THE ROMAN THEATRE OF CLVNIA: HYBRID STRATEGIES FOR APPLYING VIRTUAL REALITY ON LASER SCANNING 3D FILES

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ABSTRACT:

Digital acquisition, processing and visualization of archaeological sites require increasing performance for software tools. The application of hybrid methodologies based on digital information poses new challenges for satisfying professional and entertainment requirements, helping to have a better understanding of archaeological sites. A faithful representation of the current state is displayed by combining high resolution photogrammetric recording with Computer Vision to provide an accurate 3D model of the archaeological site. The aim of this work is to construct a 3D model for the roman theatre of Clvnia, a very large archaeological site to provide an assessment about conservation and restoration policy. To achieve it, a feedback between bottom-up approach for processing and top-down for visualizing is performed from dense clouds of 3D points captured with an ILRIS 3D scanner of Optech. The superposition of meshes and maps of level curves provides friendly visualizations with a low cost. In our approach, slices of clouds of 3D points are exported to CAD for cartographic, planimetric and visualization purposes, including Digital Elevation Maps of the archaeological site. Fitting of geometric primitives is semi-automatically performed in an interactive way. A Virtual Reality module is developed for adapting exported slices of laser scanning files and for obtaining a realistic rendering. The hybrid methodology developed in this work is enough flexible to be adapted to another environments, including urban scenarios or isolated buildings in Cultural Heritage surveying.

1. INTRODUCTION

Traditional approaches to Cultural Heritage surveying are commonly based in a combination of Computer Vision (Hartley 2000) and Computer Graphics. In presence of risks or when accurate measurements are need for documentation or conservations tasks, accurate metric information must be incorporated to the geometric model. Both aspects are present in archaeological surveying. There exists an increasing contribution of IST for archaeological surveying based in Computer Vision for capturing and processing data from several localization or with a hand-held video camera. Some important recent contributions in the uncalibrated 3D reconstruction are the visualization of Sagalassos (Pollefeys2003).

Contribution of Computer Graphics is focused towards a faithful recreation of the original state of damaged Cultural Heritage. Recent advances in Virtual Reality modules improves the understating of complex environments by means of advanced visualization with respect to traditional 2D presentations. Indeed, elevation drawings can be incorporated to traditional floor plans or static views with high degree of verisimilitude arising from low cost precise planimetry. The following step is the incorporation of high resolution photography and textured surfaces. There exists an increasing interest about the integration of techniques for surveying Cultural Heritage, as it can be seen in several collective volumes which are directly focused towards archaeological surveying (Barceló2000, Forte 1997) or proceedings of recent international conferences (CIPA meetings, Arnold2001, Boehler2002).

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The aim of a synthetic realistic presentation of original state (including ornamental details) of ruins is to try of improving an understanding of the archaeological site as a first step. A more specific goal is given by the development of software tools for assisted analysis. So, an efficient interfaces design will allow apply software tools in an interactive way for a remote exploration via web. In a third stage, a development of a virtual reality module is developed to make possible in the future an immersion in situ from identifying some beacons or to recognise meaningful elements in the archaeological environment.

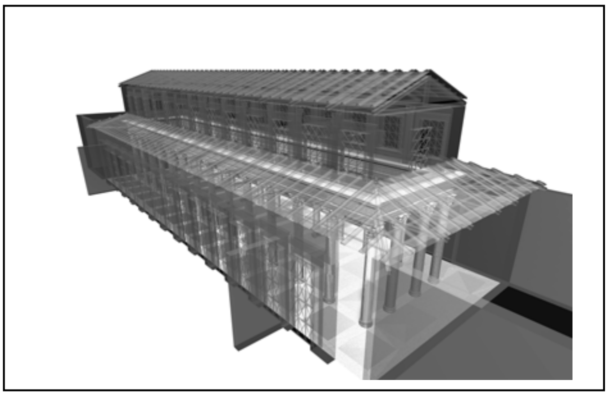

Fig 1: Transparent render of the basilica of Clvnia

In this work, a presentation of the first stage and some achievement of the second one are presented, including the application of advanced rendering techniques for three-dimensional visualizations of the basilica, and the theatre.

