Digital reconstruction and visualization in archaeology

Case-study drawn from the work of the Swedish Pompeii Project

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Abstract— *The Swedish Pompeii Project started in 2000 as a research and fieldwork activity initiated by the Swedish Institute in Rome. The aim was to record and analyze an entire Pompeian city-block, Insula V 1. Since autumn 2011 a new branch of advanced digital archaeology, involving 3D reconstructions and documentation methods, was added to the project agenda. The insula was completely digitized using laser scanner technology and the raw data were employed to develop different research activities in the area of digital visualization. This paper presents the recent results of the 3D interpretation of the house of Caecilius Iucundus. This research activity was developed employing a large variety of historical and archaeological sources such as: archaeological reports, historical image documentation (printed as well as in edited material) and analysis of the in situ structures. This work was characterized by the experimentation of a new workflow of data development, where the elaboration of the interpreted structures took place directly in virtual space, using the scanned model as geometrical reference. This method easily connected all the historical and archaeological sources collected for the interpretation, opening a new discussion about different possible interpretation of the house. Moreover, a Cave Automatic Virtual Environment (CAVE) was used in different occasions as platform where the different hypotheses could be discussed in the context given by the actual state of the archaeological structures. The use of an accurate and resolute replica of the site as a backdrop for the virtual reconstruction allowed a high level of control on the proposed hypotheses during the interpretation process. This study enabled the acquisition of new and important information about the house, thus, bringing a significant contribution to the archaeological analysis of Insula V 1, suggested as pilot project for wider use.*

Keywords— Laser Scanning, Virtual Archaeology, Digital Reconstruction, Data consistency, Interpretation

I. Introduction and Goals

A. The Swedish Pompeii project : Contents

An appeal from the Antiquarian authorities of Pompeii to the international scientific community for aid to document the rapidly eroding ancient city (mostly unearthed hastily in insufficiently recorded excavations), gravely undermined by an earthquake in 1980, explains the decision made to start the Swedish Pompeii Project. While the idea to make a whole city-block our study object – for documentation and for analysis – was bold, because of the size of the area and the number of structures to be covered, it was also necessary if we were going to add new experiences and results to an old research field.

Two principles ruled the projected research: the wish to obtain contextualization by means of quantification – meaning that a special interest should be turned towards frequently recurring features and features working on either side of major dividing walls – and to retrace changes in livelihood by means of detailed study of all alleged estates, modest as well as rich.

Insula V 1 was chosen as study object because of its varied composition. Situated in the crossing of two of Pompeii's main thoroughfares, not far from the highest positioned gate of the city and the aqueduct inlet, insula V 1 had a privileged position both for commercial activity and for stately living. In AD 79 it contained an inn, a bakery, three wealthy residences, among which two double atrium houses, and nineteen shops or workshops- the latter forming its street front face towards the two arteries.

B. Results

The results obtained go far beyond what was initially expected. Study of the standing remains has yielded history of urbanization of this city-block, whereas investigation of the floor levels revealed intricate system of water lines, drains and cisterns, informing both on social dependency and on the ancient approach to the use of the natural resources [1].

A last point of our research concerns the archaeological praxis. Considerable effort has been invested in assessing and trying different techniques in search for efficient and preferably also cost reducing methods and formats for documentation and report. Ultimately, this effort also opens new ways to approach the analysis of ancient life.

The possibility of making scientifically based reconstructions in 3D of ancient milieus entail a new way to relate to ancient life, focusing human experience and sensitivity rather than building practice and chronology; to the spatial turn [2] in research effectuated approximately contemporaneously with the first 3D models, a virtual turn is now added.

Since 2011, Lund University in collaboration with the visual computing Lab, Pisa started a sub-project called Pompeii Revived, which focused on the 3D acquisition of the standing structures of insula V 1. The results of this work (still in progress) will be used to analyze and document at a micro and macro level the spatial relations that characterize the different buildings of the Pompeian city block (Fig. 1).

