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INTEGRATED SURVEYING AND MODELING TECHNIQUES FOR THE DOCUMENTATION AND VISUALIZATION OF THREE ANCIENT HOUSES IN THE MEDITERRANEAN AREA

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Abstract

The paper is focused on the layout and testing of a workflow for the documentation of archeological remains, addressed to the study, visualization and information data input. Topographic, laser scanning and photogrammetric data have been used to build up 3D textured models of three ancient houses built in Sicily and in Tunisia in the Hellenistic and Roman age. 3D models have been used to extract conventional representations (plans and sections), analyze the geometric and proportional features and propose a virtual reconstruction of the original layout. The final step of the research work has been addressed to the creation of a web-based tools for the visualization of the models addressed to the maintenance of the ruins and of a friendly tool, addressed to non-specialist users, for the visualization of the virtual reconstructions; both tools have been developed with the real time rendering engine 'Unity'.

Keywords

Laser scanning surveying, Photogrammetric Surveying, 3D Modeling, Virtual Reconstruction, Visualization.

1. *Introduction*

The accurate 3D documentation of archaeological sites and objects is today widely used in different contexts. 3D documentation is usually carried out in connected steps: i) 3D recording; ii) 3D modeling; iii) 3D models publishing and sharing. In the last decade hardware and software updates deeply influenced the approach to each step; today each process seems having reached a stable arrangement, but some critical issues, e.g. the definition of standards for 3D models sharing and interoperability, demand further investigations. A more general (and usually less discussed) critical issue in the 3D documentation of heritage artifacts, is the lacking integration of multidisciplinary scholarships, a mandatory requisite to make 3D recording the first step in a wider process aiming at knowledge. Contents previously collected are simply attached to 3D models, thus discarding the avenues that 3D analysis and comparison may offer to the progress of archaeological studies.

This article describes the results of an investigation on archaeological documentation, developed by the authors in the framework of the research project APER, which aimed at the definition of best practices for the preservation, maintenance and divulgation of ancient housing heritage in the Mediterranean area. The team of the project APER included scholars in archaeology and in sustainable preservation, and institutions charged both with the restoration and maintenance of archaeological sites and with the promotion of archaeological heritage[1].

[1] The project APER (Architecture of the Punic, Hellenistic and Roman age) was funded by the European Programme for the interregional cooperation and was promoted by three partners: the University of Palermo, District of Agrigento (Italy), the *Institut Nationale du Patrimoine* and the *Agence de mise en valeur du Patrimoine et de Promotion Culturelle* (Tunisia). The partnership included the Archaeological Office of Agrigento and the Sicilian Centre for Restoration. The research group of the University of Palermo was initially directed by Prof. Alberto Sposito and, at a later stage, by Prof. Maria Luisa Germanà; the research on the Tunisian houses was directed by Arch. Ahmed Ferjouai, officer at the *Institut Nationale du Patrimoine*.

The research work described in this article aimed to: i) propose an effective combination of laser scanning and photogrammetric data for the creation of textured 3D reality-based polygonal models; ii) design and implement a web-based 3D information system, focused on archaeological maintenance; iii) design a user-friendly tool for the visualization of 3D virtual reconstructions. The objectives of the research work are quite common nowadays; many researchers have deeply investigated the listed issues, and many solutions have been proposed.

The investigation on 3D data acquisition is usually focused on the comparison of laser scanning and photogrammetric methods, to put into evidence strengths and weaknesses of each surveying technique (Gonizzi Barsanti, Remondino & Visintini, 2013); in this paper we propose a description of the data collection process (par. 2) and a method for the integration of these techniques, addressing the creation of 3D textured polygonal models which combine geometric and dimensional accuracy of laser scanning data to hi-res color information from photos. 3D modeling was performed with the use of both open source and commercial solutions; strengths and weaknesses of each technology are reported (par. 3). Many research works lead to the definition of 3D virtual reconstructions of the studied contexts; these reconstructions are often produced by scholars who are not directly engaged in the project, or come from previous publications. In this research work virtual reconstructions were modeled under the constant supervision of archaeologists who actively cooperated to solve incongruences that only spatial analyses could point out (par. 4).

In the heritage framework, the visualization of 3D models *per se* is no more considered an adequate solution, since the progress of studies and the maintenance/preservation processes demand tools which provide open access to information; 3D models can assist heritage knowledge and management only if contents are linked to specific spatial locations and are easily accessible by unskilled users. The provided solutions often aim to propose polygonal models segmentation, in order to optimize the computational management of spatial data (LoD) and to create clusters associated to specific classes of information (Agugiaro, Remondino, Girardi, Von Schwerinc, Richards-Rissetto, & De Amicis, 2011). These processes are usually managed by specialist users; end users can access the data but they do not usually cooperate in the segmentation process nor in the database design. When databases and information units are addressed to users involved in preservation and maintenance of archaeological heritage, it is mandatory that they actively participate to the design of databases. In this work a software *ad hoc*, based on the real-time rendering engine Unity 3D, was developed (par. 5). Suggestions from the technicians of the archaeological Office of Agrigento, of the *Institut National du Patrimoine* and of the Sicilian Centre for Restoration, were taken into account for the development of the user interface. The software, named *APER Maintenance* (par. 5.1), aims to allow authorized users to visualize and inspect the reality-based 3D models, to design and implement databases on their own, and to freely access and modify information units. The software was inspired both by the Smithsonian X3D system for 3D heritage visualization and inspection (http://3d.si.edu/), and by the collaborative information implementation successfully experienced in Wikipedia in the past 15 years.

The third issue focuses on dissemination and promotion of cultural heritage. We aimed to design a second *ad hoc* software for the visualization of 3D reality-based models and of 3D virtual reconstructions. The software, named *APER Tour* (par. 5.2), performs the superimposition of these 3D models, in order to help users to make out the role that each ruin played in the architectural framework. APER Tour is addressed to occasional users and therefore it was developed combining the design of a self-explanatory interface (par. 6) and of a user friendly interaction model (par. 7). Suggestions from the *Agence de mise en valeur du Patrimoine et de Promotion Culturelle* were taken into account to meet the specific needs of tourists and students. The Project APER was focused on the investigation of three ancient houses in the Mediterranean area: i) the 'IA-IB' house in the Hellenistic-Roman residential area in the archaeological site of Agrigento (Sicily); ii) the 'Waterfall' house in the Roman archaeological site of Utique (Tunisia); iii) the Phoenician 'Double Perystile' house in the archeological site of Kerkouane (Tunisia).

2. *Data collection*

The whole pipeline of the investigation activity was tested and evaluated on the first case study, i.e. the 'IA-IB' house in Agrigento, and, at a later stage, it was applied to the Tunisian houses.

Data collection was performed according to a widely tested pipeline.

In the first phase a topographic polygonal, surrounding the house, was planned and created; its vertices were measured with a total station and errors were corrected.

Laser scanning survey was carried out by positioning the device on multiple locations, in order to survey the most part of visible surfaces and to minimize the extension of occluded areas; before starting the scanning session, targets were positioned; each target was scanned and then measured with the total station. Point clouds were registered and referred to the topographic reference coordinate system, according to well-known procedures[2].

