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RECONSTRUCTING THE ORIGINAL SPLENDOUR OF THE HOUSE OF CAECILIUS IUCUNDUS. A COMPLETE METHODOLOGY FOR VIRTUAL ARCHAEOLOGY AIMED AT DIGITAL EXHIBITION.

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Abstract

The paper analyses the complete methodology adopted in making the computer graphic movie presetning the House of Caecilius Iucundus, Pompeii. It starts with a discussion on the philological correctness of a reconstruction based on different kind of sources, such as paintings, drawings, technical and literary texts, comparisons etc., and proceeds to explore the use of integrated 3D models (both relity-based and source-based) for improving the visitors experience. The reconstruction of the house was accomplished by means of analysing and developing the theoretical and methodological discussion faced in the last years within the scientific community. In particular, we tested the Extended Matrix (EM), a new tool able to keep track and represent the steps involved in the modelling of the source-based model, and adopted a structure that enables us to keep in consideration the different levels of certainity of our sources.

Keywords

3D movie, 3D reconstruction, virtual anastilosis, archaeological interpretation, virtual museum

Introduction

The movie about the House of *Caecilius Iucundus* was produced for the exhibition Pompeji, held at the Millesgården Museum, Stockholm, 16.9 2015-18.5 2016. The exhibition invited to experience Pompeian domestic space by means of a scenography partly reconstructing the entrance and the contiguous reception rooms, *atrium*, *tablinum* and *peristylium* of the House of Caecilius Iucundus, by means of original objects, small finds and wall decorations, found in his house and in those of his closest neighbours, and by means of the overall visualization offered by the movie.

It was based on the understanding of this house and the whole surrounding city-block (*insula* 1 of *regio* 5) resulting from the work of detailed documentation performed in annually organized field campaigns by the Swedish Pompeii Project in these premises since 2000. Both the exhibition and the city-block can be visited on line, thanks to the image data bank of the project's research platform: www.pompejiprojektet.se. Although intended for public enjoyment, the 3D movie is based on data acquired primarily for scientific purposes on site.

The entire city-block was documented by means of laser scanning in 2011 and 2012 and, finally, by a drone acquisition in 2015. After meshing, the resulting polygon structure was enriched with colours; the authentic as-is appearance of all walls and floors presented in the film, made possible when a method was developed that permitted to add digital photographs, the orthomosaics produced for the research platform, onto the polygon structure, thus creating a credible and easily recognizable 3D-visualization (Fig. 1). As further enrichment, reconstructions were produced and implemented into the model.

1. Swedish Pompeii Project and previous work

The Swedish Pompeii Project started in 2000 as on-field research activity conducted by the Swedish Institute in Rome. The goal of the project was to survey, record and analyse an entire Pompeian city-block, Insula V1. This insula was chosen as study object because it is 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. This is a privileged position both for commercial activity and for stately living. Since autumn 2011 a new branch of advanced digital archaeology, involving 3D reconstructions and documentation methods, was added to the project activities.

The insula was completely digitized using different laser scanner and image based technology and the raw data obtained were employed to develop several research activities in the area of digital visualization: one purely technical, the other technical and interpretative. A first aim is to make all structures that compose the insula available in high resolution rendering via the web[1].

A 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. The possibility of making scientific source-based reconstructions in 3D of the past, entail a new way to relate to ancient life, focusing human experience and sensitivity rather than building practice and chronology; to the spatial turn in research effectuated approximately contemporaneously with the first 3D models, a virtual turn is now added (Lawrence, 2007).

Between 2013 and 2015 the southern, most lavish part of the double atriumhouse of Caecilius Iucundus has been completely reconstructed (Dell'Unto et al., 2013). The model has been used for different scientific purposes, from architectural interpretation to visual scape analyses into 3D GIS platform (Landeschi et al., 2016; Dell'unto et al., 2015).

Another kind of outcome, mainly intended for general public but completely based on the scientific platform, is the stereoscopic movie produced for the exhibition Pompeji, held at the Millesgården, Stockholm in 2015-2016. This important event gave us the possibility to complete the reconstructive studies and produce a story-telled walkthrough of the house and its interior spaces describing in a more communicative way the function of the spaces, their articulation and decoration. In the following chapters, workflow and methodology of the movie production, from reconstruction to visual effects, will be described.

2. *3D reconstruction workflow*

The suggested as-was appearance of the house, the architecture, the colour and decorative schemes used for the interiors in the movie, results from a complex reconstructive workflow which takes into account scientific information coming from archaeological activities.

The reconstruction of the house was carried out combining the results of the theoretical and methodological discussion debated in the last years (London Charter, 2009 and Sevilla Principle, 2011) within the scientific community around the topic of virtual reconstruction and related issues. Furthermore, in this work we tested the Extended Matrix (EM)[2], a new tool for virtual reconstruction in archaeology developed within the Virtual Heritage Lab of the CNR-ITABC (Demetrescu, 2015). The project workflow has been developed as follows:

1. Preparatory work: collection and analysis of the sources produced during the archaeological activities
2. Interpretation: design of the reconstructive hypothesis, organization of the sources used and of the interpretation processes within the extended matrix.
3. 3D Modeling: creation of the reconstructive 3D model in line with the interpretation process.

3.1 Preparatory work

Before making the source-based modelling, different information was collected about the House of Caecilius Iucundus.