Different processing and visualization software tools of large archaeological or complex urban environments can be applied, depending on availability, scale and interactive capability constraints. Currently, a general multi-resolution methodology able of integrating different approaches in surveying Cultural Heritage is a challenge. Hybrid approaches must be enough flexible to identify holes or inconsistencies, and to minimize information loss in matching different formats on a common support. A list of ideal requirements for hybrid approaches can be found in El-Hakim, 2002.

Last advances in 3D laser scanning allow construct global models with high accuracy and minimal human cost. The incorporation of 3D laser scans for surveying archaeological sites allows the generation of very precise cartographic information, with a human cost which is smaller than other more intensive-time approaches. Furthermore, laser scanning avoids some cumbersome problems of another Computer Vision approaches relative to the generation of dense maps, matching views with wide baseline. However, the management of very large clouds of 3D points poses several problems which involve the merging of 2D information on 3D laser scanning files. In particular, this concerns to the insertion of high resolution digital views on 3D files, texture mapping, management of geometric primitives and the identification of archaeological primitives for constructing ideal reconstructions with a high level of accuracy making easier the virtual immersion in realistic representations of archaeological environments. Static approaches provide a good understanding of some monuments (see fig.2 below for the interior of the basilica of Clvnia), but with a hard human work, and some troubles for mobile visualization.

Fig. 2: Ideal representation for interior of the basilica.

To solve above problems, a hybrid approach can be developed on dense clouds of points provided by laser scans (El-Hakim 2002). Hybrid approaches must take in account problems derived from the diversity of sources. These problems are linked to information loss and propagation of errors due to selective processing or successive reductions for finding common reference elements in different formats. Uncertainty about losses arising from information transference can be minimized by working directly with clouds of points instead of additional structures (meshes, textured surfaces). The main troubles of working with clouds of points are linked to hyper-redundant information (optimization with very large amount of data) and the need of re-sampling design procedures for matching views and scans. Indeed, sampled points in high resolution views have not the same localization as sampled points arising from 3D laser scans. Furthermore, radiometric information contained in corresponding pixels is not the same: pixels at views contain very precise information about radiometric properties, but they lack information about absolute localization. Contrarily, pixels arising from scans have very poor information about radiometric properties, but they have very precise 3D information. Hence, it is necessary to design resampling procedures for profiting the advantages of views and scans, in a simultaneous way. Our aim is to show how can be performed a simultaneous transformation on laser scanner data and high resolution views to provide a common precise reference system for the theatre and its environment.

The plan of paper is as follows: The second section is devoted to capture and processing information, with a special accent for planning the capture based on laser scanning and some issues relative to merging scans. Next, some structures are superimposed to the merged scans files, for extracting additional information to different resolution levels and with different professional purposes. The fourth section is devoted to the application of a VR module for video-realistic rendering. A final section is devoted to sketch some conclusions and final remarks.

2. CAPTURE PLANNING

The starting point is the current state of archaeological site. The availability of historical information is crucial to determine which facts are meaningful for articulating the information as a whole. Cooperation with experts in architecture or archaeology is need for identify them, and to select an optimal capture strategy. Some meaningful data are the following ones.

2.1 Historical aspects

Clvnia has an celtiberian origin, but it is refunded by romans in Julia-Claudia time, with a foundation attributed to one of the first roman emperors (August or perhaps Tiberio). Under the administrative reform of Claudius I (41-54 a.c.), Clvnia is the capital of one of the seven roman "convents", and becomes the juridical and religious centre of Iberia. Around the second half of the first century and the second century, Clvnia occupies about a hundred of hectares with a large diversity of civil buildings (imperial hot baths, forum, theatre). Its condition as representative centre of the roman power gives an exceptional quality to the whole archaeological site till its abandon between the fourth and seventh centuries of our era. The devastation and pillage along medieval and modern ages has been very intense, with a large amount of materials disperse at religious and civil buildings around Clvnia, currently. Nevertheless the pillage, recent systematic excavations are giving a lot of very fragmented material, which allow to perform theoretical reconstructions of the original state, from the current remainders. The repetitive and modular character of the civil roman architecture makes easier the generation and the verification of different composition possibilities from founded elements in recently performed excavations.

2.2 Localization and Planning

The ruins of an archaeological site have a low number of self-occlusions. So, it is possible to capture large portions of terrain from a relatively low number of locations. Sometimes it is possible to find high places for scanning or taking views (fig 3)

Fig3: Scanning ruins of the roman theatre from high.