Photos were taken with a digital reflex camera equipped with calibrated lenses[3]. In order to fit the photogrammetric process, convergent photos were arranged in sets; each set is referred to a single room of the house.

It is well known that many laser scanners are equipped with integrated cameras and that photos shot by such cameras can be used to colorize in an almost automatic way both point clouds and meshes.

However, the use of images taken with integrated cameras implies some limitations that can affect the quality and resolution of textures: a) depending on the position of the scanner and on the spatial layout of the scene, the laser beam may hit some surfaces under a small angle of incidence; in such circumstances the quality of spatial data is partially affected, but the resolution of images is surely impaired; b) taking photos when laser scanning is performed does not provide surfaces to be homogeneously illuminated; some surfaces could be illuminated by the sun, while others could be shaded, thus affecting the acquisition of color information: 'the ideal conditions for taking the images may not coincide with those for laser scanning' (Remondino & El-Hakim., 2006, pp. 271-272). Taking photos with an external camera offers the opportunity of: a) acquire images with uniform resolution, by properly choosing the shooting points; b) take photos when surfaces are homogeneously illuminated (e.g. cloudy day).

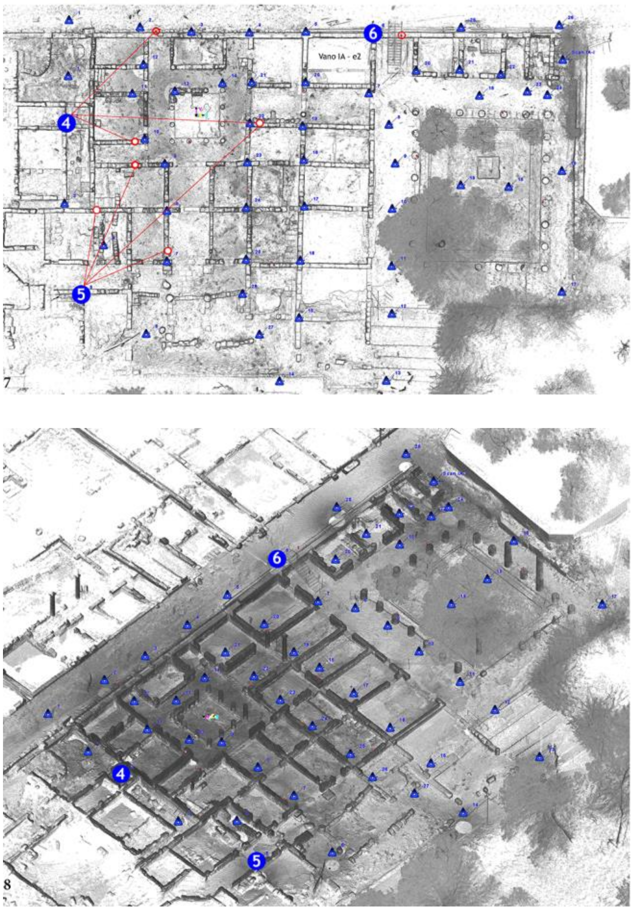

Fig. 1: Agrigento. 'IA-IB' house. Laser scanning survey.

3. Data Processing and 3D Modeling

The integration of laser scanning and photogrammetric surveying techniques aimed to obtain the best accuracy of both color and geometry.

The registered and oriented point clouds were used for the extraction of meshes, whereas the photo sets, oriented via photogrammetric processing, were used to texturize the meshes.

Archeological sites are usually open spaces under the sun, and thus the color of the surfaces of an archaeological remain constantly changes during the day.

Laser scanning data, i.e. coordinates and reflectance values of points, are not affected by

[2] Topographic survey was performed with a total station Leica TCR805; point clouds were acquired with a laser scanner Leica HDS7000; point clouds processing was performed with the software Leica Cyclone 8.0.

[3] Photos were taken with a reflex digital camera Canon EOS5D Mark II equipped with 28mm and 50mm fixed lenses..

Fig. 2: Set of photos of a single room.

illumination whereas photogrammetric processing is strongly influenced by variations in light, due to the position of the sun or to the presence of clouds.

With reference to the studied houses, the photographic documentation of each room was strongly affected by the sun: the vertical surfaces of the walls could not be illuminated at the same time and the floors were partially shaded by the surrounding walls.

Cloudy days (no rain, obviously) provided the best conditions for the acquisition of photogrammetric data; we had to wait, but not so long, since the odds were favorable to us.

Mesh extraction from laser scanning point clouds was performed with the open source software CloudCompare, using the *Poisson Surface reconstruction* algorithm (Minto & Remondino, 2014, p. 18); this software allows the processing of complex meshes only if a normal vector is associated to each scanned point. Registered and oriented point clouds were exported with the software Cyclone in the PTX file format; PTX files do not store normal information but each scan is associated to the position of the scanning device. When importing PTX files, CloudCompare uses such information to calculate the normal vector of each scanned point.

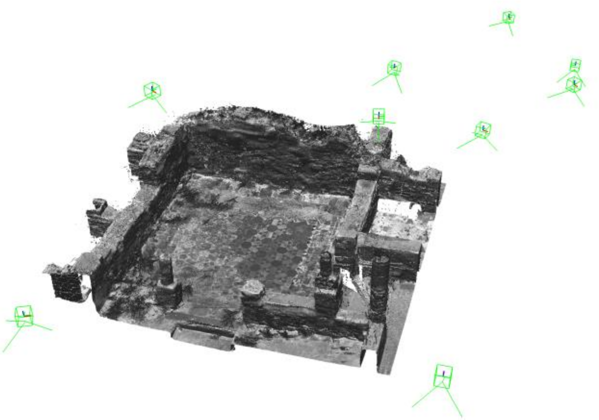

Fig. 3: Set of laser scans of a single room.

Imported scans were combined in a single point cloud and then subsampled to remove redundancies, i.e. the points that are overlaid when the same area appears in different scans. The max allowable distance in subsampling process was set to 5mm.

The accuracy of meshes calculated with the *Poisson Surface Reconstruction* is determined by the *Octree depth* value; several tests were performed, until a good compromise between geometric accuracy and computational manageability was found using the value ‘10’.

Photogrammetric processing was developed with two different workflows, using open source and proprietary software tools: the first workflow combines the open source tools VisualSFM, SfM GeoRef, and MeshLab; the second one is developed with the commercial software Agisoft Photoscan Pro.

VisualSfM[4] uses *Structure from Motion* algorithms to extract point clouds from sets of photos; in the tested workflow VisualSfM was used to align the photos and no point cloud was extracted.

The photogrammetric aligned sets were scaled and referred to the topographic reference coordinate system with the software SfM GeoRef[5]; such software allows the detection of points on the photos and the input of coordinates associated to each point. Points must be easily detectable in at least four photos[6]; in order to perform an accurate detection we used targets whose positions were measured with topographic methods; the coordinates of further natural points on the surfaces were extracted from the laser scanning point clouds.