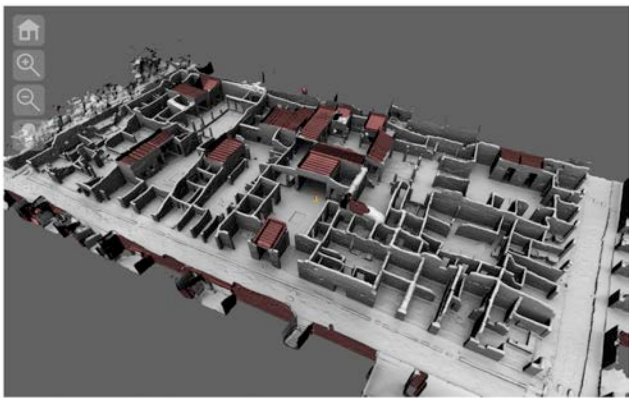

Fig 1: Digital reality-based model of the *insula* V1 acquired with laser scanning technology in three survey campaigns. (2011-2015)

[1] See http://www.3dhop.net/demos/insula/

[2] For details, see http://osiris.itabc.cnr.it/extendedmatrix/.

Different sources however mean diverging degrees of authenticity: some of them can be considered objective or even incontrovertible evidences while others hold various level of authenticity (see Tab 1).

3.1.1 Objective sources

Of highest validity are, of course, objective and incontrovertible evidences such as walls and decorations that are still preserved on site. In our case we could access to a very detailed documentation which ranges from a reality-based model of the actual house, surveyed with a TOF laser scanner (Fig. 5), to high-resolution rectified of every facade, painting and floor. To this high validity category, one may also add details removed in the 19th century and preserved as self-contained pictures in the MANN, the Naples National Archaeological Museum, such as the "Iphigenia and Tauris" removed from the tablinum and the small paintings representing "Hermaphroditos" or "Mars and Venus" found in one of rooms opening on the peristylium. The latter were easy to re-import virtually and to fit digitally in their original positions.

3.1.2 Interpreted sources

Interpreted data collect all sources in which the contents are mediated by human reasoning and can be divided as follow:

- Scientific studies

○ Data originating from archaeological documentation come next on the validity scale of the sources. Scientific reports, publications, annotations and drawings made by archaeologists and archaeological evidence found during excavation are crucial tools for designing reconstructive hypotheses.

○ Architectural studies on static equilibrium of the load-bearing structures and wall anomalies also belong to this category.

○ This kind of data were particularly useful to understand the maximum load of the walls (and deriving other information such as the presence of a second floor or the weight of the roof) or to identify anomalies generated by earthquake, erosion and repeated restoration (both before after the eruption), and to correct them in the virtual reconstruction.

- Testimonies:

○ The previous category is closely followed in veracity by information offered through photographic or artistic reproductions recording earlier states of preservation. For instance some of the most important sources for reconstructing the original colours of the frescoes was the watercolours by Vincenzo Loria, Isac Gustaf Clason and, in particular, by Luigi Bazzani, a painter notable for his prodigious technical ability of reproducing forms and colors in a very accurate way (Scagliarini, Coralini, & Helg, 2013). Furthermore the photographs from the first half of the 20th century made by the Fratelli Alinari, one of the first created among early photographic companies[3]. Another important source was the "model of Pompeii" in the Naples National Archaeological Museum, which represents a 1:100 scale replica of the town and shows the status of the buildings close in the 19th century. It is of particularly importace for its information about wall decorations, which are no longer preserved in situ. Also designs no longer extant but of known contents, because described in the early records of excavation or in travel accounts can be considered in this category.

3.2 Extended Matrix methodology for reconstruction and sources usage

The Extended Matrix (EM) is a formal language with which to keep track of virtual reconstruction processes. It is intended to be used by archaeologists and heritage specialists to document in a robust way their scientific activities. It organises 3D archaeological record so that the 3D modelling steps are smooth, transparent and scientifically complete. The Extended Matrix method, different from other approaches, starts from the assumption that every reconstructed element, labelled virtual stratigraphic unit (USV), has different "properties" (position, dimension, colour, etc.) resulting from different sources or reasonings and, this way, holding different degrees of reliability. In order to describe the elements involved in the reconstruction and also their interrelation, they are illustrated in a symbolic way in the Extended Matrix.

[3] for more information see: www.alinariarchive.it

Fig 2: Sources for the *lararium*: (**a**) Luigi Bazzani, watercolour (19th century), (**b**) Photograph taken before removal of the figured frieze (photo: the Wilhelmina and Stanley A. Jashemski archive in the University of Maryland Library, Special Collections)(**c**) After the removal of the marble frieze (photo: Hans Thorwid, Swedish Pompeii Project).

Tab. 1: Description of objective and interpretative sources used during the reconstruction

Objective sources	**Interpreted sources**		
Extant state	*Scientific studies*	*Testimonies*	*Parallels and theoretical analogy*
In-situ archaeological remains	Structural, architectural, material degradation and historical building analyses	Old photos of lost frescoes and previous state of conservation from the first half of the 20th century	On-site preserved paintings and architectural elements belonging to similar and coeval Pompeian houses such as Casa del Menandro, Casa del Torello di Bronzo etc.
3D reality based model of the house (gathered with a Faro TOF laser scanner)	Archaeological database from the SAP excavation campaigns	Watercolours made in the 19th century (Vincenzo Loria, Luigi Bazzani and Isak Gustaf Classon)	Roman modules, aesthetic rules and Pompeian decorative schemes
Removed frescoes and architectural elements whose original position is known	Published books and articles and unpublished archaeological reports	Technical drawings from 19th –20th centuries	Off-site preserved and coeval elements such as pieces of furniture from Ercolano
Orthophotos	*Non in-situ* archaeological evidence which original position is unknown	Plastic "model of Pompeii" of the Naples Nationl Archaeological Museum, late 19th century	
	Scientific discussions and debates with arcaheologists involved in the project	Historical descriptions and notes	