In other cases, it is necessary to scan from the ground. A previous careful planning for information capture is performed. By performing small rotations from the same localization, it is possible to minimize errors or artefacts in matching 2D views or 3D scans. After this planning, 23 scans provide a very large amount of information. Resulting dense clouds of 3D points, are matched without identifying geometric primitives giving near to 20 millions of points. The global management of the whole file is not practical. Thus, it is necessary to apply a selective reduction of information, which is adapted to the curvature variations. In this way, errors linked to fitting geometric primitives are minimized, and a faithful model is obtained.

Localization for scans must be selected by searching orthogonality with respect to surfaces to be surveyed. In this way, re-projections errors and self-occlusions are minimized. Archaeological surveying of large open scenes display a low number of self-occlusions. Even in this case, it is necessary to be aware that partial occlusions contribute to holes in visualization. Thus, photogrammetric strategies are adopted for localizing a minimal number of localizations to simplify merging. Regular structures appearing in the roman theatre simplify the planning for data acquisition.

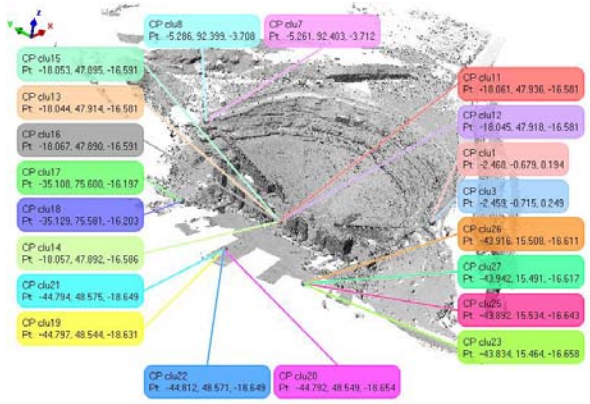

Fig4: Plan of scanning places around the roman theatre.

2.3 Data registration

Several series of high quality 2D data have been taken for the roman theatre with a calibrated camera in a regular way under diffuse light, and along a short time to minimize changes in exposure and radiometric ambient conditions. For the acquisition of 3D information from laser scanning an ILRIS 3d device of Optech has been used. Total time for capture is about 6 hours. Two important issues in initial data registration of scans concern to the angle of acquisition which is at most 40º in Ilris 3D of Optech, and spot size which can be selected by the user.

Metric information relative to the scene is captured with a very low error; errors are adaptable in capturing data, by selecting spots between nearest points in the scene to be sampled by the laser scan device. It is convenient to take several scans with different resolution. A global low resolution scan provides a general model which allows the matching of high resolution scans, and which can be deleted after finishing merging process. Automatic merging is more robust if there exists large overlapping areas, especially in presence of curved primitives (grades of the roman theatre) or repetitive structures (constant transversal sections) for geometric primitives.

Strategies for merging resulting scans are different: large differences in height for grades of the theatre and radial quasi-symmetric structure suggest to perform scans from the extreme upper circle and the nearest place to the vertex of half-cone; both of them are illustrated in *Fig 5*. In this case, a low number of scans has been enough for capturing relevant information for surveying the roman theatre.

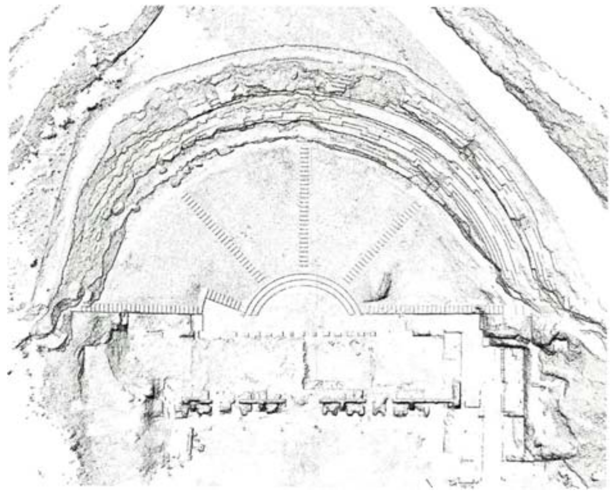

Fig.5:A plant obtained by merging clouds of points.