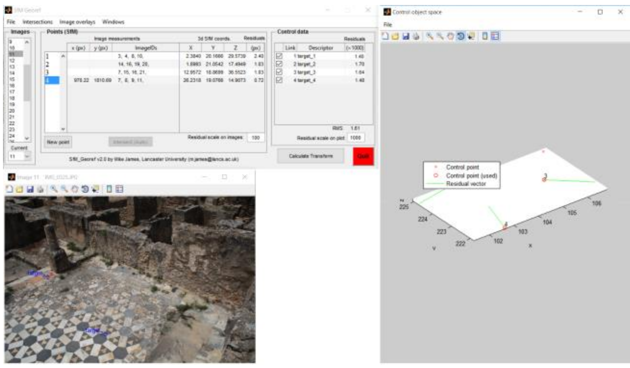

Fig. 4: SfM GeoRef interface.

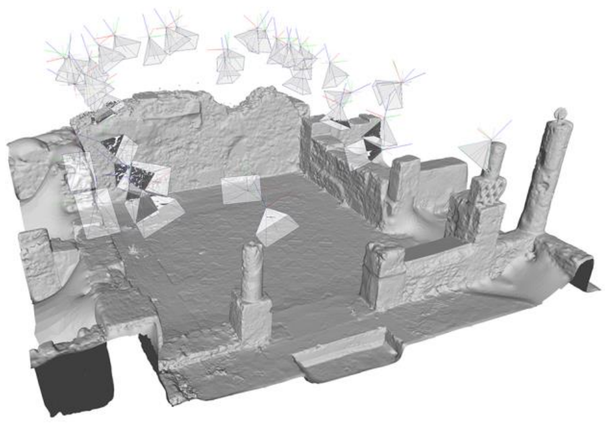

Fig. 5: Mesh and oriented shooting points.

In order to ensure the evaluation of errors, each set of photos was scaled and referred using four or five control points. At the end of the process all photogrammetric sets were exported in the file format *Bundler Output*.

Provided that both meshes and sets of photos were referred to the same coordinate system, we started the texturing process with MeshLab; when loading a photogrammetric set, MeshLab allows the 3D visualization of each shooting point. After uploading the mesh in the same project, it is possible to visually check the correspondence between the mesh and the oriented sets of photos.

The MeshLab tool *parameterization+texturing from registered raster* provides the projection of the pixels onto the mesh. Several parameters allow adjustments in the projection process: the user can control the size of textures and the blending of pixels from different photos; the *distance criterion* associates a specific area of the mesh with the pixels of the closest photos.

At the end of the texturing process MeshLab outputs a composite texture, a sort of mosaic of the fragments of images extracted from the photos; the mesh is subdivided into patches delimited by seams; each area of the texture is connected to the corresponding patch of the polygonal model.

When using photos that were taken in adequate lighting conditions, the texturing process yields a smooth transition between contiguous fragments.

Some critical issues arise when attempting to process large photo datasets. In particular we observed that MeshLab is very resource-hungry, especially in terms of memory.

The test on Agisoft Photoscan Pro shows a better optimization of memory usage, an intuitive interface and an easier file management. Photoscan can perform the entire process and does not require any additional component; sets of photos are aligned, scaled and oriented, and point clouds can be extracted. Photoscan provides tools for mesh extraction and texturing as well.

In this work Photoscan was used to perform the same processes tested with open source solutions, i.e. the alignment, scaling and orientation of the photosets. Meshes from laser

[4] VisualSFM, a Structure From Motion software developed by C. Wu., performs the extraction of 3D models from sets of photos.

[5] SfMGeoRef, developed by M. R James, operates the referencing of point clouds extracted from Structure From Motion software.

[6] The set of photos where a single point is detected must be chosen in order to assure a wide angle of convergence.

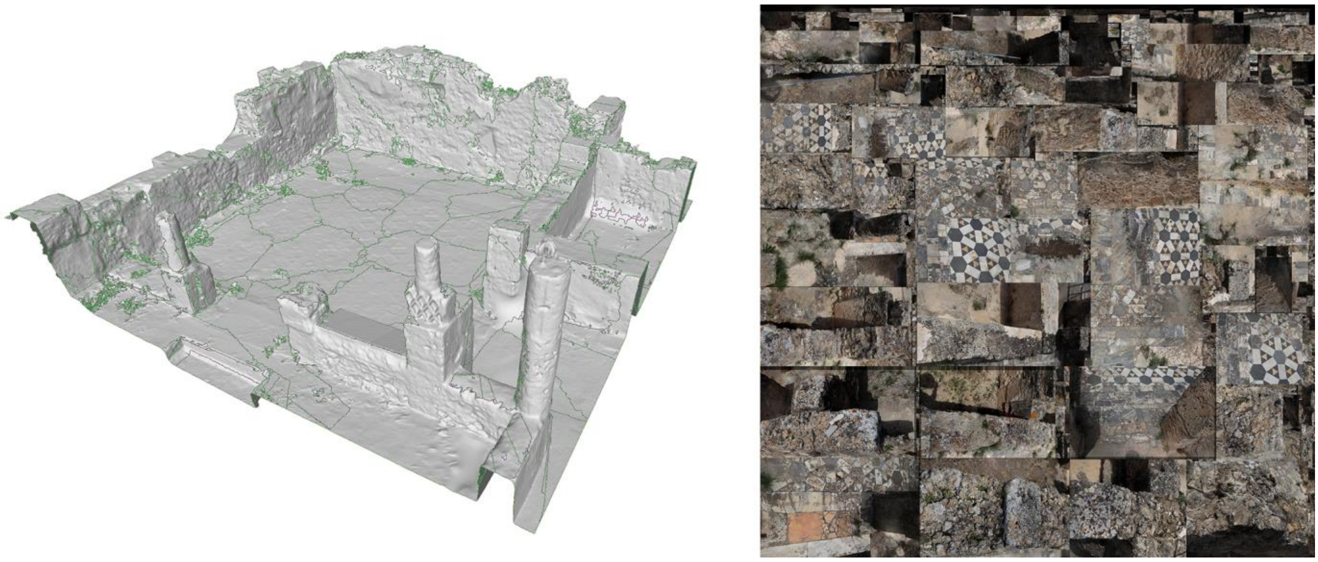

Fig. 6: Texture and corresponding mesh patches.

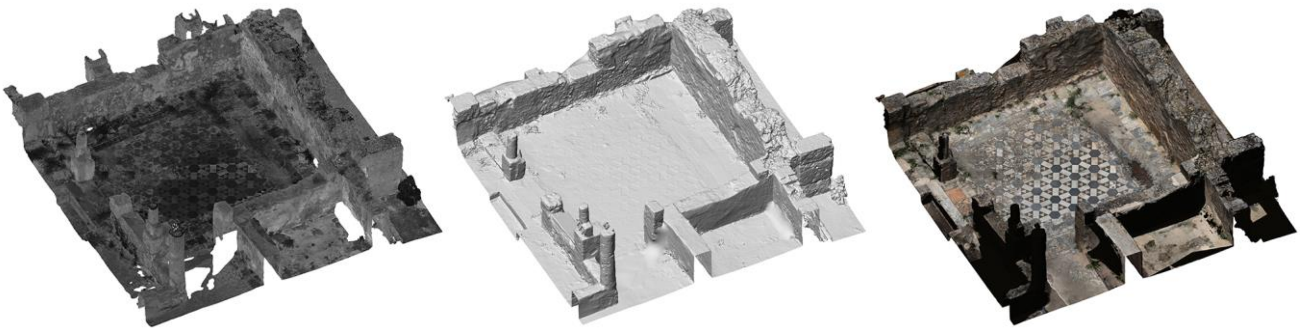

Fig. 7: Mesh extraction and texturing.

scanning data were loaded into Photoscan to proceed with texturing.

