered data for documentation purposes. The data in this project has been gathered and processed following the methodology defined there, and obtaining similar quality in the resulting geometries. Please refer to this work to have more details.

5. Data Processing

Once the raw data captured by the scanner were available, the processing of the data was carried out inside MeshLab. MeshLab (Cignoni et al. 2008) is an open source tool for the visualization and processing of 3D models. It is oriented to the management and processing of large, unstructured triangular meshes and point clouds, and it provides a set of tools for measuring, checking, cleaning, healing, inspecting, rendering and converting 3D meshes. MeshLab is freely available, distributed under the GPL licensing scheme and it is available for all the major platforms (Windows, MacOS, Linux).

The first step of data processing is the alignment. This step brings all the captured data in the same reference space.

Normally, TOF data are aligned using markers placed on the scene. However, in this case, the use of markers was quite complex, due to the large amount of different, interconnected rooms. This would have required a large number of markers, and additional time to manage them. On the other hand, the amount of walls and the same connected topology make easy the alignment based on geometric redundancy between scans.

MeshLab provides a Geometric Alignment filter based on the well-known ICP algorithm (Rusinkiewicz and Levoy, 2001), enhanced with all the optimization and tricks available in literature. This alignment filter works on triangulated surfaces (like in many analogous tools) but also on raw point clouds. Being able to work directly on the point dataset is a great advantage in terms of time and required memory, since there is no need to generate a triangulation.

The alignment is a two-step process: initially, the user picks corresponding points between scans, placing the scans in an approximate position; then, the system computes a precise alignment using the whole overlapping area between the scans.

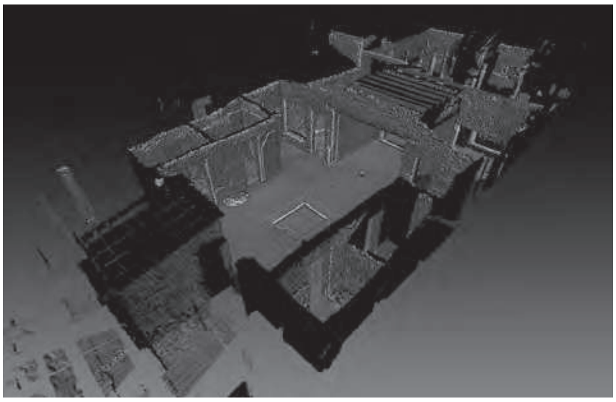

***Figure 4**. Some of the range scans of the House of Cecilio Giocondo, aligned inside MeshLab (each color is a different scan).*

Even if alignment, due to the manual input required, is still the most time-consuming part of processing (along with range map cleaning), after some practice, a user can obtain optimal results with a few hours of manual work. The final alignment accuracy is on par to the one obtainable using markers. This alignment method provides data on the residual errors of the single cloud matching (local error of the alignment of each cloud with every other overlapping), and on the final residual error (after the global optimization and bundle adjustment). The first value varied in the dataset between 1mm and 5mm, while the final residual was below 2mm.

After all the scans have been aligned, the resulting point cloud can already be used as a metric documentation, for taking measurements, or for visualization purposes (Fig. 4).

However, to fully exploit the visual potentiality of the data, it is necessary to transform this point-based representation into a triangulated surface. This will provide a much more

The process of computing a triangulated surface from a series of individual scans is called merging. This is a completely automatic process, where the user has only to decide the final geometric resolution of the output model.

MeshLab does implements various algorithms for the merging step, able to accurately generate triangulated surfaces starting from pointclouds or triangulated range scans.

Given the extent of the dataset, it is impractical to think of creating a single triangulated model for the entire area. This will require an extremely long computation time, a lot of memory and produce a model so complex to be unusable. Moreover, given that each part of the dataset has specific coverage and geometrical characteristics, using a single set of parameters for the entire extent would reduce the amount of usable detail.

On the other hand, the covered areas are divided in rooms, and this geometrical subdivision is also a logical one, since it reflects the way the houses have been designed and built, and the way they will be studied and measured.

It made sense, then, to reconstruct independently the various rooms, making the merging step much easier, but still producing a coherent geometry for the entire dataset (thanks to the properties of regularity of the merging algorithms) (Fig. 5).

The final step of the processing is the color mapping. The produced triangulated model does faithfully represent the geometry of the building, but not its appearance. For this reason, a series of photos have been acquired in order to provide an accurate description of the appearance of all the walls of the houses.