2.4 High-resolution views for textures and mosaics.

Due to the low quality of internal camera of the laser scanner device, high quality views are taken with a digital camera Panasonic FZ-20 with 5 Mpix, from locations which are very near to those of the scanner device. The application of commercial software tools for panoramic views makes possible to generate mosaics and high quality static visualizations of the current state of textured walls From these high-resolution views it is possible to extract textures which will be superimposed in posterior stages of visualization.

3. PROCESSING INFORMATION

The main goal of this section is to illustrate how can perform the processing of digital information arising from laser scans and high resolution photography. Digital processing includes the generation of global topographic information and the superposition of additional structures (meshing, wire frames and textured surfaces) for integrating the whole information in a common support for virtual restoration.

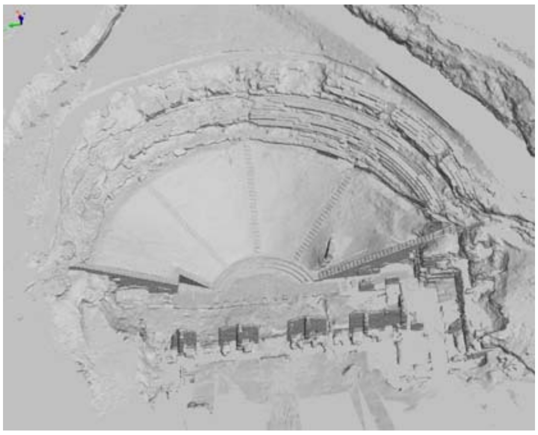

Fig7: A plant as textured surface

3.1 Merging laser scans of the roman theatre and the villa

A three-step scanning strategy has been developed to obtain a global model of the roman theatre. Due to spot differences, non-uniform distributions for clouds of points are generated, but this is not a problem for matching due to the strong presence of geometric primitives which simplify grouping and their visualization even for the lowest resolution level. Following this strategy, a first *pseudo-conical model* has been generated by merging together scans following a semi-circular pattern of scans taken from the centre of proscenium. Holes arising from non-visible zones from the proscenium have been completed with two series of scans taken from elevated place located at right and left uppers sides of the roman theatre, giving a second model which has been labelled as the *complete interior model*. A more complete *outside third model* is obtained by matching together scans taken from the back of the proscenium and a very large view taken from more than three hundred meters which includes the whole environment and accesses to the roman theatre.

3.2 Superimposed Triangular Meshing

Meshes provide a 3D support for propagating radiometric information contained in 2D views. Large shape portions with smooth variations in curvature or well delimitated contours simplify propagation models along surfaces to be coloured or textured. To avoid a too homogenous propagation model on smooth shapes, a stochastic variation can be adapted to the propagation model for textures. In this case, the roman theatre of Clvnia exhibits a stepped geometry, far from smooth shape, as it can be seen in detailed topographic maps (Fig.8)

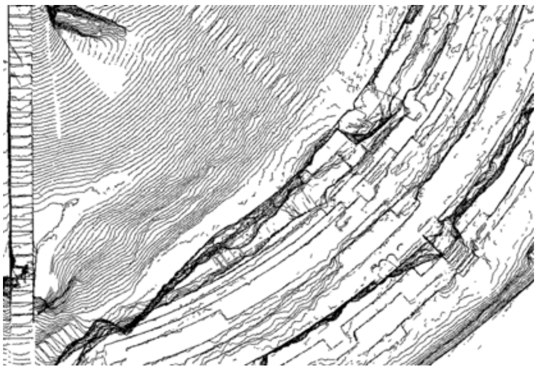

Fig.8: Plant of local topographic map

Local topographic maps are very useful for adapting constraints relative to the maximal allowed length of triangles making part of meshes. The incorporation of abrupt changes in orientation of normal vectors to small triangles and scarcely defined contours suggest apply propagation models directly adapted to the clouds of points. Matching common information contained in 2D views and 3D scans must be performed on files with the same orientation. A projection on a plane parallel to the laser screen centred on the principal point minimizes errors in visible parts for both 2D views and 3D scans.

In despite of the high resolution of 2D views, density of pixels in 2D views is far from being as high as those of clouds of points. Thus, one can not expect to find common pixels for 2D views and an appropriate projection of 3D clouds of points. To solve this problem a regular sliced-based subdivision of 3D files is generated (see below 4.1), with a reprojection adapted to a cylindrical projection of the common visible part of the theatre. Next, for each meshed slice an adaptive re-sampling is applied, following a typical nearest neighbour algorithm for spots of similar location and intensity level. After the adaptive reduction of the original cloud of 3D points, the simplified polygonal model has 1.4 millions of triangles. Meshes with more than 2 millions of triangles require a redistribution for the memory management.