More specifically, the processing of the data will follow two different paths, one purely technical, the other technical and interpretative. A first aim is to make all structures that compose the insula available in high resolution detail rendering via the web. The second aim is to investigate how the use of such documentations may influence the archaeological effort to define the original appearance of the buildings that composed the insula.

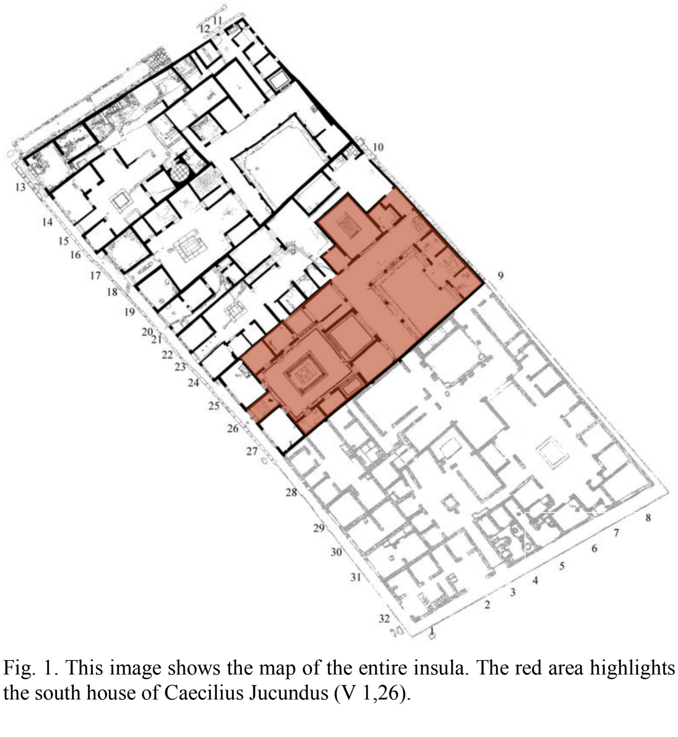

Fig. 1. This image shows the map of the entire insula. The red area highlights the south house of Caecilius Jucundus (V 1,26).

II. ACQUISITION CAMPAIGN

The acquisition campaigns took place during October 2011/2012; for each season a team of six people (three from Sweden -Department of Archaeology and Ancient History- and -three from Pisa –CNR-) started and completed the acquisition campaign of the insula employing two phase shift laser scanners: a Faro Focus 3D and a Faro PHOTON 120. Despite the similar characteristics in the quality of the data produced by each instrument, their different characteristics in terms of dimensions affected the way these tools have been employed in the field. The Faro focus 3D scanner is less heavy and easier to employ in delicate and unsteady areas such as: on floor mosaics or platforms, instead the Faro PHOTON 120 is more robust and steady and can be used more easily to acquire high structures from scaffolding. The employment of two instruments allowed a more efficient data acquisition campaign, since both teams could work at the same time in different parts of the insula [3].

Before the beginning of the campaign an acquisition strategy was established. Due to the complexity of the geometrical features that characterize the insula markers were excluded from the process and instead a manual alignment of the point clouds was executed. The complete acquisition of the insula, plus the streets that surround it was performed in 7 days (3 days 2011 and 4 days 2012), with a total of 310 scans having been recorded (Fig. 2).

The final laser scanner dataset covered around 1330 (620 + 710) square meters, acquired using 310 scan positions, each scan was performed with a 360 degree coverage, with a dense sampling rate of 1cm at 10 meters distance.

Despite the efficiency of the instruments in acquiring most of the structures, we decided to employ Computer vision Techniques to realize 3D models of complex features such as the water pipes or part of the workshops.

The use of this technique allowed the generation of very high-resolution 3D models employing a digital camera. This technique proved to be extremely efficient in producing accurate 3D models. The data in this project has been gathered and processed following a previously tested methodological approach [4], and obtaining similar quality in the resulting geometries.