The textures, produced with Photoscan version 1.1.3, were affected by a strong blending[7]. If compared to textures generated in MeshLab with the same resolution, blending caused a loss of resolution and many areas appeared 'gummed'.

The latest releases of Photoscan have overcome such limitation and blending can be disabled by the user; the quality of the resulting textures is considerably improved and is almost equivalent to those generated by MeshLab.

In order to get the best color resolution, we divided the polygonal model of each house in portions almost corresponding to a single room. Each portion was mapped[8] with its own texture, thus producing a good quality output.

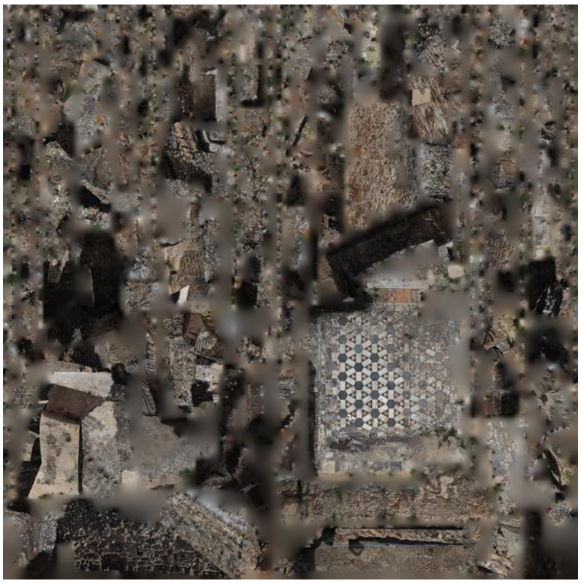

Fig. 8: Texture generated by Photoscan.

[7] The following releases of Photoscan overcame such limitation, allowing user to disable texture blending.

[8] The size of used textures is 4096*4096 pixels.

Fig. 9: Texture comparison. From left to right: MeshLab, Photoscan 1.1.3, Photoscan (blending disabled).

Textured polygonal models were used to extract orthophotos (plans, sections) of the houses and to render both 2D pictures and spherical images from selected points of view.
A further step in processing was addressed to optimize the computational manageability of textured meshes for their use in the software for the maintenance; mesh reduction was performed with Meshlab, using the command *Quadric edge collapse Decimation with texture*.(Minto & Remondino 2014, pp. 21-22).

4. *Three ancient houses in the Mediterranean area*

Archaeologists performed dimensional and geometric analyses on 2D drawings and digital orthophotos extracted from the 3D reality-based polygonal model. These analyses led to the definition of reconstruction hypotheses[9]that were represented in conventional drawings.

The reconstruction modeling process allowed to notice many incongruences that were not visible in these drawings. Such drawbacks were punctually resolved thanks to the active participation of archaeologists to the modeling process. The full integration of 3D reality-based models and virtual reconstructions put into evidence the role that each ruin played in the original architectural framework.

The 'IA-IB' House[10] was presumably built between the II and I century B.C.E. and it is a wide house (51.60*36.40m) with a huge perystile and an atrium, presumably belonging to two different houses that were joined at a later stage. The reconstruction had to face many incongruities related to the overlay of different constructive phases. Geometric analyses helped to solve such incongruities and three different reconstruction hypotheses were laid out; we finally modeled the hypothetical layout of the house at the time when the site was abandoned.

The richness and the prominent role of the patron of the 'Waterfall' house[11] is attested by the size of the house (28.85*41.67m), by a huge Triclinium paved with colored marbles, and by precious mosaics decorating the floors of many rooms. The plan is characterized by a north-south axis crossing an inner peristyle with a water basin. Two smaller basins were attached to the northern and southern walls of the Triclinium; the southern basin was divided in two parts at different heights to create a waterfall; hence the name of the house. The presence of stairs and the width of walls led archaeologists to propose that the most relevant area of the house, facing the perystile, had two elevations.

The 'Double Peristyle' house[12] is smaller and less decorated than the aforementioned ones; this

[9] Prof. Sergio Aiosa of the University of Palermo and Architect Hichem Ksouri were responsible for archaeological studies.

[10] The 'IA-IB' House is sited in a residential area (N: 37.297468, E: 13.590884) which was built in the late Hellenistic and early Roman age; this area was presumably a peripheral district of the great Greek town of Agrigento. The excavated part of the Hellenistic-Roman residential area shows about thirty houses, arranged in three strips delimited by north-south oriented roads named 'Decumani', which run for almost 150 m at different elevations.

[11] The remains of the Roman town of Utique (N: 37.057970, E: 10.063571) are located 80 km north of Tunis in an inner area 25 km far from the sea; at the Roman age the town was close to the sea. The 'Waterfall' house is sited in a residential area which was presumably built in the II century C.E.

[12] The archaeological site of Kerkouane (N: 36.946349, E: 11.099413) is located on the sea at the northern end of the peninsula that closes the eastern side of the Gulf of Tunis. The ancient Phoenician town, surrounded by walls forming a sort

Fig. 10: Utique, 'Waterfall' house: 3D textured model.

Fig. 11: Utique, 'Waterfall' house. Plan.

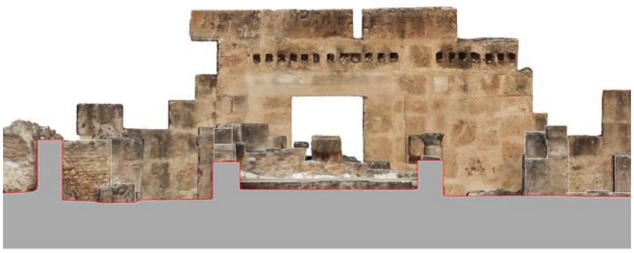

Fig. 12: Utique, 'Waterfall' house. Detail of a section.

house reveals the way of life of common people in the Phoenician culture. The plan is inscribed in a rectangular area (32.20*11.70m) and two narrow corridors lead to two open courts. A peculiar feature of this house is the arrangement of the bathroom, which recurs in many other houses of the town. The virtual reconstruction proposes the typical architectural layout of Phoenician houses, whose flat roofs were supported by simple constructive elements. All virtual reconstruction models were rendered with a solid diffuse color, since no specific studies on color were available.

Fig. 13: Utique, 'Waterfall' house: Virtual reconstruction.

5. Ad hoc software development

An extensive analysis of the aforementioned pre-requisites (portability, scalability, usability) led to the development of *ad hoc* software solutions. A preliminary evaluation on the current state of the art revealed that some of those challenges have already been solved by gaming engines and video game development frameworks.