3.3 Generation of topographical map.

A map of level contours for the theatre and its surroundings is generated with a RMS under 1cm. The generated map of level surfaces is compared with existing information arising from traditional cartography and aerial photography. In this way, a dense 3D visualization is obtained, allowing a better understanding of the archaeological site and its environment.

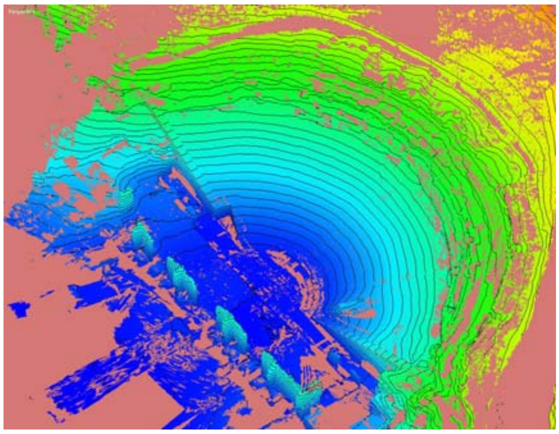

Fig.9: Global topographic map of level curves

3.4 Integration of data

Simultaneously to the scans, a large number of high resolution views has been taken with a calibrated camera. A careful photogrammetric analysis has been performed in order to determine relevant characteristics relative to focal length, principal point, etc for each view. Furthermore, several panoramic views have been stitched to have reference elements to be compared with results arising from laser scans and to provide basic textons to be inserted in 3D files.

3.5 Identification of archaeological primitives

Archaeological primitives have not necessarily a geometric character. Thus, a very precise shape evaluation is needed for accurate location. Often, only small fragments are available and some additional work must to be done for imaging the original state. A large number of ancient pieces are exhibited in near museums to Clvnia, but the best ones have been reutilised in civil or religious buildings of the surroundings. Thus, their integration to the original state is not practicable and we must limit ourselves to their virtual insertion in the current state.

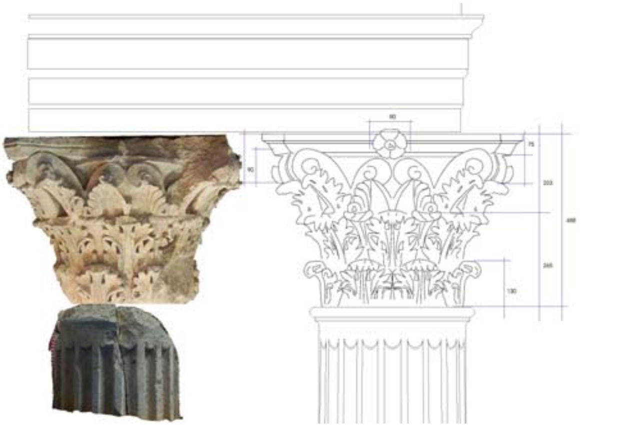

Fig.9: Reconstructed chapitel and visualization of entablature

3.6 Processing Time

It must be noticed that the availability of advanced software tools for processing and friendly interfaces does not avoid a very specialised human work with 2 hours for recording and adjustment, 2 hours for automatic processes (merging, smoothing and reduction), and more than 20 hours for data edition (data cleaning, geo-referencing, video reports, CAD export, cross-sectioning, etc).

4. VISUALIZATION AND MANAGEMENT

Original surface modellers display a very coarse approach for visualizing archaeological sites. In despite of their deliberate simplification, they incorporate essential structural elements (often hidden by ornaments) and they allow some interactive navigation around the objects. Anyway, they are not enough for accurate visualisation required for archaeological purposes. A large amount of contributions to improve such state of affairs has been developed along last ten years starting with applications to the architecture (Debevec1996)

The main goal of this section is the application of available visualization modules to provide a faithful rendering of the hypothetic original state from the current state. Typical top-down approaches are based on a coarse-to-fine methodology starting with a coarse solid modelling and adding progressively finer results till to achieve a photorealistic representation. In this way, it is possible to identify structural elements which are crucial for architectural purposes related with conservation or restoration objectives. However, this approach presents a high human cost, which can be lowered by applying recent advances arising from processing of clouds of points, directly.