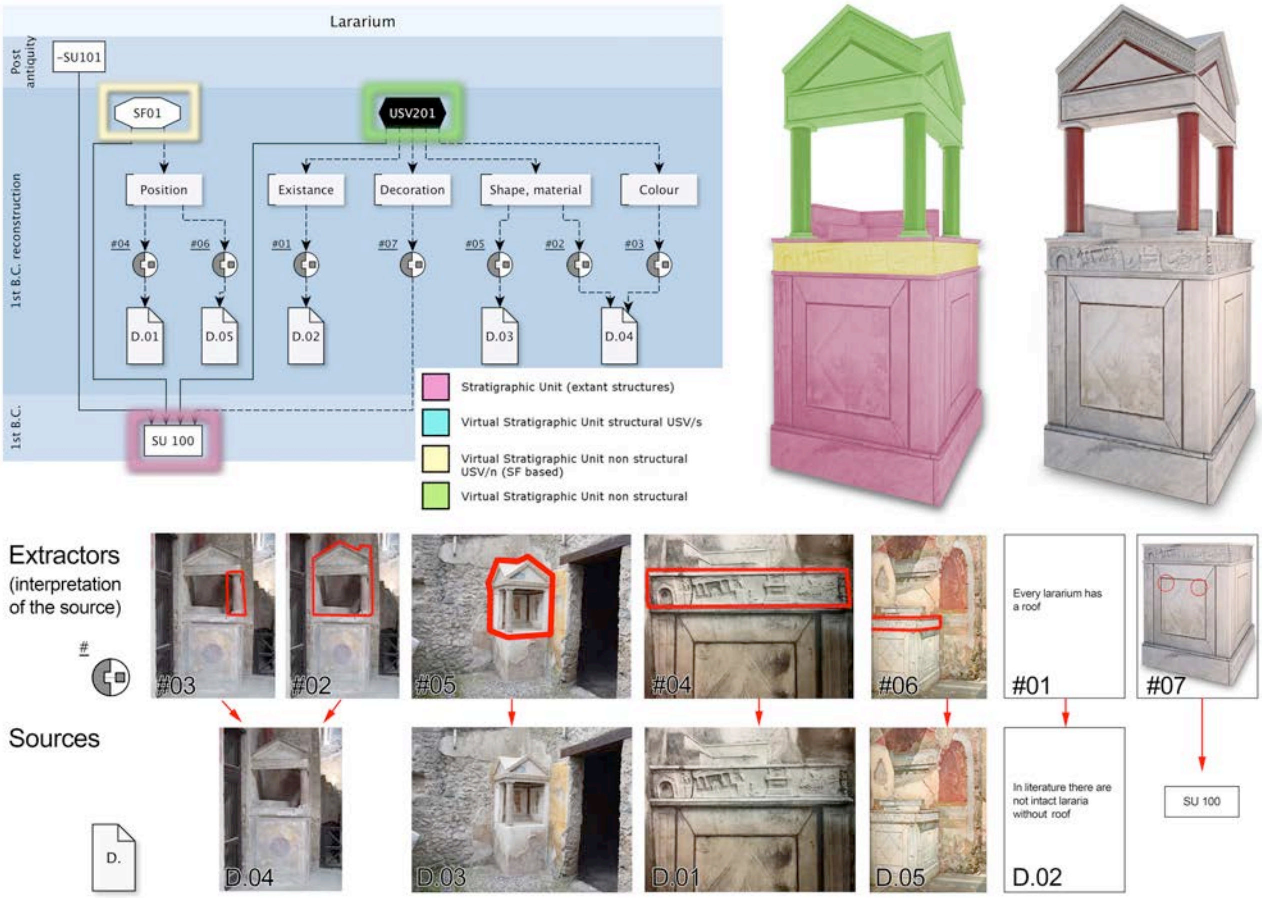

Fig 3: Reconstruction process of the lararium using the Extended Matrix approach (photos under the Creative Commons Attribution-Non Commercial License and available online at: http://www.pompeiiinpictures.com/)

Let's take the *lararium*[4] of the room B as an example of a small subset of the whole 3D reconstruction of the house. It is a quite simple representative case that can expose the steps involved in the reconstruction process using the Extended Matrix approach.

To provide a reconstructive hypothesis for the fragmentarily preserved *lararium* (Fig. 2c), some reasoning and analyses have been performed using the EM as the primary tool to represent in a symbolic way all the elements involved (Fig. 3).

First of all, a stratigraphic reading of the remains has been accomplished to highlight what is present (SU 100) and what physical evidence testify to modifications of the original shape of the artefact, such as the -SU101 (removal of the marble frieze in the 20th century).To approach what the *lararium* may have looked like in the past a series of documents was collected (Fig. 3, D.01 to D.05). We have here some images (photos and a painting) and a generalization (D.02, a special content type for the document node included in the EM).

A generalization can be considered a statement resulting from the experience of the archaeologist making the reconstruction. It is useful to make it explicit, as otherwise, this aspect of reasoning risks to remain tacit, in the mind of the researcher.

All these sources are drawn in the EM and have to be interpreted to extract information able to "populate" the property nodes of the virtual stratigraphic units (Position, Existance, etc., Fig. 3). These nodes (#01-#07), responsible for the extraction of relevant information, are the "extractor nodes". All the nodes are represented in a synoptic and synchronic way (all the elements and all the epochs of a context under the eye of the reader) and in a symbolic, human-

[4] This term meets the first time in the Scriptores Historiae Augustae and commonly means the place reserved in the Roman house at the domestic worship.

readable language (closer to the stratigraphic representation already in use in the archaeological domain).