Commercial solutions like Unity or Unreal Engine, among many others, allow the development of portable and scalable 3D games, without the burdens usually related with the development of critical software components, such as the rendering engine, the data loaders, the input manager, etc. Using those tools, developers can focus mainly on the gaming logic and on the user interface.

Considering that a video game is nothing but a software application which allows the user to interact with a 3D scene rendered in real time, the usage of such frameworks for the development of software applications which are not video games, but feature interactive 3D real time rendering, is a natural choice. For this work, the Unity game engine was used.

of circle, was presumably abandoned at the end of the IV century B.C.E.

Nevertheless, some of the features required were not available because they are not usually needed for the development of a video game, but thanks to the extensibility of the gaming engine, they were integrated in the final software application. That is, the engine allowed the development of custom shader programs, affecting the output of the 3D rendering engine at a very low level, as well as the integration of application servers and database management systems. These software integrations are discussed in the following sections.

The developed software core framework, implemented as a combination of the gaming engine features, plus our software integrations, was used for the creation of two distinct software packages: i) *APER Maintenance*, an easy to use yet advanced 3D information system specifically designed for archeological sites management; ii) *APER Tour*, a multimodal 3D interactive experience, designed to promote the archeological site and access virtual reconstructions from the web, on site installations or mobile devices.

5.1 APER Maintenance

This software application is a typical information editing and retrieval system, featuring full text search and rich text editing. However, it features an innovative user interaction paradigm, considering the way 3D models play their role. In the system presented here, 3D models are the entry point to access, store, retrieve and search contextual data. Maintenance data is meaningless if it cannot be precisely correlated to a specific location of the archeological area. In APER Maintenance spatial correlation is obvious and immediate because data can be added only after creating a placeholder on the 3D model.

The architecture of this software application is the typical client – server. Server component were implemented using well known open source software packages, such as the web server Apache and the RDBMS MySQL. The backend layer was developed in PHP language. Client user interface was implemented combining the so called "player" of the game engine with HTML and JavaScript custom code.

Several functionalities were designed to better assist the operators charged for maintenance, addressing different topics: i) navigation of the 3D area; ii) inspection of the 3D area (extraction of sections and measures); iii) data management.

The tools used to navigate the 3D model were designed taking into account the feedback obtained from the institutions in charge of the maintenance and from archeologists involved in the project APER.

First of all, the 3D camera uses an orthographic projection, because most of the technicians are more familiar with it.

The camera is orbiting around a focal point, lying on the 3D model. Using the mouse, the view point can be rotated around the focal point, and the focal point can be moved.

Fig. 14: APER Maintenance. Interaction tools.

Moreover, a double click on the 3D model will shift the focal point to the location of the click with a fast transition, allowing the possibility to jump between different parts of the 3D area with ease.

The implementation of the sectioning tool required the development of custom code. In particular, a custom shader program was written and integrated into the 3D rendering engine as a custom material. The main reason to implement the sectioning tool with a shader program, was computational efficiency. A shader program is executed by the GPU in the rendering pipeline, maximizing the overall throughput without affecting the CPU at all. A shader program, and in particular, a fragment shader program, is a little program that is executed for each pixel in the frame buffer (the "picture" that is then shown on the screen). By developing a custom fragment shader, the programmer can affect the way the 3D scene is rendered on the screen. The sectioning shader program operates by "discarding" pixels that fall on one of the two sides of the sectioning plane. By discarding unwanted pixels when rendering the 3D model, they will not affect the final result. Moreover, a second rendering is used to render the inner triangles of the 3D model, generating a solid color on the edge of the section.

With this technique APER Maintenance can extract sections from one or more high resolution polygonal meshes in real time.

Data management is implemented by the annotation tool, which allows the user to create placeholders, position them on the 3D model and then assign data. In particular, the user can assign a color and a category to each placeholder, allowing a visual discrimination on the various placeholders rendered on the scene. Data entries associated to each placeholder can be formatted as rich text and multimedia formats, including pictures, videos and audio.

To determine the position of the placeholder, the user simply clicks on the 3D model on the desired location. The precise location is picked using ray-casting: a ray is projected from the coordinates of the mouse on the screen to the 3D model using an inverse projection. An efficient tree-based lookup procedure determines which triangle of the 3D model intersects with the ray (if any) and the resulting 3D position is defined as the centroid of that triangle. Due to the high resolution of the 3D reality-based models, the lookup procedure may still be inefficient. Therefore, a lower resolution version of the same mesh was used for lookup. The positioning error is still lower than the size of the placeholder object.

Using the same picking technique, a measurement tool was implemented to allow the user to measure real distances on the 3D model itself.

All functionalities are accessible by using the mouse only, and thus the availability of different tools at the same time was a challenge. The input mapping was designed to allow the usage of some tools while others are still active (i.e. it is possible to navigate the 3D model and rotate or move the point of view while taking measurements).

The use of each of these instruments, individually or in combination, allows the user to conduct his/her own investigations and analysis of the model using a clean and non-invasive interface. Information retrieval is as natural as clicking on a link of a web site but in this case "links" are 3D placeholders in a 3D environment. Moreover, full text search tools can be used to filter the retrieved data, by hiding the placeholders which do not match with the search criteria.

5.2 APER Tour

The second application, *APER Tour*, was designed to be used by occasional users. The application is designed to run on touch screens installed in the 3 archeological sites, and it can be used freely by the visitors. Moreover, it can be downloaded from the Internet and installed on any modern PC equipped with Windows, Linux or Mac OS X.

The possibility to access a rich and detailed 3D model of the archeological area allows the visitors to access details that cannot be seen while visiting the site (inaccessible areas, weather conditions, distance, etc.). Moreover, the 3D model is enhanced by the presence of interactive placeholders located in areas of interest of the 3D environment.

When a placeholder is selected, the camera's point of view is smoothly moved to the center of the placeholder and the application switches to an alternative mode of interaction: the user's point of view is now the center of a spherical view that perfectly overlaps with the 3D environment.

