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Combination and Comparison of Digital Photogrammetry and Terrestrial Laser Scanning for the Generation of Virtual Models in Cultural Heritage Applications

Thomas P. Kersten

HafenCity University Hamburg, Department Geomatics, Hebebrandstrasse 1, 22297 Hamburg, Germany

Abstract

This paper summarizes two projects by the HafenCity University Hamburg, in which two historical buildings were recorded by digital architectural photogrammetry and 3D terrestrial laser scanning and each reconstructed as a CAD building model. In one project each procedure was used separately and compared for the 3D recording and modelling of the church in Raduhn (in Mecklenburg-Western Pomerania, Germany), while in the second project the West Tower ensemble of Duderstadt (in Lower Saxony, Germany) was reconstructed by combination of both procedures. For both projects the digital SLR camera Fujifilm FinePix S2 pro and the terrestrial laser scanner Mensi GS100 were used. The church Raduhn was modelled both from 51 images using PhotoModeler, and from the 3D point cloud of the laser scanner using 3Dipsos. In this project the accuracy, the level of detail and the amount of work expended for both generated models were compared to each other. The West Tower ensemble, consisting of tower, museum and surrounding buildings, was modelled from 58 digital images and a 3D point cloud using PHIDIAS for visualisation applications, which were used for presentation at the 500 year anniversary of the West Tower in the year 2006. The necessary work procedures from data acquisition to visualisation are described for both projects including the obtained accuracy (1-2 cm) and the amount of work expended.

1. Introduction

For 3D recording of objects like buildings terrestrial laser scanning today increasingly represents a genuine alternative or supplementary measuring method to tachymetry or to digital architectural photogrammetry. However different laser scanners are available on the market as camera or panorama view scanners depending upon requirements regarding accuracy, range, resolution and scanning speed. The processing of tachometric or photogrammetric data for the generation of 3D building models is today a proven method. The photogrammetric acquisition and 3D modelling of historical buildings e.g. with the software PICTRAN were published in [KAL04]. A software solution for the combined processing of laser scanning and image data with the program PHIDIAS of PHOCAD, Aachen is presented in [BS05a]. Practical experiences using PHIDIAS with laser scanning data of a *RIEGL* LMS Z420i combined with a calibrated Nikon D100 digital camera are described in [NDSR05]. A comparison between 3D laser scanning and stereo photogrammetry from a practical point of view was performed by [Lin05] with the conclusion that the combination of both techniques offer efficient options to generate the most suitable product. [IDST05] presented the combination of laser scanner data of the Cyrax 2500 and simple photogrammetric procedures for surface reconstruction of monuments.

In this paper two projects were carried out by the HafenCity University Hamburg, in which two historical buildings (Fig. 1 and 2) were recorded by digital architectural photogrammetry and 3D terrestrial laser scanning and each reconstructed as a CAD building model. In one project each procedure was used separately and compared for the 3D recording and modelling of the church in Raduhn (in Mecklenburg-Western Pomerania, Germany), while in the second project the West Tower ensemble of Duderstadt (in Lower Saxony, Germany) was reconstructed by combination of both procedures. The necessary work procedures from data acquisition to visualisation are described for both projects including the obtained accuracy and the amount of work expended. The virtual objects are presented and appropriate conclusions are drawn from the combination and comparison of both procedures.

2. The recorded objects - church in Raduhn and West Tower ensemble in Duderstadt

The church (Fig. 1) is located in the small village Raduhn in the district Parchim (Mecklenburg-Western Pomerania). The village was mentioned for the first time in a marriage-certificate from November 23rd in 1264, however no further documents exist concerning the building of the church. In the years 1857 to 1859 the "old church" was completely modified in the new gothic style under Grand Duke Friedrich Franz II, which is today indicated in numerous pointed arches of the windows and doors. The melange of original rock faces and clay bricks is a time witness to this serious structural rebuilding. At the north and east front arches and bricked up windows are present in the brickwork as further signs of a formerly extended church. The building covers a ground plan of approx. 7 x 8 meters and has a roof ridge height of approximately 15 meters. The tower at the west side has a height of 24 meters. Today a large meadow surrounds the church, delineated by a one meter low dry stone wall.

Figure 1: *Church in Raduhn (Mecklenburg-Western Pomerania, Germany).*

Figure 2: *Front (left) and back view (right) of the West Tower in Duderstadt (Lower Saxony, Germany).*

The West Tower (in German: Westerturm) is the landmark of the city Duderstadt (district Goettingen) in the south-easternmost part of Lower Saxony. The West Tower (approx. 35m x 8m x 52m, see Fig. 2) is the only completely preserved tower of the medieval city attachment, which was already mentioned for the first time in documents on October 16th in 1343 as Niedertor. After a fire in spring 1424 the West Tower was destroyed, but it was rebuilt in stone after a short time period. The roof structure was completed in 1505, which made the tower into the landmark of the city due to its regular twisting. Due to serious damage to the timber construction of the roof a fundamental remediation of the tower was accomplished in the year 2002. In the course of this remediation the city wall in the old Bachmann' house was also opened and the structure of the old house front was replaced by a glass construction. The restored West Tower ensemble was solemnly inaugurated on August 12th in 2004 and made accessible to the public.

3. Systems for object recording

The recording of the two buildings was performed with a commercial digital SLR camera Fujifilm FinePix S2 pro and the terrestrial laser scanning system Mensi GS100. The S2 possesses a CCD chip with a sensor of 23.3 mm x 15.6 mm, which offer a maximum interpolated resolution of 4256 x of 2848 pixels, which yields a file size of approx. 35 MB per image in TIFF. At this resolution 28 photos can be stored on one Compact Flash Card with 1 GB storage capacity. The camera was used with Nikkor lenses with focal lengths of 14 mm and 28 mm.

Figure 3: *Terrestrial 3D laser scanning system Mensi GS100 at HafenCity University Hamburg*

The 3D laser scanning system GS100 is manufactured by Mensi S.A., France and consists of a laser scanner, accessories (Fig. 3) and appropriate software for data acquisition and post processing. The technical specifications of the system are summarized in [Men04]. The optimal scanning range is between 2 - 100m. The panoramic view scanner (field of view 360° horizontal, 60° vertically) offers an uninterrupted panoramic capture of a scene of 2m x 2m x 2m up to 200m x 200m x 60m indoors or outdoors. The resolution of the scanner is 0.002gon (in horizontal/vertical direction). The laser point has a size of 3mm at 50m distance, whereby the standard deviation of a single distance measurement is 6mm. The distance measurements are performed by pulsed time-of-flight laser ranging using a green laser (532nm, laser class II or III). The system is able to measure up to 5000 points per second. Investigations into the accuracy behaviour of the terrestrial laser scanning system Mensi GS100 are described in [KSM05].

Fig. 3 shows the 3D laser scanning system Mensi GS100 (weight 13.5 kg) with accessories, consisting of a rugged flight case and a notebook for controlling the unit during data acquisition. The usage of an efficient power generator is recommended for field work, when mains power cannot be obtained.

4. Photogrammetric object recording and laser scanning

The object survey was performed via the following work procedures: signalling of control points for the photogrammetric image acquisition and for laser scanning, measurement of a geodetic 3D network including control point determination using a Leica tacheometer, and laser scanning and photogrammetric image acquisition. The recording of the church Raduhn was conducted within one day at 21st of April 2004, while the West Tower ensemble was captured in February 2005 on three days.

Figure 4: *Mobile turning ladder at the West Tower in Duderstadt for signalling of control points and for image recording*

As photogrammetric control points 45 signals (size Ø 25 mm) for the church Raduhn and 49 signals (size Ø 50 mm) for the West tower were used. The signals were well distributed and attached to the object. Due to the height of the West Tower a mobile turning ladder with a maximum work height of 28m (Fig. 4) was used for the signalling of control points and for additional photographs with the camera. For the registration and geo-referencing of the laser scanning point clouds of the West Tower nine green Mensi targets and six spheres were placed at the tower wall and on each tacheometer station, while the spheres for the scans of the church were just fixed on the eight tacheometer stations, which were well distributed around the church. Due to the building arrangement of the West tower ensemble and the integration of the internal area of the tower and the museum the geodetic 3D network consisted of four subnetworks with altogether 12 stations, from which all control points for photogrammetry and laser scanning were measured. In an adjustment with the software PANDA (GeoTec, Laatzen) the 3D network and all control points were determined with a standard deviation of better than 1.5 mm (West Tower) and 3mm (church Raduhn). The outside and internal areas of the West Tower ensemble were recorded with 137 images in total (with maximum resolution, resulting in 5 GB graphic data), but only 58 images were used for the camera calibration and the following data processing. On the other hand the church Raduhn was recorded with 60 images (resolution 3040 x 2016 pixel) using the camera with a Nikkor 14mm lens at eye-level, but here 51 images were used for later evaluation.

Figure 5: *Terrestrial 3D laser scanning system Mensi GS100 in use: church Raduhn (left) and West Tower (right)*

Both objects were scanned with the laser scanner GS100 (Fig. 5) from five (church Raduhn) and ten scanner stations (West Tower) at a grid spacing of 20 mm and 93 mm over 10 m distance, respectively. Object details such as windows or tower figures were scanned with a higher resolution of 5 mm / 10 m. The controlling of the scanner was performed with the software PointScape, whereby the selection of the scan ranges was conducted by video framing of the internal video camera. Each visible target and sphere (which was attached to the tower wall and on the tachymetry stations) was scanned separately on each scanner station for the later registration and geo-referencing of the scans. These were automatically recognized as control points by the software. With the scanning of the West

Tower spire it turned out that the black slate roof hardly reflected the green laser light, so that this part of the building had to be reconstructed later by photogrammetric methods. For the church 12 million points were scanned, which corresponds to a data volume of approx. 230 MB, while for the West Tower ensemble 13,5 million points (250 MB) were scanned.

5. Data processing

5.1. Registration and geo-referencing of scans

For manual registration and geo-referencing of the scans the software RealWorks Survey V4.2 from Mensi was used. All scanner stations were registered using three to seven targets and spheres in each scan, whereby the precision for the registration of the point clouds was between 4 mm (minimum) and 8 mm (maximum value) for both projects. The geo-referencing of the registered point cloud of the West Tower was achieved by 23 control points (6 spheres on geodetic net stations, 9 targets and 8 spheres at the tower wall) with a RMS of 8.8mm of the control points, which was sufficient for the following object reconstruction. The geo-referencing of the point cloud of the church was performed with a RMS of 5.2mm using 3Dipsos.

Figure 6: *Entire point cloud of church Raduhn represented with RGB values of the point cloud*

Subsequently each entire point cloud (Fig. 6 and 7) was cleaned up, i.e. all redundant points, which did not belong to the object, were deleted. For the object reconstruction the parts/areas in the point cloud, which were required for data processing, were segmented and exported as an ASCII file, in order to be able to be processed in PHIDIAS.

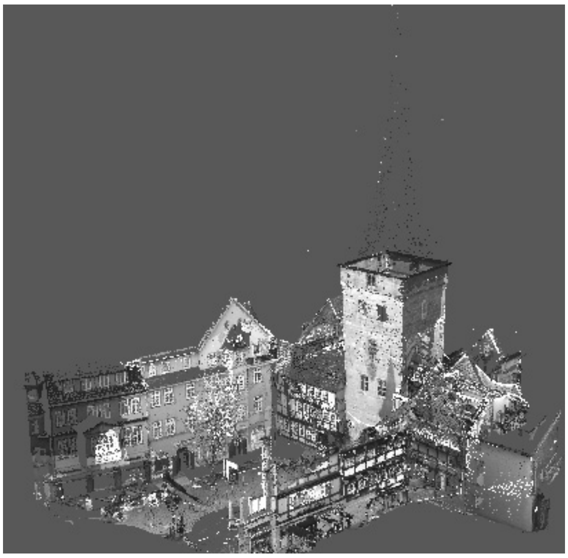

Figure 7: *Entire point cloud of West Tower ensemble*

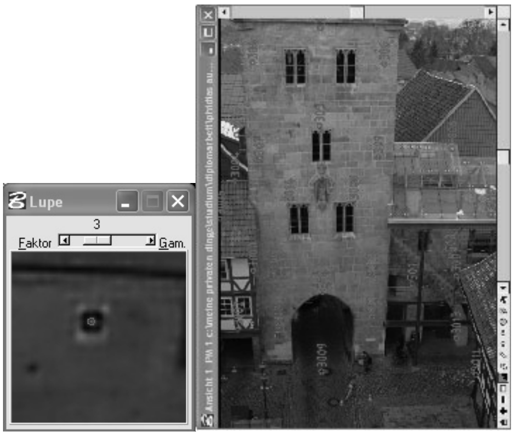

Figure 8: *Photogrammetric point measurements*

5.2. Image orientation and camera calibration

Before the actual 3D point measurements for object reconstruction could be carried out image orientation and camera calibration were performed. Therefore, 51 selected digital images of the church Raduhn were triangulated and oriented in a multiple image block by image point measurements with the software PhotoModeler (EOS Inc.). In the second project, the orientation of 58 selected digital images of the West Tower ensemble and the related camera calibration were determined by image point measurements with the program PHIDIAS (PHOCAD). Fig. 8 clearly shows the measurement of a control point (right) in a rotated representation. For both multiple image blocks a stable connection of the images and a reliable point determination are ensured by the fact, that 19 (for the church) and 12 points (for the tower) on average were measured per image and that each object point was measured, on average, in 8 and 6 images, respectively. All image orientation parameters were determined simultaneously with the camera calibration parameters in both software packages by a bundle block adjustment. Systematic errors, like the high lens distortion, were compensated in the camera calibration for the further evaluation. All image points could be measured with an image measuring precision of $s_{xy} = 3.0$ micron (church) and 4.8 micron (West Tower) respectively, which corresponds to a precision of better than a half and/or one pixel. The standard deviations for the coordinates of object points were about 2 mm in both projects for the signalised points and better than 1 cm for all natural points. These results confirm the high precision potential of digital SLR cameras for applications in architectural photogrammetry, which could be also achieved in other projects [KAL05].

5.3. Object reconstruction by different procedures

In order to be able to compare the potential of the photogrammetric and the laser scanning data for the 3D evaluation and the object reconstruction of the church, oriented images in PhotoModeler and segmented point clouds in 3Dipsos were evaluated separately.

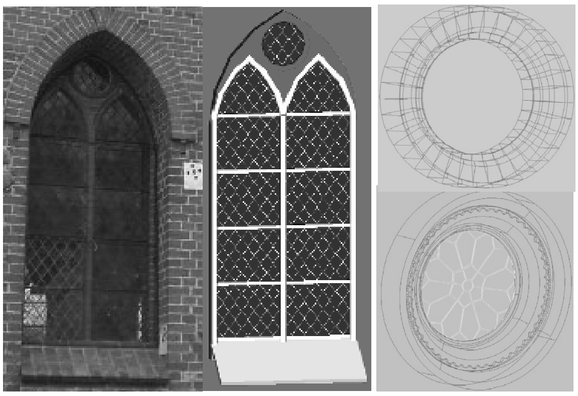

Figure 9: *Reconstruction of a window by photogrammetric 3D point measurements (left, centre) and a window detail (right) in comparison, generated from photogrammetric data (bottom) and from laser scanning data (top)*

In PhotoModeler the necessary object points were measured in at least three images with a standard deviation of better than 10 mm, whereby identical objects, as e.g. windows or stucco volumes were measured only once in detail and were inserted later in CAD as CAD copy in a measured insert point. For the generation of the 3D volume model the points were imported via a DXF file into AutoCAD. For constructive working with AutoCAD the different main elements, like facades, windows, stanchions, tower, main and side entrance were modelled in separate files. Smaller objects and details, e.g. roofs, pattern of the ornament and crosses, were directly designed in the respective files of the associated elements. The individually modelled objects were built up afterwards to an entire volume model. Fig. 9 presents a window, which was generated from digital images. Furthermore, a 3D window detail, which was generated from photogrammetric data (bottom right) and from laser scanning data (top right) is shown in Figure 9.

Due to the geometrical structure of the building the modelling of the point clouds was made predominantly in 3Dipsos by best-fit-functions, i.e. most geometry elements were produced over an approximation of a plane. E.g., in the segmented point cloud of a facade an adjusted plane was computed without basic conditions. These geometrical elements were pruned afterwards with other planes. In such a way, the facades, the roof elements, stanchions and gables could be generated. For the embrasure of the windows, adjusted planes right-angled to a further plane, and for the vaults of the windows, adjusted cylinders, were calculated. The ornaments were modelled with the geometrical element torus. For the production of the 3D volume models the modelled data were transferred via a DXF file to AutoCAD.

Figure 10: *3D volume model of church Raduhn in comparison: photogrammetry (left) vs. laser scanning (right)*

Fig. 10 shows the church Raduhn as two comparable rendered 3D volume models, where one was generated from digital photogrammetric images (left) and the other from laser scanner data (right). For both models some distances were controlled by geodetic determined distances. For this quality control an accuracy of up to 20 mm could be achieved, whereby the differences between photogrammetry and laser scanning were also in the same range. However, it must be stated, that the point identification and the generalizations for object reconstruction have an influence on the accuracy of the compared distances. A detailed description of the comparative reconstruction of the church Raduhn using both procedures is summarized in [Hof05].

5.4. Object reconstruction by combination of both procedures

The object reconstruction of the West Tower ensemble was accomplished with the photogrammetric system PHIDIAS, which is an MDL-application for the CAD system MicroStation. The measured data from PHIDIAS can be displayed directly in MicroStation and further processed by the combination of these programs. The point clouds, which were imported in ASCII format, are converted into an internal binary format, in order to accelerate further processing of these data and to reduce the file size.

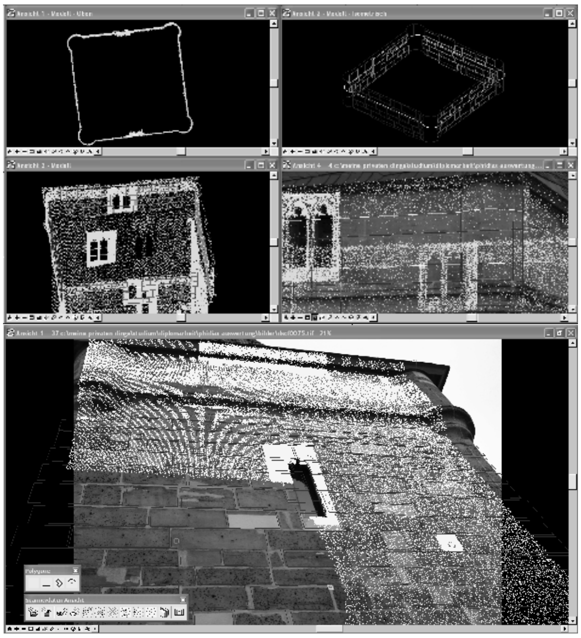

Figure 11: *Representation of the point cloud in combination with image data (top) and monoplotting of stones using information of an image and laser scanning (bottom)*

3D point determination by monoplotting in PHIDIAS is possible by the combination of photogrammetric and laser scanning data. Therefore, the point cloud and the pertinent image are displayed on screen at the same time (see Fig. 11). In a first step a mapping plane must be specified, whereby it must be defined that the axis of the coordinate system is right-angled on the building facade, in order to simplify a later mapping of each single stone. The necessary depth information is received from the point cloud after the definition of a plane. For the mapping of the single stones the point cloud was hidden and the drawing of each single stone was executed in 3D as a "closed polygon". The single stones were drawn over the actual edges of the building as well as over the windows and passages, in order to determine the accurate corners and edges in the CAD program by pruning according to the reconstruction of all building facades. Afterwards, all single stones were extruded into a 3D volume body on the actual wall thickness, which was determined by hand measurements with a strength of up to 1,55 m. A detailed description of the reconstruction of the West Tower is summarized in [BS05b].

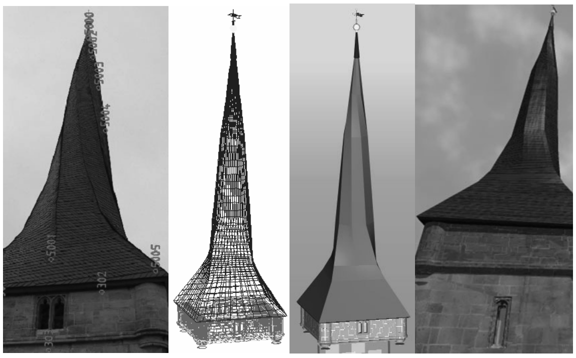

Figure 12: *Generation of the top of the West Tower: photogrammetric image, wire frame, rendered model in AutoCAD and visualisation in Highlight pro*

5.5. Visualisation

For the visualization of the West Tower ensemble the surrounding topography (roads, ways, paving stone transitions, traffic signs, lanterns, trash cans and watercourse) and the adjacent buildings (generalized) were recorded by tacheometry with Leica TCRP 1105+. This recording was supplemented by detailed hand measurements (sketches) of some objects such as lanterns and traffic signs.

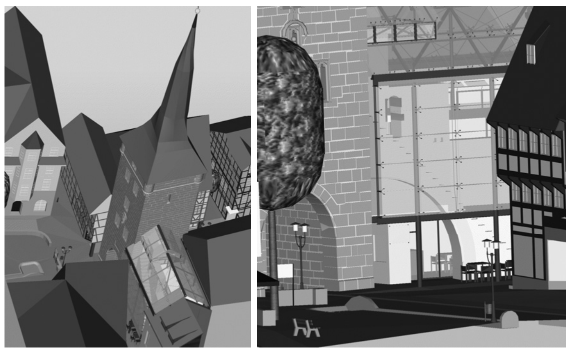

Figure 13: *Rendered perspective scenes of West Tower ensemble Duderstadt generated by AutoCAD*

The visualization of both objects was realised with different programs: AutoCAD, AECViz of TORNADO Technologies Inc., Canada, 3D Studio VIZ and Highlight pro. In AutoCAD the 3D volume model was rendered to obtain a quality control of the modelled data (Fig. 13) and to provide perspective view in BMP format. An interactive animation was created for each data set with AECViz (Fig. 14), i.e. the entire DWG file (church: 12 MB, West Tower: 132 MB) was converted into 3 and 5 MB large executable programs (EXE file), respectively, which can be viewed from all perspectives and which also can be used for an interactive walk or fly through. In Highlight pro a video sequence was created for both projects with a length of 53 (church) and 161 seconds (West Tower) at a resolution of 640 x 480 pixels as a coded MPEG file (30 and 57 MB, respectively) (see Fig. 15), while a virtual walk through was generated additionally with 3D Studio as a film sequence of the West Tower (3:31 min, AVI, 727 MB). Some visualizations of the West Tower ensemble are available for the public at a computer terminal in the tower cafe.

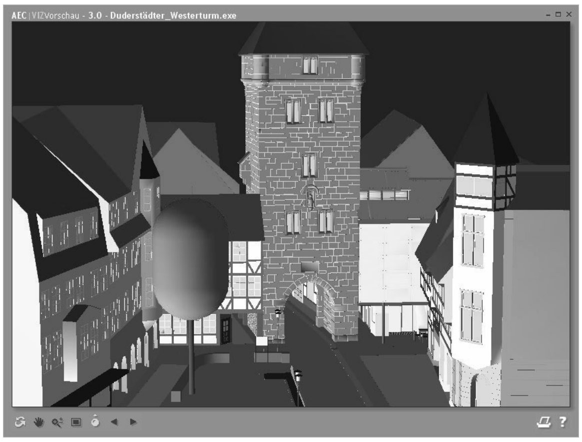

Figure 14: *Interactive virtual model of West Tower ensemble Duderstadt generated by AECViz*

6. Time and cost aspects

The work load for the entire processing of project West Tower ensemble Duderstadt amounted to 623 working hours. In total, theoretical costs of approx. € 35,000 for the project were induced using appropriate current hourly wages for measuring assistant, technician and engineer. In Fig. 16 the proportional work expended of the individual work procedures are represented. It is evident that 52% of the entire work time was spent with CAD modelling and visualization. In the time for visualization only the work with AutoCAD and AECViz is included, since the video sequences were generated later.

In the project church Raduhn the following working hours were needed: laser scanning 161h (object recording 6 h, 3Dipsos 91h, AutoCAD 63h) and photogrammetry 251h (object recording 2h, PhotoModeler 144h, AutoCAD 105h). Thus, the following costs of the project result without the necessary 3D geodetic net measurements and control point determination: € 7,000 (laser scanning) and € 10,000 (photogrammetry). The higher costs of photogrammetry are to be justified by the much higher degree of achieved detail. Potential for optimisation for such projects could be possible by reducing of the number of used control points and their geodetic control point determination, by focussing on laser scanning of important object parts, by using more experienced personnel for CAD modelling and by omitting details.

Figure 15: *Perspective scene of the virtual model of church Raduhn (top) and of West Tower ensemble Duderstadt (bottom) generated by Highlight pro V3*

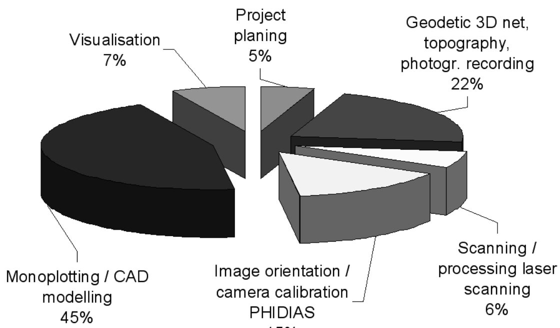

Figure 16: *Expenditure of human labour for project West Tower ensemble Duderstadt in percent*

7. Conclusions and outlook

The church Raduhn and the West Tower ensemble Duderstadt were successfully reconstructed by digital architectural photogrammetry and terrestrial laser scanning as virtual 3D volume models. The assigned technologies (instruments and software) offer a detailed and accurate reconstruction of the objects with an accuracy of 1-2 cm. The combined evaluation of photogrammetric and laser scanning data with PHIDIAS proved very efficient, since a direct connection for the CAD modelling was available. In project church Raduhn a more detailed model could be created by photogrammetric evaluation of the images compared to the model derived from point clouds, but the work expended was clearly higher with the photogrammetric procedure. With a higher resolution of laser scanning a detailed model could be generated, however at expense of a higher expenditure of human labour for the data acquisition and for the evaluation of the point clouds. For applications in architecture (e.g. building acquisition) it is appropriate and viable to use the laser scanner for stone-fair mapping or for the modelling of object details, such as sculptures and ornamentations, in combination with photogrammetry if such objects can be scanned with a very high point density. One can easily model these object details in CAD using simple cuttings (Fig. 17). Nevertheless, manual point measurements and CAD modelling still remain a substantial cost factor for such detailed 3D models in future. In addition the combined object recording and evaluation sets high capital outlays for the laser scanning system (approx. € 120,000). On the other hand a photogrammetry system (camera and PC incl. software) with approx. € 7000 represents a low-cost system.

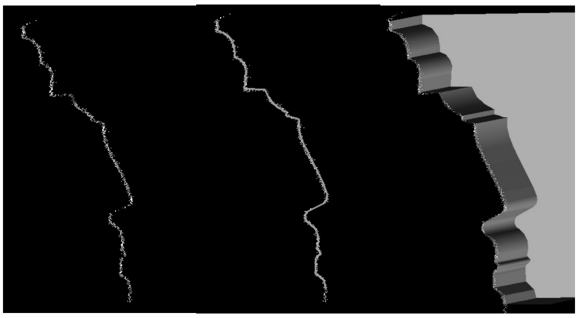

Figure 17: *Modelling of ornaments by laser scanning data: cutting of the point cloud (left), CAD line derived from the laser scanning data (centre), extrusion of the CAD line (right).*

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Applications in the field of cultural heritage using "off-the-shelf" 3d laser scanning technology in novel ways.