3.2.1 Level of certainty of the reconstruction.

The main goal of the EM is to describe the elements involved in a virtual reconstruction with a special attention to their interrelation. The EM defines the degree of reliability of the reconstruction using the theory of gaps of Nicholas Steno (Hansen, 2002) as an objective criterion to develop virtual stratigraphic units (USV). USV tipology can be determined as follow:

- structural (USV/S): is directly related to a tangible stratigraphic unit (SU) that proves "the presence of an absence". An example is an interface of destruction -SU (negative Stratigraphic Unit) which affects an SU wall and testifies to the missing upper part of the wall itself.
- Non-structural (USV/N): the reintegrated element has no physical continuity with the remains and it is based only on sources (like paintings, historical maps, photos, etc.).
- Anastylosis: extant objects that are not found *in-situ*.

Given that, we can define four levels of reconstruction certainty that follow the typologies of USV (nodes) of the EM (*see* Fig. 4 and legend in Fig. 3):

1. Extant structural stratigraphic units: certain, eventually some properties may have to be integrated using sources;
2. anastylosis using *non in situ* elements: the original position only is not certain;
3. non structural stratigraphic units based on *non in situ* elements: only some properties of the original object are known;
4. non structural stratigraphic units: all the properties have to be reconstructed using interpretative sources.

3. 3D modeling

Once the first reconstructive hypothesis was settled and the extended matrix was structured and filled with the most reliable sources, a first source-based model of the Pompeian house was designed.

The three-dimensional modeling and texturing was developed using two powerful 3D computer graphics software: Autodesk 3DStudio Max and Blender.

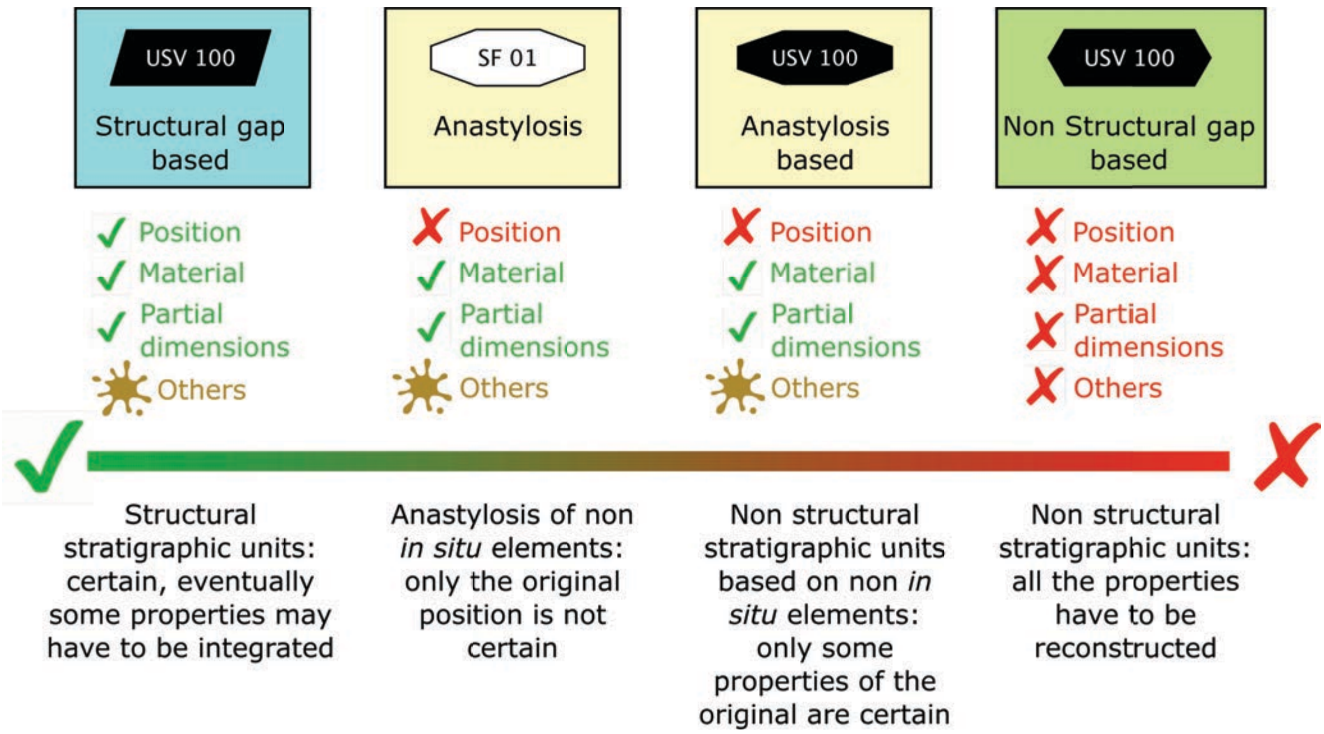

Fig 4: Level of certainty of the reconstruction, based on the Steno's theory of gaps in stratigraphy.

Fig 5: Digital acquisition with Faro (Photo by Stefan Lindgren, Humanities Laboratory)

Fig 6: Volumetric representation of the reconstructed *atrium* (room B)

The starting point was the 3D model obtained during the survey campaign in 2011 performed by the Institute of Archaeology and Ancient History and the Humanities Laboratory, Lund University in collaboration with Visual Computing Lab and Humanities Lab, CNR, Pisa. The house was acquired using two laser scanners: a Faro Focus 3D and Faro PHOTON 120. The reconstruction has been modeled on top of the 3D reality-based one and inherits its correct measures and proportions allowing great accuracy and control during the technical drawing. Indeed, the possibility of displaying the reality-based and the source-based models overlapping made possible real-time comparisons of dimension, orientation, height and stratigraphic units between objective data and its 3D reconstruction.