In this mode the user can rotate the camera zooming in and out, and can use a timeline control to visualize the 3D model at different stages of its evolution in time. The transition of the camera's point of view from its original position to the selected placeholder and vice versa is obtained by

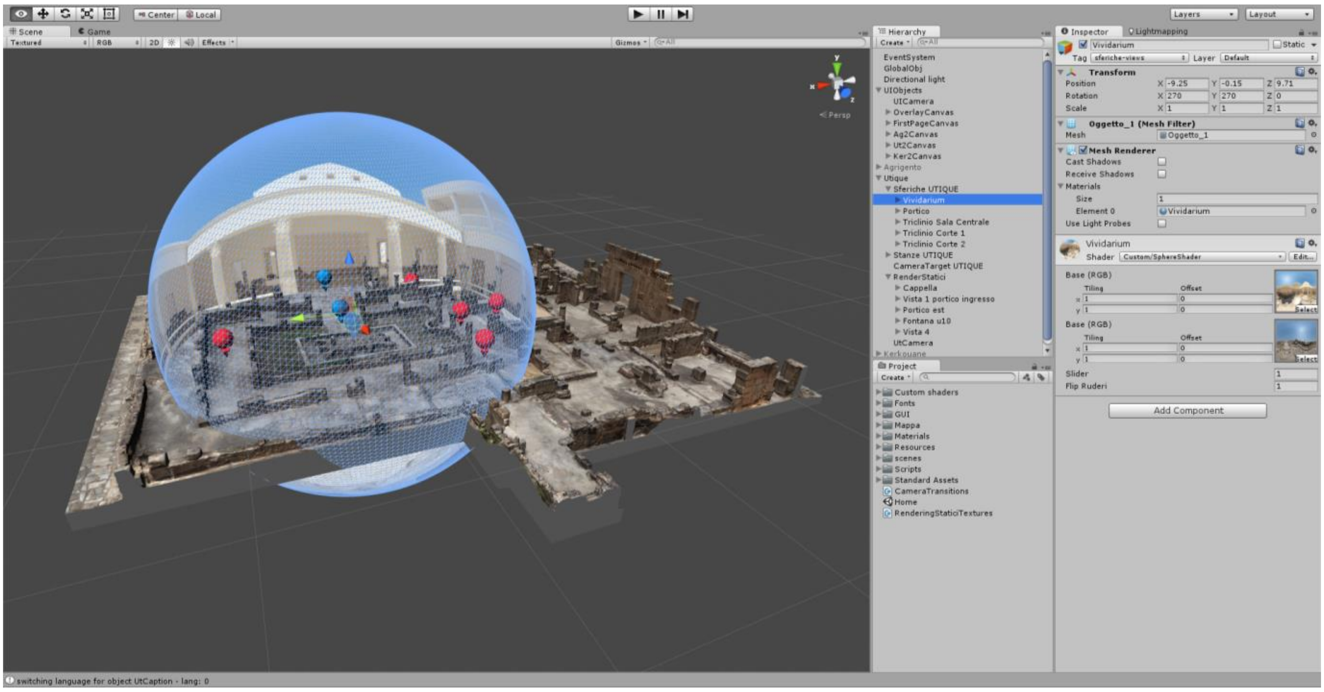

Fig. 15: APER Tour: the spherical image from the virtual reconstruction model referred to the 3D textured model.

performing a continuous transform of spatial coordinates.

During the transition, the parameters of the rendering camera (position, target vector, field of view) are determined by interpolating the start and end points. This results is a smooth and seamless transition of the point of view.

To address portability issues, the user interface can respond to both touch commands or traditional mouse and keyboard inputs.

6. *User Experience Design*

A preliminary step in *User experience* design is the layout of an *Information Architecture (IA)*, i.e. the logical and semantic structure of the information, of the contents, of the process and of functionalities. With reference to end users, the *IA* determines the level of usability of a digital system.

The basic components of an *Information Architecture* are:

- *the classification schemes*, i.e. the classification of information;
- *the labeling systems*, describing the relationship between the units of information, i.e. the paths leading the user into the space information;
- *the logical structure of taxonomic hierarchical type*, provides the classified elements are arranged in a hierarchical tree, i.e. a set of classes ranging from the *parent* categories (classes) to the *child* categories (subclasses). Hierarchy of information allows a faster, intuitive and understandable logical sequence, and takes into account the time needed to access the digital contents.

The *IA* of APER Tour defines the guidelines for *User Interface* design, which features few useful and self-explanatory items providing easy understanding and a functional interaction.

The *Home page* is the macro category that provides access to the pages of the archaeological sites. The main area contains a stylized geographical map where the archaeological sites are shown with colored placeholders.

The pages of each archeological site show a central area where digital contents are delivered; a set of images of the site can be accessed from the thumbnails placed in the bottom area of the page; on the right, the *Function Bar* contains the captions of images and three colored buttons:

- *info* shows historical records;
- *Home* leads back to the home page;
- *3D* accesses the 3D models;

The areas of the User Interface host titles and icons; assuming that the user does not usually read the texts in the information space, the user interface provides contents through codes, signs and icons. The available actions are therefore signaled by *Pictograms*, i.e. symbols that are quickly and easily recognizable. The button *3D* depicts a *temple* with broken columns, to point out that we are accessing an archaeological ruin; the text ‘3D’ is associated to the perspective

Fig. 16: APER Tour Home page.

Fig. 17: Icons of the sites in the Home page.

Fig. 18: Archaeological site page.

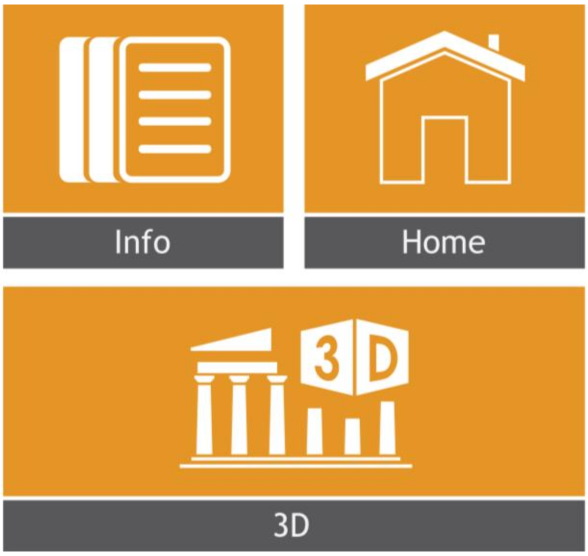

Fig. 19: Pictograms in the Archaeological site page.

image of a cube, to point out that the next page will propose a 3D model visualization. The button *Info* depicts a stylized page with inscriptions inside, to make it clear that the user is accessing the historical documentation of the archaeological site. The button *Home* depicts a house, to suggest the return to the Home Page.

When clicking the *3D* button, a panel shows instructions for the 3D navigation.

By closing this panel the user enters the *3D* page; the reality-based 3D model is shown with some colored placeholders on it. These placeholders lead to pages where 3D hypothetic virtual reconstruction are displayed. A relevant feature of these pages is the *temporal slider*, whose pictograms show three variations of the icon of the Temple: a) the left icon, referred to the view of the reality-based model, is full patterned and the upper-right area is removed; b) the central icon, referred to the combination of reality-based and virtual reconstruction models, is partially patterned (at the top right only boundaries are visible); c) the right icon outlines the temple with no pattern, to point out that only virtual reconstruction is displayed.

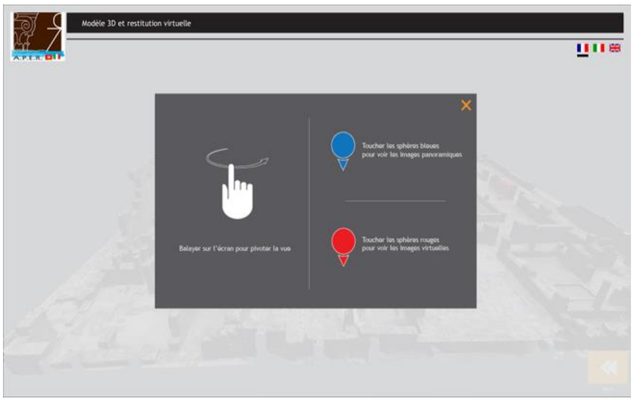

Fig. 20: Navigation instructions panel.