4.1 Slicing clouds of points

The large volume of acquired information makes some difficult to work in a simultaneous way with the whole file when colour and texture are incorporated. Furthermore, architectural information is easily visualized in terms of transversal sections along some axis. Because of this, it seems convenient to develop software tools for and automatic decomposition adapted to the global file in smaller portions which are called “slices” and which can be obtained from the global model of grades

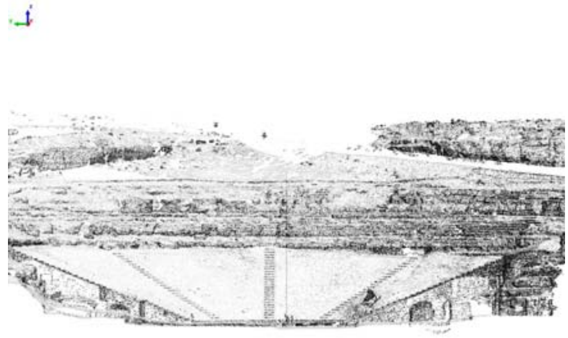

Fig.10: A view of the global model of grades before slicing

In our case, to obtain a balanced amount of information for each slice and a quasi-homogenous distribution for different slices, one can take five radial cuts along the axis of the 3D model for the roman theatre with the same step, giving 6 half-conical slices with step equal to 30º. The scene and proscenium of the roman theatre is treated as a whole with a different strategy. Additional information of the current state for external walls is incorporated later.

4.2 Identifying and Fitting of geometric primitives

Solid geometry helps to understand the role played by structural elements. Often, structural elements are hidden or they appear in a very incomplete way due to constructive needs or deterioration produced by natural or human actions. In addition, simple volumetric elements make easier a robust management of large amount of 3D data for rendering tasks. Furthermore, it is possible to perform transversal sections helping to understanding some structural aspects which are sometimes hidden by visible elements. Thus, even if solid geometry is not displayed to the final user, it is convenient to have a low-level robust module based in coarse level geometric primitives which is in charge of the finer level management of architectural or archaeological primitives.

Geometric coarse models must be taken in an approximate sense. In this case, a coarse global model is given by a truncated half-cone, whose grades have locally the shape of half-cylinders (see Fig.12, below). Coarse geometric primitives are useful for understanding the architectural structure and for visualization. Indeed, the design of dynamical models for textures propagation can be adapted to geometric primitives to reinforce the photo-realistic aspect of rendering.

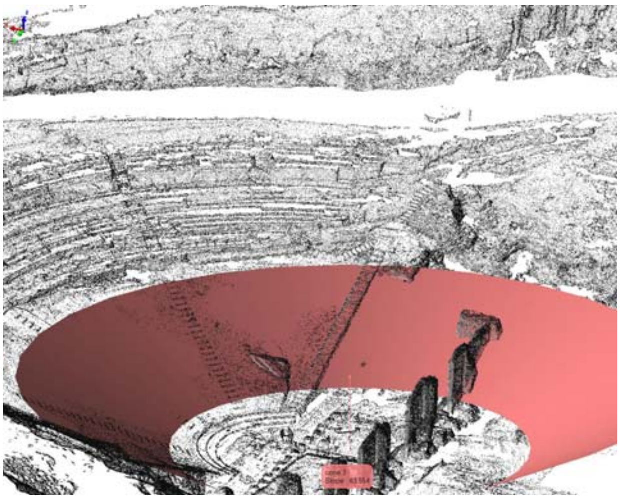

Fig.12: Fitting geometric primitives to a slice

4.3 Export to CAD files

The management of simplified geometric primitives can be performed with conventional CAD software tools. The export of dense clouds of points allows draw directly on files, and contribute to give a more realistic aspect to final presentation. An application of CAD software tools has been performed on partial views corresponding to slices and the global model with a lower resolution. In this way, it is possible to draw directly on exported files to DXF format.

4.4 Semi-automatic modelling

Surface modelling is achieved from the identification of geometric primitives. The coarsest level of analysis provides a concave model for the global shape of the terrain which has been adapted to its use as roman theatre. The availability of simple primitives (lines, planes, spheres, cylinders, e.g.) in dedicated software allows to select zones included in clouds of points and search for fitting the correspondence with a selected primitive. Currently, we are developing a module to generate an automatic segmentation of the whole cloud of points allowing the automatic identification of large portions of the cloud to identified geometric primitives.