The scanned model is complete at least till the upper part of the doors. Lost features whose existence can be assumed by negative stratigraphic units (beam-holes, hinges, thresholds, etc) or by the logic of space (ceilings, doors, staircases etc.), were reconstructed using old engravings as reference (Fig. 3) or by comparisons with similar features still extant in other houses or following recurrent modules and structural rules (Fig. 4). These kinds of reconstructed elements belong in the USV/s (virtual stratigraphic units based on structural-physical gaps).

Simulation of materials (of paintings, flooring, plasters, woods, etc.) was the bigger effort of this project and was carried out using different types of sources. As starting point for creating textures, we used rectified photographs taken in situ. These images were employed as reference for virtual restoration of the lost or degradated colours of the frescoes or for completing geometrical patterns of damaged floors (Fig. 9). In particular, for reconstructing lost motifs and designs no longer existing but of known contents, information offered through photographic or artistic reproductions (engravings or watercolours) recording earlier states of preservation, were used.

Fig 7: Actual state of the peristylium since the restorationworks of 2009 (photo by Hans Thorwid, Swedish Pompeii Project)

Fig 8: Comparison between the grapich source used for reconstructing the peristylium and the 3D model: (left) Sole known documentation of the state of the peristylium close to its date of the excavation in 1874-75: watercolour made by the Swedish architect Isak Gustaf Clason in 1884 (Picture in possession of the Royal Swedish Academy of Arts. Photo: Linn Ahlgren); (right) Reconstructive hypothesis of the *peristylium*. 3D modeling is an useful analytic tool for interpreting use and articulation of interior spaces and for their illumination and moreover to undestand the sensual perception of ancient environment.

In case of complete absence of information due to the level of deterioration, missing details – such as the central figure of a wall decoration, could be and were integrated into the reconstruction by way of the lead offered by designs, similar in theme, position and decorative scheme, known from walls in other Pompeian houses, or from early reconstructive drawings; sometimes representing other since long deteriorated Pompeian wall decorations. In our case (Fig. 10), the source for borrowing the iconography of a mantle dancer was borrowed from a decoration copied by Wilhelm Zahn in 1898.

From a technical point, of view we created "diffuse", "normal" and "specular" textures in our model for simulating the material surface in a realistic way. The diffuse texture affects the colour and the main appearance of the objects. Normal texture simulates the small reliefs and displacements of the surfaces. Finally, the specular texture controls the roughness of the materials and the way in which light interacts with them, resulting in different kinds of material surface reflection (from rough to glossy reflections).

4. *The 3D video documentary on the House of Caecilius Iucundus*

The 3D movie is the result of a wide effort of collaboration involving personel from three Swesish institutions: Lund University, Stockholm University, and the Swedish Institute in Rome. The reconstructive model was realised by Daniele Ferdani and Emanuel Demetrescu under the scientific guidance of Thomas Staub, Anne-Marie Leander Touati, Renée Forsell and Arja Karivieri and with the support of Nicolò dell'Unto, Stefan Lindgren and Giacomo Landeschi.

The film has been presented in 3D at the Millesgården, Stockholm, exhibition Pompeji (Fig. 16), (16.9.2014-18.5.2015) where it reached the number of 65000 visitors and at the Sciences Park Museum of Granada during the Digital Heritage Expo (28.9.2015-02.10.2015).

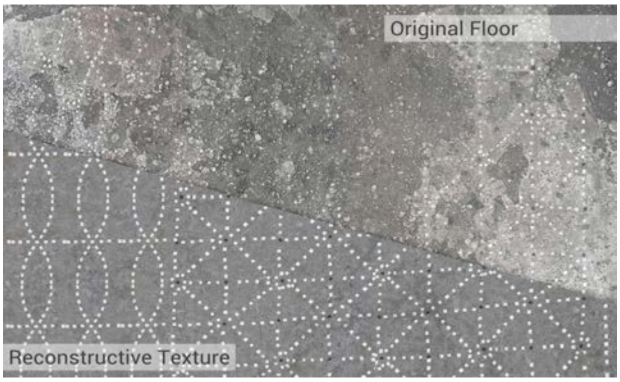

Fig 9: Virtual restoration of a damaged floor. The reconstruction is possible by cloning the recurring geometrical pattern.

Fig 10: Wall painting in one of the garden rooms of the House of Caecilius Iucundus (left): actual state of conservation and reconstruction of the decortive scheme

5.1 Communicative aspects.

The reconstructed model shown in the video provides a detailed impression of the original condition of the interior spaces. We focused on all the architectural and decorative elements that compose the house and on the way they are connected with each other trying to simulate in the most reliable way colours, space composition, light condition and visibility allowing the audience to experience a full immersion.

The immersion was furthered by the movie's combination of an as-is appearance, based on 3D-scanning and photographic material, with a suggested as-was appearance, created from a compilation of a vast amount of sources. It opens for the understanding of the relation between what can be seen today and the thoroughly researched, suggested reconstruction. In the movie this experience is enhanced through smooth alternation between the two versions.

This approach also allowed us sidestep the guidelines proposed by Frischer and Stinson, stating that the restored frescoes used in VR reconstructed models should be made in a way that makes it possible to recognize the original parts from the reconstructed one (Frischer, & Stinson, 2007).