Fig. 21: Temporal slider.

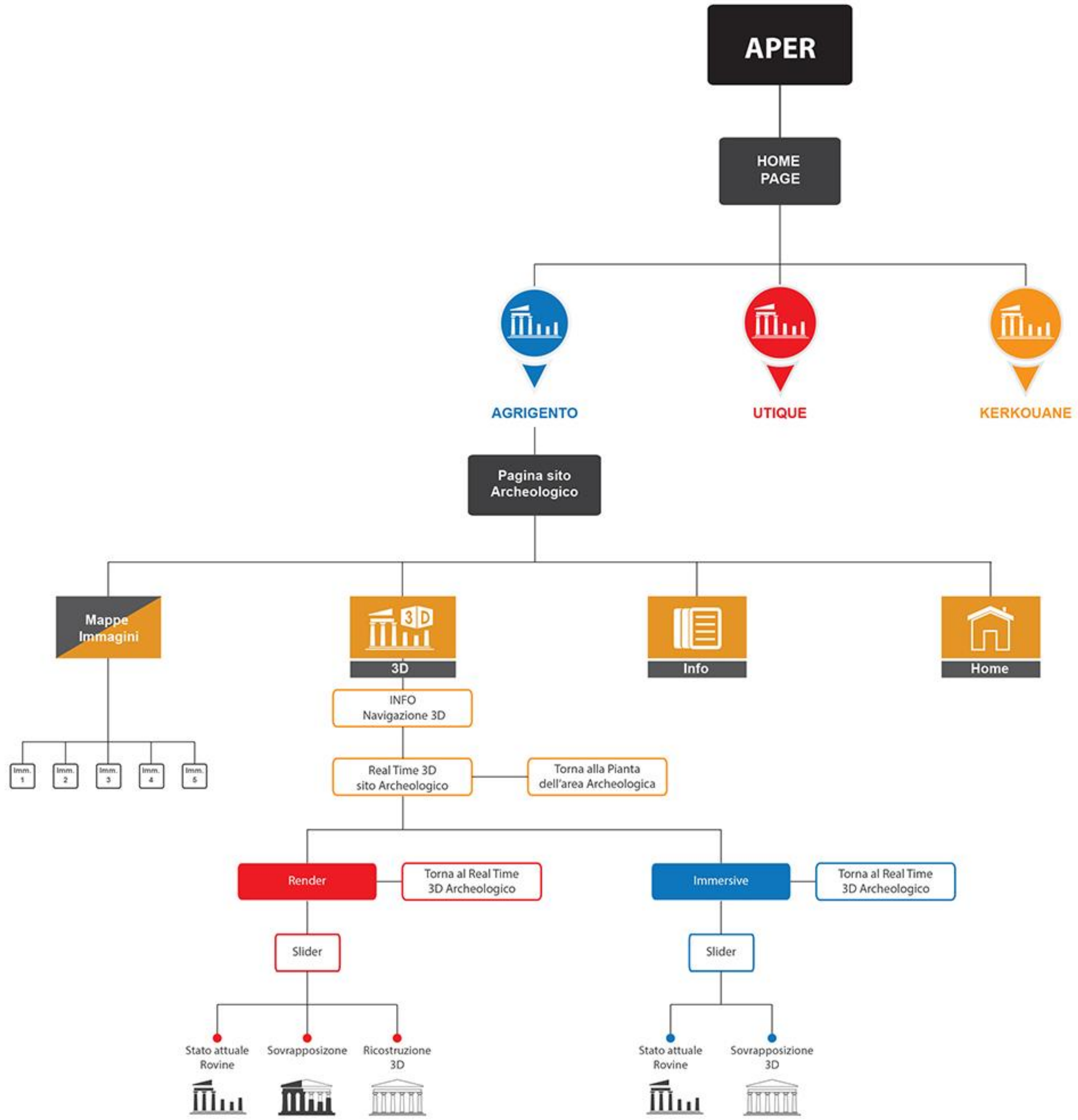

Fig. 22: Layout of the User experience design.

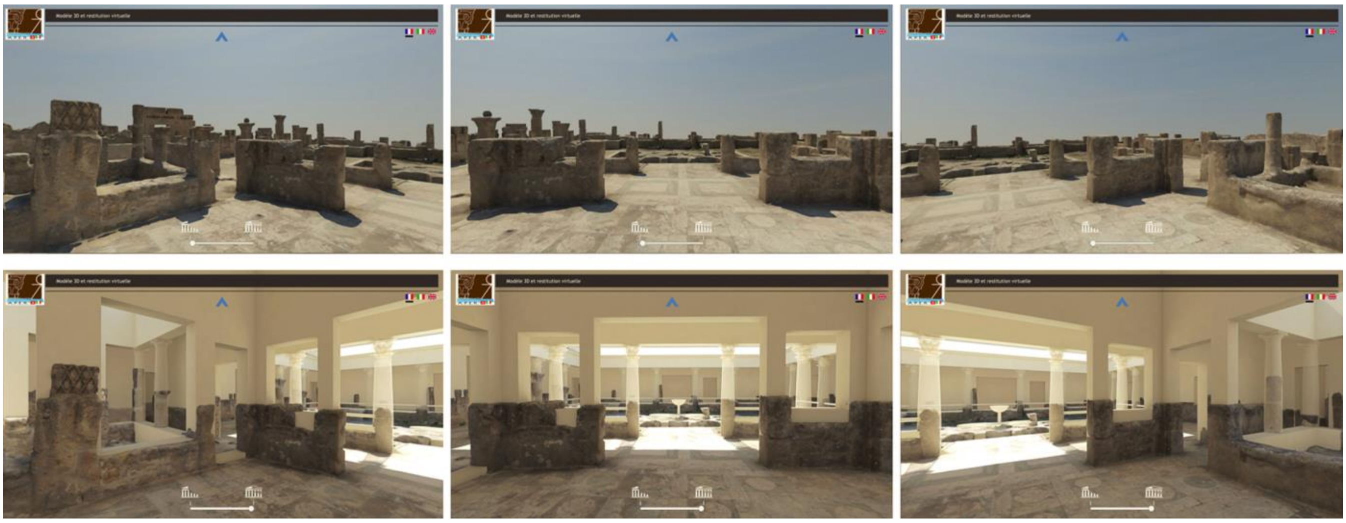

Fig. 23: 'Time machine' in spherical images. 3D environment strip (top) and virtual reconstruction overlay (below).