The identification of simple geometric primitives provides the basic pieces for solid geometry which is the input for the virtual reality module. Thus, virtual model is generated from previously identified geometric primitives which unfold from the archaeological site.

5. VIRTUAL ARCHAEOLOGY FOR THE UNDERSTANDING OF THE ROMAN THEATRE

Hypothetical recreation of the original state of archaeological site provides tools for recreating realities which no longer exist. Realistic visualizations are still expensive in computational effort and human cost. In addition, the diversity of buildings reliques and the very large extension of the archaeological site of Clvnia make difficult a global high quality representation of the environment. Thus, we have restricted ourselves to some meaningful examples based on crystal visualizations with radiosity maps with atmospheric simulation for the basilica (see Fig1 and Fig 2) and geometric reconstructions with static lighting linked to frontal views for the roman theatre.

5.1 Virtual Archaeology for the roman theatre of Clvnia

Virtual Archaeology is the computer-based generation and management of extended representations from the current archaeological reliques for a faithful representation of the original state for improving the understanding of complex realities. It involves to the identification of relevant data, their management in relational data structures (including as labels those which can not be quantified properly), the image processing based in Digital Photogrammetry and Computer Vision, and the rendering in hybrid artifacts based in Computer Graphics. We are still far from integrating all these software tools in a general flexible module which can be adapted to objects (pottery, statues, e.g.), buildings or general archaeological sites. Thus, the following paragraphs are dedicated to illustrate some partial advances in the domain of Virtual Archaeology.

5.2 The 2D virtual model of the theatre

Fragments of coryntian chapitels have been founded in recent fillings of the proscenium. An example of the careful reconstruction is displayed in *Fig.9.* From recent excavations, there is available information about the architectural structure of the theatre, including localization of columns, entablatures and other decorative elements. The displayed localization of statues would must be considered as temptative. A first version of an ideal reconstruction from data currently available is displayed in Fig.14.

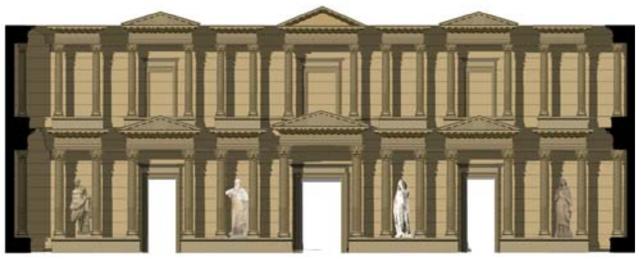

Fig.14: Ideal reconstruction of the roman theatre of Clvnia.

5.3 Wire-frame model of the roman theatre

The 2D frontal ideal reconstruction of the roman theatre is matched on a frontal visualization of the 3D model by identifying geometric characteristics of currently existing walls, and intermediate holes between them. After matching, a coarse visualization can be performed by using the whole 3D structure of the model. There are no information about sculptures appearing in the scene of the theatre, and some of them are inserted as plane objects. High quality scans of small pieces can be inserted in general 3D models. Several experiments have been performed including sculptures of façades with a very rich ornamentation, e.g.. However, we have not still the opportunity of scanning original sculptures. Thus, the visualization of the scene is still unfortunately incomplete.

5.4 Some remarks about matching textures

Textures provided by ILRIS 3D of Optech have a geometric character, but they lack of true color information. However, these partial results can be improved with high resolution images obtained in situ or in the near roman museum. The aim of this paragraph is to show some elements for the application of a general texture mapping on two examples of Clvnia.

To avoid troubles with discontinuities linked to the discrete character of files a coarse-to-fine strategy based on adapted triangular propagation (ATP) for textures is followed. The ATP strategy has two levels of propagation: The coarse level works directly on performed meshing by adding constraints about the allowed size and orientation of triangles and by propagating from barycenters of triangles. The fine level uses the identified geometric primitives in slicing step to propagate according to the approximate shape of object. In this way, the rounding effect of coarse propagation is corrected and adapted to a more believable model.

However, the treatment of textures is still too plane. There is still some work to be done to improve this visualization, by means of a propagation of an ideal representation of textures on identified remainders on an ideal representation of architectural elements.