A. A. La Pensée, M. I. Cooper, and J. B. Parsons

National Museums Liverpool

Abstract
*Pioneered in the manufacturing sector in the late 20th century, 3d laser scanners have become commonplace on the production line. As the possibilities for use within the heritage sector became obvious, there has been much research in the area of hardware and software of this type for heritage applications. For example[LPC*00]. Our group, based within a museum has been using a range of commercially available hardware and software, within the field for ten years. The data processing and visualisation must be undertaken on standard office-based PCs, as this is what is most widely available within the museums and heritage sectors. We report our findings on the types of laser scanner and accompanying software available, the ethical and practical issues surrounding 3d documentation of heritage, and the vast range of applications available to the guardian of a heritage object once 3d data has been obtained. We present each of these applications through discussion of applied projects we have recently completed. Examples include; the documentation of an Anglo-Saxon Cross; the replication of a bust of Caligula in marble to aid colour reconstruction; the replication of an Asian bronze figure in modern materials for the conservation of a large sculpture of Buddha; the replication in plaster of a marble 18th century portrait bust; and the production of a bronze fairy's head for the restoration of a sculpture of Peter Pan.*

A.O. Literature---Conference proceedings - P

1. Introduction

Laser scanning was pioneered in the automotive, aeronautical and military industries in the late 1980s, and soon became highly important in the field of reverse engineering. For example [MWBV96], [Cho97]. The idea that laser scanning could be a useful tool in the documentation of heritage artefacts emerged a few years later [BRTL88], [Lar94], and [Lar95]. The widespread use of laser scanning in the documentation of cultural heritage began in the last 10-12 years, [TBBC*99]. Many projects have been undertaken, including several large high profile surveys. For example [BRMM*02], [LPC*00], [STHM*03], [BPEG*02], [F00]. Often such surveys are carried out as "one-off" programmes of documentation by university departments or interested parties and pursue the development of novel hardware, software and methodologies. For example [LPC*00]. Such work is obviously fundamental to the research, progression, and development of laser scanning, both within the documentation of cultural artefacts and in its broader applications. However, these projects by their nature are concerned primarily with the research and development of hardware, software and the management and processing of large data sets. Moreover, these projects often identify high profile works of art to use in their survey. Such work does not take place routinely in the field of heritage. There are some institutions worldwide that have a programme of documentation using 3d scanning or other methods of 3d documentation, either using bespoke systems, for example [RGG*02], off-the-shelf equipment, or a mixture of both. In addition, museums, institutions and public interest groups do commission the laser scanning of certain works from commercial companies, universities, or, as in our case, other museums. The works recorded in this way are often "singled out" because they are of special interest, inaccessible or in a location that threatens their survival in their current condition. However, despite these examples laser scanning (and recording in three dimensions in general) is still rare in the vast array of the documentation underway in the field of cultural heritage. There are a variety of ways in which cultural heritage can be documented in three dimensions, examples include; photogrammetry, systems that employ structured light, holography, and CT scanning. These applications, and their merits are all well documented and on this occasion fall outside the scope of this paper. However, in the author's view, often the best results are obtained when a combination of the most suitable techniques is applied to a project, [BPEG*02].

2. Laser scanning of cultural artefacts

Our group has been exploiting triangulation-based laser scanning systems in the field of cultural heritage for 10 years. We are based within a national museum, but in the main, our work is funded by external bodies. Our current funding aims to provide us with the means to be a self-sustaining specialist team within the museum, using contract work to pay for our people-costs, equipment and research. We use only commercially available hardware (3D Scanners ModelMaker X 35mm, 70mm and 140mm sensor heads mounted on a seven-axis Faro Gold arm; Minolta V1-900; Mensi S25 LR - all triangulation laser scanning systems), and software (ModelMakerv7 {3D Scanners UK}; Scanworks {Mensi-Trimble}, Rapidform2006 {InusTechnologies Inc.}, Polyworks V9.1.7 {InnovMetric Software}, 3D Studio Max 6), and our computer power is limited to several good workstations. There is a bewildering array of software and hardware commercially available, and heritage institutions need time to understand their own requirements and then to identify examples of best practice before purchasing equipment. As a specialist unit we have had the time to identify equipment most suitable to our needs by testing a variety of hardware and software, and by examining work undertaken by others, [BVM03], [BHMS02]. It is essential that we have the capability to record objects ranging from a few centimetres to several meters in size, and to be able to document sub-millimetre features on the surface. To meet this need we currently use three different laser scanning systems. There is no one way to use a laser scanning system on a given object to obtain a data set. Once that data set has been obtained there are a number of ways in which that data can be processed, and importantly, the individual working on the task has to make numerous crucial decisions. In response we have developed, and maintain, methods of best practice in scanning, post processing, metadata, and data storage, based on our experience and the equipment available to us. It is clear, that although every institution that has undertaken 3d documentation using laser scanning should be adhering to the same methods of working and certainly metadata creation, this is currently not the case. There are bodies who are now examining this problem in more detail. For example, The Metric Survey Team, English Heritage and "The big data project". At the current time we do not have the facilities, nor is there the demand for us to undertake a documentation project of an entire museum collection. The projects that we have worked on are those where the availability of a 3d digital data set of an object can significantly enhance the understanding of an object and its condition [EF03]; serve to widen access to the object; and where a digital reconstruction [FLDS03] or a replica [F00], is in the object's, the public's, or the guardian of that object's, interest.

3. Accuracy and resolution

Accuracy and resolution are terms which do not appear to have uniform meaning in the field of 3d documentation. In our view, the definitions of accuracy as the closeness of the agreement between the result of a measurement and the true value of the point in space, and of resolution as, "the smallest difference between indications that can be meaningfully distinguished", are the most descriptive and workable [BG03]. The other term without a common meaning is uncertainty, which we recently deduced was interchangeable with "precision" by some, "characterizes the dispersion of the values that could be reasonably attributed to the measurand" [BG03]. It is certainly our experience that the accuracies and resolutions quoted by the manufacturers of scanning equipment are those collated under ideal conditions, and are in the main unattainable. This needs to be kept in mind when institutions commission work, as often they will give the work to the supplier quoting the best accuracy and resolution – which in theory are substantiated by the manufacturer of the equipment, rather than with the supplier who gives them a realistic idea of the overall resolution. Moreover, a guardian of cultural heritage often won't know if the data they commissioned is of a certain accuracy and resolution, as they will have no methods to interrogate that data. Guidelines for the commissioning of work are being developed (for example) by The Metric Survey Team, English Heritage, The National Physics Laboratory and I3Mainz and are urgently required so that the beginnings of a uniform approach to the 3d documentation of cultural heritage across the field take shape.

4. Computing power

As we are providing data sets and digital-products to the heritage sector, in most cases the computer power available to the end user of the data is very ordinary. However, although the final use of a data set may require it not to be at the highest resolution available, it is essential to record as much, and as accurate data of an object that we can at the time of scanning. The reasons for this are manifold. 3d laser scanning is an expensive and time consuming process, compared to most forms of documentation used in the field of cultural heritage. Access to the object is often a one-off allowance made by the guardians of the object. It can also be the case that the object is threatened by a harsh climate or change, vandalism, or even theft. The chance to document an object in 3d can be viewed as a "one-off" opportunity. Moreover, computing power is always on the increase, and even though one cannot produce future-proof digital records, this may extend their useful lifetime by some considerable degree.

5. Practical considerations of laser scanning cultural objects

Museum objects, public sculpture and other cultural objects should be moved as little as possible, due to the inherent risk associated with any movement. It is for this reason that in the main, we go to an object or site to carry out 3d recording using laser scanners. This means that there has to be a way of physically getting the equipment, people and power supply to the object in question. Problems associated with access often include; getting security clearance to a site (this is usually straightforward for us, due to our status as a UK National Museum); having to negotiate awkward and delicate areas, often of cultural significance, to get to the object; and the problems associated with working at height. In addition, cultural heritage objects are often on view to the public, and this has to be taken into consideration when documentation is being planned. If the object needs to be obscured during scanning, for example by scaffold, or sheeting to minimise light, the impact to the visitor must be taken into consideration, especially if the object is of national or international acclaim. In such cases, the work needs to be undertaken when the gallery is closed (overnight) or in full public view. It is our experience that the second option, is an excellent opportunity to widen public interest in 3d documentation, but that time has to be allowed for to interact with the public - ignoring them is not an option. In addition, the safety of the public and the workers is paramount, and so keeping the public a safe distance away for the scanning area is essential. It is our experience that when one is scanning "on-site" there may be unforeseen problems, or problems that one cannot do anything about. These have included adverse weather conditions, generator failure and extreme scaffold movement. It is important that despite any problems the data capture is completed in one phase, in as short a time as possible, and to be absolutely certain, that one can get all the information in the allotted time window, and that no information has been missed. Going back at a later date may mean that something major has changed, such as for example, the appearance of a wall, or a sculpture's condition having deteriorated significantly.

6. Data storage

Digitizing objects means by definition that large amounts of data is generated. This data is a highly important archive of an object, and can also be very valuable. Unlicensed and possibly low quality replicas could be made from the data, potentially in large quantities. Or the object can be misused in visual art. This may seem trivial to some, but can be a serious issue if the work is either of political or religious significance. So we are in the situation where we have large data sets (small projects several GB, larger projects 50 GB) and ever more data to look after. In addition, we have the responsibility to guard against data obsolescence and media deterioration. We keep all data backed up on CD or DVD both in our studios under museum standard security and off-site in another museum building in a fire proof-safe. We have a cataloguing system so that we know what data is where for easy retrieval. We provide clients with the raw data in ASCII format if required, as this is regarded in the field as the most robust format. However, we feel that a lot of associated data is lost when converting a raw scanner format file to ASCII and for this reason we have chosen to keep the original file formats of the scanners and to take steps against data obsolescence such as monitoring developments in file format changes, and being prepared to upgrade data as formats go out of use. Media deterioration is well documented [SLZB*04] and we keep the data media in a climate controlled atmosphere, as well as observing the more obvious rules of protecting CDs/DVDs [B04]. Copyright is another interesting area to consider. Technically, once someone has created a digital data set, under current copyright law, that person holds the copyright to that data provided the object is already out of copyright. Interestingly, some heritage institutions and museums do not know this and assume that they will automatically retain any copyright over the data. This is not the case and copyright issues need to be sorted out before 3d documentation begins. All suppliers we use for rapid manufacturing are bound by tight data agreements before we pass any data on to them. In theory, when commissioned to undertake a piece of scanning documentation, we would be entitled to hand the data over to the client and let them look after it. However, we are aware that we have the skills and know-how to look after the data and as a museum see this as a crucial part of our role. There are several projects around the world which aim to collect 3d data and to make it accessible to the wider scanning, art archiving community, and we are in the process of adding some of our data to one of these. The 3d data we hold on our museum's publicly owned collection, should be available is as many forms and to as wider audience as possible, with the necessary safeguards to avoid miss-use. This is currently achieved by not making the dataset available, when displaying the data on web-sites or on kiosks. One way to safeguard data is to watermark the data; certainly this is essential if the data-set is to be made available to a wide audience to avoid miss-use. However for routine security, the watermarking of data is beyond the budget of many heritage institutions, and watermarking technology will almost certainly move at a faster pace than the lifetime demanded of the data in the heritage field.

7. Why do guardians of cultural heritage consider having a 3d digital record of an object?

Laser scanning can provide a highly accurate surface model of an object. Under good conditions typical resolutions of 0.2 mm and accuracies of 0.1 mm can be achieved with commercially available equipment. This surface record can supply extra information to that which is provided by 2d photography. Some details of a surface show up better in the data than in photographs or to the naked eye, especially when the surface is viewed in a bespoke lit environment, without surface colour texture [EF03]. Whatever method of documentation is chosen, it is of the utmost importance that there is no contact at all with the object at any time during data capture, and that no potentially harmful radiation is applied to the object. Laser scanning is non-contact and the laser power is very low and completely harmless to the artefact. In conjunction with other methods such as photogrammetry, digital visualisation, and photography, laser scanning can give the most complete record of an object that is currently available. Moreover, once the data has been obtained, and post-processed there is a vast range of applications available for the data. Such applications include documentation and monitoring, study, research and access, restoration of museum objects, restoration of public sculpture and the built environment, virtual reconstruction, education, and revenue generation. Some of these uses are detailed in the case studies below.

7.1 Documentation and monitoring - the documentation of an Anglo-Saxon cross

In the churchyard of St. Peter's Church, Prestbury, (Cheshire, UK) stands an important Anglo-Saxon Cross, thought to mark the arrival of Christianity in the North West of England (*figure 1*). The sandstone cross measures 940 mm by 400 mm by 240 mm, and the surface is weathered and some green moss obscures the upper east face. The original location of the cross is unknown; however it was found in the internal fabric of the church in 1841. The cross consists of three fragments cemented together. The lower two section belong together but the top fragment has a different interlace pattern and appears to be from another cross. Crosses such as these are predominantly found in the North of England and were erected throughout the 8th, 9th and 10th centuries. Prestbury Parochial Church Council are examining how best to preserve the cross. Prior to any work being undertaken English Heritage, recommended that the object be accurately recorded. Taking a mould of the object was not an option in this case due to the friable nature of the sandstone surface. A Minolta VI 900 laser scanning system was used for data capture. Sensor-object separation was maintained at approximately 1000 mm. The calibration of the system was checked using a 100 mm calibration board, prior to scanning and again on completion of data capture. A tent was erected over the scanning area to reduce the ambient light levels. We collected 121 frames in 6 hours. The individual frames were registered and merged into a coherent model. The average shell-shell deviation for this process was 0.3 mm. Large areas of overlapping data were deleted prior to merging, with the best data being chosen wherever possible.

Figure 1: *Scanning an Anglo-Saxon Cross using a Minolta VI-900.*

Post-processing entailed cleaning polygons and filling small holes manually. The raw data, the post-processed files (*figure 2*) and all accompanying metadata associated with the project was archived, and provided to the church council with access to an open source viewer - in this case, IIMView v9.0 (InnovMetric Software).

Figure 2: *A screenshot of the digital record of the Anglo-Saxon Cross.*

7.2 Study, research and access - a replica to help in the research and understanding of a bust of Caligula

The collections of the Ny Carlsberg Glyptotek (Copenhagen, Denmark) include a marble bust of the Emperor Caligula, thought to have been carved between 39 and 41 AD (*figure 3 right*). Originally such sculptures were painted and this piece has traces of the original polychromy remaining. Examples of Roman marble sculptures retaining their original polychromy are exceedingly rare. The curators and conservators in Denmark wished to study the pigments to determine their exact composition and then reconstruct a possible colour scheme on a replica object in the same material as the original. Their intention was to display the original and a painted replica side by side. Due to the fragile pigmented surface of the bust, traditional moulding techniques could not be used.

Figure 3: *The original bust of Caligula (right) and the marble replica before colour reconstruction (left).*

Figure 4: *CNC machining a new block of Carrara marble and a screenshot of the data (insert).*

Data capture took place in our studios using a ModelMaker H laser scanning system. The sensor has a 40mm stripe width and was mounted on a 6-axes Faro silver arm. Sensor-object separation was maintained at 100mm throughout. Once scanning was complete, the data was meshed and post-processed (small holes filled and the mesh cleaned). The final model comprised 2.3 million polygons. The raw data is stored in ModelMaker file formats and as ASCII files. From our scan data, a full-scale replica in Carrara marble was produced using 5-axis CNC (computer numerically controlled) machining (*figure 4*). The replica required twelve hours of hand finishing by our sculpture conservators. Colour reconstruction on the marble replica was undertaken by Doerner Institute, and Glyptotek, Munich. The reconstructed replica and the original were displayed side by side in Munich, Rome and Copenhagen during 2004 and 2005 as a part of the exhibition, “ClassiColor”, examining colour in Greek and Roman classical sculpture.

7.3 Restoration of museum objects - the replication of missing fragments of a figure of Buddha

A 17 cm tall bearded Asian bronze figure (*figure 5*) stands on one corner of the base of a large bronze sculpture of Buddha on display at World Museum Liverpool. On the opposite corner a figure is missing. Based on other elements on the statue and holes for fixings, it was deduced that this figure would have been a mirror image of the existing bearded figure on the opposite corner.

Figure 5: *Asian bronze figure (left) and nylon replica (right).*

Prior to going on display, the sculpture underwent conservation treatment in the metals conservation department at the National Conservation Centre. The metals conservator had ascertained that the missing piece was not required structurally, but after discussion with the curator it was agreed that the replacement of the missing figure would enhance the legibility of the sculpture on display. It is a premise of conservation that from two metres away a repair/restoration cannot be identified, but that at closer than half a metre, the restored element should be identifiable. In addition, in later years it should be totally clear what is original and what it not. For these reasons we were approached to scan the existing figure, mirror it to create the missing element, and then to produce the figure in a modern synthetic material easily distinguishable from bronze, but patinated to look sympathetic. The figure was scanned at the conservation studios in Liverpool in low light using a ModelMaker X scanner with a 35mm sensor head mounted on a seven-axis Faro gold arm. Three scanning stations were required and the resulting file contained 6 million polygons. The file was given to a commercial selective laser sintering (SLS) supplier, who produced the nylon model with a build layer of 0.1 mm. The replica (SLS) model required some sharpening of detail with a scalpel. The replica was coloured with alkyd paints to a bronze tone (*figure 5 right*). The replica was fitted onto the pedestal of the statue of Buddha and went on display in the World Cultures Gallery in World Museum Liverpool in 2004.

7.4 Restoration of public sculpture - the production of a bronze fairy's head

The large bronze statue of Peter Pan by Sir George Frampton has stood in Liverpool's Sefton Park since 1928, and is a much loved piece of public art. In 2001 the sculpture required extensive conservation to restore it to its former glory. Amongst other damage, vandals had removed the head of one of the fairies at Peter Pan's feet. As the sculpture is sited outdoors there was no question of not sealing the hole caused by the removal of the fairy's head, as water would cause structural corrosion (*figure 6 left*).

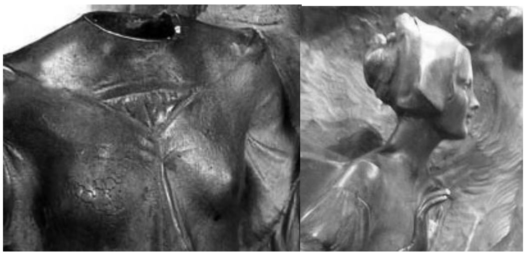

Figure 6*: The fairy's head had been removed (left), and the replica in-situ (right).*

In addition, as this piece is a work of public art it was decided to restore the sculpture, replace all missing parts, and obviously to do this as faithfully as possible. Although the original plaster moulds used to cast the Peter Pan statues by the artist in the 1920s still exist, they are too significant and delicate to be used to cast another head. The mould for the fairy's head was recorded using a ModelMaker H laser scanning system mounted on a six-axis Faro silver arm. The resulting model was scaled up in x, y and z by 3% to compensate for the shrinkage of the molten bronze metal. A replica head was produced using stereo lithography; in effect resulting in a resin master. This master was supplied to a foundry that created a mould and then cast a new fairy's head into bronze. The newly cast head was reattached using stainless steel pins and polyester resin coloured to match the bronze. The sculpture was recently re-sited in the park for the public to enjoy.

7.5 Revenue generation - the replication of an 18th century portrait bust

Figure 7 shows a plaster replica of a fine 18th-century marble portrait bust created from a laser scan dataset. A private collector, with connection to the subject of the bust, had approached the museum and requested a copy. The museum deemed that traditional replication techniques such as moulding and casting were out of the question for this piece. An agreement was reached between the museum and collector and a small number of plaster replicas were commissioned. This process generated income for the museum. The original bust was scanned on-site using a ModelMaker X scanner head with a 35mm stripe width mounted on a seven axis Faro gold arm. The post-processed digital file contained 7.5 million polygons. A logo and the date "2005" were inserted under the right shoulder of the digital bust to easily identify the plaster copies. The completed model was cut into three sections using geometric shapes. This was necessary as the SLS tank used by our supplier was too small to manufacture the bust in one build. The pieces were built in nylon using a build step of 0.1mm. These pieces were then fitted together and the joins sealed. A three-sectioned cast of this SLS master was taken in silicone rubber to provide the mould which was supported by a fibreglass jacket. A small number of busts were then cast in plaster and hand-finished for both the museum and the private collector.

Figure 7: *Plaster replica of a fine 18th-century marble portrait bust created from a laser scan dataset.*

8. Conclusions

In conclusion, 3d documentation in not routinely used in the field of cultural heritage by institutions and museums. The advantages of having a 3d digital data record of an object such as that which laser scanning can provide is often in the interest of the object, the public and the guardian of the object. To date most 3d surveys have been undertaken using bespoke hardware and software. The hardware and software available commercially can be used to record objects in 3d with good accuracy and resolution. We have demonstrated various ways in which we have exploited the data obtained by laser scanning in the field of cultural heritage.

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ARCHIE: Disclosing a Museum by a Socially-aware Mobile Guide

Kris Luyten[1], Heleen Van Loon[1], Daniël Teunkens[1], Kris Gabriëls[1], Karin Coninx[1] and Elke Manshoven[2]

[1] Hasselt University – transnationale Universiteit Limburg
Expertise Centre for Digital Media
Wetenschapspark 2, 3590 Diepenbeek, Belgium
{kris.luyten, heleen.vanloon,daniel.teunkens,kris.gabriels,karin.coninx}@uhasselt.be
[2] Provincial Gallo-Roman Museum
Provincie Limburg
Kielenstraat 15, 3700 Tongeren, Belgium
emanshoven@limburg.be

Abstract

We present ARCHIE, a research project which aims to discover how handheld guides can be used as powerful instruments to enhance the visitor's learning experience. Although mobile devices are becoming a common aid to support a museum visit, they often lead to an individualized experience. However, most people do not visit a museum alone, and recent research has pointed out that social interaction is a prerequisite for an intensified and improved learning process. To accommodate the shortcomings in many of the current solutions, we are designing a platform that enables us to create a socially-aware handheld guide that stimulates interaction between group members. They can communicate with each other either directly (by voice) or indirectly (by collaborative games) by means of their mobile guides.

Besides the aforementioned communication possibilities, handheld guides can also provide a way to present personalized content. By using a personal profile, it is possible to adapt the interface and tailor the information to the needs and interests of every visitor.

The combination of personalized content and interfaces, communication channels between visitors in the same group and support for localization might lead to an innovative mobile guide that integrates with the museum as well as with other visitors. Our platform enables social, and, in many cases, playful interactions with other visitors in the same group. At the same time the context-awareness (proximity and personalization) increases the involvement of the visitor with the content presented in the museum.

1. Introduction

In this paper we describe ARCHIE, an interdisciplinary research project of the Expertise Centre for Digital Media (Hasselt University) and the Gallo-Roman Museum (Province of Limburg). This museum is located in Tongeren, Belgium's oldest city, and tells the story of the region from prehistory up to and including the Merovingian period. The museum's visitor approach focusing on temporary exhibitions, exploring fascinating themes and a professionally-run educational programme has proved very successful. Annual visitor numbers rocketed from 20.000 to 150.000 in just ten years. The restrictions of the existing museum building and new trends in museum presentation explain the extensive expansion project of the museum. The new museum is due to open its doors in 2008.

As part of this expansion, the Gallo-Roman museum has rephrased its mission and aims. The main objective became to create an optimal learning experience for different visitor groups. The museum wants to provide information in the future exhibition in such a way, that any person can make his visit a personally meaningful one. Furthermore, the museum wants to develop a tool to encourage and steer social learning. Families are a good example of a group where social learning takes place: a mix of different age groups with different interests can share their interests and opinions.

The current trend to introduce PDA-based mobile guides to enrich the visiting experience of a museum [PT03, Fis05, Exp05], has led us to investigate how such guides can support the social processes that are fundamental for learning in a museum. The challenge in the ARCHIE project is the combination of a personalized mobile guide that is still part of a group of cooperating guides. While information can be tailored to the needs and interests of individuals in a group, there has to be a way for these individuals to interact with each other and exchange knowledge and interpretations during the visit.

The development of our ARCHIE Mobile Guide System is done by an interdisciplinary team. The team consists out of people with different backgrounds: historians, educationalists, computer scientists and graphic designers. The content of what is presented on the mobile guide is defined with great care and in close collaboration with the museum team.

In this paper we give an overview of the Mobile Guide System that supports the key missions of the museum such as social learning and personalization. Section 2 delves deeper into the context in which we developed the mobile guide: section 2.1 identifies the expectations of the (potential) museum visitors, section 2.2 shows the importance of social interaction and section 2.3 concludes with our objectives. The objectives are translated into a concrete mobile guide in section 3, where we focus on group communication (section 3.1), personalization (section 3.2) and location-awareness (section 3.3). We conclude the paper with a framework overview in section 4 that shows how the different parts are integrated in one complete system and make some conclusions.

2. Defining the context

2.1. Know your visitors

In order to accomplish the realization of the new objective, the Gallo-Roman Museum needed to get better acquainted with its public. For this reason the museum conducted an extensive investigation among visitors and potential visitors, to find out what prompted them to visit the museum, what their interests are, and in which way they would want to learn about the museum collection [PGR05].

Concerning visit expectations, 61% of the (potential) visitors indicate they want to learn something, look at/admire objects (53%) and experience something, relax (33%). Questions about visit behaviour reveal they also prefer a social museum visit: 56 % wants to talk to family or friends about what there is to see. These results correlate with recent studies about visit motivations; Falk and Dierking argue in their leading reference work *Learning from museums* [FD00] that "dozens of studies document that the primary reason most people attend museums, whether for themselves or for their children, is in order to learn". The second most cited motivation is entertainment: most visitors mention they go to museums in their free time to have fun and/or to see new interesting things in a relaxing and aesthetically pleasing environment. Museum-going is also commonly viewed as a social event. Visiting a museum is widely perceived as a 'day out' for the whole family, a special social experience, a chance for family members or friends to enjoy themselves separately and together.

2.2. The importance of social interaction

Starting from a social-constructivist approach, Falk and Dierking came to emphasize the role of the social group in the way visitors construct meaning in their contextual model of learning. In this model, three overlapping contexts contribute to and influence the consequent learning and meaning-making: the personal context (visitor profile and learning style), the physical context (museum environment) and the socio-cultural context (social interaction).

Following this model, social interaction does not only promote, but is a prerequisite for intellectual, social, personal and cultural development [Mor02]. Recent studies with children also recognize the important role of social interaction: "the potential of the learning environment and its objects largely depends on the social atmosphere generated and the support young children receive through positive, reciprocal interactions. [...] The successful learning setting functions as a community of learners, where all individuals are respected, their learning is supported, and opportunities for collaboration are provided." [PW02] However, the social aspect of a museum visit is often neglected, especially when using new media. Audio-tours for example generate the unintended side effect that it is a quite individual, isolated experience: it can put individual visitors in a bubble, making it difficult for them to keep track of companions or family members, let alone chat about what they have seen [Ang06]. In spite of the many opportunities and benefits a PDA-tour can offer, recent research on the visitors' use of the first PDA-tours in museums does share the same conclusion [VH05]: "the PDA makes it difficult for visitors to talk and engage in discussion." Main reason is that the hardware and content of the current solutions are designed and structured for retrieval by one person rather than by multiple persons.

2.3. Objectives

One of the main objectives of the project is to deal with the (possible) negative side effects and therefore to encourage and stimulate interaction between visitors and the museum by use of the PDA. This can be done by providing opportunities to communicate with each other directly (using Voice-over-IP) and indirectly (by collaborative games) (see 3.1).

The inquiry of the museum also reveals that visitors have different preferences concerning the way they want to learn in a museum. Some visitors have a strong need for hands-on and minds-on activities and want to 'experience' the museum (38%), while other prefer a rather reflective discovery and space for abstract conceptualization (27%). There are also differences in visit behaviour, preferred profundity and nature of information, favourite type of media, object display and interior design. Not to mention different levels of knowledge, ages, types of groups, and personal interests. While traditional mobile museum guides often offer a uniform tour and presentation, the ARCHIE project wants to discover the opportunities and benefits of a personalized approach while exploiting the social relationships between the visitors.