To perform color mapping, it is necessary first to align the photos onto the 3D model: this is obtained by estimating the camera parameters associated to each image.

These parameters describe the position and orientation (extrinsic parameters) and internals of the camera, like sensor size, lens distortion and focal length (intrinsic parameters) at the moment of the shot. By obtaining these parameters it is possible to reconstruct the perspective projection that created the photo. This opens up two possibilities: being able to see the 3D scene trough the same camera that took the shot (thus, exploring the photographic dataset spatially), and project back the color information onto the 3D model (to generate color mapping).

This alignment has been done inside MeshLab using a user-friendly approach, based on Mutual Information (Corsini et al. 2009). This is based on the calculation of a statistical measure of correlation between the image and a rendering of the model, and has a very simple interface, making the photographic alignment easy for the user.

The photos aligned in this way may be spatially-explored directly in the 3D space, instead of browsing a folder on the disk, looking at the photos like see-through transparencies suspended in space or projected one by one onto the 3D surface.

An interesting possibility offered by this strategy is to use also unconventional images, like photos with annotations, historical photos, hand drawings or sketches or even near-visible lighting photos (ultraviolet, multispectral, infrared, thermography, etc.). This possibility of spatial exploration of the georeferenced photographic set is a powerful tool to effectively browse a collection, and has multiple uses in the documentation and study of this dataset.

However, since our aim was to obtain photorealistic 3D models, we proceeded to map the color from the images onto the triangulated surface. To this aim, MeshLab offers different color mapping tools to better cope with the different needs of the various datasets. By using the color data from the calibrated images, it is possible to generate detailed, artifact free per-vertex color encoding, or create a texture map.

We employed both solutions, in order to produce high resolution 3D models with per-vertex color for study, documentation and measurement purposes, and lower resolution models with texture mapping, for real-time visualization (Fig. 6).

This final step is still ongoing, given the amount of images to be mapped, and the extent of the dataset.

6. Virtual Reality

During the autumn 2014 an exhibition in Stockholm about the insula V,1 will be organized. In that occasion a Virtual Reality system, developed using the results of this work, will be prepared in

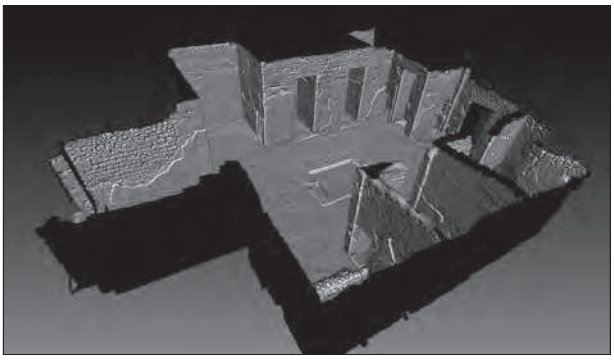

***Figure 5**. One of the rooms (the atrium of the House of the Torello di Bronzo), reconstructed as a triangulated surface.*

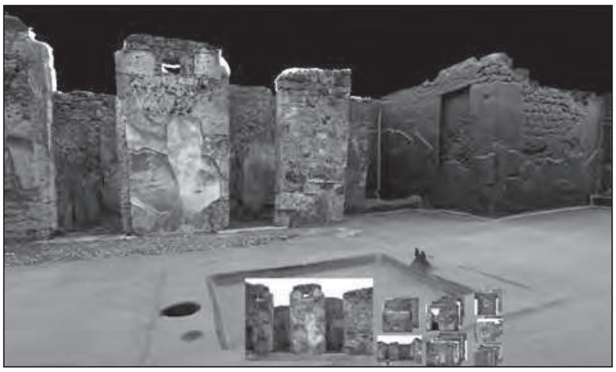

***Figure 6**. The aligned photos browsed spatially, over the geometry of one of the rooms.*

order to show to the public the investigated area and the results of the virtual interpretation of the ancient structures. Despite the data have not been entirely processed and more than half insula has not jet been acquired, we are already discussing the possibility to build a virtual reality systems to explore -through the use of devices that allowed natural interaction such as Microsoft Kinect-the insula and having an easy understanding of the connection between the interpretation of the environments and the archaeological research developed during these years.

7. Online Publishing

One of the focal points of this project was the objective of making the entire dataset available over the net.

The web platform has acquired through the years the ability to efficiently incorporate and deliver many different kinds of digital data such as still images, videos and sound. With respect to these additions, the management of 3D content through the web still presents many problems.