Fig. 2. Point cloud of the Insula acquired with the Faro laser scanner

III. Post processing

The whole post processing process was carried out inside MeshLab [5], an open source software for the visualization and processing of 3D models. MeshLab is oriented at the manipulation and processing of large triangulated surfaces and point clouds. MeshLab is freely available, distributed under the GPL licensing scheme and it is available for all the major platforms (Windows, MacOS, Linux).It covers all the steps of the 3D Scanning pipeline, including the procedures for color projection from set of uncalibrated images.

As a first step, we aligned all the captured data in the same reference space. MeshLab allows the use of a Geometric Alignment filter based on the ICP algorithm, which works on triangulated surfaces (like in many analogous tools) and on raw point clouds.

The possibility to work directly on the point dataset represents a great advantage in terms of required memory and time, since it does not require the generation of polygons.

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 had a variation in the dataset between 1mm and 5mm, while the final residual was below 2mm (Fig. 3).

After the alignment, a triangulation of the surfaces was performed. The process of computing a triangulated surface from a series of individual scans is called merging. This is an automatic process, where the user has the possibility to establish the final geometric resolution of the output model.

MeshLab does implement various algorithms for the merging step, able to accurately generate triangulated surfaces starting from point clouds or triangulated range scans. Considering the large number of information acquired, it was unreasonable to think of creating a single triangulated model for the entire area. This would have required an extremely long computation time.

Moreover, considering the specific coverage and geometric characteristics that characterize each part of the dataset, the use of a single set of parameters for the entire extent would have decreased the amount of detail.

For this reason we decided to reconstruct the various rooms independently, making the step of merging the single scans lighter. This strategy - thanks to the properties of regularity of the merging algorithms- allowed producing a more coherent geometry for the entire dataset.

The final step of the processing was the color mapping. For this reason, a series of photos was acquired in order to provide a description of the walls that compose the insula [6].

In order to perform color mapping, an alignment of the pictures onto the 3D model was required: this was gained by estimating the camera parameters associated to each image. The alignment has been done inside MeshLab, using a user-friendly approach, based on Mutual Information [7].