3. The ARCHIE Mobile Guide System

The ARCHIE Mobile Guide System provides a basis to develop customized mobile guides, that can differ in presentation (visualization), structure, behaviour and style but still communicate the same content to the visitors. This is accomplished by a unified framework that can load an arbitrary *interface shell*. Independent of the interface shell, the framework also offers other components such as a person-to-person communication component and localization component, two services that enable a more immersive visitor experience when using a PDA to visit a museum.

3.1. Group-Based Communication

Our Mobile Guide System provides different types of communication through the mobile device. A server application keeps track of the different groups of visitors. During the visit, the system allows visitors to communicate with other visitors in the same group in two different ways:

- a *direct communication* style that is voice-based and uses Voice-over-IP (VOIP). This allows a visitor to address the other members of the same group directly and to talk with each other regardless their locations. An audio forwarder on the server handles the communication traffic. First user tests pointed out that there is a little noise on the communication channel when nobody is talking; such noise should be filtered out. A short delay on the messages is not experienced as annoying.
- an *indirect communication* style that allows people to exchange other types of data related with the interface shell. This style of communication does not require the visitor to address the other visitors of the same group directly, rather it is used by collaborative games to share game (shell) related data. The synchronization between different clients involved in a collaborative game depends on the game and should be taken care of by the shell developer.

Because the wireless network is deployed in the complete museum, visitors can communicate with each other no matter their location in the museum. The combination of both types of communication opens up several possibilities to implement collaborative applications such as games that need to be played in group (e.g. by families, schools, ...).

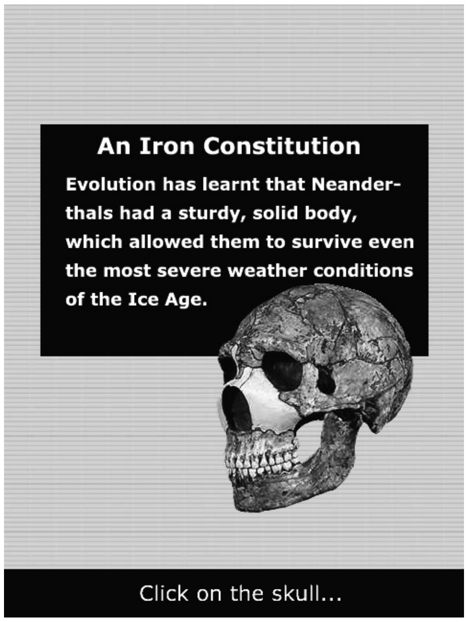
3.2. Personalization and visualization

In section 2 we mentioned the importance of a personalized approach to enhance the visitor's museum experience. The most visible part of the personalization component embedded in our Mobile Guide System are the different interface shells that can be loaded. Figure 1 shows two possible interface shells: 1(a) shows the interface shell that is more suitable for kids and 1(b) is an interface shell that is typically used for adult visitors. The multimedia tour for kids is an animation movie with their buddy Orf who guides them through the virtual world of the Neanderthal man. By clicking on the animated skull, an edugame can be started. Adults receive a more formal presentation using realistic images and accompanying short texts. By clicking on the picture more information can be retrieved. These two different presentations (or visualizations) of the same content, explaining the Neanderthal skeleton, are deployed on top of the same Mobile Guide System. Since an interface shell is used to support a rather large group of users, further personalization is required to increase the personal involvement and interaction with the museum.

In order to create a more personalized museum visit, a user profile has to be composed. This can be done in advance or dynamically during the museum visit. Entering a user profile may not require much effort and time from the visitor and therefore should be limited. When no profile is entered, a default profile is provided. At each moment, the user profile can be (manually) changed by the user. Notice the creation of a user profile does not necessary exclude any information for the visitor, it can also be used to highlight information or change the presentation of the information according to the user interests and preferences. If identical information is available in different media types, one can prefer e.g. an animation to a documentary movie.

Based on the user's interactions with the device, the profile can be automatically adapted. Similar adaptations are also investigated in the PEACH project [KBGB*05]. The way the visitor uses the digital content gives us a clue about his preferences: stopping an explanation prematurely may indicate a lack of interest, whereas asking for more, or bookmarking it, suggests a genuine interest. We use a weighted algorithm to adapt the user profile: the user profile will evolve slowly and does not change constantly, in order to avoid confusion. According to the action the user takes, the weights assigned to the different parts of the user profile will be changed. The following non-exhaustive list shows actions that can change the weights, they are listed in order of importance (actions at the top will have a greater influence than the actions at the bottom):

(a)



(b)

Figure 1: *Interface shells for children and adults.*

- Explicit questions about appreciation of what is currently on screen;
- Bookmarking a current screen for later retrieval;
- Information retrieval actions (the user shows more interests in items he clicks on for more information);
- Time spent at a certain position (the user might want to learn more about the displayed objects at that position).

Notice the time spent at a certain location can have very different reasons, so only when a certain threshold is reached will this action be taken into account (e.g. a minimum amount of time spent at a location while the user is actively retrieving more information about an artefact in the vicinity). We are currently experimenting with this kind of automatic adaptation of user profiles in order to avoid forcing the visitor to go through a extensive questionnaire before starting a visit. Preliminary tests have shown that this approach is feasible.

3.3. Localization

Part of making the environment more immersive is done by adding an indoor localization system. In most traditional settings, an electronic mobile guide requires the user to manually input the location by entering a number or scanning a tag. Other rudimentary localization systems use IR-based localization techniques (e.g. Portable Cicero [CP03]). A more advanced technology makes use of object recognition based on an artefact's photograph taken by the visitor [BBZB05]. Current networking technologies allow us to use the wireless network to give an estimate of the location of the user or the proximity of the user to an artefact [BCLN05]. We use this as an interaction modality: the user can interact with the system by just moving around and changing her/his location. Additional reasons why we currently use a WiFi-based localization technique are: the infrastructure will be available in the museum, it provides a cheap way to support localization and it offers us the required granularity.

Although there are several commercial solutions for indoor location detection available, we started with creating a customized location detection system based on the signal strengths of the various wireless access points in the vicinity of the user. Implementing a usable WiFi-based localization system turned out to be a challenging task: there are still several ongoing research projects that try to accomplish this [HFL*04, YA05, CCC*06]. The first drawback of using WiFi signals is that they tend to be quite erratic. Simply calculating the distance to the access point based upon the strength of its received signals will give back anomalous results. Consequently, trilateration of those results will not produce any accurate locations. We introduced a learning phase where we collect fingerprints (a set of signal strengths per access point per location) in the areas we need the localization algorithm to be more reliable. From this data we can derive the probable signal strength on a whole set of locations. Afterwards we can use the set of measured signal strengths per access point and search for the closest match with the recorded signal strength of each access point to determine the location. In order to cut down on the processing cost, only the best signals are used, since they tend to be the most reliable. With this approach we find the location with the highest probability.

While this approach gives good results in estimating the location of the visitor in a static environment, in museum settings with clusters of moving visitors the precision in locating visitors decreases. Though this may seem to result in a system that is less usable, in an exploratory environment such as a museum this could lead to a more enjoyable user experience. Careful design of the application and its user interface can turn the lack of granularity into an asset that motivates the visitor to explore its environment, looking around for information. Observations and interviews with children who were exploring a museum by means of a PDA even indicated that they really liked to search for an artefact.

4. Framework Overview

The different core components presented in section 3 are integrated in one framework. The shell developer can make use of this framework to create a new shell that uses personalization, localization and communication. Figure 2 gives an overview of the framework and shows the core services that are available through the framework interface. The core services are in fact proxies that communicate with a central server that keeps a database with visitor profiles, visitor groups, artefact locations etc. This is completely transparent for the shell developer.

Figure 2 shows the framework interface is structured as an event bus: a user interface shell can subscribe to events originating from one of the services, and process these events according to the shell. The event bus can also include direct user interaction events (e.g. tapping on the screen), so both direct and indirect interaction with the interface shell can be easily supported. This approach results in a flexible mobile guide system rather than one particular mobile guide: various shells that behave differently can be deployed on top of this framework. By using the communication service a shell will be able to engage in a collaborative game.

One example that we developed using the localization service are the 'artefact notification messages'. These type of messages will notify the visitor when she/he approaches a particular artefact. This is accomplished as follows: the shell developer registers for events from the localization service and events from the personalization service. The personalization service can be queried for artefacts that are of high interest to the visitor according to its profile. The proximity of the visitor with regard to these artefacts is available through the localization service. An interface shell can use this data to emphasize information in the user interface. Figure 1(a) shows the skull in the presentation is highlighted: this is caused by the visitor approaching a skull object in the museum. If the shell also uses the communication service, it is possible to start a conversation with another visitor, all triggered by the event of the visitor approaching an artefact.

We are currently developing this framework and defining its interface. Only the three core services presented in this paper are currently used by the shells we developed, but one can imagine other core services being included. Their functionality is still subject to changes and evolves according to the requirements of the interface shells we are building on top of the framework. However, the architecture of the framework is created to be extensible and allows us to include other core services without changing the architecture. Also creating new interface shells does not require a new software structure since there is no hard binding between the interface shells and the core services because of the event bus interface.

5. Conclusions

Starting from the new objective of the museum *to create an optimal learning experience for different visitor groups*, and the project objective *to discover the opportunities and benefits of a personalized approach while exploiting the social relationships of the visitors*, we created a framework to build customized mobile guides that meet these desires. In contrast to many existing systems that work similar to a portable information kiosk, the ARCHIE Mobile Guide System stimulates interaction among visitors while offering a personalized interface and enhancing the immersive feeling of the visitor in the museum environment. Three core services were developed and integrated into one unified system to accommodate this: a group communication facility, automatic personalization and localization detection. An event based framework integrates these core services, so different interface shells may use these services and can co-exist. Collaborative applications can be built using these services and the framework.

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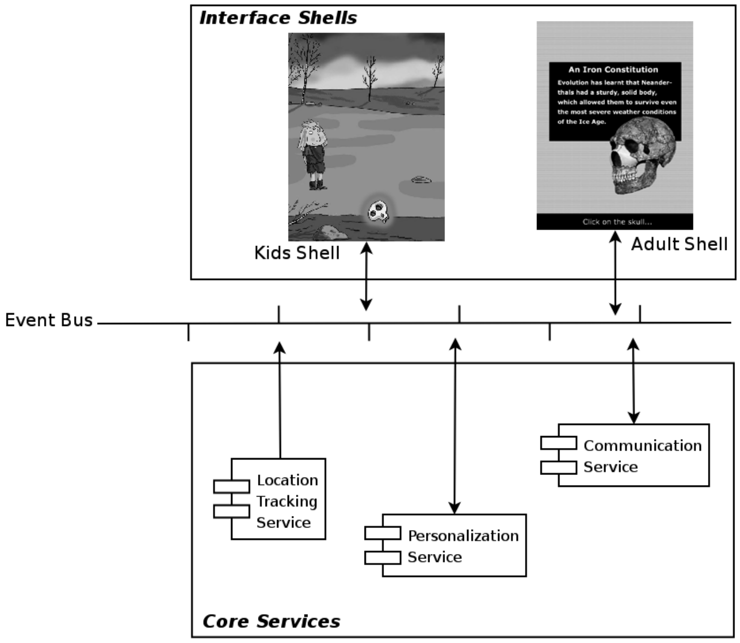

Figure 2: *Framework overview*

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SemanticArchaeo: A Symbolic Approach of Pottery Classification

C. Maiza and V. Gaildrat

Department of Computer Science, IRIT
UPS, 118 route de Narbonne
31062 Toulouse Cedex 4, France
E-mail:{maiza,gaildrat}@irit.fr

Abstract

During archaeological excavations, one of the most time consuming stages is the treatment of the great number of pottery fragments found on the site. A very complex treatment is the matching of every potsherd with the pottery model it belongs to. This step is based on archaeologists knowledge and usage-based nomenclatures.

Studied ceramics are revolution shapes so we first obtain a 2D profile and then we segment every pottery model in characteristic elements by detecting 2D geometric attributes and according to the characteristics defined by the archaeologists. A label is then associated with each characteristic element of models and potsherds so as to ease and speed up the process of matching. In our approach, we have organized the complete objects database in a different way than the archaeologists' classical style so as to facilitate the treatment of the potsherds. In order to perform a matching between a potsherd and a model, the pottery models present into the classification are analysed and picked so as to provide a first level of matching: a symbolic matching. Thus, one can achieve matching using first the symbolic description and in a second way the exact geometry of the objects.

Categories and Subject Descriptors (according to ACM CCS): I.3.8 [Computer Graphics]: Applications

1. Introduction

During archaeological excavations, a small number of entire potteries and a great quantity of potsherds are found. The archaeologists have to label every sherd, represent them by a two-dimensional drawing and take different measures (height, diameter, thickness, etc.). Then, they have to classify each sherd in order to find the shape it comes from, consulting voluminous paper catalogs which reference the identified shape models. This research stage is not documented because it is only performed from the gained knowledge of archaeologists, thanks to their field experience. This is why it takes at least one to six hours to match a fragment.

As digitalization techniques become affordable, new computerised solutions can help the archaeologists to solve the fragment matching problem. Different approaches have been presented for achieving geometrical matching between fragments and database shape models in [MG05, SMK98]. The major problem is the time needed to perform this matching over a big database, because all the objects must be tested. This is due to the fact that pottery databases are organized according to the archaeologists usage i.e. the objects are in classes that depend on the objects usage.

In the framework of a project named SIAMA *(Système d'Imagerie et d'Analyse du Mobilier Archéologique)* [SMM*05], we study well standardized ceramics, called "*sigillées*" potteries. These objects were mass-produced by molding or turning and are assimilated to revolution shapes. They were produced in different French sites during the first centuries of our era, and were sold all over the Roman world. We focused on a subgroup issued from the site of "*La Graufesenque*" in the south of France near the town of Millau. These potteries have been produced in a relatively standardized manner, in ovens that contained over 40,000 pieces [BJ86, Mar96]. So, retrieving shape models from "*sigillées*" fragments is very useful for sites dating.

We dispose of a manifold classification of these vessels already done by archaeologists [Dra95, D04, Kno19]. And a precise description of all these vessels has been carried out.

This description is driven by the study of the pottery profiles, see Figure 1. A profile is segmented into the three principal pottery feature i.e. the base, the wall and the rim. Each principal feature being itself segmented into parts representing curves.

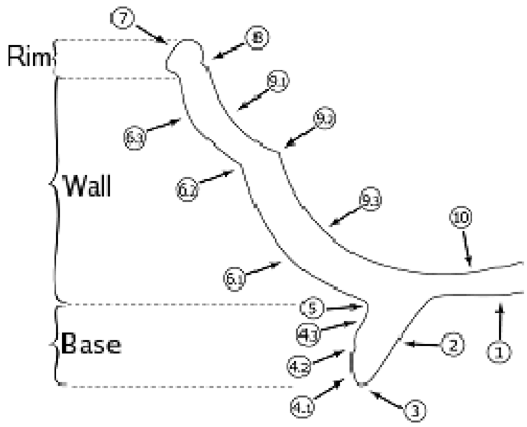

Figure 1: *The relevant description of the* Dragendorff 27b*(done by archaeologists).*

In order to speed up the matching stage, we propose to build a new database structure based on the descriptions and the geometrical characteristics of the potteries instead of their usage. One can then realize high level shape-based searches on the database using the descriptions of the potteries. This method consists in removing the classes of objects that cannot correspond to the searched fragment, before achieving geometrical matching between a sherd and the shape models.

We take advantage of studying shapes of revolution to present a segmentation algorithm that works in 2D. We segment the object's profiles into parts that are labeled. This segmentation must be as conform as possible to the archaeologists' description. Then, we transpose this segmentation in 3D to the object's meshes. The new database structure is then inferred from the segmentation of the shape models.

Once that the database is available, the matching process between a complete vessel or a fragment and database objects is divided in two stages:

A high-level search based on a description of some part's characteristics of the searched object. It eliminates the vessels that cannot correspond to the queried object.

A geometrical search based on the profiles. It finds the shape models that present the best probabilities of matching with the searched object.

In the following part, we are going to present some background methods which tried to solve similar problems. Then in section 3, we will present and detail our approach, followed by our experiments in section 4. Finally, we will conclude and give future ways of research in section 5.

2. State of the Art

Many projects have already tried to make easier the work of archaeologists by providing computerized solutions to some of their faced problems.

In order to manage the great amount of potsherds, some researchers are interested in the estimation of the main characteristics of these rotational shapes, namely the axis of rotation and the 2D profile. Different approaches have been used: an algebraic model of the surface [WOC03], the spheres of curvatures [CM02], a Hough-inspired transformation [YM97, KS03], a multi-step optimization technique using notably M-estimators, circle and line fitting [Hal99, HF97]. Also, two approaches try to imitate the archaeologists' work by taking advantage of the potteries concentric circular rills [KSM05], or by using a semi-automatic system using genetic algorithms to treat rim-fragments [MTL03].

Once that the profile and the axis of rotation are computed, the fragments are stored into a database. They are used even for reconstruction of potteries (by associating two fragments at a time and aligning their curves [KS04], or by using a Bayesian approach to reconstitute the entire object [WC04a, WC04b]), or for studying the standardization of hand-made potteries [Sim02] and the uniformity of wheel produced potteries [MSKS04].

Sablatnig et al. represent their profiles database as a graph [KSC01], where each profile is segmented into the three principal pottery features (base, wall and rim). They carry out matchings between profiles by applying a similarity measure in this graph.

The 3D Knowledge Project is the only one that permits to search the vessels database by sketching a 2D profile [RLB*01]. But their stored profile curves are excessively simplified: they only use the external profiles and the curves do not contain a lot of points (less than 15 per profile while our profiles contain about 2300 points). This makes their data less realistic. Thereafter, they also segment the profiles into base, wall and rim.

We have previously presented an algorithm that realizes matchings between fragments and model shapes [MG05]. This approach was based on both the use of Implicit Surfaces to obtain a distance metric and Genetic Algorithms in order to find the best possible position relatively to the previous distance measure. We faced a speed problem while browsing the whole database in a dummy manner. The issue is that the database of digitalized objects must not be managed like the archaeologists equivalent one and we have to organize the data in a different manner. Taking advantage from the available high-level description of our potteries we have

Figure 2: *The 22 objects Database.*

considered a database where objects have to be segmented in parts that can be easily classified.

3. Contributions

We dispose of a database that contains twenty-two 3D objects that represents eleven vessels in different scales and from different period (i.e. with significant differences), see Figure 2. These objects have been digitized with a Minolta VI-910 laser scanner in the museum of Millau in south of France.

Each object is represented as a 3D mesh (Figure 3), a 2D inner and outer double-profile (Figure 4) and a textual description of the profile made by an archaeologist (Figure 1).

Preliminary remarks:

- First remark: a classification made by archaeologists always contains pottery descriptions, measures and ratios for complete objects and for fragments. These informations are sometimes stored in digitalized objects databases but never used in a matching process.
  This is the basic idea of our work: using these descriptions to achieve efficient matchings. We then focused on the way to automatically obtain these descriptions. We need to segment these shapes into meaningful parts that we classify.
- Second remark: most of the matching operations that have to be done in an excavation site are matchings between fragments and complete objects rather then matchings between two complete objects or two fragments.
  This is why detecting a part as a rim or a base on a fragment and identifying it allow us to discard all the database objects that are not composed the same parts.
  This could be considered as partial matching, i.e. matching between a complete object and a piece of an object. This research domain is very poorly documented even for non revolution objects. Funkhouser et al. have presented an approach to enable weighted comparisons between two objects and giving a bigger weight to the searched part of an object in [FKS*04]. Suzuki et al. divide every shape into a huge number of parts based on the angles of the normal vectors, then similarity comparisons are carried out between a part and all parts of the database objects [MS05]

Figure 3: *The* Dragendorff 33 *3D mesh.*

- Last remark: 3D vessels are considered to be shapes of revolution: objects that are completely defined by a profile and an axis of revolution. This means that shape segmentation can be done on the profile and reported directly to the 3D object. This avoids us the use of a 3D segmentation method like watersheds [MW99, PRF02], especially knowing the drawbacks of such methods (oversegmentation, noise sensitivity and need of dynamic tolerance when dealing with large data sets).
  We segment profiles by studying their curvature plots. And once that the profile is segmented, we find the endpoints of the parts on the 3D mesh, and we segment the 3D object according to horizontal planes passing through these points. We use the inner and outer double profile in order to decrease noise influence.

3.1. Segmentation

One of the important characteristics of a curve is the curvature. The curvature is very useful for analysis and classification of vessel shapes. In 3D space the curvature of curves is nonnegative by definition. However, we can obtain signed curvatures $\kappa(u)$ for planar curves using:

$$\kappa(u) = \frac{\ddot{x}(u)\dot{y}(u) - \ddot{y}(u)\dot{x}(u)}{\left[(\dot{x}(u))^2 + (\dot{y}(u))^2\right]^{3/2}}$$

where, dots denote derivatives with respect to the given parameter u.

We first tried to use this curvature to segment the profile, see Figure 5. But, our curves were too noisy. Thus, we used

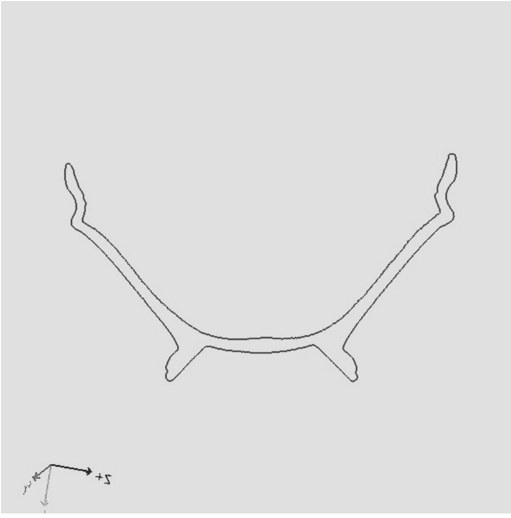

Figure 4: *The* Ritterling 5 *2D double profile.*

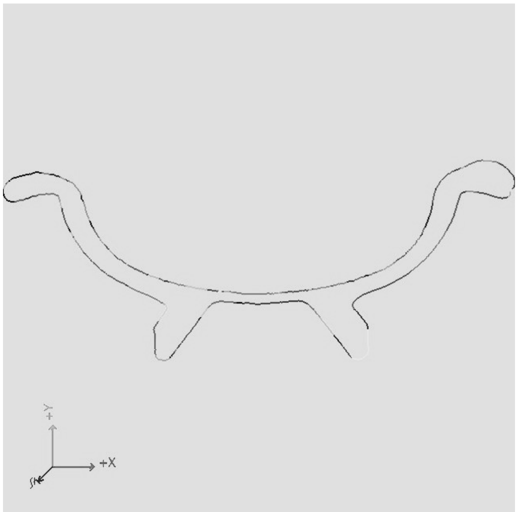

Figure 5: *An over-segmented profile of a* Dragendorff 35.

a B-spline curve to smooth the profile curvature as shown in [Far96]. Then, we segment the profile by detecting the inflection points and the extrema of the curvature.

The user is lastly allowed to accept the segmentation as it is; to stick again some parts in case of over-segmentation; to re-segment under-segmented parts; or, to completely define a manual segmentation if the automatic one does not meet his needs. See Figure 6 for an example of a relevant segmentation result for an archaeologist.

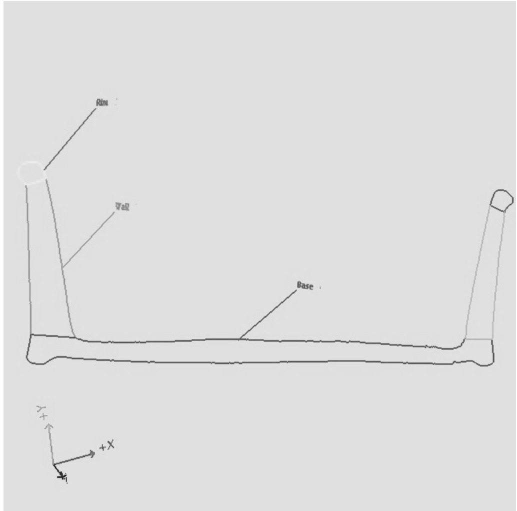

Figure 6: *A relevant profile segmentation of a* Dragendorff 22.

3.2. Labeling

Once that a profile has been segmented into parts we can group them into the three principal features, namely the base, the wall and the rim. This allow us to take advantage of the description conventions of the "*sigillées*" potteries, see Figure 7, then, we label each part with its corresponding name.

There are two steps in the labeling algorithm:

1. Describing each part detected at the segmentation stage, i.e. a curve description like the ones of Figure 1.
2. Merging parts (curves) together to form the base, the wall and the rim. Matching each of the principal features with those provided in the description conventions and labeling it with the corresponding name.

For now, the automatic analysis of the segmentation in order to generate the corresponding labeling is not fully implemented. So, we still have to do it manually.

3.3. From 2D to 3D

We obtain the 3D segmentation of the potteries into their principal features using the labeled segmentation previously computed. All the potteries are placed in the same pose, their bases are parallel to the $y = 0$ horizontal plane just as if they were put on a table.

From the base part, we compute two planes. One plane that passes by the two end points of the outer profile curve and is parallel to the $(y = 0)$ plane. And an other one that passes by the two end points of the internal profile curve. All the triangles that are below the lower plane are grouped to form the object's base. This separates the base from the

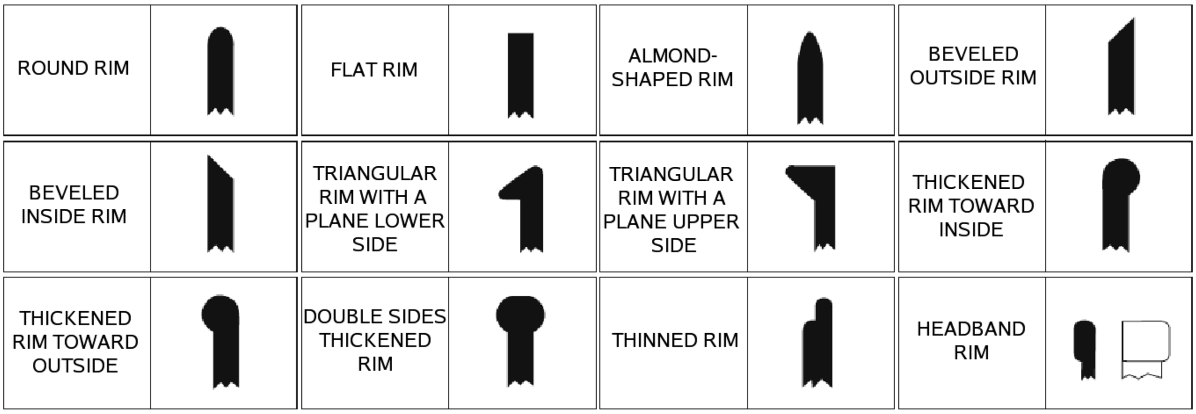

Figure 7: *Some possible rims for the* "sigillées" *potteries.*

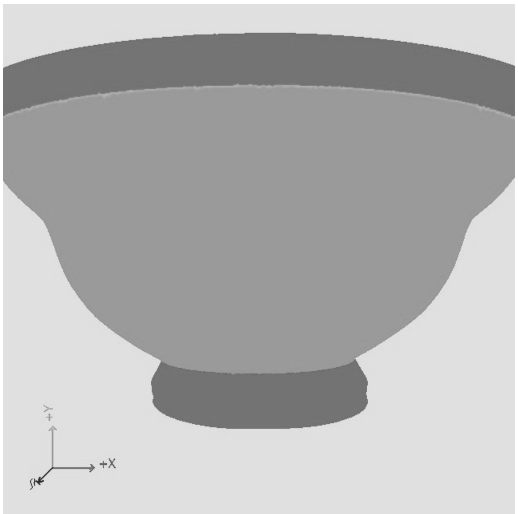

Figure 8: *A* Dragendorff 27 *mesh segmentation.*

rest of the vessel and creates in the same time a transition part that belongs to the two parts.