5.2 Technical aspects about the production of the 3D stereoscopic video

A suitable "virtual set" has been created in order to shoot a video. Following the narrative voice, a set of cameras has been set up to follow and visually highlight the elements involved in the description. Different camera animation techniques have been used to have smooth movements and a pleasant effect: steadicam walk, aerial shot, arc shot, close up, deep focus, dolly zoom, pan, camera crane, top shot.

The movement of the virtual camera is directed by control points (fixed handmade positions in the 3D space) and "animation curves" that express interpolated changing position values over the time (timeline representation, *see* Fig.11 C).

All the camera animation is performed inside a RT engine (Unity 4) and the video output file is a full frame rate (30FPS) recording of the engine window (using a custom C# scripting solution). Normally a CGI animation requires several time consuming rendering passes (animatic, raw render, post-production).

A video creation completely inside the RT engine made it possible to use a WYSIWYG approach (What You See Is What You Get) just as in video shoots in the real world. This solution has dramatically reduced the production time, made the workflow smoother and the creative tasks more flexible and intuitive.

In order to obtain a 3D stereoscopic video, the virtual recording device was made by two different cameras (left and right eye) and at a convergent focus (able to correct distortions that occur when closer objects are shooted).

A crucial topic during the camera shooting is the technical and stylistical solutions chosen to render light conditions. In the movie on the House of Caecilius Iucundus, the supposed original light sources (the opening of the compluviate roofing of the *atrium*, the garden area and some oil lamps) made some of the rooms too "dark" to enable proper appreciation of the painted walls. For that reason, the overall luminosity has been increased; to force all the painted walls to be fully readable.

This option has underlined a limitation of the RT engine: AAA game engines have auto-luminosity qualities able to imitate the natural light correction of the eye's retina. On the other hand, different available FX effects like fog, glow and God rays (volumetric light in the *atrium*) and real time ambient occlusion (AO) added some realism to the model. From a video making point of view however, a most important ability of the RT, its addition of depth of field to the image, decided our use: it permits in a convenient way to highlight certain details adding a pleasant effect to the animation. Unfortunately, the used shader model has different technique limitations. The recent introduction of PBR (photo realistic realtime lighting capabilities) opens for the possibility to dramatically enhance a future version of the 3D video visit to the House of Caecilius Iucundus.

5. *Conclusions and future works*

After the exhibition *Pompeji*, the 3D movie of the House of Caecilius Iucundus is available on the website of the Swedish Pompeii project: http://www.pompejiprojektet.se (main page).

Next step will be the online pubblication of the whole EM dataset and the source based model in order to make the reconstruction process completely transparent and available for researchers and students.

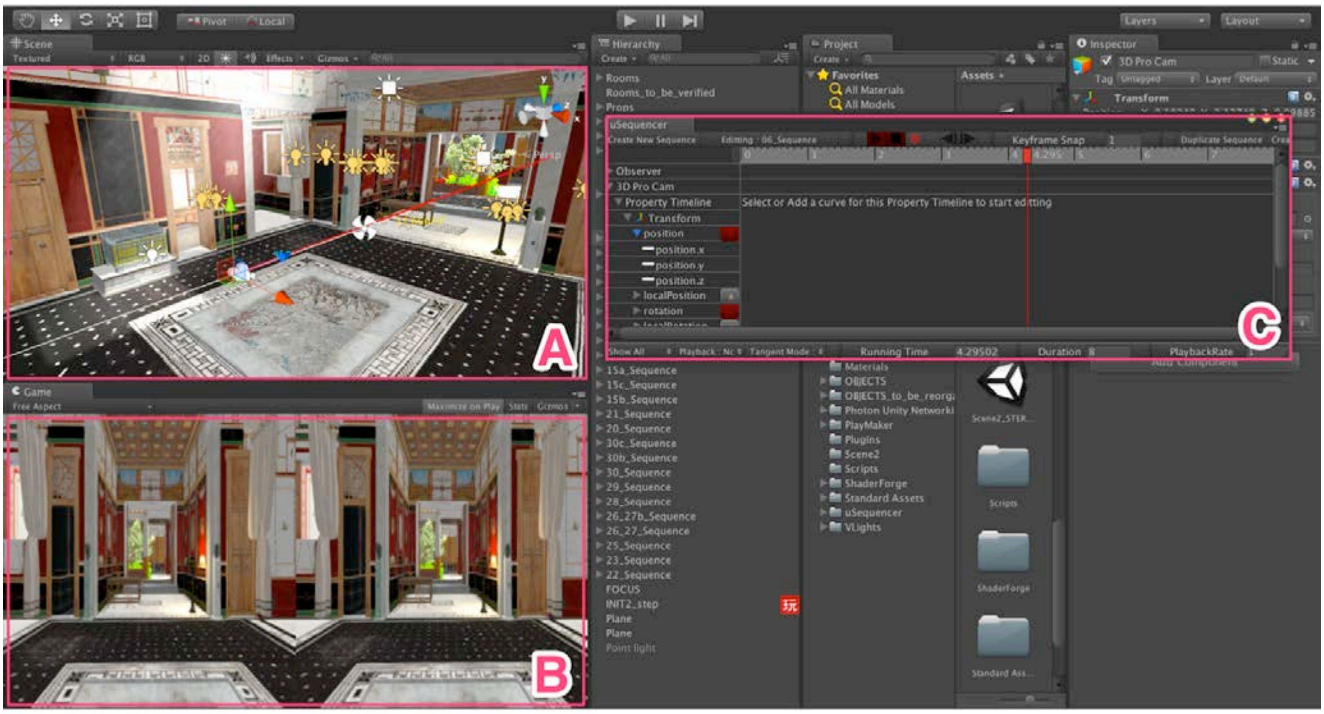

Fig 11: A) Stereo 3D camera animation in real time environment, B) Stereo 3D output, C) time line of the camera