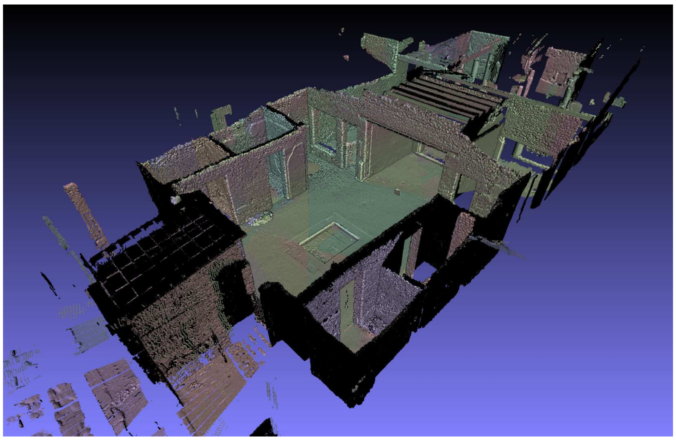

Fig. 3. Some of the range scans from the Insula, aligned inside MeshLab

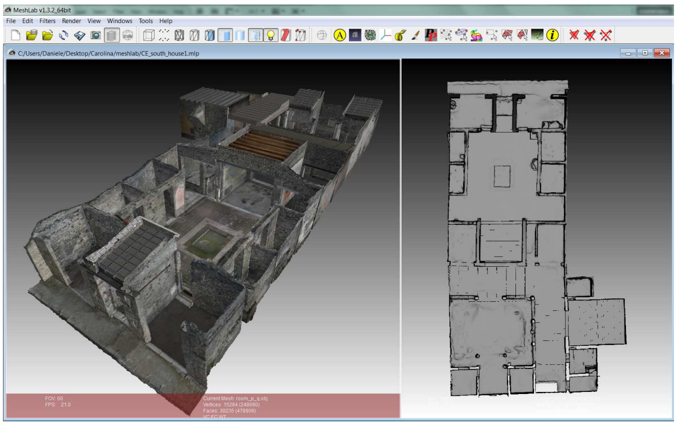

Fig. 4. A snapshot of the final colored model

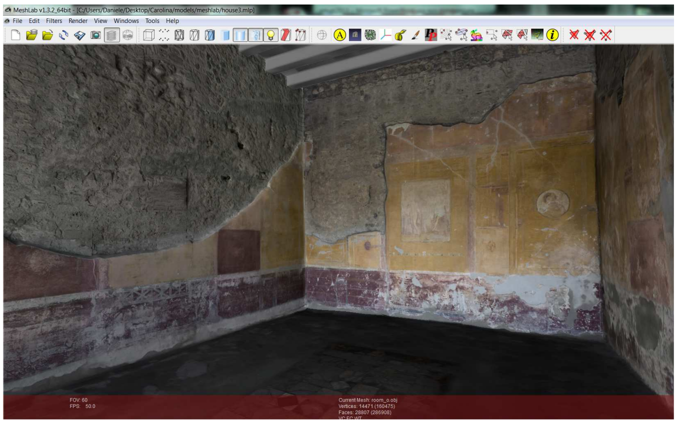

Fig. 5. detail of a colored mesh

IV. 3D Interpretation and Reconstruction

A. Methodology

The reconstructive workflow (from fieldwork to the 3D interpretation) was carried out taking into account the results of the theoretical and methodological discussion built so far around the definition of Virtual archaeology.

In the last years a lot of efforts have been spent in defining guidelines for the implementation of workflows to construct virtual interpretations, in specific documents such as the London Charter (LC) and in the Principle of Seville (PS) [8] [9], that had the purpose of supporting and promoting interpretation and simulation based on a theoretical and multidisciplinary scientific approach [10].

The possibility to have a direct access to a large number of different sources and the opportunity to acquire the archaeological structures employing a number of different acquisition technics, make insula V 1 a perfect case study where experimenting new workflows for the development of virtual interpretation. The southern part of the double atrium house that belonged to the "banker" Lucius Caecilius Iucundus (floruit in the 40s and 50s CE) has been chosen for the full virtual reconstruction described below. The reconstruction project has been carried out in four steps (Fig. 6):

- Data Analysis: all data previously acquired during the field campaign (plans and photographs housed in the, archaeological database: www.pompejiprojektet.se, scanned model), were analyzed and put in relation with a different typology of information such as: 19th and early 20th century water colors and photographs (published as well as unpublished material).
- Discussion: several experts have been involved in order to discuss different interpretation hypotheses. The discussion has been supported by the employment of a 3D platform capable of merging the 3D reconstruction and the scanned model in the same 3D space.
- Modeling: in line with the interpretation process, a 3D model was created. In order to map the evolution of the virtual interpretation, several 3D layers were saved together with the final model.
- Validation: the models were examined and approved by the scientific experts.

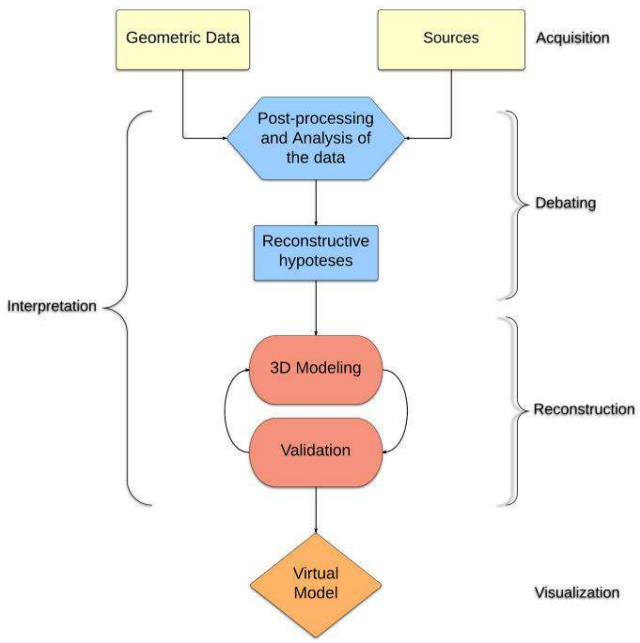

Fig. 6. Work performed in order to develop the virtual interpretation of the insula

B. Prototyping the reconstruction

The construction of a prototype of several types of archeological and geometric data was organized analyzed and interpreted with the support of experts from Lund University.