We repeat this algorithm for the wall part to obtain the segmentation into wall and rim, as shown in Figure 8.

3.4. Matching

For retrieving a complete pottery in the database, we segment its profile to achieve a first high-level search form its labels. The selected objects are then used in a geometrical search step using the tool presented in [MG05].

For retrieving the location of a fragment relatively to the database model shapes, we first extract the profile curve using a technique from the section 2. Then we apply the same algorithm as for the complete objects (a high-level search, followed by a geometrical one).

4. Experiments

The approach presented in section 3 was implemented in a tool named SemanticArchaeo using Java/Java3d.

We first have segmented the available potteries in 2D and in 3D. We have labeled the segmentations (with a manual verification since it's not fully operational). Then, we have generated a database that contains all the segmentations with the associated labels for each object. This database should be available at the http://semanticarchaeo.online.fr, that is a PHP website associated with a mySql database. So one can browse the database and try to find matching objects based on their descriptions.

This database is extensible: new potteries have to be segmented and labeled with SemanticArchaeo before they are added to the database.

5. Conclusion

We have proposed in this paper a symbolic approach of pottery classification by taking advantage of the ceramic descriptions established by archaeologists. Taking advantage of shapes of revolution, we presented a 2D segmentation algorithm that works on the potteries profiles. Processing these segmentations with a part-labeling method, we have obtained two levels of potteries descriptions: a simple curve segmentation based on the curvature changes, and a decomposition into the three principal pottery features (base, wall and rim) with a description conform to the archaeologists one. These data are then used to build a database of archaeological vessels that can be queried from our two steps matching algorithm: a high-level search using SemanticArchaeo and a geometrical search using CLAPS.

The interactivity on the segmentation of the profile is a powerful characteristic because it allows the user to avoid possible errors due to noise or smoothing.

We have presented an easy way of segmenting the pottery's three dimensional mesh using the two dimensional segmentation. This allows us to achieve fragment matchings directly in 3D by comparing a sherd to the three principal pottery features using a shape descriptor.

Soon, we will have to improve the robustness and the quality of our segmentation process, especially our labeling algorithm. And as an outlook for further research, we plan to develop a complete pottery classification system by adding methods of profile extraction like those from section2. Then, we will have to test this system on data issued from an excavation site.

We also plan to build a greater database (currently containing twenty-two objects) with objects that are not only "*sigillées*" potteries in order to test the efficiency of our segmentation pipeline(to recognise and classify such objects).

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Multimedia Annotation through WebGIS and Mobile Devices: Wireless Infrastructure Project for the UNESCO Site in Cerveteri - Italy

A. Cinnirella[1] S. Faralli[2] A. Labella[2] P. Maurelli[1] M. Pierro[2] and F. Rosa[1]

[1]ECOmedia s.c.r.l., Via A. Rocca, 2B - 00135 Rome Italy
[2]Dpt. Informatica, University of Rome "La Sapienza", Via Salaria, 113 - 00198 Rome Italy

Abstract

In this paper we present an original integration of technologies. The main objectives of the general project for the UNESCO site of Cerveteri are: solutions that integrate survey techniques and organize data in the GIS - called Sistema Informativo Territoriale Archeologico Ceretano (SITAC) - dedicated to this case study; accessibility and fruition of a complex archaeological area within a continous intervention process; offer the general public, researchers, and managers an important cognitive base that integrates multimedia and geographic scientific data through remote or on-site interaction with the SITAC. The proposed system is based on the integration of data communication and LBS devices connected in the wireless network with multimedia and multimodal characteristics in the archaeological area. This innovative and powerful solution - called MA(geo)RIS Multimedia Annotation of Geo-Referenced Information Sources - will allow collaborative construction and fruition of annotations made by users on georeferenced information by combining three web-enabled applications: a plug-in annotating multimedia content (MadCow), an environment for multimodal interaction (Chambre), and the WebGIS application (MapServer). The resulting system is unique in its offering a wealth of possibilities for interacting with geographically based material especially where there is a high quantity of resources in a complex site.

Categories and Subject Descriptors (according to ACM CCS): H.5.1 [Multimedia Information Systems]: Hypertext navigation and maps Artificial, Augmented, and virtual realities J.0 [Computer Applications]: General, field sciences J.5 [Arts and Humanities]: Archaeology J.4 [Social and Behavioural Sciences]: H.3.4 [Systems and Software]: Distributed systems

1. Introduction

The combined GIS and WebGIS application, called Sistema Informativo Territoriale Archeologico Ceretano (SITAC) [CMR06], was developed within an integrated project for the UNESCO site in Cerveteri - the Etruscan Necropolis "La Banditaccia" in proximity to the ancient Caere city developed between the 9th and 2nd centuries BC, 40 km from Rome (Italy). The SITAC GIS initiative was created in conformance with the Management Plan approved by UNESCO and it responds to knowledge, planning and management needs, while the general valorization project aims to preserve cultural heritage and promote tourist fruition of the archaeological, natural, and landscape resources of this site. Since May 2006 a light-weight electrical train circuit is the backbone of accessibility of a large area that contains thousands of tombs and several kms of Etruscan roads. The main objectives of the new project for innovative technologies in the valorisation of the site are: provide a solution that integrates problems relating to the survey; accessibility and fruition of a complex archaeological area in an evolutionary vision of the valorisation procedures; offer the general public, scholars, and managers an important cognitive base that integrates multimedia and geographic scientific data through remote or on-site interaction with the SITAC. The main strategy is to converge data, analysis, and applications into a single computerized geographic system connected to a series of mobile devices that offers users an assisted visit as well as multimedia and multimodal interaction. The system is installed on a centralized web server and includes applications that provide the various user profiles (tourists, experts, historians, archaeologists) a series of services in remote mode (on-line) as well as direct (on-site): new possibilities for surveys, representations, and research in collaborative mode and for guided fruition of the site tourists.

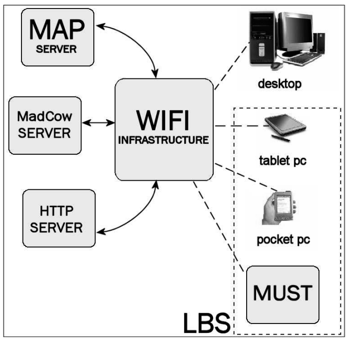

Figure 1: *Architecture overview.*

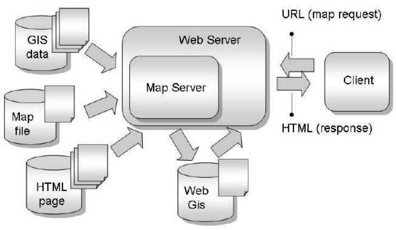

Figure 2: *MapServer architecture.*

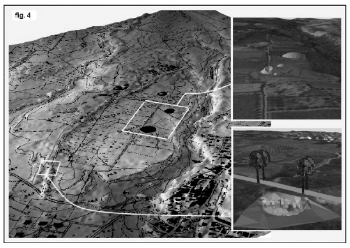

Figure 3: *3D models.*

2. The project framework

The workgroup acquired the guidelines and actions proposed in the UNESCO Management Plan for the site and the proposed strategy is centred on the construction of an IT environment with multiple input-output possibilities. We consider four typologies of users: 1) expert users surveying and making annotations for technical purposes: historical analysis, cataloguing, excavation, conservation and restoration plans, risk evaluation; 2) tourist agencies and promoters; 3)

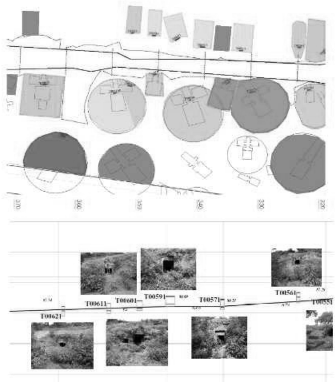

Figure 4: *Vertical iconometric views.*

Figure 5: *The tourist pen based LBS application running on a tablet pc device.*

tourists - providing them with interactive and multimedia solutions: mobile devices such as on-site guides, personal tour planning and recording, web services and virtual tours; 4) researchers and students that can use the innovative annotation WebGIS environment, for collaborative and for e-learning purposes. The proposed system is based on the integration of data communication and LBS solutions with multimedia and multimodal characteristics in the archaeological area of "La Banditaccia". A wireless network infrastructure (wi-fi) - that covers the plateau of the necropolis - it will be possi-

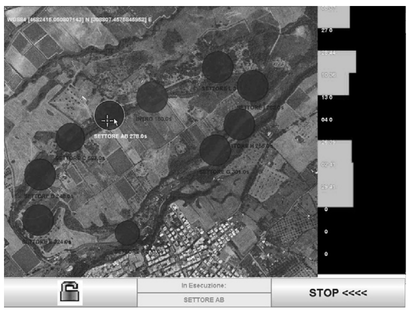

Figure 6: *The MUST user interface.*

ble to further develop the functionality of a series of mobile data acquisition systems and the referencing of geographic and multimedia information collected in the SITAC and published with the WebGIS. The portable instruments in wireless communication with the central server (Figure 1) are diversified in relation to the tourist and technical-scientific users: from the multilingual audio-guide system onboard the electric train, to the palms with GPS, from Tablet-PCs with GIS functions, to Quick Survey Kit equipment. The centralized system enables the web publication of useful tourist and technical-scientific information through a web site with public sections and sections reserved for registered users. The portable systems will be equipped with GPS receivers for automatic position recognition and therefore the proximity to archaeological structures. They will be able to present multimedia material (text, video, audio, images) relative to the actual position of the user. Through portable equipment (Tablet-PCs and Palms) tourists will be able to create personal textual notes, enter sensations and comments, or store photographs and brief audiovisuals associated with the location of the shot. Technical-scientific users can take advantage of more advanced functions of interaction with the SITAC, of interactivity and communication via web, and auxiliary application functions for the various types of surveys in the field. Furthermore, a client-server GIS application is useful to support site surveying, surveillance and security management in terms of risk and vulnerability. The role of the wireless network is to deliver the data exchanged between client applications and servers. The set of server is divided in three main category: MAP, MadCow and HTTP servers. A MAP server create maps for the internet using GIS data from shapefiles, tabfiles, or SDE. Also can utilize data from any database. Can run as CGI or through scripting languages such as Perl, Python, Tk/Tcl, Guile and even Java. In particular, a cartographic view is produced from the overlay of vector and raster layers with symbol legend and scale and orientation indicators. The MAP server publishes the Web version of this material, thus allowing interaction with its visualisation, as well as queries to a database, containing the data and metadata associated with the cartographic layers. Links to multimedia objects can be added as well. Any object is associated with its coordinates with respect to a projection and a geographic reference system. Figure 2 shows the typical structure of a Map server application. The MadCow server [BCL*05] handle all the multimedia annotation aspects. MadCow is a client server application exploiting HTTP to transfer information between a standard Web browser and an annotation server. The server uses a database to store webnotes, which are created by following a typical pattern of interaction: while browsing documents, users identify portions for which they want to create an annotation and open a plugin window in which to specify the annotation content. The user can associate the portion with a new link to a different URL, thus creating an active zone, or with some interactively defined complex content, thus defining a webnote. One or more HTTP server is used for access the WWW. MAP and MadCow servers can be alternatively located in a remote address and accessed trough the HTTP server.

2.1. The SITAC WebGIS application

The SITAC basically integrates iconometric and topographic elements, organized into layers of objects and dataset, for layouts that can be used by archaeologists in direct surveys, but its integration with a web server and an interactive WebGIS application makes it a special multimedia content management system with a geographic attitude. The SITAC shared through the web is a collaborative platform accessible to all participants involved in the different activities concerning the site. Their work on data and documentation can gradually increase the multimedia offer to the tourists and the promoters. This is the ideal progression in order to foster the convergence of various fields of expertise and the implementation of a collaborative web-based platform using GIS and DBMS [BCL*05]. Several thematic layers concerning the Necropolis Area were collected in GIS environment including: topographic and dGPS survey, 3D models (see Figure 3), photo-interpretation of aerial views based on their historical overlay mapping, vertical photogrammetry views (Figure 4), other multimedia documentation (short digital and real movies, audio commentaries and storytelling, video documentation of cultural events). Additional pictures document the interior of the relevant monuments with the aim to build the multimedia georeferenced archive at the basis of the remote visiting web services. In particular the data relationship inside the GIS application between the planimetric and vertical thematic, organized in different views with an innovative technique, allowed for extremely dynamic navigation of SITAC information and for quick organization of useful and understandable visualization output (map/prospect). A synthesis of the SITAC dedicated to the archaeological sites in the Cerveteri has been published on Internet through the implementation of an open-source Map Server. The development of the Map Server within a larger web application foresees both the public side of the website, as a promotional tool for cultural heritage, and intranet side with accounting for technical activities. In addition to the geographic visualisation, this system will further develop the information storing, modification and updating functions in remote mode through portable equipment used directly on the archaeological areas.

2.2. The multimedia annotation system

An innovative and powerful solution - called MA(geo)RIS Multimedia Annotation of Geo-Referenced Information Sources - will allow collaborative construction and fruition of annotations made by users on georeferenced information by combining three web-enabled applications: a plug-in annotating multimedia content (MadCow), an environment for multimodal interaction (Chambre) [BFL*06], and the WebGIS application (MapServer). The resulting system is unique in its offering a wealth of possibilities for interacting with geographically based material especially where there is a high quantity of resources in a complex site. Interaction with the system occur in different modality and through different devices. We identify two main client application class: Desktop and Location Based System (LBS) applications. Desktop and LBS applications allow the user to operate in a georeferenced environment of multimedia sources with different kind of polices for user interaction. LBS applications use a GPS receiver in order to understand the exact location of the user, while Desktop applications are user location independent. Users of the system are: tourists, tour operator, site maintainers, security agent, students, researchers, teachers, cultural heritage institutions. For example a tourist can interact with the SIT through Desktop application on site (in a multimedia laboratory) or from a generic internet access point by opening the main web page of the SIT. After a login, the tourist user can access to GIS information (obtained from the MAP server) and annotate it (using the MadCow toolbar) in order to create a virtual georeferenced tour of the archaeological site. When the tourist arrive at the archaeological site he can choice between a tablet pc and a pocket pc (devices for tourist LBS applications) in order to be guided by the "virtual path" planned before (see Figure 5). The tourist's detected location is used for automatically guide through the archaeological site, and for obtain multimedia related contents (retrieved by the HTTP server). By annotating the "virtual path" directly on site, one can record text, audio, photos, and locate this media in the georeferenced environment (via MadCow server capability of handle multimedia annotation). When the visit of the archaeological site is finished, the tourist can access the georeferenced annoted path, either via a multimedia support (CD or DVD) either via an internet access point trough the SIT web portal. In a more complex scenario a site maintainers can edit the georeferenced environment either via Desktop either via LBS applications by a dedicated client for the MAP server. Finally the MUltilingual Simultaneous Transmission (MUST) subsystem is a combination of hardware and software used for a simultaneous radio transmission of audio tracks. This system is located on board of an electrical train. We have developed this technology in order to guide groups of tourist coming from different nations. The MUST system can operate in two different modalities: manual and LBS. In the MUST's LBS modality the train's location is used to detect the proximity to a particular Point Of Interest (POI). If a POI is considered near the train position (see Figure 6) an audio commentary is transmitted to the user's headphones. Each headphone is carried with a small radio receiver and can be configured for receive a particular radio channel. Different channels are used for different languages. In the MUST's manual modality the selection of the POI is not automatic. In order to help and improve the activities relating to investigation, excavation, monitoring and planning, the operators were given a field survey kit: a set of instruments and procedures for georeferencing, quick surveying and positioning of archaeological findings or other phenomenon. It contains a digital camera, a GPS and tablet-pc that interact with the central information system. The goal is to gradually create an intelligent map of the site, its intelligence deriving from two factors: the mapping valorises the expertise that collaborated on the site and it was also implemented in a highly interactive network system.

3. Related works

While, to the best of our knowledge there is a lack of specific literature on georeferenced annotation, there are several studies on the individual components of the technologies involved. Annotation systems are becoming widespread, as the interest for enriching available content, both for personal and collaborative use, is increasing. Apart from generic annotation facilities for proprietary format documents, professional users are interested in annotating specific types of content. As an example, AnnoteImage allows the creation and publishing of personal atlases about annotated medical images. In I2Cnet, a dedicated server provides medical annotated images. Video documents can be annotated in dedicated browsers, such as Vannotea or VideoAnnEx. However, these tools are generally not integrated into existing browsers, so that interaction with them disrupts usual navigation over the web. Moreover, they usually deal with a single type of document and do not support the wealth of formats involved in modern web pages. Architectures for multimodal interaction are also becoming available, usually devoted to specific applications, for example in the field of performing arts [SHK03] [IBM] [KM95]. In these cases interaction capabilities are restricted to specific mappings between multimodal input and effects on the rendered material, while Chambre open architecture allows the definition of flexible patterns of interaction, adaptable to different conditions of usage. The field of Geographical Information Systems (GIS) has recently witnessed a growth in the number of web applications, both commercial and open source [PT03]. Among the commercial ones, the most important represent web-based versions of stand-alone applications, usually running on powerful workstations. For example, ArcIMS derives from ArcInfo, MapGuide from Autocad and MapXtreme from MapInfo. In the field of open source solutions, MapServer represents to date the most complete, stable and easy-to-use suite offering a development environment for the construction of Internet applications able to deal with spatial data [Mit05]. The MapServer project is managed by the University of Minnesota which also participates in the Open Geospatial Consortium (OGC) [OGC03] by setting specifications and recommendations to support interoperable solutions that "geo-enable" the Web, wireless and location-based services. Current developments are focused on the production of front-end for the publication and personalization of HTML pages, starting from .map files. Among these, FIST offers an environment of editing on-line, enabling also non-expert users to exploit features of remote mapping. However, these environments require that the user possesses writing rights on the original GIS content, or on some private server, while our solution enables the collaborative construction of geo-referenced resources starting from publicly available data offered by existing GISs. See also the recent successful experiences of tourist fruition schemes around excavating areas, where the attraction is not only the archaelogical resources but also the technical activity itself, made of intelligent solutions and methodical jobs.

4. Conclusions

We assumed that the different phases, from surveying to tourist exploitation, had to be coordinated and parallel: interventions gradually increase the fruition possibilities of the site and meanwhile the surveying activities employing the networked equipment produce documentation and support the site knowledge. By collecting georeferenced documentation it's possible to offer, on demand, a multimedia description of the localized resources. Fruition of these contents can occur both on-site, through the local wireless infrastructure using the mobile devices, and also through Internet. In order to recognize real-time positions and resources in the area, these devices have to be equipped with Location Based System and connected to web applications oriented to high interactive use. The spatial and geographical dimensions of the information sources on the Web are usually overlooked. The Ma(geo)ris framework strengthens the relation between the information available on the Web and its geographical dimensions, thus allowing interaction between users and georeferenced information published with WebGIS. The annotation system, the WebGIS application, the multimedia and multimodal approach to objects represent the innovative perspective of the presented project. Benefits can be obtained for different activities: remote learning, collaborative enrichment of available resources about cultural heritage, enriched experience while visiting some artistic or archaeological site. Moreover different multimedia sources, whether georeferenced or not, can be connected among them and interacted with exploiting multimodal interfaces, thus supporting also users suffering from sensorial-motor impairments. The question of local expertise is both strategic and transversal to the entire project so e-learning modules are foreseen in the general architecture of the web services. In the field of archaeology GIS has become indispensable because it enables a territorial approach on a variable scale of an environment with complex georeferenced documentation. Now it is only a question of benefiting from the recent growth of geographic culture and interactivity in order to draw new experts and tourists to locations where there is much to discover. The WebGIS has to be conceived as a collaborative platform for research and dissemination producing benefits for the technical and scientific community as well as for the network of cultural promoters and tour operators. Finally, this process can grant the rapid enrichment of the content base that has to be offered to the public fruition of local resources.

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Starting the CENOBIUM Project: The cloister of Monreale (Sicily) Revealed

C. Baracchini[1], M. Callieri[2], M. Corsini[2], M. Dellepiane[2], U.Dercks[3], D. Keultjes[3], C. Montani[2], M. Scognamiglio[4], R. Scopigno[2], R. Sigismondi[5] and G. Wolf[3]

[1]Soprintendenza ai Beni Architettonici e per il Paesaggio, per il Patrimonio Storico, Artistico e Etnoantropologico per le Provincie di Pisa e Livorno, Pisa, Italy
[2]Istituto di Scienza e Tecnologie dell'Informazione "A. Faedo" (CNR), Pisa, Italy
[3]Kunsthistorisches Institut in Florenz (Max-Planck-Institut), Florence, Italy
[4]Soprintendenza per i Beni Culturali ed Ambientali di Palermo, Palermo, Italy
[5]Freelance Journalist and Photographer, Rome, Italy

Abstract

The paper presents the guidelines of the CENOBIUM project and the first results on the capitals of the cloister of Monreale (Sicily). The CENOBIUM project aims at demonstrating the strength of the integration of modern representation and analysis technologies in the context of the knowledge, documentation and fruition of 3D cultural heritage. The wonderful capitals of the cloister of Monreale are the case study of our project. In fact, most of the capitals represent episodes of the Holy Bible and they can be completely appreciated, studied and documented merely by integrating 2D and 3D technologies. The paper describes the different acquisition and documentation modalities adopted in the project: high resolution digital imaging, short range 3D laser scanning for the capitals, long range 3D laser scanning for the cloister, panoramic views, integration of the geometry of the capitals with the high resolution color images. Moreover, it outlines the main components of the system which will allow the user to virtually move inside the cloister, to choose a particular capital, and to analyze and study the 2D, 3D and text information related to it. By means of innovative technological solutions, all the information, at the highest level of detail and resolution, will be available locally, on a kiosk installation, and on the web.

Categories and Subject Descriptors (according to ACM CCS): I.3.3 [Computer Graphics]: Methodology and Techniques, Digital Imaging, 3D Scanning

1. Introduction

The project CENOBIUM (Cultural Electronic Network Online: Binding up Interoperably Usable Multimedia) faces the necessity to improve scientific and educational communication on the one hand and public information systems on the other hand, integrating new investigation instruments, not systematically connected until now . It will provide a web-based, openly accessible work environment, which includes 3D models created by scanning, CAD-representations, digitized historical photographs and digital photography of the highest professional quality. The technical work will be devoted to the integration and extension of available technologies (database, image-viewers, 3D-viewers, content management, etc.) now dispersed and not-interoperative. The project points to the introduction of multimedia investigation of artworks as a regular research-instrument in the service of its different user groups. The specific case study considered for the assessment of our approach is a selected group of important capital-cycles in medieval cloisters of the Mediterranean region, starting with the cloister of Monreale. With the beginning of the 12th century a new type of sculpted capital evolved within the currents of Romanesque art which was to play a decisive role in changing and determining the future appearance of interior religious space and its cloisters.
The art-historical material is highly adequate for multi-dimensional representation, given the 3-dimensionality of the capitals and their spatial connection with the surrounding architecture - aspects that can not be explored adequately relying exclusively on 2-dimensional photography.

The cloister of the Cathedral of Monreale in Sicily demonstrates particularly well the diversity and the range of opportunities a Romanesque sculptor had in expressing his art. The monastic complex was commissioned by King William II and executed between 1174 and 1189. It unites various artistic currents of Romanesque monumental sculpture into an architecturally homogeneous setting. Each of the cloister galleries consists of 26 twin colonnettes, whereby the corner piers join the columns and capitals into groups of four. The southern and western galleries merge by creating a small square courtyard with a fountain in the center and five additional twin colonnettes with capitals. Researchers identified various contemporaneous workshops composed of artists from various Mediterranean countries, such as mainland Italy, France and Spain, who worked on the spoliated marble shafts and capitals. In this respect the high-quality execution of the cloister capitals of Monreale unites, with its rich formal and iconographic repertoire, the main currents of artistic production of the second half of the 12^{th} century.

In this paper we present the very first steps of this project, started on 2006. The initial work has been focused on the acquisition and processing of 3D and 2D data, i.e. the raw basic data that will be used to populate an interactive system which should integrate all the information in a easily accessible way. After a very brief overview of related work in Section 2, we describe our data acquisition experience in Section 3. The overall structure of the system which will integrate all the data is sketched in Section 4. Finally, we present our conclusions and the future work in Section 5.

Figure 1: *The Monreale cloister.*

2. Related work

Many previous works concern the use of 3D technology either to reconstruct digital 3D models of Cultural Heritage masterpieces or to present those models through digital media. An exhaustive description of those works goes well beyond the brief overview that we can draw in this section. We prefer to cite here only some seminal papers on the technologies proposed for 3D scanning and interactive visualization. Automatic 3D reconstruction technologies have evolved significantly in the last decade. An overview of 3D scanning systems is presented in [CS00]. Unfortunately, most 3D scanning systems do not produce a final, complete 3D model but a large collection of raw data (*range maps*) which have to be post-processed. The post-processing pipeline is presented in the excellent overview paper by Bernardini and Rushmeier [BR02]. Many significant projects concerning 3D scanning and Cultural Heritage have been presented in the last few years [LPC*00, BRM*02, FGM*02, PGV*01, STH*03, BBC*04, BCF*04, BCC*05]. Some of these projects considered also the issues arising when the aim is to sample not just shape but also the reflectance properties of the surfaces [BRM*02, STH*03, LKG*03] and the mapping of this information on the geometry [CCS02, FDG*05].

The high resolution meshes produced with 3D scanning are in general very hard to render with interactive frame rates, due to their excessive complexity. This originated an intense research on simplification and multiresolution management of huge surface meshes [GH97, Hop99, CMRS03] and interactive visualization, where both mesh-based [CGG*04] and point-based solutions [BWK02] have been investigated.

3. Data acquisition and processing

The comprehensive acquisition campaign we performed in Monreale was the starting step for the creation of a large database of high quality 2D and 3D data. In the next subsections we describe the acquisition setup and the technology used for the different types of data. The specific high-quality devices used for the photographic campaign and the acquisition setup are presented in Subsection 3.1. Then, the technologies adopted to scan (with a triangulation laser scanner) a selection of the most important capitals of the cloister are presented in Subsection 3.2. The approach adopted for mapping the photographic detail on the capitals' 3D models and to obtain a very realistic digital visualization is described in Subsection 3.3. Finally, the entire cloister has also been digitized with a time-of-flight scanner and with panoramic imaging technology, as briefly described in Subsection 3.4.