HTML 5 introduced, as a new part of the standard, the WebGL component. Using this component, it is possible to display 3D content directly inside a webpage, without the use of browser plugin.

However, WebGL alone is not enough to answer the needs of people interested in web 3D visualization; following the design philosophy of OpenGL, WebGL is a very low-level API. It is therefore necessary, to ease the use of this technology, to introduce a library able to wrap the most low level function, while giving the user the ability to dive into implementation details, when needed.

To do so, we chose SpiderGL (Di Benedetto et al. 2010), which is JavaScript library designed to provide an easily usable but powerful wrapping to the lower-level WebGL functions.

The idea of this library is to provide a complete wrapping layer to WebGL that, while hiding the details through higher-level functions, allows full access to the native API. To ease the creation of graphical applications, SpiderGL provides a series of classes and functions that cover the various aspects and levels of implementation of a modern computer graphic application. Using this technology, it has been possible to create a visualization scheme for the web platform, able to display the 3D models of the various rooms in a web page, with a simple user interface for the 3D navigation.

This visualization scheme uses, thanks to the functionalities of SpiderGL, a multiresolution model. Multiresolution is a way to encode the three-dimensional data in such a way that, for each part of the object, the geometry is available at different level of details. During rendering, for each part of the model, it is chosen the optimal resolution, the better trade of between the visible detail and the available resources, to ensure. This makes possible to show in real time very complex 3D models, composed by millions of triangles.

Another interesting feature is that a multiresolution model, being composed by small chunks of data, it is extremely well suited for network transmission. Exploiting this property, the visualization code is able to effectively stream the data from the server, resulting in a very short startup time (the model is almost immediately ready for the user) and a reduced network load (only the used data is transmitted).

The idea is to start from a standard navigation paradigm, based on plans and prospects, which exploits the natural room-based environment. This navigation method is already used in the current version of the project website. With it, the user can access datasheets of the individual rooms, making possible to visit, room by room, the entire dataset. Adding to this hierarchical visit, at the level of the rooms, a link to explore the corresponding 3D model of the room will make the integration of 3D data easy and accessible.

While the visualization and exploration part is already working, we are now adding more advanced features. The prototype of the visualization tool will be made accessible online from the website of the project (http://www.pompejiprojektet.se/insula.php) before the end of the year.

The idea, for the next step, will be to enrich the interactive visualization by adding the possibility to take measurement, pick points and save the current view as a bookmark or as an image. This can be done easily using JavaScript, and the early tests of this capabilites have been promising.

A more complex option, which will require server-side support, is the creation of high-resolution snapshots using the complete dataset (and not only the current room), or more sophisticated documentation like cut-through sections or maps views. It is easy, in the Javascript visualization scheme, to define the parameters of such documentation using a simple interface. However, it will then be necessary to forward the request to the server, which will compute the required data on a separate process and, later on, delivered to the users.

This tool, once complete, will enhance the possibilities for the analysis of the documentation of the archaeological remains, proposing a starting point for additional actions like annotation, complex interaction, collaborative work.

8. Conclusions

In this paper, we presented the first results of the scanning campaign of the Insula V 1. We described the aim of the campaign, and the technical choices taken during the planning, execution and data processing.

More than the description of specific technical details and a series of figures describing the dataset, we do believe the main goal of this presentation is to justify technical choices in the framework of an articulated documentation and study project.

We showed how, with a clear idea of the needs of the project and the aim of effectively use all the collected data, we set-up a complete software pipeline for the processing and visualization of this large three-dimensional dataset.

We believe that the integration on the web platform is an important and almost mandatory feature for a modern documentation project, to ensure ample access and easy data interaction.

We plan for this next fall a new acquisition campaign that, if it proves to be as fast as the one here described, could succeed at completing the sample of the entire Insula.

The development of the web-enabled visualization component will continue and, hopefully, the new measuring features will be ready when the final, complete insula dataset will be available for the scholars.

References

Balzani M., N. Santopuoli, A. Grieco, and N. Zaltron. 2004. "Laser Scanner 3D Survey in Archaeological Field:the Forum of Pompeii." In *International Conference on Remote Sensing Archaeology, Beijing, October 18–21*, 169–175. Beijing: Joint Laboratory of Remote Sensing Archaeology.