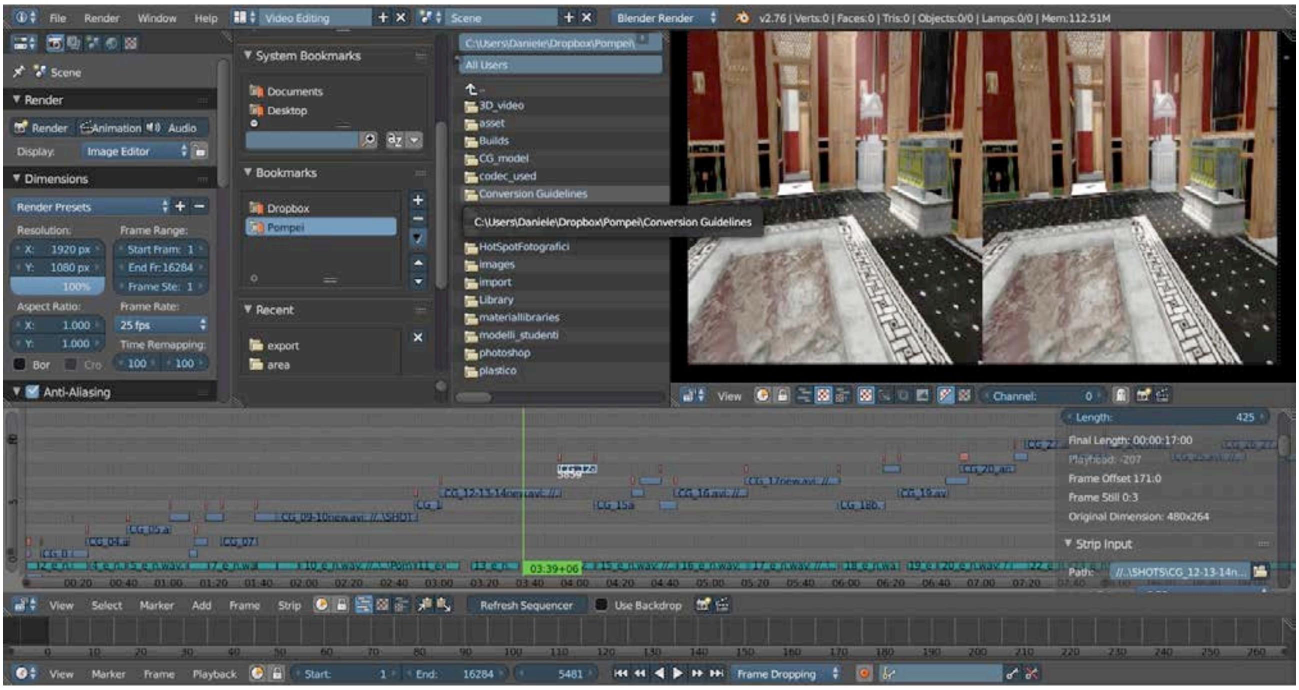

Fig 12: Editing of the stereoscopic video using Blender

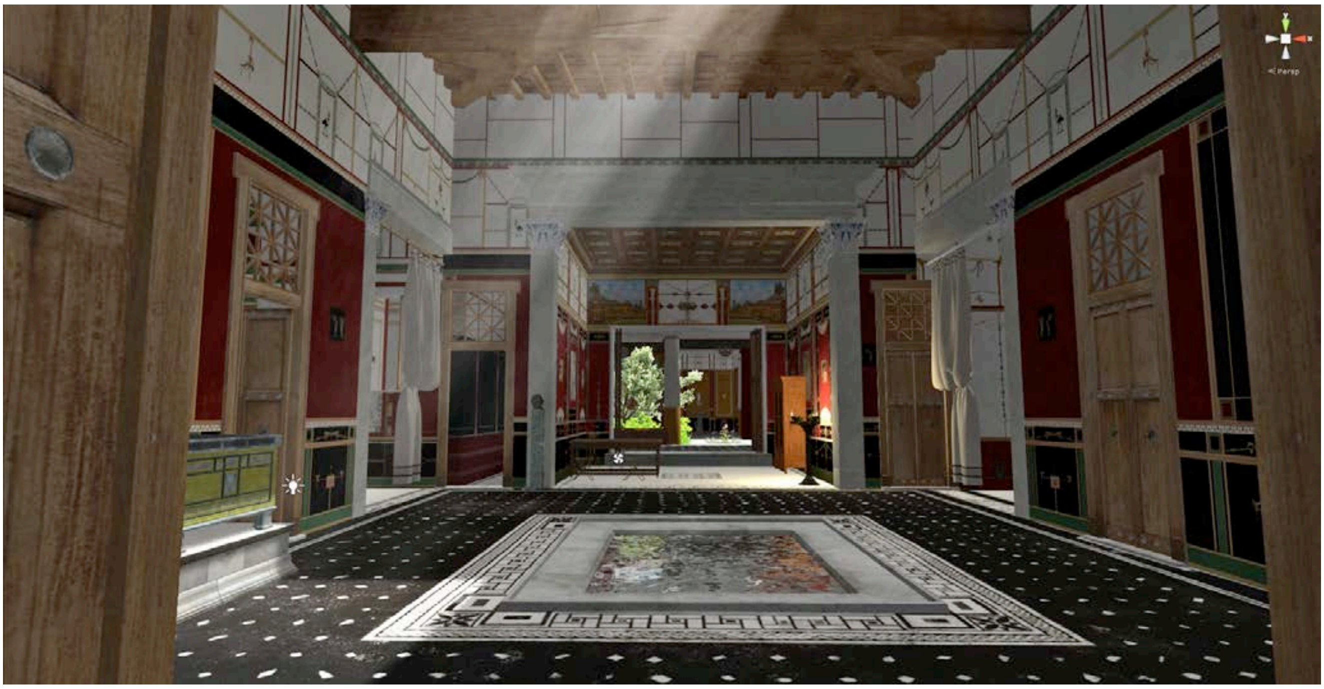

Fig 13: Snapshot of the real-time application, room B (*atrium*)

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Fig 14: *Peristylium* of the house, snapshot of the real-time application

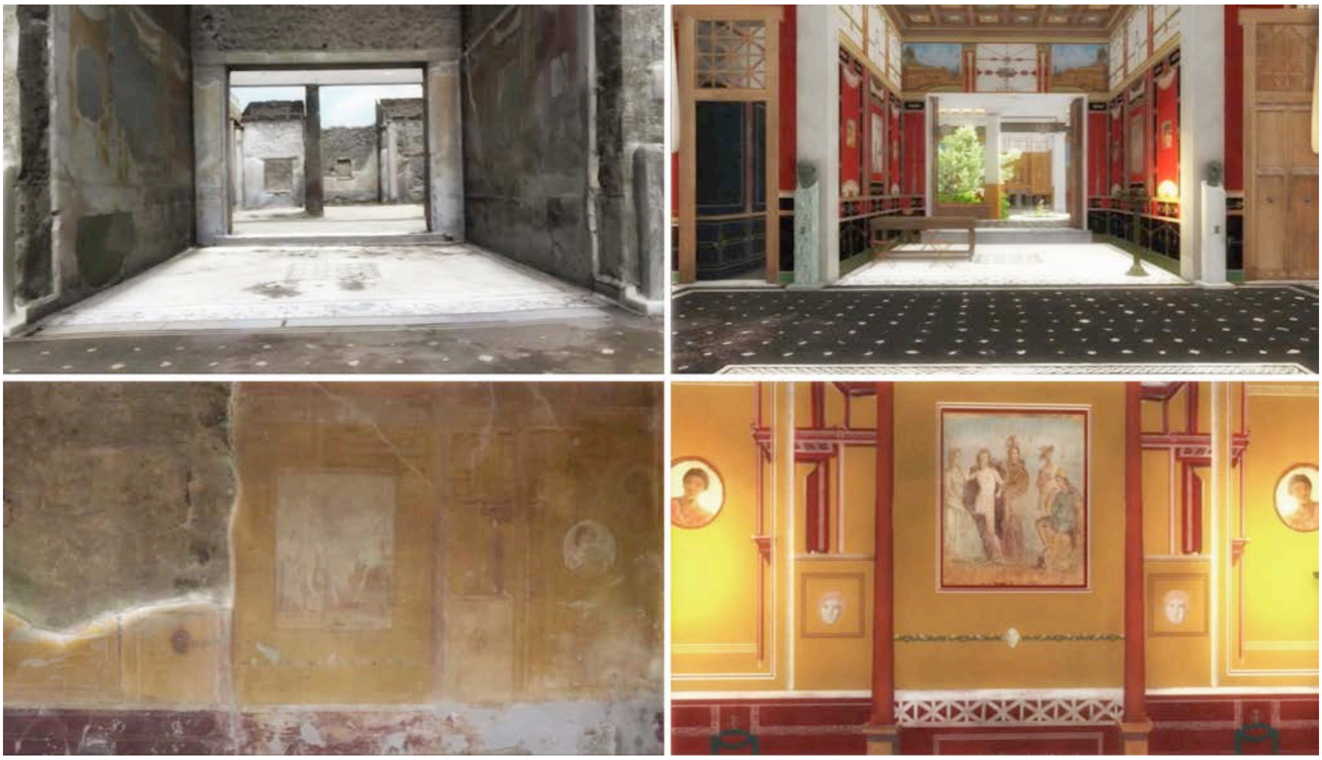

Fig 15: Two examples of the combination of the as-is appearance (to the left), based on 3D-scanning and photographic material, with (to the right) the suggested as-was appearance of the house. Smooth alternation between the two versions enhances the understanding of the architecture and the lived-in room.

Acknowledgment

The 3D movie of the House of Caecilius Iucundus is the result of an effort of collaboration between the archaeologists of the Swedish Pompeii Project, affiliated to the Swedish Institute in Rome and administered by Lund university, and the technical know-how of the staff belonging to the Humanities Laboratory, Lund University, and researchers, teachers and students of Digital Archaeology employed by or received within the institutional frame of Department of Archaeology and Ancient History of Lund University.

Important work pertaining to the acquisition and post-processing of data has been offered generously by the CNR-ISTI, Pisa. Photography was made by Hans Thorwid. The text that accompanies the movie was written by Thomas Staub and Anne-Marie Leander Touati and was translated from the original manuscript in Swedish by Carol Gillis and read by Sian Anthony. The production was made possible by a grant from the Marcus and Amalia Wallenberg Foundation.

Fig 16: 3D Movie of the House of Caecilius Iucundus shown for the first time at the Millesgården, Stockholm, exhibition Pompeji. Courtesy of Hans Thorwid

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