3.1. High resolution digital imaging

A Sinar P3 digital camera was purchased by the Photo Library of the Kunsthistorisches Institut, providing for the integration of the digital backs Sinarback 54 H and Sinarback eMotion 22, both of them with a resolution of 22 million pixel (sensor resolution 5440×4080 pixel), as well as various Sinaron lenses. This is a very expensive but also very high quality device, which can produce impressive results if used by a professional photographer. The high-resolution digital images are created in a two-step process. First, a digital image is produced with a colour management tool by Gretagmacbeth, following the intent to save as much information as possible with the one-, four- or sixteen-shot

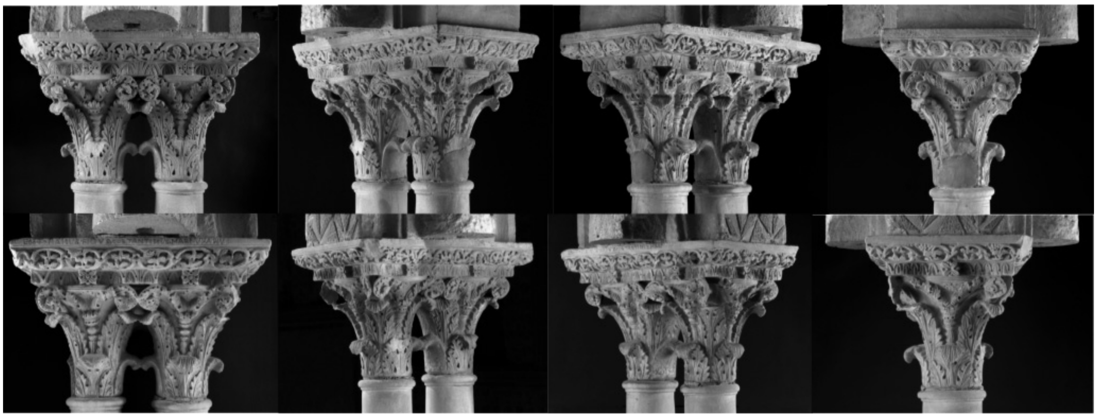

Figure 2: *An example of the set of photos acquired for sampling the color of each capital.*

(taken at different exposure levels). This master copy is used for producing further copies and for long-term preservation. Its size ranges from approximately 130 up to 520 Megabytes (TIFF format uncompressed, 16-bit colour depth and 300dpi). A working image copy is created from this master. This copy is digitally enhanced to allow improved quality on a low-dynamic range output device (screen or printing device). Its size is approximately 65 Megabytes (TIFF format uncompressed, 8-bit-per-channel colour depth, 4000×4000 pixels - approximately 33 cm on a 300 dpi printout). A set of 8 photos, documenting a capital, is shown in Figure 2.

Figure 3: *The acquisition setup adopted to scan the capitals.*

3.2. Scanning the capitals

High quality 3D models of the capitals have been produced by using a Konica Minolta VI 910 Laser Scanner (a device based on optical triangulation), which permits to acquire accurately geometry of an object with a sampling density of around 10 samples/sq.mm. and a sampling error lower than 0.05 mm. Since the scanner works at a distance between 50 and 100 cm from the objects, it was necessary to put it on a scaffolding, as shown in Figure 3.

It is well known that scanning any 3D object requires the acquisition of many shots of the artefact, taken from different viewpoints, to gather geometry information on all of its shape. Therefore, to perform a complete acquisition usually we have to sample many *range maps*; the number of range maps requested depends on the surface extent of the object and on its shape complexity. A number from 120 to 200 single scans (each scan samples around 0.3 Million points) was needed to cover the entire surface of each capital. In the first scanning campaign (February 2006), which lasted for an entire week on site, we were able to scan 20 out of the more than 100 capitals of the cloister. To sample this initial subset we shot nearly 4000 range maps. Each set of range maps has to be processed to convert it into a single, complete and non-redundant 3D representation. As usual, the processing phases are:

- range maps *alignment*;
- range maps *merging* (or fusion), to build a single, non redundant mesh out of the many, partially overlapping range maps;
- mesh *editing*, to improve (if possible) the quality of the reconstructed mesh;
- mesh *simplification* and conversion into a multiresolution representation;
- *color mapping* (see next Subsection).

In order to obtain detailed 3D models, we used the ISTI-CNR tools, which give the possibility to deal with large number of range maps and to produce the final model with the lowest possible human intervention. A complete overview of these tools is presented in [CCG*03].

Twenty highly detailed 3D models of the most artistically interesting capitals of the cloister have been reconstructed. The screenshots of two models are shown in Figure 4 and 5. The number of triangles of each model ranges from 4.1

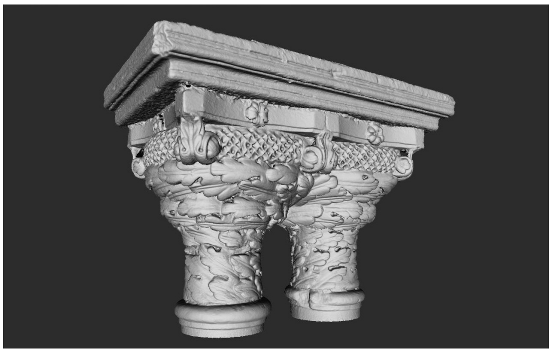

Figure 4: *The "Sh10" capital: ornamental leaves .*

Figure 5: *The "Sh20" capital: Samson.*

to 6 millions, depending on the shape complexity and size of each capital. We show in Figure 6 that even when a limited degree of mesh simplification has been performed, the detail of the geometry are preserved and the capitals can be represented in a very realistic way.

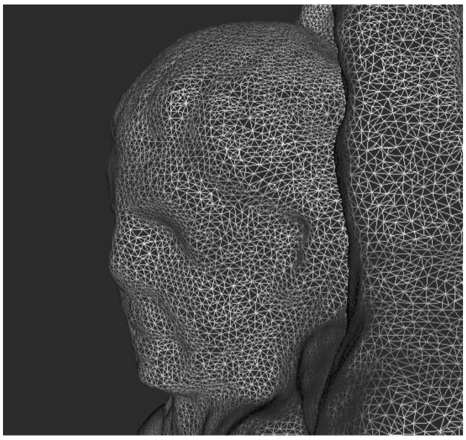

Figure 6: *A wireframe rendering of a small section of the "Sh23" capital (section height 5 cm.).*

3.3. Integrating color on 3D geometry

As already mentioned in the previous subsection, color mapping is an important step in the scanning pipeline. As a result of our acquisition campaign in Monreale we had high quality 2D and 3D information: the objective was to integrate them in a unique model, preserving the detail of both color and geometry.
In order to produced a detailed colored model starting from the set of photos provide, two phases are necessary:

- each photo has to be "aligned" to the model: the extrinsic (position in the space) and intrinsic (focal length and lens distortion) parameters of the camera which took the photo have been estimated with an appropriate tool [FDG*05];
- due to the highly detailed geometry, we chose to represent color following a per-vertex approach: for each vertex, the color assigned is computed as a weighted sum of the contributions of every photo which framed that vertex.

Figure 7: *The model of "Sh37" capital with color information.*

Following this approach, we produced a set of very detailed colored models: an example is shown in Figure 7. The union of 2D and 3D information can lead to a new way to archive and remotely represent Cultural Heritage objects.

3.4. Digitizing the cloister in 3D and as a panoramic image

The complete cloister has been also the focus of other digital acquisition actions. We planned to produce a 3D model of the entire cloister together with high-resolution panoramic images. The goal of these acquisition is first for the sake of providing a digital documentation and improved knowledge, but also to have digital models which could be used as a visual index to access the single capitals.
The panoramic images have been created by processing a set of digital photos (medium resolution, acquired with a consumer digital reflex camera) with the Stitcher tool by RealViz inc.
The 3D model of the entire cloister has been produced with

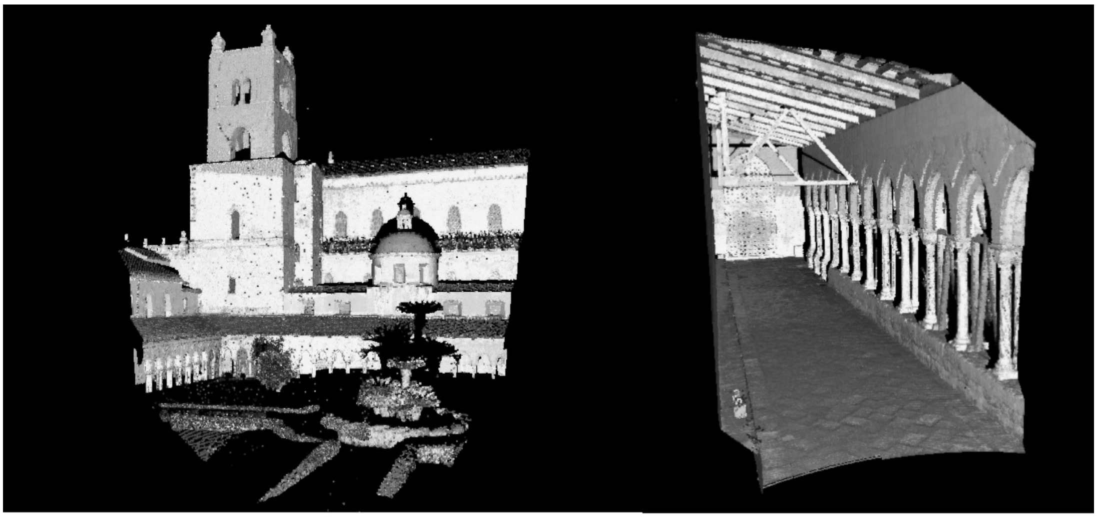

Figure 8: *Examples of time-of-flight scannings.*

a Leica Geosystems HDS 2500 time-of-flight scanner. Time-of-flight devices give the possibility to scan large areas in a short time, with an error in acquisition of less than 1 cm. We show an example of the results of several scans depicting a portion of the cloister in Figure 8.

4. Exploring the capitals of the cloister of Monreale

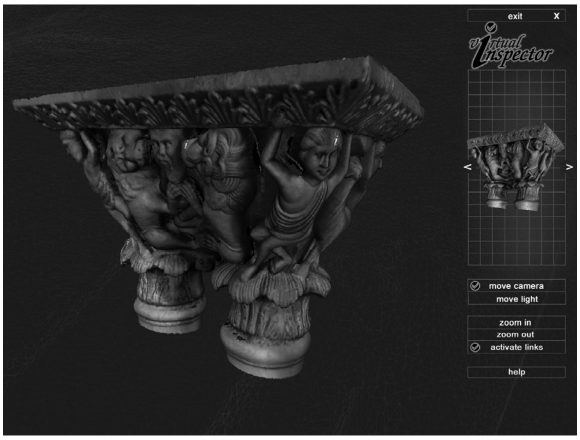

Figure 9: *Visualization of a capital using Virtual Inspector.*

With the first phase of the CENOBIUM project we have just scratched the work we planned. Just 20% of the capitals have been acquired (even though they are the most significant, from an artistic point of view).
The main goal of the project is to make these data available to both experts and public. This will be implemented by using the ISTI-CNR Virtual Inspector tool (see Figure 9). Virtual Inspector provides a framework which allows the easy inspection and virtual manipulation of a complex and highly detailed 3D model. The system allows also to add to the 3D surface a number of *hot spots* which could be used to link multimedia information to selected points of the surface (see the small red circles with an inscribed *i* in Figure 9); by instantiating hot spots we can tell the story of the artifact or encode annotations on the mesh. The system inter-operates with a standard web browser, which supports the visualization of the MM content spatially indexed by the 3D mesh. *Virtual Inspector* has been recently extended to work also on the net, by adopting a remote rendering approach, and has been already used for a number of projects (e.g. [BBC*04, BCF*04]).
The final goal of the CENOBIUM project is also to contribute to the evolution of the Virtual Inspector system, since we plan to transform it from a static system (i.e. all the links should be defined statically) into a dynamic and cooperative system, where users will be allowed to add hot spots and the corresponding MM descriptions via an easy to use interface, following the "Wiki approach". The details of this will be the subject of our future work.

5. Conclusions and future work

We have presented the overall goals of the CENOBIUM project and the results produced in the first phase of the project, devoted to the acquisition of the digital models (2D and 3D) of the selected case study: the cloister of Monreale. Therefore, the work so far has been mostly technical: acquiring 2D/3D data and setting up the HTML and interactive framework needed to show them both locally (a kiosk installed in the Kunsthistorisches Institut) and on internet: the focus of the second phase, i.e. our future work, will focus on some extension of the Virtual Inspector tool, to make it a cooperative instrument, and the production of all the multimedia content needed to enrich the visual digital representations of the sculptures of the cloister.

Acknowledgments The CENOBIUM project is dedicated to the memory of our colleague and friend Martina Hansmann. We would like to thank Leica Geosystems Italy for borrowing us a HDS2500 scanner.

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Integration issues for tools to create interactive Cultural Heritage experiences

K. Rodriguez-Echavarria[1], T. Jenkins[1], C. Moore[1], M. Généreux[1] and D.B. Arnold[1]

{K.Rodriguez, T.Jenkins, Craig.Moore, M.Genereux, D.Arnold}@brighton.ac.uk

[1]Faculty of Management and Information Sciences, University of Brighton, United Kingdom

Abstract

Recent years have seen substantial efforts to produce tools which address individual sub-areas of the process of building an interactive virtual experience of a Cultural Heritage (CH) site and its artefacts. Research in shape representation and modelling has developed techniques for image based modelling, multi-resolution modelling, level of detail manipulation, and optimisation of rendering techniques. All of these must fit together efficiently and seamlessly in order to allow non-IT professionals to focus on the content creation of the experience rather than on the technology. In this paper, we report on some real issues which arise with the integration of modelling, interactive graphics, knowledge representation and language technologies and discuss some alternative strategies for addressing the issues.

Categories and Subject Descriptors (according to ACM CCS): I.3.2 [Graphics Systems]: I.3.6 [Methodology and Techniques]: Standards I.3.8 [Applications]: H.5.2 [User Interfaces]: Graphical User Interfaces, Natural Language J.2 [Archeology]:

1. Introduction

The application of Information Technology to Cultural Heritage (CH) poses many unique challenges. Visualisation, whether as a tool for documentation, interpretation or presentation of CH information, is an area particularly challenging as it aims to incorporate an extremely diverse and extended set of knowledge and data definitions from this discipline. Where other disciplines may use Visualisation without thought to the explicit or implicit logic or semantic behind a visualisation or how it will be perceived, CH benefits strongly from a more variable approach to the structures and techniques used during production. Moreover, CH requries levels of accountability in accuracy and providence of its visualisations that other disciplines may ignore. Virtual environments are commonly used for presentation of CH information, such as archaeological sites, historical cities or reconstructed artefacts. The production of these virtual environments may rely on data of many different types and source, such as from original site photography or sampling, previous documentation, or articially produced data, using modelling software or handmodelled according to the needs of the visualisation. It is intended that all these techniques interoperate efficiently and transparently in order to allow non-IT professionals to focus on the content creation of a CH experience rather than on the technology used; as it stands, most CH visitor experiences rely on handcrafted content [GCP04, CSA04, LB04], which usually require experienced graphic professionals to build and tune the interactive virtual environment for their target audience. Where visualisation for other disciplines don't necessarily require semantic data to be embedded into the modelling structures used during visualisation, this type of data has tremendous influence in bringing the full potential of visualisation to CH. Therein lies a great challenge to visualisation for CH. Where many CH projects are able to produce data and structures modelling their particular visualisation needs, it is the integration of projects that gives the greatest potential for visualisation in CH. It is in the interest of the discipline at large to recognise some of the fundamental issues concerning the integration of structures and techniques that allow the reuse and re-examination in the future, and give greater control over their selection and use in future projects. An example of such a project might be the virtual reconstruction and visualisation of the Royal Pavilion in Brighton. Built as a palace for the Prince of Wales between 1787-1821, the Royal Pavilion is a building with varying amounts of detail in its construction, both of its interior and exterior. There are a great many different techniques that could be used to construct a geometric structure of this nature, however, such a building would benefit strongly from many different types of model structuring and rendering techniques, both for real time rendering and pre-rendered visualisation. As a man-made structure, it contains many simple architectural premises upon which many of the details are applied, some in great number. Where no single modelling techniques would be ideal, a hybrid approach is suggested. Such an approach might make use of the best techniques for modelling particular features, for example,

1. The core geometries of the building using architectural plans, the minarets using the Geometric Modelling Language [GML],
2. unique objects such as the Dragon in the Music Room to be modelled by hand using modelling software such as Blender [BLE],
3. Photogrammetry based scanning of architectural features [VvG06].

Whilst each of these techniques produce geometry to be integrated into a CH scene, different considerations can be taken for each technique for rendering, both for pre-rendered visualisation, where the emphasis is upon realism and optimum quality, to real-time rendering, where interactive speeds are required and specialist techniques can make good use of semantic scene data for optimisation. Each representation of

Figure 1: *Illustration of hybrid model of Brighton Royal Pavillion*

CH, whether from original source or artificially produced, will have its' own qualities such as accuracy, its' own digital and technical considerations. It is not the intention of this paper to dictate the best way to integrate multiple types of representation within a CH scene, but to raise awareness of the need to take steps to make this type of integration possible.

2. Technology Integration Framework

For present purposes we assume that a significant part of the virtual heritage content is typified by considering digital representations of architectural sites (towns and cities composed of buildings and houses with a distinctive historical style) along with digital representations of historical objects, including those discovered by archaeologists on excavations. Other digital representations, such as virtual avatars, flora and fauna could be used to add realism to the scene and portray more effectively the historical context of a place, building or object. In addition, semantic technologies allow the addition of interactivity to the environment with users interrogating the system through the use of tailored intuitive natural language interactions. The engineering processes to build such an application are roughly as follows (see figure 2):

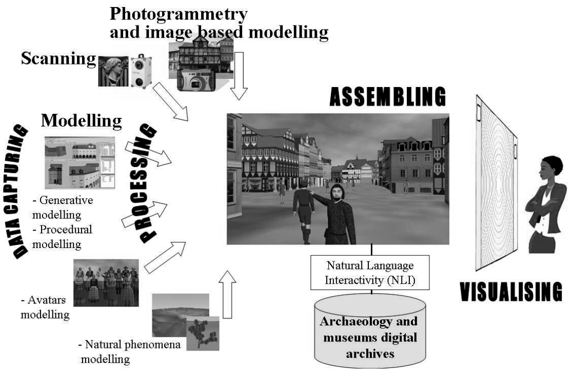

Figure 2: *Framework for the creation of a virtual CH environment*

1. The raw data is digitally captured and processed,
2. The virtual environment is assembled
3. The user interfaces, dynamic behaviours and interactivity are added and the experience scripted; and,
4. The user navigates, views and interrogates the environment

These activities are normally iterated with prototyping and usability studies. The efficient integration of the technologies used is essential for effective operations. To better understand integration issues, we selected a number of tools and used them to capture one of the sections of the Brighton Pavilion to assemble an interactive visualisation.

2.1. Capturing semantic data for 3D CH objects

In order to enhance CH environments, semantic information needs to be linked in, for example, on the style, material and history of its construction. This can be encoded using standardised ontologies so that meaningful relationships between graphical components and other data can be captured. Most CH archives have been constructed using proprietary formats, which impede interoperability without standardized concepts and structures. The International Council of Museums Conceptual Reference Model (CIDOC-CRM) [CC] is a new ontology standard developed for documenting artefacts within the museum and gallery domain. CIDOC-CRM structures can be implemented over traditional database systems, with application concepts specified precisely, using a, domain-specific vocabulary thesaurus. By standardising on conceptual structure with embedded semantics, such knowledge bases allow inference and automated reasoning, enabling intelligent interaction in an experience.

3. Assembling the virtual environment and adding interactivity

Once the digital content has been created, it needs to be integrated with the scene description, the dynamic behaviour of the objects and the user interaction via input devices. CH interactive environments have normally been handcrafted using device-independent graphics libraries (e.g. OpenGL) or scene graph based libraries (e.g. OpenSG, OpenScenegraph, Performer or Inventor). Although this affords a great degree of freedom, it requires experienced graphic professionals as developers. As a consequence museum curators or other CH professionals who may not have this experience, are unable to participate fully and the development focus can be diverted from creativity to technology. In the absence of tools focused on the CH application domain we suggest the open source scenegraph system OpenSG [Opec] to handcraft the experience, which requires translation of the graphic content to meshes, since application specific data types are unavailable. The first stage of integration is to translate the content from the original applications to a format that could be integrated by OpenSG. Almost all digital content creation applications rely on proprietary data formats that either cannot be reused by other applications at all or can only be reused by hand crafting modifications to the files, which can both be inefficient, inaccurate, time consuming and difficult to document changes. Although, most packages offer translators to other formats, there is still a lack of common standards for exchanging data, such as generalised scene topology, individual models and behavioural mechanisms, as well as offering flexibility for custom components. As an example, we found applications using incompatible versions of VRML, even though X3D supplanted it some years ago. This meant that everything tends to be reduced to the lowest common denominator. This data exchange problem has a direct impact on those applications that use data formats that store environmental and application specific data, such as information about the scene or the objects. The lack of integration becomes more evident as we try to take advantage of the capabilities of individual applications. The potential of GML, for example, is based on the way it encodes the geometric information. However, there is no standard way to integrate this format in an interactive experience along with objects in other formats particularly where those objects are conjoined geometrically, as interfaces are not defined to their common properties. The complexity of the integration of content and/or functionality when assembling an interactive environment is, in our opinion, due to the nature of the area (in particular the unique or rare opportunities to digitize fragile objects or environments) and partly related to the software development cycle that most projects follow. Hence, different technologies, such as data capture or image based modelling techniques, are designed and developed with the intention to be self contained applications. Only rarely are they designed to interface with other types of applications, such as applications to assemble and visualise virtual environments. In addition the opportunities to digitse CH data or artefacts are severely limited (if not "one-off") and data, once captured is expected to be preserved and re-used.

4. Visualisation of the 3D virtual CH environment

Once the CH interactive application has been assembled users can explore it, interacting with objects including buildings, artefacts and avatars. The user could explore the model and click on features of interest to obtain more information (see figure 1). The number of large meshes produced in assembling the multiple sources, proved to be an obstacle when rendering the complete scene. This highlighted the need to use application specific representations to allow efficient rendering with encoded information within the 3D object, both to identify the most efficient mechanism and to link to other domain specific information. Whilst a virtual environment can be created by integrating 3D objects from low-level capture methods to assemble the scene, low level interoperability is not a sufficient for realtime applications. Many of the content creation applications, especially research tools, rely on custom modelling, using particular techniques, geometry or pieces of a scenegraph. Whilst these can be packaged in serial representations the real benefits are only felt when the interactive manipulations of the environment can be accomplished using the special purpose data structures. There are thus two types of integration and standardisation required - serialised data exchange and runtime object manipulation. The need for standards for these two areas has been recognised for about 30 years (e.g. CGM and CGI - [AB88, AD90]). The previous section highlighted the need for common guidelines and recommendations on the use and/or adaptation of general purpose standards for *serialised data exchange* for both geometric and other knowledge about objects. *Application Specific Profiles (ASPs)* would allow a standard for categorising specific objects assembled into a CH virtual environment (e.g. museum objects, buildings in a city, avatars). The ASP approach could be applied to *runtime object exchange protocols* and *protocols for interfacing* with other functionalities, such as natural language technologies. Some of the standards that might address these needs are considered below.

4.1. General purpose standards for serialised CH data exchange

Serialised data exchange are a linear traversal of internal data structures and raw data encoded in computer-readable, and sometimes human-readable, form. Standards enable integration by allowing successful reuse of data and sub-systems. By standardising data exchange formats for 3D objects, data files from unspecified sources can be interpreted to build data structures for use applications for which the original data was not envisaged. This ability is fundamental for CH data where conservation of data well beyond the lifetime of current systems is essential. Currently, X3D (succeeding the earlier VRML) and COLLADA (COLLAborative Design Activity) are two popular standards for encoding 3D objects into common formats for sharing between applications. COLLADA is increasingly used in 3D content creation whilst X3D has particular legacy value and familiarity in the field. Both formats can encode a scene using an XML syntax. Some of their main differences are:

- X3D (Web3D Consortium 2006) is an ISO standard, while COLLADA was originally established by Sony and then adopted by other main players in the gaming industry. These will have an effect on which applications will take advantage of these formats as they are being directly supported by the tool vendors.
- COLLADA is designed as an interchange format, while X3D is designed as a content deployment format, targeting web type applications.

These types of standard allow the transfer of text based files over http and other non-binary protocols and thus allowing easier transfer of data across networks, although there are potential versioning issues and extra processing to serialise and deserialise data structures. Also, at runtime, real time modelling and rendering techniques may require different data structures than those implied by simply reflecting the structure of the serialised data.

4.2. Application Specific Profiles (ASPs) for the CH application domain

Often efficient modelling and rendering of domain specific 3D objects have to be closely coupled. As an example, in [MVcSL05] new techniques for recording and presenting coins were developed. These techniques would be ripe for integration into a CH experience, but use specially developed modelling and rendering techniques which would not be a native part of a scenegraph such as OpenSG. An agreed set of ASPs would allow developers to go beyond the generalised standardisation and use application specific constructs. ASPs for the CH domain could consist of two parts: firstly, an abstract data layer including original source data, a unique Digital Object Identifier (DOI), and other metadata. This data corresponds to the abstract functionality of a "class" of object. A second, implementation layer would map or bind the abstract into common implementation environments such as OpenSG. The underlying implementation would allow custom algorithms for development of new techniques and experimentation whihc implemented the specification as defined. The domain knowledge embedded in ASPs can be used to optimise both at runtime and in the assembly of the virtual environment. These optimisations could include precognition of possible scenarios for user interaction, optimisation for rendering, behaviour of avatars, and other types of intelligent content delivery. ASPs also allow the specification of fallback mechanisms for system behaviour, whether due to system specifications or user requirements, such as accessibility requirements. Optimisations for particular object types could be developed and agreed to produce ASPs based on project experience and, as a natural extension, a centralised registration body for both object representation and implementation mechanisms could be developed. The organisation of these profiles will enable the standardisation of digital representation of objects in CH, which in turn will lead to the standardisation in development of content creation tools, facilitating greatly the production pipeline of CH experiences based on properly curated digital objects. In addition, format standards, such as X3D and COLLADA will facilitate the flow of data between the development tools, supporting the Application Profiles, although custom data will be required to be preserved under format conversions as part of the ASP. A further consideration may be whether to extend standards such as COLLADA to explicitly include this information, or simply use the standard user defined data fields with restrictions.

4.3. Protocols for runtime object exchange

In order to take advantage of optimisation and other modelling and rendering mechanisms at runtime, internal data structures can be traded between processes or between a process and a runtime library using data structures common to both. Examples include any Windows-based C++ application using DLLs and using a standard data currency. The requirement for this is the use of a standard library of objects and access between them, such as C++/ Windows DLLs, and an API such as OpenSG as a trade mechanism. This will provide the advantage of very fast memory transfer of objects, meaning that runtime modelling could be farmed to specific algorithms in externally developed software modules. However, the disadvantages would be that developers will be forced to conform to an interface API and that the exchange must take place within the same system environment, as well as it would not be possible to save data exchange explicitly for future reference. Figure 3 shows the use of 3^{rd} party modelling processes communicating with runtime objects. In this case, the 3^{rd} party processes will require the use of a standard API as a data currency to quickly trade data with the main User Agent or viewer at runtime. This will allow the encapsulation of algorithms within the separate process to be used for runtime modelling, such as pieces of the scenegraph itself. Both serialised and runtime objects have

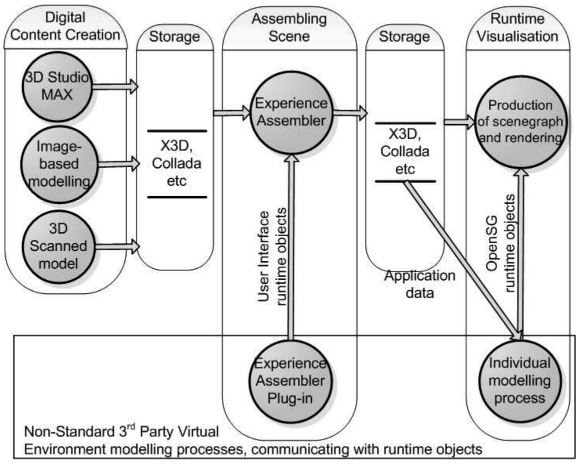

Figure 3: *Runtime object exchange*

their place within a common framework that is both flexible and data driven, in combination with Application Profiles. Use of custom components is dictated by the interface definitions made publicly available. So where individual specialists may develop unique techniques for modelling and storing different types of data, their research would not be locked into their own application framework, but instead allowed different pieces to be developed concurrently, whether the aspect be 3D geometric representation, rendering techniques, or other types of content.