Brizzi M., S. Court, A. d'Andrea, A. Lastra, and D. Sepio. 2006. "3D Laser Scanning as a Tool for Conservation: The

Experiences of the Herculaneum Conservation Project." In *Proceedings of the 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage VAST*, edited by M. Ioannides, D.B. Arnold, F. Niccolucci, K. Mania, 111-117. Nicosia: Eurographics Association.

Callieri, M., N. Dell Unto, M. Dellepiane, R. Scopigno, B. Soderberg, and L. Larsson. 2011. "Documentation and Interpretation of an Archeological Excavation: an Experience with Dense Stereo econstruction Tools." In *VAST The 11th International Symposium on Virtual Reality Archaeology and Cultural Heritage*, edited by F. Niccolucci, M. Dellepiane, S. Peña Serna, H.E. Rushmeier, L.J. Van Gool,, 33-40. Prato: Eurographics. http://vcg.isti.cnr.it/Publications/2011/CDDSSL11.

Cignoni, P., M. Callieri, M. Corsini, M. Dellepiane, F. Ganovelli, and G. Ranzuglia. 2008. "MeshLab: an Open-Source Mesh Processing Tool." In *Proceedings of Eurographics Italian Chapter Conference*, 129-136. http://c2.etf.unsa.ba/file.php/71/ZavrsniRadovi20092010/SelmaRizvic/tema3.doc.

Corsini, M., M. Dellepiane, F. Ponchio, and R. Scopigno. 2009. "Image-to-Geometry Registration: a Mutual Information Method exploiting Illumination-related Geometric Properties." *Computer Graphics Forum* 7 (28): 1755-1764 .

Di Benedetto, M., F. Ponchio, and F. Ganovelli. 2010. "SpiderGL : A JavaScript 3D Graphics Library for Next-Generation WWW." *Library* 1 212: 165-174. http://portal.acm.org/citation.cfm?id=1836075.

Dell'Unto, N., F. Galeazzi, and M. Di Ioia. 2006. "Via Flaminia project: relief and post processing data techniques." In *Proceedings of the "From space to place" Conference, Rome, Italy, 4-7 December*, edited by S. Campana and M. Forte, 52-60. Oxford: Archaeopress.

Dylla, K., P. Müller, A. Ulmer, S. Haegler, and B. Fischer. 2009. "Rome Reborn 2.0: A Framework for Virtual City Reconstruction Using Procedural Modeling Techniques." In *Proceedings of Computer Applications and Quantitative Methods in Archaeology*, edited by B. Frischer, J. Webb Crawford and D. Koller, 62-66. Oxford: Archaeopress.

Forte M., N. Dell'Unto, P. Di Giuseppantonio Di Franco, F. Galeazzi, C. Liuzza and S. Pescarin. 2010. "The Virtual Museum of the Western Han Dynasty: 3D Documentation and Interpretation." In *Space, Time, Place, Third International Conference on Remote Sensing in Archaeology, 17th-21st August 2009, Tiruchirappalli, Tamil Nadu, India*, edited by S. Campana, M. Forte and C. Liuzza. Oxford: Archaeopress.

Hori Y., O. Ajioka, and A. Hanghai. 2007. "Laser Scanning in Pompeian City wall: A comparative study of accuracy of the drawings from 1930s to 1940s." In *3D-Arch'2007 3D Virtual Reconstruction and Visualization of Complex Architectures,* edited by F. Remondino, S. El-Hakim. Zurich: International Society for Photogrammetry and Remote Sensing.

Leander Touati, A.-M. 2010. "Water, well-being and social complexity in Insula V 1. A Pompeian city block revisited." *Opuscula* 3: 105-161.

Poehler E., and S. Ellis. 2012. "The 2011 Season of the Pompeii Quadriporticus Project: The Southern and Northern Sides." *Fasti On Line Documents & Research* 249. Accessed January 2013. http://www.umass.edu/classics/PQP.htm.

Rusinkiewicz, S., and M. Levoy. 2001. "Efficient variants of the ICP algorithm." In *Proceedings Third International Conference on 3D Digital Imaging and Modeling*, 145-152. Quebec: IEEE Computer Society 2001. http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=924423.

Staub, T. 2009. "Decorative effects and room functions. Evidence of thresholds studied in the residential quarters of Insula V 1, Pompeii." *Opuscula* 2: 205-218.

Stumpfel J., C. Tchou, N. Yun, P. Martinez, T. Hawkins, A. Jones, B. Emerson, and P.E. Debevec. 2003. "Digital Reunification of the Parthenon and its Sculptures." *VAST*: 41-50.