A hypothetical reconstruction was created, based on the historical, archeological and geometric data acquired during the survey campaign, also taking into account the constructive and aesthetic rules of the last life period of the house (first half of the first century CE). The virtual hypothesis was created with markers indicating different levels of consistency, in order to map how the different reconstructed structures that compose the house relate to the archaeological evidences and other available sources.

The consistency criteria adopted in this work was based on the experience gained during the development of previous experiences conducted by the authors on similar case studies [11] [12] [13] [14]:

- Reconstruction by "objectivity" or data analysis: The reconstruction is based on objective and incontrovertible evidences such as the 3D model coming from the laser scanning survey, the photogrammetry session and the historical and archaeological sources.
- Reconstruction by "testimony": The reconstruction is based on elements that are no longer available on site, but verified from old documents and pictures. One of the most powerful sources used in this project, was the "model of Pompeii" in the Archaeological Museum of Naples. This model, built during the second half of the XIX century, represents a 1:100 scale replica of the town and it shows the status of the buildings close in the XIX century, which means in the case of most building of insula V 1, at a date close to their rediscovery. Even though the model is not geometrically reliable, it represents a valuable reference for what concerns the frescoes and mosaics, which are no longer preserved in situ. In particular, the pictorial elements reconstructed in the physical model have been important sources of information to virtually re-build the decorative outfit of the house.
- Reconstruction by "deduction": Formal characteristics of the buildings, or the repeated patterns (eg: the partially ruined columns of the peristyle were completed by reference to the complete ones) have been used to re-construct part of the houses no more available. In other cases the information about missing parts of the structures were deducted by the geometrical matching between existing and missing elements such as cuttings in the thresholds, suggesting former presence of door hinges, or the array of beam holes in the wall, suggesting a second floor sustained by beams.
- Reconstruction by "comparisons": The reconstruction is based on direct comparisons with similar archaeological remains found in the surrounding area (eg. the roofing of the triclinium "O" was made after comparison with the suggested reconstruction to be found in Casa del Menandro)

- Reconstruction by “analogy or styles”: The reconstruction is based on analogy with a well-known and recognizable theoretical model such as Roman modules and wall painting styles. Despite the possibility of only having partial objects, the reconstruction was carried out by referring to widespread standard elements such as: mosaics, frescoes, doors and wooden elements, corner masonry and capitals.
- Reconstruction by “hypothesis”: This is the most complex process of the reconstruction. Hypotheses are based on conjecture such as roofing, height of the ceilings etc.

During this work each level of consistency has been connected with a level of certainty, thus producing a 3D reconstruction characterized by several “values of reliability” in accordance with the consistency criteria presented above (Fig. 9 - Fig. 10 -Fig. 11 - Fig. 12).

C. 3D Modeling of the structures

Once the interpretative hypotheses were settled, a first prototype of the reconstructive model was realized. The reconstruction process was developed using Autodesk 3DStudio Max; this instrument is a powerful 3D computer graphics software for making 3D animations, models, and images.

The modeling work was tackled by using the scanned model of the insula as a geometrical reference for the reconstruction. This approach allowed great accuracy and control during the technical development of the structures. Moreover, the possibility of displaying the two models overlapping in the same virtual space made instant comparisons and real-timed visual feedback possible (Fig. 7).

The use of such a method allowed building a 3D interpretation of the house keeping into account the original architectural irregularities and the small asymmetries that characterized that specific group of buildings. Moreover this method allowed keeping a high control on the walls that displayed anomalies generated by earthquakes or that occurred after the eruption (e.g. irregularity in the floors) and eventually to correct them in the virtual interpretation.