5. Conclusions

The paper presents several issues with our current development cycles of interactive experiences, not only for the CH application area, but for many others. Although, some of these issues are commonly being experienced by developers, a thorough analysis is presented in order to draw useful conclusions and recommendations from them.

1. In the CH domain, access will be limited so the opportunity to create digital representations may occur rarely (due to the unwillingness of curators to make fragile objects available for digitisation) or unique (for example due to the destruction of a unique archaeological site during excavation). Since the access to create new digital representations is precious it is inevitable that data from old digitisations will need to be used where available and fully integrated into the experiences even where the potential quality of a new digitisation would be vastly preferable. This, inevitability of future reuse, applies as much to new digitisations undertaken now as to those that were done a long time ago. The implication is that new digitisations should be established such that the provenance of the digitisation process accompanies the digital artefact so that the tools, accuracy and subsequent manipulations of the data describing the digital artefact are not lost with time.
2. At the level of creating and assembling the virtual environment it is essential that the systems are capable of integrating several data formats. These will arise for a variety of reasons that are independent of the CH field - for example because different representations are most appropriate for different geometric data types and require specific manipulation techniques. However there are also compelling reasons for the inevitability of this requirement arising specifically in the context of CH.
3. At the level of visualising virtual environment, current tools are not taking advantage of rendering and modelling optimisation techniques as there is not a common framework for serialised and runtime data exchange.
4. There are two different types of requirement for additional data commonly stored in fields reserved for application data in file formats. The first applies to allow individual digital artefacts to cohabit a virtual space but be compatible to some degree. The second is required to allow the integration or linkage of non graphical metadata with the representation of the visible aspects of objects.
5. Many of the operations of assembling disparate sources of data turn out to be non-commutative and or irreversible. Thus the association with particular elements of metadata may be maintained as an object is translated from form to another for inclusion in the integrated scenes. However subsequent alterations whether in the unified environment or via additional editing of the original digital artefact will need to be propagated through the manipulations that were applied to the original artefact.

The situation might be improved through adoption of standards and protocols based on widely available technologies, both for serialised data exchange and runtime object exchange. Furthermore, the adoption of Application Profiles for the CH domain could provide a common framework for embedding metadata to individual or groups of objects via common linkage techniques - e.g. url's or Digital Object Identifiers (DOI's).

6. Further Work

In order to overcome some of the integration problems described in the paper, further research work will be conducted on the analysis and design of a common method of registering common Application Profiles, for open source implementation documentation, and simplified extension as well as maintenance as new techniques are developed. For example, the development of unique OpenSG modules to allow the representation of artefacts as best developed by experts in the field. In addition, where 3D standards exist for storing specific types of data, their usage will involve a detailed analysis of the best mechanism for adoption in order to allow the many types of representation to be referenced for use within a single environment. This includes the provenance of data, trace-ability and application-specific identifiers to account for data, ensure its reliability and track its progress through original source to storage, analysis and presentation. The design of complementary set of interfaces for the transfer of data at runtime will be based on a common set of functionality, to allow interoperability of virtual environment components, such as Natural Language Interfaces.

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Interactive Simulation of Ancient Technology Works

G. Nikolakis [1], K. Moustakas[1], D. Tzovaras[1], T. Harissis[2]

[1]Informatics and Telematics Institute / Centre for Research and Technology Hellas,
1st Km Thermi-Panorama Road 57001 (PO Box 361)
Thermi-Thessaloniki, Greece.
[2]Systema Technologies S.A. 215 Messogion Avenue, 115 25 Athens, Greece

Abstract

The objective of the proposed application is the development of an interactive system for the presentation and simulation of Ancient Greek Technology works with the use of advanced virtual reality and computer vision technologies. The system consists of the haptic interaction module, gesture recognition algorithms, software agents simulating ancient Greek technology mechanisms and the scenario-authoring tool. The components of the system are integrated together through the APEIRO core simulation support unit. Extended evaluation of the system has been performed with visitors of the Science Center and Technology Museum of Thessaloniki.

Categories and Subject Descriptors (according to ACM CCS): H.5.1 [Information interfaces and presentation]: Artificial, augmented, and virtual realities, I.3.8 [Computer Graphics]: Applications D.2.6 [Software Engineering]: Interactive environments

1. Introduction

A recent trend of museums and exhibitions of Ancient Greek Technology is the use of advanced multimedia and virtual reality technologies for improving the educational potential of their exhibitions [Ili02, Mal78, Mal79].

In [LS03] the authors utilize augmented reality technology to present an archaeological site. They use a scaled model of the roman "Heindentor" with virtual overlays that provide the visitor with additional information about the exhibit. An attempt to visually enhance archaeological walk-throughs through the use of various visualization techniques is presented in [GPC03]. A collaborative virtual environment system to navigate to a virtual historical city is presented in [BP01]. Authors of [SDP00] present a variety of specialized hardware used in order to create interactive virtual spaces for museums or other cultural exhibitions. These include interfaces for navigation in large scale virtual spaces in museums utilizing new techniques in order to virtually enlarge and augment the exhibit surface.

The aforementioned examples show that museum exhibitions tend to be more and more interactive. Following this direction, the Thessaloniki Science Centre and Technology Museum (http://www.tmth.edu.gr/), has created representations of ancient Greek technology in the form of small-length video films in a PC, so that the visitor can comprehend exactly the operation of specific exhibits and observe their use in their initial operation environment. In a virtual representation enriched with narration, the visitor is provided with a very pleasant educational environment, where he/she can potentially achieve familiarization with the exhibit and in this manner obtain educational benefits.

Even if the acceptance of these applications by the museum visitors is considered to be high, there is a clear need for more realistic presentations that should be able to offer to the user the capability of interacting with the simulation, achieving in this way enhanced educational / pedagogical benefits.

Furthermore, from the technological point of view, interactivity is recently focused on haptic interfaces used in a large variety of applications. Such applications include blind and visually impaired users accessing information presented in 3D [TNF*04], engineers performing assembly planing [NFT03] and students learning geometry [NFTS04] via the use of virtual reality environments (VEs).

The proposed paper presents the evolution of the application presented in [NTMS] as well as results of the evaluation procedure. The application aims to contribute to the development of a new perception of the modern era needs, by making reference to the technology evolution, demonstrating Ancient Greek Technology works, presenting their evolution in time and linking this evolution with corresponding individual and social needs. The objective of the proposed application is the development of new techniques for the simulation of Ancient Greek Technology works, with the use of advanced virtual reality technologies and user-simulation interaction. The main goal is to enhance the realistic simulation and demonstration of these technology works and to present the educational/pedagogical use and the continuously development of each technology work.

In order to achieve these objectives haptic interaction mechanisms and a gesture recognition system were implemented in a virtual environment platform. The user is allowed to interact with ancient technology mechanisms in the virtual environment either by constructing or using them via the proposed haptic interface or by selecting options using the gesture recognition system. In order to provide real time haptic feedback to the user a novel collision detection algorithm is used, based on superquadrics, for detecting collision between the hand and scene objects.

The paper is organized as follows. The interaction system is presented in Section 2. The authoring tool is presented in Section 3. Section 4 describes the novel haptic rendering scheme while Section 5 presents the evaluation scenarios and Section 6 analyzes the evaluation procedure. Finally the conclusions are drawn in Section 7.

2. Interaction System

The main components of the interaction system are:

- The **APEIRO core simulation support unit**, which is the main unit of the application and integrates all other units.
- Adjustable **software agents simulating ancient Greek technology mechanisms**. Intelligent software agents that adapt the simulation response on the input from haptic interaction and gesture recognition modules.
- A **haptic interaction system** which includes subsystems for handling user-simulation interaction via the use of virtual reality devices (wireless trackers, force feedback haptic virtual reality devices, etc.).
- **Gesture recognition** algorithms based on depth information for natural user interaction with the virtual environment. For the development of this particular application an innovative 3-D camera was used to acquire the information corresponding to hand gestures.
- A **multimedia database** supporting the efficient storage of the educational / entertainment scenarios.
- **Educational / entertainment scenarios** for the simulation and demonstration of ancient Greek technologies.

2.1. APEIRO core simulation unit

The APEIRO core simulation unit supports data input and output, controls the simulation agents and opens and saves scenario files. This unit does not implement the connection to the peripheral devices but receives the input data through the Haptic Interaction System. Thus, changing the virtual reality hardware components used in the application does not affect the core simulation support unit. The core simulation support unit controls the data flow between the software components and is actually used to integrate all the components that constitute the APEIRO platform. [NTMS]

2.2. Intelligent agents

Another important part of the proposed application are the mechanism simulation agents The agents are used in order to enable the usage of the ancient technological works in a more realistic way. There are five types of agents created in order to support the scenarios: the 'Move agent', the 'Rotate agent', the 'Scale agent', the 'Trigger agent' and the 'Snap agent'. [NTMS]

The first three agents apply constrains to the movement of the objects while the trigger agent enables or disables specific actions and the snap agent enables assembling components in order to construct a mechanism. Each of the agents gets a transformation matrix as input (which includes positioning rotation and scaling information), a speed vector, an angular speed and the maximum and minimum allowed values.

2.3. Haptic interaction system (HIS)

The haptic interaction system (HIS) of APEIRO is responsible for the communication with the motion trackers and the haptic devices. It enables connection of the APEIRO core unit with the CyberGlove, CyberGrasp and CyberTouch devices and the wireless Motionstar tracker. The system is responsible for receiving, preprocessing and sending to the core unit the data from the devices. HIS is also responsible to perform the collision detection between the hand and the objects in the Virtual Environment, calculating the force feedback and sending the appropriate data back to the devices. The collision detection algorithm that is used in APEIRO must be very fast in order to respond in real-time and with high accuracy. In order to achieve this, a novel approach is followed in the proposed system, where the virtual hand is modelled using superquadrics [SB90]. Collision detection is performed in real-time, based on the analytical implicit formula of the superquadric, as will be shown in the sequel. [NTMS]

2.4. Gesture recognition

A system for the real-time recognition of hand gestures from 3D data was developed. The system is robust against orientation of the user body, background and illumination. Several 3D image analysis algorithms were developed: segmentation of the body from the background, segmentation of the arm from the body, segmentation of the hand from the arm, measurement of 3D position, volume and orientation of the hand. The sequence of 3D measurements was subsequently used as input to a tracking system capable of mapping these measurements to application specific actions. [NTMS]

The segmentation of the subject's arms is achieved by means of a hierarchical un-supervised clustering procedure [MAS02]. This is based on the observation that the various parts of the body, such as the arms, torso and head, form compact 3D clusters in space. Classification algorithms are prone to rigid transformations of the input pattern. In our case all input patterns are transformed to a canonical frame. Availability of 3D information leads to efficient estimation of the orientation of the hand, making the second approach more appropriate.

Finally, a multimedia content dataset exists for each scenario, which includes one or more of the following: video, images, sound and description of the scenarios.

3. Authoring Tool

In order to support the extensibility of the proposed system an authoring tool was created that provides a user friendly environment to the expert user in order to manipulate all the necessary data in order to create an educational scenario

This is a very powerful and extensible authoring tool for the creation of ancient Greek technology presentation scenarios to be simulated by the application. The tool provides: a) functionalities for the composition of 3D simulations, b) capability of connecting with the interactivity support applications (using either VR devices or gesture recognition), c) capability of parameterizing the intelligent software agents that simulate the functionality of parts (or the whole) of Ancient Greek mechanisms, d) capability of composing, processing and storing scenarios, e) integration of various scenarios and the possibility to save in a new scenario and f) capability of modifying haptic parameters of the objects.

The authoring tool allows the user to create and modify educational scenarios that can be imported in the APEIRO platform. The expected complexity of the scenario files, lead to the adoption of X3D standard as the scenario format, in order to be able to create more realistic applications. Information that cannot be supported directly from the X3D format is stored as a meta tag of the X3D scenario file. The tool allows the user to select virtual reality agents, associate them with objects in the scene, insert and modify their parameters and provide constrains to them. Each scenario may contain one or more steps. The objects may have different characteristics and associations in each step according to the scenario needs. The author can control the flow of a scenario using simple arithmetic rules (i.e. <, >, =) in order to trigger the next step in the scenario depending on the actions of the user.

4. Haptic rendering

In the context of the presented framework a novel haptic rendering scheme was developed that is integrated with the superquadric-based collision detector of [NTMS]. Its main aspects are presented in the following.

Consider that point P is detected to lie inside a superquadric as illustrated in Figure 1.

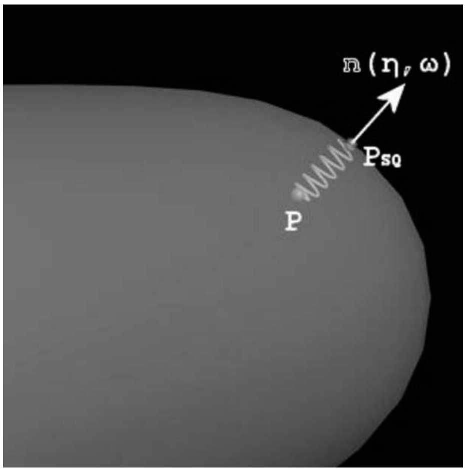

Figure 1: *Force feedback evaluation*

Let also S_{SQ}^{P} represent the distance of point P from the superquadric, which corresponds to point P_{SQ} on the superquadric surface, i.e. P_{SQ} is the projection of P onto the superquadric. The amplitude of the force fed onto the haptic devices is obtained using a simple spring model as illustrated in Figure 1. In particular:

$$\|\mathbf{F}\| = k \cdot S_{SQ}^{P}$$

where k is the stiffness of the spring. The rest length of the spring is set to zero so that it tends to bring point P onto the superquadric surface.

The direction of the force feedback is evaluated in most state-of-the-art approaches using the triangulated mesh of the objects. In particular, it is set to be perpendicular to the triangle, for which collision has detected. This approach is not only computationally intensive, but also results in non-realistic non-continuous forces at the surface element boundaries. In the present framework the already obtained superquadric approximation is used in order to rapidly evaluate the force direction. More precisely, the direction of the force feedback is set to be perpendicular to the superquadric surface at point P_{SQ}. In particular if:

$$r(\eta,\omega) = \begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} \alpha_1 \cos^{\varepsilon_1}\eta \cdot \cos^{\varepsilon_2}\omega \\ \alpha_2 \cos^{\varepsilon_1}\eta \cdot \sin^{\varepsilon_2}\omega \\ \alpha_3 \sin^{\varepsilon_1}\eta \end{bmatrix}, \quad \forall\eta \in \left[-\tfrac{\pi}{2}, \tfrac{\pi}{2}\right], \omega \in [-\pi, \pi)$$

is the parametric definition of the superquadric, the normal vector is defined at point $r(\eta,\omega)$ as the cross product of the tangent vectors along the coordinate curves.

$$\mathbf{n}(\eta,\omega) = \mathbf{t}_\eta(\eta,\omega) \times \mathbf{t}_\omega(\eta,\omega) = \\ = s(\eta,\omega) \begin{bmatrix} \frac{1}{a_1}\cos^{2-\varepsilon_1}\eta \cdot \cos^{2-\varepsilon_2}\omega \\ \frac{1}{a_2}\cos^{2-\varepsilon_1}\eta \cdot \sin^{2-\varepsilon_2}\omega \\ \frac{1}{a_3}\sin^{2-\varepsilon_1}\eta \end{bmatrix}$$

where

$$s(\eta,\omega) = -a_1 a_2 a_3 \varepsilon_1 \varepsilon_2 \sin^{\varepsilon_1 - 1}\eta \cdot \cos^{2\varepsilon_1 - 1}\eta \cdot \sin^{\varepsilon_2 - 1}\omega \cdot \cos^{\varepsilon_2 - 1}\omega$$

If several points lie inside the superquadric, the force fed to the haptic device is the average force of all penetrating points. Thus, the force feedback is obtained using the following equation.

$$\mathbf{F} = \frac{k}{N}\sum_{i=1}^{N} S_{SQ}^{P_i} \frac{\mathbf{n}(\eta_i,\omega_i)}{\|\mathbf{n}(\eta_i,\omega_i)\|}$$

The CyberGrasp provides feedback only along the perpendicular direction to the user's fingers as illustrated in Figure 2.

Thus, if $\mathbf{n}_f$ is the perpendicular direction to a finger, the effective force, $\mathbf{F}_{eff}$, fed onto the haptic device is:

$$\mathbf{F}_{eff} = \langle \mathbf{F}, \mathbf{n}_f \rangle \cdot \mathbf{n}_f$$

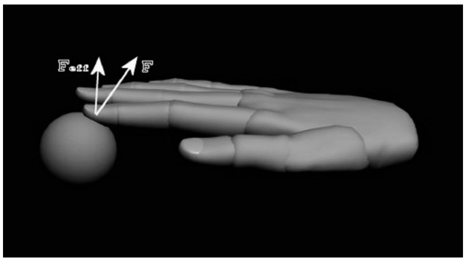

Figure 2: *Force feedback for the CyberGrasp*

5. Scenarios

5.1. Integration scenario: "The Ancient village".

The Ancient village shown in Figure 3 allows the user to select the desired scenario. The user can select the scenario by clicking on a sign with the mouse or by touching the sign with his/her index finger.

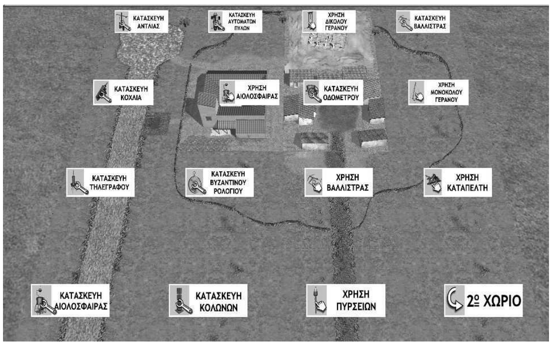

Figure 3: *The ancient village.*

Figure 4: *Archimedes screw pump.*

5.2. Pumps

Two pumps are simulated using the application the Archimedes screw pump and the Ktisivios pump. Archimedes screw pump: The Archimedes screw pump is shown in Figure 4.

The user can either assembly or use the pump. In this scenario the user has to grasp the handle of the pump and rotate it along the axis in order to pump water from the river. The level of the water in the pump depends on the angular speed of the handle. When the speed exceeds an upper limit water flows of the pump. The assembly scenario is a very simple scenario where the users can grasp the inner part of the pump and place it inside the outer cylinder in order to complete the task. This is used as a first step to get the user acquired with the application.

Ktisivios pump: The Ktisivios pump is shown in Figure 5. The assembly scenario is a simple scenario where the user has to put the inner parts of the pump inside the main body of the pump and then add the handle on the top.

5.3. Cranes

Single pulley crane: The single pulley crane is shown in Figure 6. The user has to pull a rock in order to construct a wall,

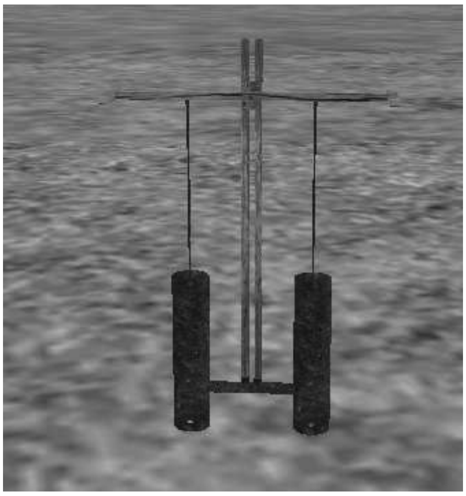

Figure 5: *Ktisivios pump.*

using the single pulley crane. To achieve this the user must grasp the handle that lies on the floor next to the crane and rotate it. In the right bottom corner the user can see a detail of the mechanism.

Double pulley crane: The double pulley crane is shown in Figure 7. The user has to pull a rock in order to construct a column, using the double pulley crane. The functionality of this scenario is similar to the single pulley crane. In the right bottom corner the user can see a detail of the mechanism.

5.4. War machines

Catapult: The catapult is shown in Figure 8. The user must grasp and pull the handle on the right side of the catapult in order to wind up the catapult mechanism. Then the user can throw a rock to destroy the wall by pulling the security trigger.

Crossbow: The crossbow is shown in Figure 9. The user must wind up the crossbow mechanism and the throw an arrow by pulling the security trigger.

5.5. Other Ancient works

Sphere of Aiolos: The sphere of Aiolos is shown in Figure 10. The user can either construct or use the mechanism. The assembly scenario is a very simple one. The user must put the sphere on the top of the mechanism. The use scenario the user lights a fire on the under the mechanism and the sphere starts rotating.

Odometer: The Odometer is shown in Figure 11. The user can either construct or use the odometer. The side of the odometer is transparent so that the user can view how it works. Moreover on the right bottom a secondary view exists so that the user can see measurement changes.

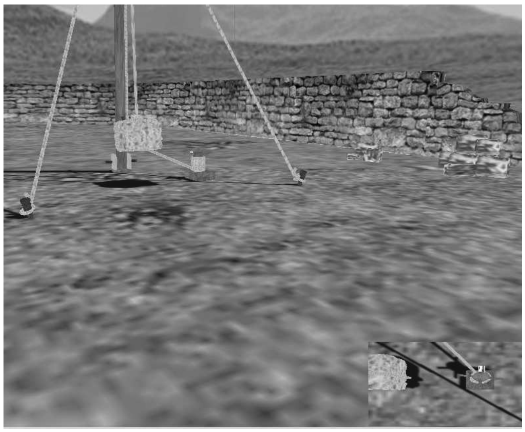

Figure 6: *Single pulley crane.*

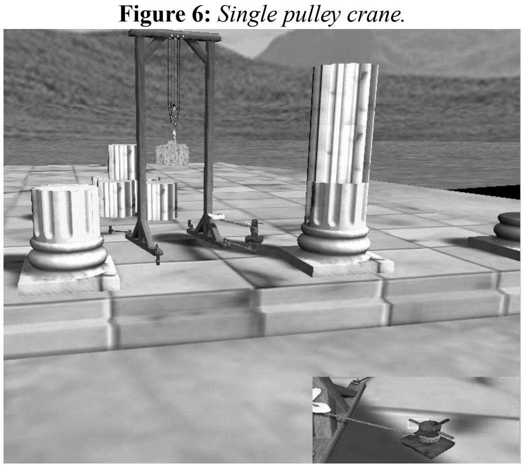

Figure 7: *Double pulley crane.*

6. System Evaluation

The evaluation was designed in order to help the qualitative / quantitative estimation of:

- The overall usability of the proposed technologies to non-specialized individuals.
- The extensibility and expansibility of the use of the proposed technologies into other application fields.
- The acceptance of the tools, the user-friendliness and the points where improvement is needed.
- The easy understanding of hardware.
- The added value produced by the introduction of new interaction techniques in the educational/entertainment procedure of Ancient Technologies simulation.
- The acceptance of the demonstration of the novel interaction technologies by the users.
- The educational value of the applications.

The system has been evaluated in tests with visitors of the Science Center and Technology Museum of Thessaloniki, in Greece (Figure 12).

Figure 12: *Users practicing the scenarios*

The test procedure consisted of two phases: In the first phase, the users where introduced to the system and they were asked to use it. During this phase, the users were asked questions that focused on usability issues and on their interest in participating to each test. The questionnaire used contained also questions to the test observers, e.g. if the user performed the task correctly, how long did it take him/her to perform the task, etc. The second phase was carried out immediately after the tests, using an after tests questionnaire. Specifically, the users where questioned after finishing all the tests about general issues such as: (a) the benefits and limitations that they foresee on this technology, (b) the usability of the system in a museum environment, (c) other tests and applications or technologies that they would like to experiment with the APEIRO application, if any, etc.

The system evaluation results have shown that users consider it very innovative and satisfactory in terms of providing a presentation environment in a real museum. The percentage of the satisfied students was reported to be more than 90%.

7. Conclusions

The described application focuses on the presentation and dissemination of Ancient Greek Technologies in order to produce awareness to the major part of the young population of the country. Specifically, the analysis of the basic characteristics of Ancient Greek Technologies are presented using virtual reality environments, so that they can become easy perceptible even in those that are not familiar with the technology. In this way, the platform contributes substantially in the general effort to promote the knowledge on Ancient Technologies. This research work is expected to contribute significantly in the general effort of sensitization and briefing of the public, regarding the Ancient Greek Population.

The system architecture provides a platform that enables the system to achieve a number of technological and pedagogical targets.

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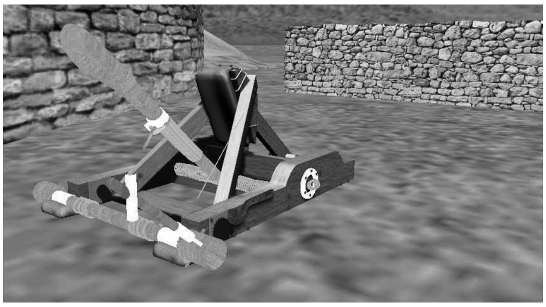

Figure 8: *Catapult.*

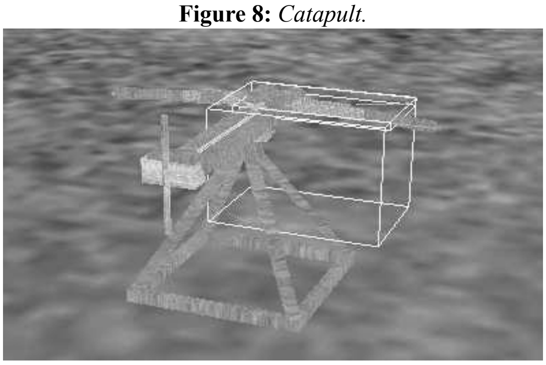

Figure 9: *Crossbow.*

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Figure 10: *Sphere of Aiolos.*

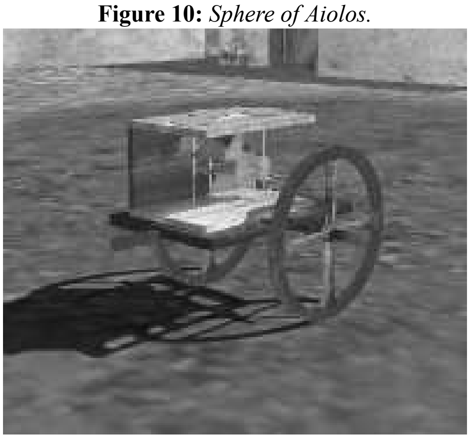

Figure 11: *Odometer mechanism.*

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Project Presentations

Digital Documentation of Cultural Heritage Objects using hybrid recording techniques

Boochs F.[1], Heinz G.[2], Huxhagen U.[1], Müller H.[1]

[1] i3mainz, Institute for Spatial Information and Surveying Technology, University of Applied Sciences Mainz, Germany
[2] Roman Germanic Central Museum Mainz, Germany

Abstract

Using hybrid recording techniques is a well established procedure in the documentation of cultural heritage objects. Due to changes in the technological process, to choose the appropriate techniques and systems may be difficult and has to be adopted for every single project. The potential of new technologies sometimes tends to be overestimated whereas the need for especially adopted usage and processing may be underestimated.
In combination with the needs of the appropriate and concerned historians or humanists the special requirements for the investigation and documentation of the objects have to be checked.
The paper shows concepts and present results for several example sites in Germany e.g. the documentation of Porta Nigra, a roman city gate in Trier, and the Herkules-Monument in Kassel. Used techniques in the projects are 3D laser scanning, high resolution textured-light scanning, total stations, digital and analytical photogrammetry and high resolution digital surface images - all of them in combination with the conventional manual inspection and evaluation of the objects themselves by the particular experts from other disciplines.