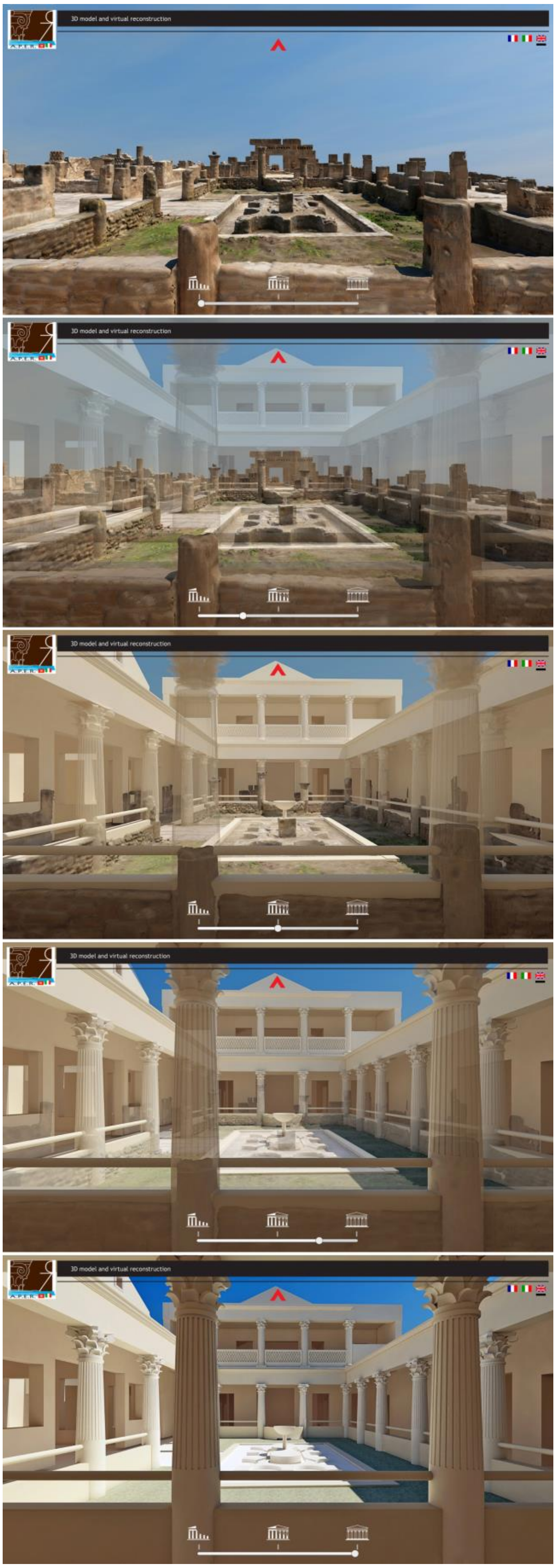

Fig. 22: 'Time machine' in rendered images provides smooth transition from 3D environment to virtual reconstruction.

7. *Interactive criteria of visualization.*

One of the most relevant features of the *APER Tour* software is the overlapping of images of the site in its current state and of images of its virtual reconstruction. Images of the real space can be taken on site with a camera, or rendered using the reality-based 3D model which can effectively substitute the real environment for such tasks.

In this work we decided to not use photos of the site in the overlapping process, since the accurate matching between the point of view of photos and the position/orientation of virtual cameras was hard to achieve. Moreover, the use of rendered images prevented the unpleasant effect of swerve between shadows in the photos and shadows in rendered images. Overlapped images show clearly the connection between reconstruction and ruins, otherwise featuring a hybrid effect which joins photorealism and abstraction.

In this research work renderings were performed to compute both 2D pictures and spherical images of the 3D models. Spherical images were automatically created with the software 3DSMax.

Virtual cameras were positioned according to the spatial layout of the scene: the views of an atrium or a perystile were generated by positioning the camera on the axis of symmetry of the space.

The field of view ranges from 65° to 70°, so to produce a 'natural' perspective and prevent distortions.

The 3D reconstructions were overlapped to the reality based 3D model with some transparency factor, to allow the visualization of both models at the same time.

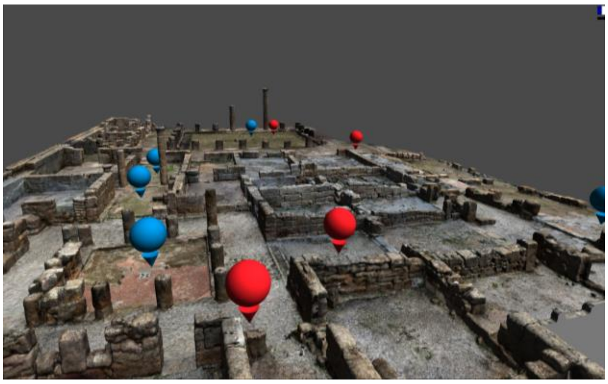

Fig. 24: Place holders in the 3D view.

The aforementioned temporal slider was implemented to allow a gradual and smooth transition from images of the reality-based models to overlapped images and finally to the views of reconstructions.

The level of interactivity is quite good because the user can control the parameter of time and make the virtual reconstruction more or less visible.

Spherical images provide a higher level of interactivity, since they allow the user to navigate the virtual environment, thus looking around from the point of view.

In spherical images the temporal slider provides the view of the 3D reality-based model and the view of the overlapped models; the view of the virtual reconstruction alone was discarded, since the lack of information on constructive techniques makes the spherical images of the reconstruction model uninteresting, especially when we look up at the ceilings of the rooms.

The User Experience design provided placeholders leading to images visualization: red placeholders are linked to 2D pictures, whereas blue placeholders open spherical images; the functionalities of placeholders are explained in the panel that appears when clicking the button '3D'.

The transition from the 3D view to the spherical images and vice versa is seamless, because the software maintains the orientation of the point of view correctly aligned. This way the user feels like gliding inside the house.

8. Conclusions and outlooks

In this article a pipeline for 3D archeological heritage recording, modeling and publishing has been presented. The investigation on the integration of laser scanning and photogrammetric data techniques led to the generation of 3D textured polygonal models of three ancient houses in the Mediterranean area. Orthophotos and conventional drawings supported archaeological studies addressed to the layout of virtual reconstructions. 3D reconstructions were modeled onto the 3D reality-based models, to allow the comparison and superimposition of the ruins and the hypothetic reconstruction of the houses.

Two *Ad hoc* software applications were developed: the first one, named *APER Maintenance*, means to facilitate the work of institutions involved in the preservation of the sites; the second one, named *APER Tour*, is intended as a tool for the dissemination of ancient housing heritage. Both applications are based on the real-time rendering engine Unity 3D, which provides scalability and cross platform compatibility. A meaningful part of the work was aimed at the design of interfaces and user interaction of the *APER Tour* software, in order to obtain the best user experience.

Further investigations will be focused on the development and optimization of the tools of the software *APER Maintenance* and, in particular, of the approach to content creation and editing. In the proposed release the user creates placeholders linked to a specific point of the model; end users pointed out that updates should allow the creation of polygons delimiting areas affected by specific decay phenomena and otherwise assist the computation of areas, for restoration purposes.

The on site installations and the websites of the APER project are still work in progress; the feedback from users after their release will surely lead to further improvements. [13]

[13] Authorship specifications: Paragraphs 1-2-4-8 (Agnello); Paragraph 3 (Cannella); Paragraph 5 (Monteleone, Giordano); Paragraph 6 (Albano); Paragraph 7 (Avella).

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