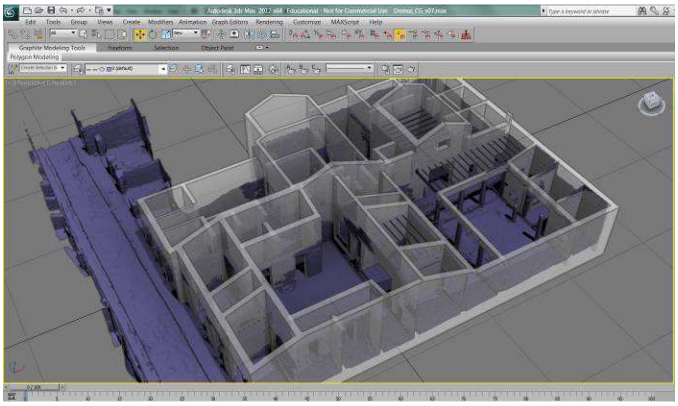

Fig. 7. Screenshot presenting the reconstructed structure overlapping the scanned model. Double atrium house of Caecilius iucundus.

The first 3D prototype created was used as a discussion tool for the development of further hypotheses of the space. The possibility to geometrically validate different interpretations was a crucial instrument to define the space. In this project, the 3D models coming from the 3D scanning were employed not just as the final result of an interpretation process, but more as a scientific tool to define and test theories and hypotheses.

In order to enhance the discussion about the interpretation of the house, we visualized the system into a Cave Automatic Virtual Environment (CAVE). A CAVE is an immersive virtual reality environment delimited by walls made of projector-screens. It was used in the project as a collaborative immersive three-dimensional environment, where visualizing and discussing the virtual structures of the house could take place. The use of such a visualization tool allowed archaeologists to discuss the different interpretations standing inside the scanned models of the house. (Fig. 8).

An interesting example on how this interpretation method contributed to understand and reconstruct the space is put forth by the discussion concerning the north side of the Peristyle of Casa di Caecilius Iucundus. After a visual analysis of the structures acquired by the laser scanner, experts became aware that the large triclinium “O”, opening onto the peristyle and initially interpreted as a two floor structure, was probably characterized by a tall room crowned with a high ceiling and lit by a big window situated on a level above the roofed portico of the peristyle.

After several tests performed with the goal to find a reliable arrangement of a second floor, this conclusion was accepted.

An analysis of the load–bearing structures and of the archaeological marks (beam holes, traces of vaults, splits etc.) was performed on the 3D model generated with the scanner. This work allowed estimating position and typology of the original architectural elements as well as of second floor plans, making informed inferences about the typology of the ceiling (i.e.: tunnel vault or paneled wooden ceiling), the gutter’s line and the shape of the roofs themselves.

Fig. 8. A group of archaeologists discussing the structures of the house in the CAVE

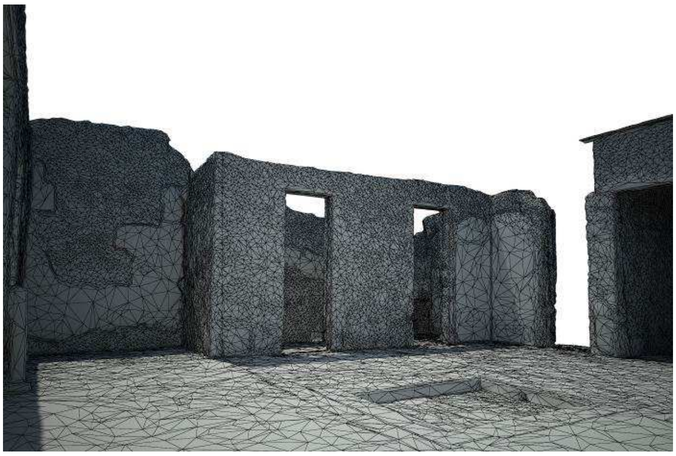

Fig. 9.