3D-Scanning, Archaeology, Cultural Heritage, Documentation, Hybrid Sensor, Laser Scanning, Photogrammetry, Visualisation,

1. Introduction

For the documentation of extended or complex cultural heritage objects usually different aspects have to be fulfilled in data recording. One of them is the measurement of geometry data, another is the recording of image data to describe the surface and texture of the object. Due to different technologies and limitations of available hardware these data sets are often independent from each other and not freely combinable. Additionally the customers needs in certain aspects of the data sets differ in such a way, that a full integration of the data sets is not required or desired in all projects. For architectural projects geometry information is often sufficient for particular structures like e.g. edges or joints of blocks to generate plans of sections. A complete 3D surface model is often not needed, whereas high resolution texture data may be absolutely necessary.

Taking stereo images with non-metric consumer digital equipment allows to record situations with high resolution for further inspection in three dimensions with low additional operation expenditure. 3D-viewers and tools supporting the non-technician operators in orientation and basic measurement functionality can extend the usability of this data source widely.

Currently available technologies often still have limitations in hybrid sensor hardware and/or processing software for the generation of hybrid data sets. These systems cannot be optimum solutions for all problems, but adopted use and processing is essential.

2. Motivation

The documentation of cultural heritage objects in many cases comprises a more or less large number of challenging tasks. First of all, a detailed and carefully elaborated requirement specification is a must to achieve a sufficient quality of the results. Quality standards have to be formulated, which are needed as the base for the selection of feasible equipment and for the definition of well suited data interpretation procedures, as well. The specification which is of utmost importance for the subsequent steps typically has to be developed in close co-operation between persons with different professional background. Persons who are familiar with all kind of relevant state-of-the-art technology jointly have to work together with persons who are able to formulate the requirements from the users point of view. The requirement specification task is far from being trivial. Overestimation as well as underestimation of the potential of, particularly, new technologies has to be avoided, the same holds for the trend to misstate the needed quality of the results, the combination of different technologies has to be designed in an appropriate way, financial and human resource factors have to be observed, and so forth.

In this context the paper particularly discusses the use of hybrid recording techniques for the documentation of cultural heritage objects. Credit is given to the progress of technology as well as to the selection of feasible measuring equipment depending on the requirements of specific documentation tasks. Special attention is given to the use of high resolution images, particularly in the context of digital stereo models within photogrammetric processing procedures. This technology in many cases is a cost effective alternative as compared to complete 3D model generation of complex shaped objects.

Best practice case studies are dealing with several locations in Germany like the city of Trier with its Porta Nigra, a roman city gate, and the city of Kassel with its Herkules monument. The described methods cover the wide field of many techniques which are nowadays available, like 3D laser scanning, high resolution textured-light scanning, use of total stations, application of digital and analytical photogrammetric methods and high resolution digital surface image processing - all of them in combination with the conventional manual inspection and evaluation methods of the objects themselves.

3. Technologies

The catchwords surrounding the term of metrology at the preservation of historical monuments can be described by manual inspection, tacheometry, 3D laser scanning and stereo photogrammetry. With regard to the requirements of an expert for the preservation of monuments, but being not familiar with the field of metrology, the most common demands are aiming at a simplification of the measuring techniques. The millions of 3D laser scanner points of a recorded object are often described by an overcharge of information. Thereby, it has to be paid attention, that the desired simplification of data capturing and proceeding does not lead to a loss of critical object information and an apparent uselessness of the data as well as the applied metrology.

Nevertheless, at the view of stereo photogrammetric proceeding, a simplified strategy of data ascertainment and proceeding is thinkable and often demanded from the operator's view. Helpful in the task of recording stereo models by non-experts could be the development of an object oriented observation and capturing instruction followed by an analytic proceeding at digital workstations with the help of special developed software tools.

Even though, in case of possible error sources at measurements and a demanded enhanced resolution of the object as well as an increased accuracy in geometrical and morphological ways, geodetic know-how is indispensable.

4. Geometric and visual Documentation of the Herkules Monument in Kassel

4.1 Projects purpose

The Herkules Monument, located at the Wilhelmshöhe in Kassel/Germany, was built in the early years of the 18th century in the care of earl Karl von Hessen-Kassel following the design of master builder Francesco Guerniero.

The memorials eye-catcher is the more than 8 meters high copper statue of the antique hero Herkules, reposing on a pyramid on top of the octagon shaped castle. The basalt-tuff, which was used as building material, was descended from regional quarries and has suffered from weather conditions through out the years. Owing to this, a basic remediation was decided by the responsible administration department.

Figure 1: *View of the Herkules monument*

To find suitable means of documentation for the different parts of the building, an exemplarily axis of the monument was picked out to get a formative impression of proceeding in view of the whole Herkules. These investigations are building the base for extensive analysis of the monument and the call for proposals for the monument's restoration. The i3mainz, the Institute for Spatial Information and Surveying Technology of the University of Applied Sciences at Mainz, is carrying out the task of the metrological documentation of the instancing sample.

4.2 Initial situation

The i3mainz has worked several days on site and a large bandwidth of measuring techniques have been used. To get a solid documentation of the building in geometrical and image based ways, analogue and digital close-range photogrammetry, tacheometer measurements as well as 3D laser scanning have been applied.

4.3 Geodetic observations

Whenever geometrical contexts needs to be explained, geodetic networks are building a solid groundwork of an adjusted coordinate system. Even if high precision is not the point of view in case of the projects purpose, it is still of importance that all measurements and observations can take place in the same environment. To achieve this aim, direction observations and distance measurements to signalised an natural marked points were done by tacheometers. With regard to the clients claim and the following evaluation of the achieved precision, those measurements were done with over determination where at least each point was constituted by three rays. On the whole, a precision of +/- 3 mm (1 sigma) was reached for all datum points.

Figure 2: *Geodetic observations at the monument*

Signalising for the different methods mentioned before is the arising data and the consequential workflow. Where pre-selected single points are associated with total station measurements, close-range photogrammetry and 3D laser scanning come up with lots more of information of the recorded object. Besides a lot of 3D points, texture and intensity values are describing the recorded object more likely.

This additional information has to be carved out and can be orientated to the customers questions. In case of the Herkules project, the formulated requirement by the client has been the geometric documentation. Other important tasks have been the mapping of defects, the determination of mass for remediation purposes and the presentation of the possibilities for visualisation of the collected point data and the images. Still, the project's working environment demanded for a presentation of the evaluated data in 2D and as a matter of fact, a lossless reduction of the data's third dimension had to be done.

4.4 Stereo photogrammetry

Figure 3: *Photogrammetric work at the monument*

In case of the Herkules monument, on hand, the most common proceeding of close-range stereo photogrammetry has been the digitalisation of joints, for which metric analogue medium format images have been building the data basis for the stereoscopy. Especially with regards to the monument's domes, the captured stereo models were utilised in analytic plotters and after the step of digitalisation, the high resolution images were interpreted in digital stereo tools, too. Due to good accessibility of the wall areas and the floor space, other measuring and documentation techniques got into action. On those parts it was worked conventionally by manual inspection and evaluation at the objects surface.

Only natural and not signalised points were used as photogrammetric control points. They were coordinated by tacheometer measurements, too.

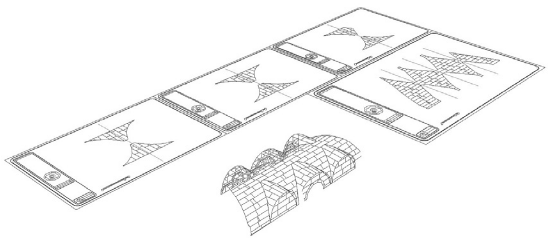

Figure 4: *Collage of a 3D CAD model and the associated 2D joint graphics*

The maps of the curved domes (of the monument) are presented in 2D. To achieve a lossless graphical representation, a cylindrically projection to the plane was done and as a result the displayed joints appear with effective length. The plans are used for mapping the defects of the building's material by experts and are the base for length evaluation of joints, which was an important task in the course of restoration.

Another aspect has been the photographic documentation of some interesting parts of the monument. The images were made in view of stereo photogrammetric means and shall serve for evaluation purposes on the part of historians and architects. With the help of the middle format images and a suitable stereoscopes, those gainful observations can be done in a common and easy way.

4.5 3D laser scanning

Another part of the project's work is focussed on 3D laser scanning. This technique was brought into the project to show the possible abilities and it was applied to a few grottos and facades. The clients questions around this measuring technique have been of same nature as in case of the applied stereo photogrammetry – finding an adopted way of generating 2D plots of the building's joints for evaluation purposes.

The digitalisation of some interesting parts of the monument was done. This was made possible by treating the point cloud data, which was including intensity values, in usual CAD systems. The digitalisation depends on many object and observation parameters and the evaluation is mainly relied on intensity values which are resulting of surface colour and structure. In case of the monument's facades, the available third dimension of the laser scanner points eclipsed by increasing the model's density. A proper result could only be achieved by evaluating the intensity values of the joints. As the case arises, the effect of outliers and noise of measurements still is an important issue, which has to be reviewed and estimated correctly.

Figure 5: *Basic 3D surface model of a grotto*

In addition, surface modelling of the laser scanner data was done and the possibilities of registration and point cloud treatment with regard to outliers and noise were shown to the client The modelled closed surfaces can serve for mass and inspection purposes but do not achieve the projects main goal. Never the less, the created models are intended to be applied at public exhibitions and presentations due to the projects public agenda.

4.6 Hybrid solutions

With the advantages of both the stereo photogrammetry and 3D laser scanning the combination is supposable and surely productive. The arrangement of high resolution images and digital elevation models was performed in the course of the project and was commented feasible for evaluation and public relation.

Figure 6: *Image textured 3D facade model*

Nevertheless, the creation of hybrid data sets does not provide a seamless workflow. Still noisy and outlying measurements occur moreover geometric and radiometric improvements have to be done which requires the use of several software tools. This aggravation complicates the data handling and builds a great barrier for non-experts. To achieve this, the choice was to present the results in common viewers and data formats like DXF and VRML.

5. The Porta Nigra / Trier

Figure 7: *Overview of the Porta Nigra, World Heritage Site at Trier/Germany*

Another motivation of detailed analysis can be found at the Porta Nigra at Trier/Germany where strictly defined, partially commercial aims of civil works do not stand in foreground. In fact, the allocation of digital data for the use of historians and architects for means of construction research is taking place and it was found out, that a determined object documentation can only be achieved by using several, hybrid used measuring techniques.

Figure 8: *Hybrid data model of parts of the Porta Nigra – 3D laser scanning combined with high resolution images*

The Roman city gate has obtained an enormous variety of construction phases from its surely inducing history where a lot of conversions took place. From the original use as a roman city gate, to the transformation to a mediaeval church, over to the Napoleonic deprivation of building materials to the point of today's monument, a lot of surveys can be done. Accordingly, a large spectrum of measuring techniques were used so that geodetic measurements, 3D laser scanning, digital stereo photogrammetry, structured light based scanning and manual inspections on site were executed.

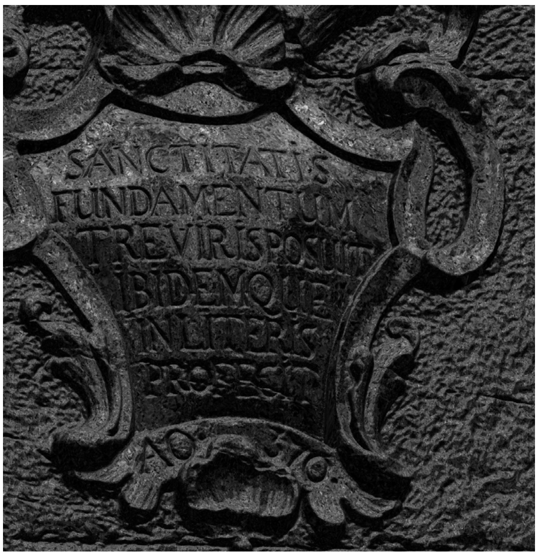

Figure 9: *High resolution 3D surface model of a relief*

The measurement's results are intended to be presented with the help of suitable and easy to use software tools for further processing by experts. Therefore, the dialog between the involved faculties and the surveying department as a data provider is playing an important role within the project since the interpretation of the construction phases and the mapping of mortar and joint defects can only be done by colleagues of other professions. As a result, suitable software tools in view of the needs of the involved departments mentioned before are specified and developed at which a defined workflow particularly with regard to the Porta Nigra is intending the object's studies.

6. Conclusions

The main concern of the paper was to describe how to combine different measuring techniques in order to guarantee maximum efficiency in the appropriate process of cultural heritage object recording. The recording tasks were performed by using currently available state-of-the-art technology while observing carefully the specific properties of all methods in use. Technology may, and most probably will change in future in the same way as it did in the past. In the same way it can be expected that the tasks of appropriate method selection will persist in the foreseeable future, as well.

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An Introduction to the London Charter

Richard Beacham[1] , Hugh Denard[1] and Franco Niccolucci[2]

[1] 1King's College, London, UK
[2]PIN, Prato, Italy

Abstract

While 3-dimensional visualisation methods are now employed in a wide range of humanities contexts to assist in the research, communication and preservation of cultural heritage, it is increasingly recognized that, to ensure that such work is intellectually and technically rigorous, and for its potential to be realised, there is a need both to establish standards responsive to the particular properties of 3D visualisation, and to identify those that it should share with other methods. Numerous articles, documents, including the AHDS Guides to Good Practice for CAD (2003) and for Virtual Reality (2003) and initiatives, including the Virtual Archaeology Special Interest Group (VASIG) and the Cultural Virtual Reality Organisation (CVRO) have underlined the importance of ensuring that 3D visualisation methods are applied with scholarly rigour, and that the outcomes of visualisation-inclusive research should accurately convey to users the status of the knowledge that they represent. There remains, however, a significant gap between theory and practice. Last February, therefore, as part of an AHRC-funded project, King's Visualisation Lab, King's College London, convened a Symposium, jointly sponsored by the AHRC ICT Methods Network and the EU FP6 Network of Excellence, EPOCH, during which over 50 international delegates debated approaches to the issue of "transparency". A smaller expert group then debated a discussion document on which the first draft of The London Charter for the use of 3-dimensional visualisation in the research and communication of cultural heritage was subsequently based. "Cultural heritage" domains here encompass museums, art galleries, heritage sites, interpretative centres, cultural heritage research institutes, arts and humanities subjects within higher education institutions, the broader educational sector, and tourism. It is hoped that the Charter, currently in its first draft and being discussed by an international panel of experts, may be adopted as an EU and international benchmark. The Charter aims to define the fundamental objectives and principles of the use of 3D visualisation methods in relation to intellectual integrity, reliability, transparency, documentation, standards, sustainability and access. It does not aim to prescribe specific aims or methods, but rather to establish those broad principles for the use, in research and communication of cultural heritage, of 3D visualisation upon which the intellectual integrity of such methods and outcomes depend. The Charter attempts to establish principles that are sufficiently focussed to have an impact, but sufficiently abstract to remain current as methods and technologies evolve. Therefore, up-to-date guideline documents with specific recommendations about, e.g. technologies, standards, and methodologies, will be needed at subject community level.

Categories and Subject Descriptors (according to ACM CCS): H.3.7 [Standards]:

1. Introduction

The London Charter for the use of 3-dimensional visualisation in the research and communication of cultural heritage seeks to establish what is required for 3D visualisation to be, and to be seen to be, as intellectually rigorous and robust as any other research method.

The initiative has to be seen in the context of what has become a constant burning issue in 3D visualisation applications to cultural heritage: "transparency".

Transparency is crucial if such applications are to mature as a research method and acquire widespread acceptance within subject communities. In particular, it must be possible for those communities to evaluate the choice of a given visualisation method, and how it has been applied in a particular case without having to rely exclusively on the "authority claims" of the author. This applies not only to Cultural Heritage, but to all those disciplines where 3D visualisation rightfully belongs as a methodology.

2. The Historical Background

An essay published some years ago [FNRB02] summarized some of the most important open questions concerning VR applications in the archaeological domain. In particular, it dealt with the most challenging one, the credibility and validity of reconstruction models of objects, monuments, sites or landscapes partially or totally modified or destroyed, and virtually reconstructed based on archaeological interpretation. The essay originated from the debate developed during a symposium taking place at the end of 2000, and summarized a number of issues already represented in publications within the scientific community.

This discussion had started reasonably early among scholars. One of the first to analyze critically the risks of computer visualisation was Nick Ryan, who published two papers [Rya96] and [RR96] some ten year ago, in which he pointed out that computer reconstructions need to take into account alternative possibilities and the varying reliability of the components of a 3D model. The publication [BFS00] of *Virtual Reality in Archaeology* (2000) following the Virtual Reality Festival at CAA98 was more a celebration of results than a critical appraisal of them, although some authors as Juan Antonio Barcelò, in [Bar00], offer interesting reflections. By then an awareness of the necessity of critically analyzing the impact of computer reconstructions was rapidly spreading in the scientific community (e.g. [Nic99], [GG00]). It was not just a matter of academic debate, because it also involved people active in operations, such as Maria Roussou, then director of the heritage department at FHW and in charge of many reconstructions of Greek cities in Asia Minor. Maria organized and chaired in those years several symposia (like Medi@terra, 1999, and VAST2001) where such issues were debated. Her most recent work [RD03] takes into account visualisation issues pertaining to heritage reconstructions, suggesting that hyperrealism is not always the best solution.

In the above cited paper by Frisher, Niccolucci, Ryan and Barcelò [FNRB02] it was suggested that the interpretive/reconstructive process of model creation consists of three steps, as in the philological analysis of a text: verify sources; analyze their reliability; and interpret/integrate data with the missing parts. The final result must show the traces of this philological work, using signs, perhaps still to be defined in 3D modelling, to denote elements corresponding to interpolations, additions and conjectures.

Nowadays, determining the credibility of a 3D reconstruction and conveying it to the user has definitely become a scientific question and many scholars are aware of its importance. However, there is still much work to do to define how this can be achieved.

Credibility is important not only for the academy. For example, in the Technical Description of the activities of EPOCH, the EU-funded project on Intelligent Heritage, it is stated:

> Validity*: there has been some concern in the heritage community about the validation of computer reconstructions [. . .]* Reliability *can people rely on what is shown by visual explanations of heritage? How can they distinguish between scientifically valid communication and fantastic, videogame display? [. . .] important issues as validation and scientific annotation of reconstruction models." This is perhaps the first time that such questions are being considered in a EU-funded, technological project. Similar principles are stated in the German project that reconstructed Troy "TroiaVR", created by the University of Tübingen and by ART+COM [JKS03]. Authors define the methodology of virtual reconstructions as "based on the same theoretical and methodological principles as an interpretation of archaeological texts". They state that the "inherent limits of archaeology become much more apparent in a visualisation than in a text". Their solution: "To emphasize the difference between actually excavated remains and free reconstructions, all reconstructions not based on almost complete ground plans can be switched on and off [. . .] plans and images shown on the interface screen [. . .] allow for comparison between excavated remains and reconstructions.*

Although some methods have been proposed to quantify uncertainty [NH06], or at least to communicate it in a meaningful way, and visual metaphors are available (see for instance [ZCG05] on techniques for the visualisation of uncertainty), guidelines for documenting how such uncertainty arises and how the modeller devises solutions to overcome it and arrive at a cohesive proposal for a complete model, are still missing. This was recently discussed at a workshop at VAST2005 and during a subsequent symposium at King's College, London, hosted by King's Visualisation Lab (KVL), King's College, University of London.

In July 2005, KVL commenced a project called "Making Space" to investigate "a methodology for tracking and documenting the cognitive process in 3-dimensional visualisation-based research," funded under the ICT Strategy Projects scheme of the Arts and Humanities Research Council (UK), and led by Richard Beacham and Hugh Denard. In the course of this project, Drew Baker proposed the term "Paradata" to denote the intellectual capital generated during research, and highlighted that a great deal of the information essential for the understanding and evaluation of 3D visualisation methods and outcomes is currently being lost.

The project subsequently convened a Symposium and Expert Seminar at the British Academy, London and the Centre for Computing in the Humanities, King's College London, from 23-5 February 2006, jointly sponsored by the AHRC ICT Methods Network and EPOCH. During the two-day symposium, 50 delegates debated approaches to the issue of transparency, and on the third day, a smaller group of experts chaired by Franco Niccolucci, debated which issues and concerns should be addressed in the first draft London Charter, which was subsequently drawn up and circulated by Hugh Denard..

The Charter initiative builds on the initiatives of several groupings, such as the CAA Virtual Archaeology Special Interest Group (VASIG), which first met in Sweden 2001; and the Cultural Virtual Reality Organisation (CVRO), launched at VAST in November 2000 with the above-mentioned paper [FNRB02]. Although now inactive, CVRO was important for having established principles which have deeply influenced important projects on both sides of the Atlantic Ocean, including EPOCH. In addition, the recommendations of the AHDS Guides for "Creating and Using Virtual Reality" [FR03] and for CAD [EFHR03], both of which appeared in 2003, have been drawn upon in the Charter initiative, which aims both to establish principles applicable across a number of domains, and to foster the development of subject-specific implementation guidelines. This initiative is now offered for the attention of the scientific community.

3. The Scope of the London Charter

The London Charter is not discipline specific; it aims to serve the whole range of Arts, Humanities and Cultural Heritage disciplines using 3D visualisation for research and dissemination.

The Draft adopts the format and style of the ICOMOS ENAME Charter to provide a ready-to-hand language, but also to facilitate ease of recognition within cultural heritage contexts.

The Charter adopts a wide definition of the term "cultural heritage",

> *encompassing all domains of human activity that are concerned with the understanding and communication of the material and intellectual culture. Such domains include, but are not limited to, museums, art galleries, heritage sites, interpretative centres, cultural heritage research institutes, arts and humanities subjects within higher education institutions, the broader educational sector, and tourism.*

It is hoped that the Charter will acquire sufficient standing to be adopted as an EU and international benchmark and guideline.

The Charter initiative does not aim to propose radical new proposals, but rather to consolidate major principles that have been published by numerous authors, but not yet fully taken up by the community. This is why the idea of a "Charter", rather than another article, seems appropriate, and why it is important that it should emerge out of, and evolve through, discussions within its target communities.

The term "Charter" is usually reserved for documents enouncing principles of very wide generality, as the well-known Venice Charter on conservation and restoration and the Florence Charter on historic gardens and landscape [CHA]; or to documents less well-known than the above, and not yet adopted as Charters by international institutions as ICOMOS, but nonetheless of comparable relevance and importance to the Ename Charter on interpretation [ENA]. The London Charter by contrast, which concerns a research and communication method, may as yet appear rather limited and circumscribed, and is presently perceived as having less impact on cultural heritage than the ones quoted above. However, it is our opinion that what we presently propose as methodological principles will acquire an increasingly greater importance in a future in which digital communication and visualisation technologies will pervade every aspect of culture.

Next, the most important aspects of the London Charter will be summarized and commented upon.

The current full text of the Charter, which is undergoing a review process refining its content and formulation, is available as a leaflet on request, and may be downloaded from the Charter web site [LC]. Comments and contributions are welcome.

4. Principles of the Charter

More fundamental issues underlie what is frequently the presenting problem of transparency; tackling these at the level of principles, as opposed to on a purely pragmatic level, requires us to think through disciplinary contexts, and how we formulate and assess the aims, methods and sources of 3D visualisation-inclusive research and communication operations. Consequently, these form the subject of the first three principles in the first draft of the Charter.

4.1. Subject Communities (i.e. disciplinary contexts)

While the London Charter aspires to be "valid across all domains in which 3D visualisation can be applied to cultural heritage", nevertheless, different subject areas differ very greatly in their understandings of what research is, and therefore what research methods such as 3D visualisation ought to achieve. This imposes strict limits upon the level of detail a cross-subject document can entertain. The draft consequently recommends that, while "subject areas should [. . .] adopt and build upon the principles established by this Charter," (Principle 1) they should also "develop more detailed principles, standards, recommendations and guidelines to ensure that use of 3D visualisation coheres with the aims, objectives and methods of their domain." (Section 1.1)

4.2. Ensure Cohesion between Aims and Methods

The draft recognises that "3D visualisation methods and outcomes can be used to address a wide range of research and communication aims" (Principle 2). It appeared also necessary to establish that it is only one method among many; that "it should not be assumed that 3D visualisation is the most appropriate method of addressing *all* research or communication aims." (Section 2.1) This is to ensure that, in serious contexts, it is not used simply because it is available or to impress; the draft therefore proposes that "3D visualisation should not normally be used when other methods would be more appropriate or effective."

Another exigency consisted in ensuring that the full range of 3D visualisation options should be considered: that no single approach (photo-realism or real-time navigation, for instance) should be considered a "default" expectation, but rather that each visualisation technique "should be carefully evaluated to identify which is the most likely to address each given aim." (Section 2.3)

4.3. The nature and integrity of Research Sources

This arose, in particular, out of a presentation at the London Symposium by Daniel Pletinckx, in which he demonstrated how important and complex is the task of rigorously assessing the research sources we use, in particular of paying attention to the kinds of aesthetic and ideological factors that may condition our visual sources.

The draft proposes a definition of "sources" as "all information, digital and non-digital, considered during, or directly influencing, the creation of the 3D visualisation outcomes." (Section 3.1) and recommends that "in order to ensure the intellectual integrity of 3D visualisation methods and outcomes, relevant sources should be identified and evaluated in a structured way."

4.4. Transparency Requirements

The draft recommends that "sufficient information should be provided to allow 3D visualisation methods and outcomes to be understood and evaluated appropriately in relation to the contexts in which they are used and disseminated." (Principle 4)

This section on "transparency requirements" goes on to propose that "it should be made clear what kind and status of information the 3D visualisation represents. The nature and degree of factual uncertainty of an hypothetical reconstruction, for instance, should be communicated." (Section 4.1)

It also recognises that "the type and quantity of transparency information will vary depending on the aims and type of 3D visualisation method and outcome being used, as well as the type and level of knowledge, understanding and expectations of its anticipated users. Transparency information requirements may therefore differ from project to project, or at different phases within a project." (Section 4.2)

The transparency requirements of 3D visualisation projects may differ from those of other projects because of "the high occurrence of dependency relations within 3D models" which means that, if the process and its outcomes are to be evaluated by those outside the project, "it may be necessary to disseminate documentation of the interpretative decisions made in the course of a 3D visualisation process." (Section 4.5)

A dependency relationship is defined as a dependent relationship between the properties of elements within 3D models, such that a change in one property will necessitate change in the dependent properties. (For instance, a change in the height of a door will necessitate a corresponding change in the height of the doorframe.)

A further point that came out of the Symposium was that "the level of documentation required regarding 3D visualisation when used as a research method will vary depending on how widely and well that method is understood within the relevant communities; novel methods will require more explanation." (Section 4.6)

4.5. Documentation

"The process and outcomes of 3D visualisation creation should be sufficiently documented to enable the creation of accurate transparency records, potential reuse of the research conducted and its outcomes in new contexts, enhanced resource discovery and accessibility, and to promote understanding beyond the original subject community." (Principle 5)

Indeed, while the provision of adequate documentation about research sources, methods and interpretative decisions is at the core of solving the "transparency" problem, it is also, in practice, among the most intractable challenges.

Whereas conventional research and dissemination methods operate, by definition, within an economy of established and understood approaches which have typically evolved through long histories of explicit methodological and theoretical debate, 3d visualisation methods and outcomes lack such a history, or economy, and must more explicitly discuss the rationale for their methods. An additional layer of complexity arises in that 3d visualisation methods are often used in interdisciplinary contexts which, again, by definition, lack a common episteme or set of conventions that generally characterise subject communities.

The draft therefore notes that the frequently interdisciplinary nature of 3d visualisation requires additional consideration in which systematic documentation can play a valuable role "by articulating the relevant unspoken assumptions and different lexica of the different subject communities engaged in the common visualisation process."