5.5 Multimedia processing

Several video presentations have been generated from the 3D model based on clouds of points, adaptive meshes and textured surfaces. Video presentations start with an aerial navigation around the archaeological site, with two levels of information (landscape and cartographical), identifies the meaningful places where surveying is performed, and it allows the selection of each place. From each selection of the site (roman theatre or villa) to be surveyed, the video presentation starts with a panoramic view is generated from high resolution images for simplifying the relative location and to provide finest details of the site. Finally, several videos of the current state of 3D model with different resolution have been generated. Next step to be done is a recreation of the hypothetic old state of the roman theatre by inserting dynamic textures adapted to an ideal reconstruction. In this way, we hope to contribute to achieve a better understanding of the roman theatre of Clvnia.

6. CONCLUSIONS AND FUTURE WORK

Laser scanning of the archaeological sites allows integrate modern digital techniques for conservation, restoration and diffusion of Cultural Heritage. A hybrid strategy for laser-based archaeological surveying of the roman theatre of Clvnia is developed in this paper. The strategy combines image-based and range-based approaches for information processing and fusion. Human costs are much lower than traditional approaches based in conventional Computer Vision or Digital Photogrammetry. The adaptation of a virtual reality module to 3D support arising from scanning files simplifies the generation and management of solid elements supporting complex renderized models. Furthermore, the 3D visualization provides educational tools for making globally accessible via web and simplifying the understanding of complex realities.

Currently, we are adapting multimedia data structures for an interactive management of 3D information of archaeological sites. A mid-term challenge is the generation of volumetric sections or different perspective-based adaptive visualizations of the archaeological site. The adaptive models take in account shape variations locally incorporated as slices to provide a support for fine propagation models for textures. In this way, an advanced rendering model will be generated. An efficient design of interfaces with interactive systems for immersion in an augmented reality environment is the goal to be achieved in the next future. The generation of digital templates for assisting field work of archaeology experts will contribute to improve the communication between different methodologies to improve the understanding of archaeological sites.

6.1 References and Selected Bibliography

References from Journals:

Pollefeys, M., VanGool, L., Vergauwen, M., Cornelis, K., Verbiest, F, and Tops, J.: *3D capture of Archaeology and Architecture with a hand-held camera*, The Intl Archives of the ISPR*S*, Vol.34, Part 5, W12.

References from Books:

Barceló, J.A., Forte, M. and Sanders, D.H., 2000: *Virtual Reality in Archaeology*, ArcheoPress, Oxford, British Archaeological Reports, International Series, #843.

Forte, M (ed),1997. *Virtual Archaeology: Great Discoveries Brought to Life Through Virtual Reality*, Thames and Hudson, London.

Hartley, R. and Zisserman, A.: *Multiple View Geometry in Computer Vision*, Cambridge University Press, 2000.

References from Other Literature:

Arnold, D, Chalmers, a. and Fellner, D.W. (eds): *Proceedings of the 2001 Conference on Virtual Reality, Archaeology, and Cultural Heritag*e, Glyfada, Greece, November 28-30, 2001.

Boehler, W., ed: *Scanning for Cultural Heritage Recording*, Proc. Of the CIPA WG6 Intl workshop, Corfú, Greece, 2002.

CIPA 2001: *"Surveying and Documentation of Historical Buildings-Monuments-Sites. Traditional and Modern Methods"* (Potsdam, 2001).

CIPA 2003*: "New Perspectives to Save Cultural Heritage"*, XIXth International Symposium (Antalya, 2003)

Debevec, P., Taylor, C. and Malik, J.: "Modeling and Rendering Architecture from Photographs: A Hybrid Geometry- and Image-Based Approach", Proc. SIGGRAPH'96, 303-312, 1996.

El-Hakim, S.F., Beraldin, J.A. and Picard, M.: *Detailed Reconstruction of Monuments using Multiple Techniques*, in Boehler, ed, 2002, 58-64.

Roessler, M. (ed), 1999. *World Heritage Cultural Landscapes. Identification, Conservation, Monitoring.* ISPRS Proceedings, UNESCO-ICOMOS-CIPA-ISPRS World Heritage Session. Amsterdam 2000.

References from websites:

Links related with Virtual Archaeology in
http://www.mnsu.edu/emuseum/archaeology/virtual/links.html

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