Fig. 10

Fig. 11

Fig. 9 – 10 – 11. The images above show the relation between the 3D models realized with the laser scanner and the virtual interpretation of these remains. On top: the solid model of the Atrium visualized in wireframe model after optimization and polygons decimation; below: the solid model of the Atrium with color information after "color projection procedure"; the virtual interpretation of the Atrium: geometry and decoration are reconstructed according to consistency criteria.

Fig. 12. Different level of consistency adopted in the reconstruction of the atrium of Casa di Caecilius Iucundus

Once generated the geometry, the models were "unwrapped" and mapped with textures created "ad hoc" in 2D computer graphic software. The use of high resolute photographic material realized by the Swedish Pompeii Project allowed obtaining enough information to partially restore the original decoration of the house.

The frescoes were digitally restored and re-located in their original positions. This approach proves how the digital reconstruction was not a one-way work but a recursive connection and dialogue between experts and modelers, where the validation aroused new debates and hypotheses and made researchers aware of new solutions and need of more study.

V. Conclusion and Further Development

This work allowed gaining a deeper knowledge on the complex process of virtual interpretation of archaeological structures. It has offered new ways to assess and furnished a new discussion method based on the employment of a large amount of different typologies of data, visualized and discussed in the same virtual environment.

The results of this project are proving how the exploiting of 3D digital models exponentially increases the quality of the interpretation through the creation of a visual language capable to bring together experts and specialists with different backgrounds.

This effort also opens new ways to approach the analysis of ancient life. The possibility of making scientifically based reconstructions in 3D of ancient milieus entail a new way to relate to ancient life, focusing human experience and sensitivity rather than stop investigation after the basic discussion on building practice and chronology. The ambitious project of reconstructing Insula V 1 in Pompeii will continue following two objectives: a scientific one and a communicative one.

The scientific objective aims at elaborating software that permits links from the presentation of 2D photographs that structure the web publication of the Swedish Pompeii Project (www.pompejiprojektet.se/insula.php) to the 3D model and thus make the integration of the model into the web platform.

The 3D model would be a perfect complement to the already existing documentation since with a simple interface could allow the user to obtain any desired measure within the modeled space. It may also be developed into a new and fast means to document complex areas, whole urban sites such as Pompeii. The Pompeii Revived Project is actually implementing ways that allow navigating the 3D model and, at wish, switch directly from the model to the documentation provided by the web publication.

The communicative objective is focused on visualization and dissemination issues. The final 3D models, both the scanned one and the reconstructive one, will be addressed to explore different way of communication. In particular a real-time immersive exploration system of the virtual archaeological environment will be developed in 2014 and shown in a public exhibition in Stockholm during autumn and in Lund in spring 2015.

The system will allow the public to visualized and navigate the virtual archaeological sites into a CAVE, to explore the architecture as it is today (the ruin) and the potential reconstruction (as it may have been in the days of Iucundus). In particular we will focus on the problem of the "transparency of the data" to non-expert users (Fig. 13).

Usually data and criteria used to get the reconstruction remain hidden to the general public and sometimes even to the scientific community. Thus they can only reach a vague awareness of the entire work that has been done as well as on its trustworthiness.

Conversely, in the CAVE, three different layers of exploration (the Insula as it is today, the model in false colors that represent consistency levels and the model as it was in the past) and a contextual help tool, to deepen the archaeological information, will be provided to the users. In this way the user will be able to fade out from one model to another, making comparisons and examining the architecture with much more awareness.

The designing of the application and the user interface is still under development, but some promising experiment have been done in Unity 3D (a game engine).

For the navigation system, 3D models optimization (Fig. 14), natural interaction interface and 3D glasses for a full immersive experience will be experience and implemented (

Fig. 15).

Fig. 13. Simulation of the effect between the architecture of the house as it today and as it was in the past

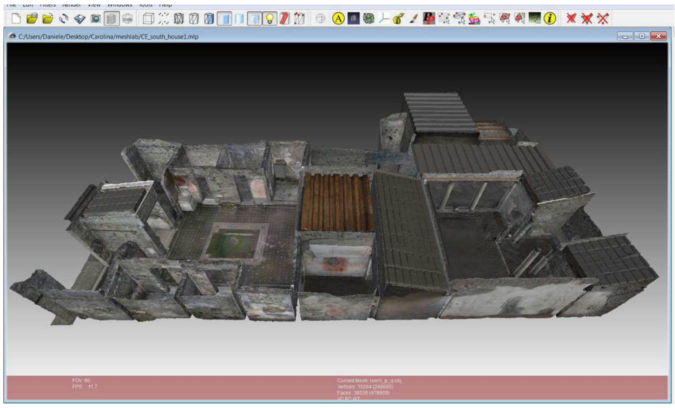

Fig. 14. The low-poly version of scanned model. The model has been optimized to be used in real-time application

Fig. 15. First test of immersive navigation of the insula into a Cave using 3D glasses

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REFERENCES

[1] A-M. Leander Touati, Water, well-being and social complexity in Insula V 1, A Pompeian city block revisited. Opuscula 3, 2010, 105-161 (http://ecsi.bokorder.se/default.aspx) .

[2] A. Laurence, “Roman Pompeii: space and society”, London: Routledge, 1994; 2007 (2nd updated ed.).

[3] N. Dell’Unto, M. Callieri, M. Dellepiane, S. Lindgren, A. Leander Touati, M., C. Larsson, “Pompei revived: Scanning Mission- insula V 1”, CAA 2012, in press

[4] M. Callieri, N. Dell'Unto, M. Dellepiane, R. Scopigno, B. Söderberg, & L. Larsson, 2011, “Documentation and Interpretation of an Archeological Excavation: an experience with Dense Stereo Reconstruction tools”. Dellepiane, M., Nicolucci, F., Pena Serna, S., Rushmeier, H. & Van Gool, L. (eds), Eurographics Association, pp. 33-40.

[5] M. Callieri, P. Cignoni, M. Corsini, R. Scopigno, “Masked Photo Blending: mapping dense photographic dataset on high-resolution 3D models”, Computer & Graphics, Volume 32, Number 4, page 464--473 - Aug 2008

[6] M. Dellepiane, N. Dell'unto, M. Callieri, S. Lindgren & R. Scopigno, 2012, “Archeological excavation monitoring using dense stereo matching techniques”. Journal of Cultural Heritage, 14, Elsevier , pp, 201-210.

[7] R. Scopigno, M. Callieri, P. Cignoni, M. Corsini, M. Dellepiane, F.Ponchio, G. Ranzuglia, “3D models for Cultural Heritage: beyond plain visualization” in IEEE Computer, 2011 Vol. 44, N. 7, p.48-55.

[8] LC 2009, London Charter, for Computer-Based Visulaization of Cultural Heritage, last accessed June 15th 2013, http://www.londoncharter.org/principles.html

[9] PS 2011, Principle of Seville, International Principle of Virtual Archaeology, last accessed June 15th 2013, http://www.arqueologiavirtual.com/carta/

[10] J.A. Barcelò, M. Forte, D.H. Sanders (ed. by) 2000, “Virtual Reality in Archaeology”, BAR International Series 843, Oxford.

[11] S. Pescarin, B. Fanini, D. Ferdani, G. Lucci Baldassari 2012, “Archeologia Virtuale a Montegrotto”, in M. Bassani, M. Bressan, F. Ghedini (ed. by), Aquae Pataviane. Montegrotto Terme ed il termalismo in Italia. Aggiornamenti e nuove prospettive di valorizzazione, Padova pp. 309-326.

[12] M. Forte (ed. by) 2008, “La Villa di Livia. Un percorso di ricerca di archeologia Virtuale”, L’erma di Bretschneider, Rome.

[13] M. Medri 2003, “Manuale di rilievo archeologico”. LaTerza Roma.

[14] D. Borra 2004, “Sulla verità del modello 3D. un metodo per comunicare la validità dell’anastilosi virtuale”, in Proceeding of eArcom 04 tecnologie per comunicare l’architettura (Ancona 20-22 maggio 2004).