4.6. Standards

Work on standards needs still to be done and although we acknowledge their importance this is still a less developed part of the Charter. Relations with existing standards need to be fully explored when declining the charter in individual domains. For instance, when developing Charter implementation guides for Cultural Heritage domains, it will be necessary to explore how the goals of the Charter may benefit from the adoption of documentation standards as CIDOC-CRM [CRM].

It is likely that it will be necessary to develop appropriate ontologies at subject area level. This task will be facilitated as we improve our understanding of *what* we are doing when we use 3D visualisation methods and outcomes, and *how* we are doing it. Consequently, the current draft simply proposes that: "appropriate standards and ontologies should be identified, at subject community level, systematically to document 3D visualisation methods and outcomes to be documented, to enable optimum inter- and intra-subject and domain interoperability and comparability." (Section 6)

4.7. Sustainability

The draft notes that "3D visualisation outcomes pertaining to cultural heritage [...] constitute, in themselves, a growing part of our intellectual, social, economic and cultural heritage" and that "if this heritage is not to be squandered, strategies to ensure its long-term sustainability should be planned and implemented." It also points out that "a partial, 2-dimensional record of a 3D visualisation output should be preferred to an absence of record." (Section 7)

In the next draft of the Charter it has been proposed to lay more emphasis on digital preservation, with the understanding that preservation of digital content is included in many specialized research agendas; research in this field will determine optimal strategies for preserving 3D digital content as well.

In other words, the importance of adopting preservation strategies for 3D content is acknowledged, by monitoring the results obtained from elsewhere, and without committing now to any one in particular.

4.8. Access

During the London Symposium, David Robey, Director of the AHRC's ICT Programme, underlined the importance of continuing to make the case for technologically expensive work in the Arts and Humanities — to explain its value, and value for money — and also to consider that work in cultural heritage (broadly defined) is, for the most part, publicly funded, and many 3D visualisation outputs have a high re-purposability, as it is incumbent upon us to consider whether our work might have a value beyond our own immediate uses. Hence, draft Principle 8 states that "consideration should be given to the ways in which the outcomes of 3D visualisation work could contribute to the wider study, understanding, interpretation and management of cultural heritage assets."

3D visualisation clearly has important roles to play in "enhancing access to cultural heritage [that is] not otherwise accessible for health and safety, disability, economic, political, or environmental reasons, or because the object of the visualisation is lost, endangered, dispersed, or has been restored or reconstructed." (Section 8.2)

The draft recognises that "3D visualisation permits types and degrees of access not otherwise possible, including the study of change over time, magnification, modification, virtual object manipulation, multi-layered embedded data and information, instantaneous global distribution, with consequent expanded curatorial possibilities", (Section 8.3) but it is worth noting that there may also be potential *economic* benefits to both the research/education and tourism/interpretation sectors from increased communication and collaboration with each other.

5. Charter Implementation

The Charter is designed to establish principles that are sufficiently focussed that they have an impact, but sufficiently abstract that they remain current as methods and technologies evolve.

While the Charter operates on the level of principles, therefore, more specific recommendations (e.g. about technologies, standards and methods), while they are needed, belong to a different kind of document: Charter Implementation Guides.

The importance of subject perspective is enshrined as a principle in the Charter (Section 1.1):

> *Specialist subject communities will need to develop more detailed principles, standards, recommendations and guidelines to ensure that use of 3d visualisation coheres with the aims, objectives and methods of their domain.*

Implementation guides might help, for example, to develop consensus around visual conventions and technical approaches for different methods.

We hope that the Charter initiative will provide the impetus for a series of guides, to be developed within different subject areas, as well as a series of case-studies designed to test the implementation of "Charter compliancy".

The case-study process has already begun. At the Expert

Seminar, it was proposed to conduct a number of case studies to see what kind of paradata should be recorded in 3D visualisation projects, and how.

It has been suggested that, in order to do this, we may first need systematically to observe, how we reflect upon, choose, and communicate ('traditional') research methods. This would help us to build up a profile of what kinds of methodological and processual information it is considered necessary to document for other research methods, and to base our recommendations on comparability with established academic standards. In addition to benefiting from their example, it could enable us to make persuasive arguments to 'traditional' scholars about the validity of 3D visualisation methods in terms that they would more readily understand.

A number of researchers has volunteered to develop case studies; additional ones would be of course welcome.

6. Future work

It is envisaged that as the London Charter is revised in response to consultation within the various subject communities for which it has direct relevance, it will both stimulate debate on key issues and, in its various versions, may progressively come to act as a *de facto* standard.

As 3D Visualisation refers to a widely-used method, rather than a domain, there is at present no single organisation that can coordinate structured consultation and redrafting among key stakeholders. The Charter process will therefore be Chaired by Franco Niccolucci (VAST Lab PIN and EPOCH) and Richard Beacham (KVL), while Dr. Anna Bentkowska-Kafel and Julie Tolmie, Research Fellow and Network Development Officer (respectively) for the JISC 3D Visualisation in the Arts and Humanities Network (3D VISA) will act as "Secretariat" under the direction of Hugh Denard.

A website, www.londoncharter.org has been launched, carrying the current draft, the history of the initiative, and an explanation of the consultation process, and a list of consultation events. Other recommendations are welcome.

In particular, we need to identify how to set in motion a high-profile consultation exercise among the Charter's target communities. Without doubt, EPOCH and other such organisations will have a pivotal role here.

As far as the Cultural Heritage domain is concerned, involvement of ICOMOS is paramount. On this regard, contacts with the ICIP (ICOMOS scientific Committee for Interpretation and Presentation) have already been established. It is likely that the London Charter declination relevant for CH will be presented as a set of technical guidelines aiding the implementation of the principles of the Ename Charter that pertain to 3D visualisation techniques. However, such a low-profile starting point may eventually grow into a major contribution as the visualisation technology is acknowledged by heritage scholars and professionals for the importance that it is increasingly gaining in culture as in many other fields of human life.

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Content-based Indexing and Retrieval of Cultural Heritage Data: an Integrated Approach to Documentation with Application to the EROS Database

E. Paquet[1,3] C. Lahanier[2†] D. Pitzalis[2] G. Aitken[2] S. Peters[1] and H. L. Viktor[3]

[1]Visual Information Technology, National Research Council, Ottawa, Canada
[2]Centre de Recherche et de Restauration des Musées de France, Paris, France
[3]School of Engineering and Information Technology, University of Ottawa, Ottawa, Canada

Abstract

Over the last few decades, Cultural Heritage documentation has been characterized by the massive use of digital media. Recently, the use of three-dimensional scanner technologies has provided us with the opportunity to obtain an unambiguous body of information characterizing the three-dimensional shapes of the artefacts. These vast repositories are now structured in databases, for easy access. Such databases contain not only the artefacts, but also relevant information such as restoration reports, data regarding quantitative analysis, chemical formulae, etc. It follows that storing such information is not enough. Rather, it should be indexed in order to be searched and retrieved easily and rapidly. In addition, the data should be preserved as technologies evolve over time, in order to ensure long-term preservation and access. This paper presents a framework for indexing and retrieval of 2D and 3D Cultural Heritage data. In our approach, novel archiving and indexing techniques, developed by the National Research Council of Canada, are employed. We present the results as applied to the EROS (European Research Open System) Database of the C2RMF. This database consists of an impressive collection of scientific and technical data about paintings and artefacts found in all the museums of France. Our results indicate that our content-based approaches are able to accurately index and retrieve diverse images and 3D objects, based on the artefacts as well as their fragments. That is, using for example a fragment of a picture, we are able to retrieve the correct image even in conditions where lighting, orientation and the surroundings of the reference are different. The content-based retrieval system is also able to retrieve different views of the same object, e.g. of a Chalcidian amphora. In addition, our approach is able to find groups of similar images or objects, such as white figurines from the same period or 3D scans of an Anadyomene Venus.

Categories and Subject Descriptors (according to ACM CCS): H.3.1 [Information storage and retrieval]: Indexing methods

1. Introduction

Cultural Heritage applications are now characterized by their massive utilisation of digital media [LAC*04]. This has been employed to document sites, artefacts and restorations. Up to recently, such documentation was mostly based on pictures, reports and physical and chemical analysis. In recent years it has been realized that to describe a work of art only with pictures is not enough: an unambiguous body of information characterizing the three-dimensional shape of the artefacts is also needed, for example, to evaluate the deterioration of the shape over time. That is why 3D scanning has become a common practice in Cultural Heritage [LDP02, LFJ*05].

With the improvement of these acquisition techniques [GBT*02] and technology, the amount of information, both in terms of required storage space and number of items has become enormous. For that reason, it has become necessary to structure this large amount of information in databases. To structure data is not enough, we need

† R. Pillay[2]

to index them in order to search and retrieve easily and rapidly [FP02].

Text-based indexing has been making tremendous progress over the last few years and we refer the reader to the literature for a review on the subject [AML*05, PPLA05]. In the present paper, we would like to concentrate on content-based indexing and retrieval of images and 3D models. Our motivation is twofold. Firstly, as many of our examples will show, words are not enough to formulate many queries which, if formulated in terms of pictures and 3D models, are self-evident. Secondly, even if an adequate text-based description is available e.g. historical information, images and models constitute a valuable complement. In addition, if no textual information is available, content-based indexing can rapidly be created since, as opposed to its textual counterpart that need human intervention and judgement, the creation of the indexes is entirely automatic.

Our paper is organized as followed. After some general considerations on images, an algorithm for content-based indexing and retrieval is presented. We will then address the issue of content-based indexing and retrieval to 3D artefacts based on three-dimensional shape. Such algorithms are applied to the EROS Database [ALPP05, ALPP06, PPLA05] of the C2RMF (Centre of Research and Restoration of the France Museums). Some particularly interesting and relevant results are later discussed. The combination of all the above constitute an integrated approach to Cultural Heritage documentation.

2. General Considerations on Images

Images and models are of the outmost importance in virtual collections. They are (and will remain in the foreseeable future) the easiest, fastest and most economical mean for creating virtual collections. Furthermore, most three-dimensional models are covered with textures. The texture constitutes an important visual descriptor for the model under consideration and convey essential historical, artistic and archaeological information.

Images are difficult to describe [TS06]. They convey a large amount of complex and ambiguous information. The ambiguity is due to the fact that an image is a two-dimensional projection of the three-dimensional world and due the fact that the illumination of this world is arbitrary and cannot be controlled. Because of this ambiguity and complexity, it is difficult to segment images and to understand them. For the above-mentioned reasons, we propose a statistical approach in which the overall composition of the image is described in an abstract manner.

2.1. Indexing and Retrieval of Images

We now depict the algorithms developed by the National Research Council of Canada. The colour distribution of each image is described in terms of hue and saturation. This colour space (*HSV*) imitates many characteristics of the human visual system: the hue corresponds to our intuition of colour (for example red, green or blue), while saturation corresponds to the colour strength (for example light red or deep red).

Next, a set of points is sampled from the image. A quasi-random sequence generates the points. In the present implementation, the Sobol sequence has been selected. Each point of this sequence becomes the centre of a structuring element. For each centre position, the pixels inside the corresponding structuring element are extracted and the associated hue and saturation images are calculated. The statistical distribution of the colours within the window is characterized by a bi-dimensional histogram. The first dimension of this histogram [FTT05] corresponds to the hue or the saturation quantified on a discrete and finite number of channels. The second dimension corresponds to the relative proportion of each channel within the window. This two-dimensional histogram is computed and accumulated for each point of the sequence, i.e. the current histogram is the sum of the histograms at the current and at the previous position. From this process, a compact descriptor or index is obtained.

This index provides an abstract description of the composition of the image i.e. of the local distribution of colours throughout the image. This is very important. This index does not represent a global description of the image nor is it based on a particular segmentation scheme. Instead, it characterizes the statistics of colour distribution within a small region that is moved randomly over the image. Consequently, there are no formal relations in between the different regions, which means that the different components of a scene can be combined in various ways while still being identified as the same scene. That is why that algorithm is robust against occlusion, composition, partial view and viewpoint. Nevertheless, this approach provides a good level of discrimination.

As we know, an image is worth a thousand words, which means that it is difficult to describe an image based solely on words. For that reason, our retrieval approach is based on the so-called "query by example" or "query by prototype" paradigm. To this end, we created a search engine that can handle such queries. In order to initiate a query, the user provides an image or prototype to the search engine. This prototype is described or indexed and the later is compared with a metric to a database of pre-calculated indexes, which correspond to the images of the virtual collection. The search engine finds the most similar images with respect to the prototype and displays them to the user. The user then acts as an expert: he chooses the most meaningful image from the results provided by a search engine and reiterates the query process from the chosen image. The process is repeated until convergence is achieved.

2.2. Indexing and Retrieval of 3D Objects

The indexation of three-dimensional artefacts differs fundamentally from the indexation of images [IJL*05, TV04]. If the three-dimensional information has been acquired accurately at a sufficiently high resolution, the three-dimensional geometry constitutes an unambiguous body of information in the sense that there is a one-to-one correspondence between the virtualized geometry and the physical geometry of the artefacts. As explained in the previous section, the situation is entirely different for images. Shape also constitutes a language of its own right. In addition to verbal language, humanity has developed a common shape language. This is particularly evident in fields like art and architecture. For that reason, the "query by prototype" approach is a powerful paradigm for the retrieval of similar artefacts. As far as the overall structural design is involved, the three-dimensional artefacts retrieval system is very similar to its image counterpart: the artefacts of the collection are indexed offline and a database of indexes is created. In order to interrogate this database, the query is initiated with a prototype artefacts. From the proto-artefacts, an index is calculated and compared with the help of a metric to the indexes of the collection in order to retrieve the most similar objects in terms of three-dimensional shape. As stated before, the user can act as an expert in order to reiterate the process until convergence.

Consequently, the main differentiation between the two systems (image versus 3D) is the index. We now describe our algorithm for three-dimensional artefacts description. We assume that each artefacts has been modelled with a mesh. This is a non-restrictive representation for virtualized artefacts since most acquisition systems generate such a representation. In the present case, a triangular mesh representation is assumed. If the mesh is not triangular, the mesh is tessellated accordingly. Our objective is to define an index that describes an artefacts from a three-dimensional shape point of view and that is translation, scale and rotation invariant. The later invariants are essential because the artefact can have an arbitrary location and pose into space.

The algorithm can be described as follows. The centre of mass of the artefact is calculated and the coordinates of its vertexes are normalized relatively to the position of its centre of mass. Then the tensor of inertia of the artefact is calculated. This tensor is a 3 x 3 matrix. In order to take into account the tessellation in the computation of these quantities, we do not use the vertexes per se but the centres of mass of the corresponding triangles; the so-called tri-centres. In all subsequent calculations, the coordinates of each tri-centre are weighted with the area of their corresponding triangle. The later is being normalized by the total area of the artefact, i.e. with the sum of the area of all triangles. In this way, the calculation can be made robust against tessellation, which means that the index is not dependent on the method by which the artefact was virtualized: a sine qua non condition for real world applications. In order to achieve rotation invariance, the Eigen vectors of the tensor of inertia are calculated. Once normalized, the unit vectors define a unique reference frame, which is independent on the pose and the scale of the corresponding artefact: the so-called Eigen frame. The unit vectors are identified by their corresponding Eigen values. The descriptor is based on the concept of a cord. A cord is a vector that originates from the centre of mass of the artefact and that terminates on a given tri-centre. The coordinates of the cords are calculated in the Eigen reference frame in cosine coordinates. The cosine coordinates consist of two cosine directions and a spherical radius. The cosine directions are defined in relation with the two unit vectors associated with the smallest Eigen values i.e. the direction along witch the artefact presents the maximum spatial extension. In other words, the cosine directions are the angles between the cords and the unit vectors. The radius of the cords are normalized relatively to the median distance in between the tri-centres and the centre of mass in order to be scale invariant. It should be noticed that the normalization is not performed relatively to the maximum distance in between the tri-centres and the centre of mass in order to achieve robustness against outliers or extraordinary tri-centres. From that point of view, the median is more efficient that the average. The cords are also weighted in terms of the area of the corresponding triangles; the later being normalized in terms of the total area of the artefact. The statistical distribution of the cords is described in terms of three histograms. The first histogram described the distribution of the cosine directions associated to the unit vector associated with the smallest Eigen value, the second one describe the distribution of the cosine directions associated with the unit vector associated with the second smallest Eigen value ant the third one describe the distribution of the normalized spherical radius as defined in the previous paragraph. The three histograms together constitutes the shape index of the corresponding artefact.

2.3. Application to the EROS Database

The C2RMF is a pioneer in applying new technologies in the field of Cultural Heritage. The activities of the C2RMF in the field of High Resolution imaging for Cultural Heritage started in 1989 with the high quality digitization of large size transparencies (photos and X-ray plates) via the Thomson-Broadcast flatbed scanner developed for the NARCISSE European project. Then we proceeded with the acquisition of direct digital imaging, by panoramic views of objects, by direct 3D acquisition of the surface of paintings and objects, by 3D reconstruction from panoramic views and by multispectral imaging from ultraviolet to infrared allowing us to reconstruct the colour for any illuminant.

All these techniques give us an enormous amount of data and information to organize and to exploit. This information is focused on scientific and technical data.

The EROS system is organized in several parts: the storage back-end, the relational database, the image server, the

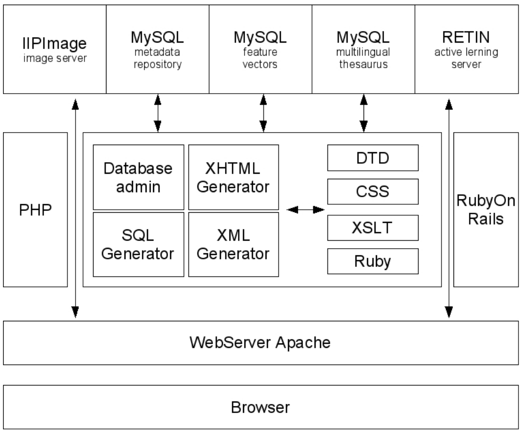

Figure 1: *EROS database organization.*

middle-ware and the web server. The data are stored on 15TB HP RAID 5 hard disk racks managed by a file server and consist of:

- meta-data related to 65,000 works of art, 200,000 high resolution images, 10,000 reports, 170,000 analysis, analytical reports, restoration reports, 6,600 conservation surveys, the chemical, structural, isotopic and molecular quantitative and qualitative analytical results and published papers;
- high definition digital images (some of them are gigapixel images);
- feature vectors for 2D and 3D image content recognition for automatic classification and image category retrieval (for different engines).

The EROS system is an Open Source project available under the GNU Public License (GPL). It is based on powerful and industry-leading free software.

In the following examples we compare the results obtained using the meta-data with the ones using "query by content".

Finding 2D images from 3D models.

A snapshot of the 3D model of a Chalcidian amphora is used to query the database (Figure 2).

Our content-based recognition algorithm allows us to retrieve in the first screen the 36 2D images (from a panoramic view) of the same vase and then similar Greek vases. As 3D acquisition techniques are improving, more and more 3D models will be produced in place of high quality 2D images. As this algorithm is able to compare 3D models with 2D images, our existing image database will continues to be useful.

Finding the overview using a detail.

Lost pictures and slides are sometimes registered with wrong reference number. In this case content-based recognition can help us to retrieve the overview of the work of art.

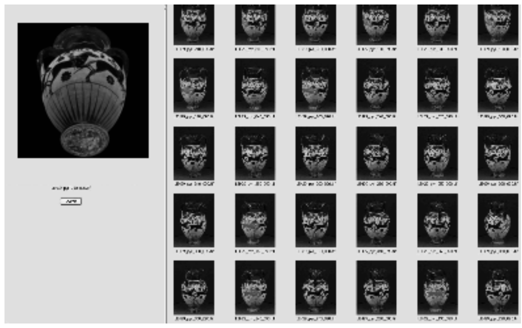

Figure 2: *Chalcidian amphora - Louvre Museum, Paris, inv. E795. This amphora was made during the Archaic Greek Period (620-480 B.C.) and was found in the South of Italy*

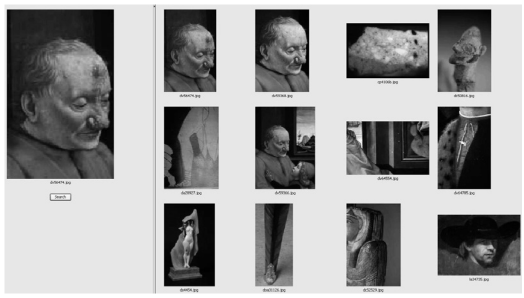

Figure 3: *PORTRAIT OF AN OLD MAN WITH A YOUNG BOY - GHIRLANDAIO Domenico (1449-1494), Louvre Museum, Paris, inv. RF266*

For example the detail showed in the left side of Figure 3 was compared to the contents in the database. Similar images made at various periods of time under different experimental conditions are retrieved first as well as the overview of the painting.

Style recognition.

Figure 4: *SITTER SEEN FROM THE FRONT - SEURAT Georges-Pierre (1859-1891), Louvre Museum, Paris, inv. RF1947-13*

When the meta-data related to the image content are not indexed, our algorithm is very useful in retrieving similar paintings having the same pictorial style. For example images characteristic of the "pointillism" style, which is the painting technique of, for example, Georges-Pierre Seurat, can be automatically retrieved using a detail of one of his paintings (Figure 4).

The first results are images representing part of the same painting and then images of paintings having the same pictorial style.

Figurine classification by type.

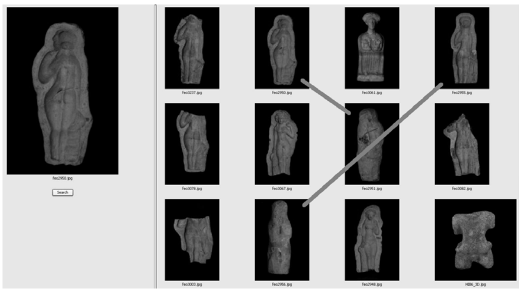

Figure 5: *ANADYOMENE VENUS - PRISCUS, France, Moulins, Anne de Beaujeu Museum, inv. 5.3.20*

5.500 Gallo-Roman figurines produced in workshops in France between 40-300 a.C. are stored in the EROS database. 500 3D models and several thousand images were compared. In Figure 5 a 2D image of a mould of "Venus", characteristic of the "Anadyomene" type, is used as a reference. Content-based recognition applied to flat images (Figure 5) gives results of groupings of similar object moulds and then figurines issued from these moulds. This example is typical of situations in which one wants to retrieve a certain group of pictures that are very similar but that do not necessarily correspond to the same artefact. In the following examples a 3D model of a statue (Figure 6) of a "Prudish Venus" and after a 3D model of a mould (Figure 7) of an "Anadyomene Venus" are used. We obtain an impressive level of coherence in the results.

The system was able to retrieve very similar Venuses irrespective of their orientation in space. Shape is a powerful retrieval paradigm for 3D models in Cultural Heritage.

Content-based recognition can be used for semi-automatic classification of ceramic production presenting similar artefact and can be used also to link signed moulds to figurines for attributing the production of an antique workshop.

Robustness of the algorithm.

A test of robustness in detecting images both before and after restoration was made using a shroud.

It appears that the content-based recognition algorithm is able to retrieve images corresponding to the same object in

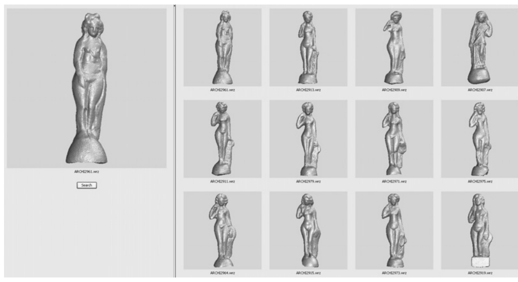

Figure 6: *PRUDISH VENUS - France, Moulins, Anne de Beaujeu Museum, inv. 5.7.6*

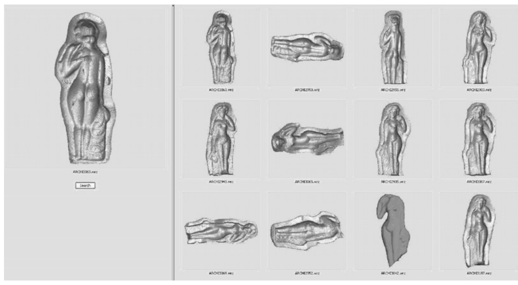

Figure 7: *ANADYOMENE VENUS - France, Moulins, Anne de Beaujeu Museum, inv. 5.3.33*

Figure 8: *Shroud - Louvre Museum, Paris, inv. AF6482. Made around 200-299 A.D. in Egypt*

different states of conservation (Figure 8). It means that in addition to the pictorial information, for example the painting, there is a significant amount of information that is related to the deteriorated textile. It is relatively easy for a human being to make an abstraction of the deterioration information and to solely concentrate on the pictorial one. For a content-based retrieval system, it is extremely difficult to handle such a situation. This is because the system does not know a priori which information is original and which is related to the deterioration. Nevertheless, we managed to retrieve many views (partial and complete) of the work of art. This demonstrates that the algorithm is maintaining a good balance between colour information, which here corresponds to the pictorial information, and textural information, which corresponds to the deterioration.

3. Conclusions

In this paper, we have presented novel indexing algorithms developed by the National Research Council of Canada for 2D and 3D digital data for Cultural Heritage. In particular, we have applied the proposed approaches to the heterogeneous EROS Database of the C2RMF.

Our results have shown the efficiency of our algorithms. In many situations, content-based retrieval has proved itself to be, not only a complement to text-based retrieval, but as a sine qua non condition for efficient retrieval. The retrieval of the "pointillist" paintings from a detail as start point is a spectacular example of such a situation. In any case, the synergy between text-based and content-based searching should be exploited to the maximum.

At the moment, around 150,000 images have been indexed at low resolution (1,000x1,000 pixels), 14,000 at high resolution (up to 12,000x8,000) and around 300 3D models (from 30,000 to 3,000,000 vertices). The feature vectors at low resolution have been calculated on a high-end laptop while the indexes for the high-resolution paintings have been calculated in Paris on the C2RMF server (this operation took about 5 hours on both machines). The fact that 150,000 images can be indexed on a laptop and that the query, on the same laptop, takes between 1 to 3 seconds, shows that the algorithms are well optimized.

All the indexes were calculated offline. An evaluation of the system has shown that paintings and artefacts should be indexed automatically as soon as they are store in the database. This would ensure that a content-based index is attached to each item as soon as it becomes available in the database. We are currently working on a grid-computer architecture in order to be able to index a massive amount of ultra-high resolution 2D and 3D. By distributing the load of many nodes, it will be possible to increase substantially the performance of the system. This task will be facilitated by the fact that the approach is well-suited for parallelization.

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Modeling and Digital Fabrication of Traditional Japanese Lacquer Ware

T. Vilbrandt [1], C. Vilbrandt [2], G. Pasko [3], A. Pasko [4]

[1] MIT-FabLab, Norway, turlif@fablab.no
[2] Mythworks, Chile/USA, carl@cgpl.org
[3] University of New York / Tirana, Albania, galinapasko@unyt.edu.al
[4] Hosei University, Tokyo, Japan, pasko@k.hosei.ac.jp

Abstract
We present a long-term project on the development of the mathematical basis, software tools, technology, and creation of the research and development facilities for desktop or personal fabrication using compact, cheap, and environmental friendly fabrication devices including so-called "3D printers". The test application area for the development is traditional Japanese lacquer ware craft called "shikki", which includes hand-making wooden parts, assembly, and covering using natural lacquers. This craft is considered living cultural heritage in need of preservation and support. Our project includes modeling existing artifacts and Web presentation of them, automation of the wooden parts and items fabrication, and design and experimental manufacturing of new types of lacquer ware.

1. Introduction

One of the important characteristics of the object in digital preservation is its shape, especially for tree-dimensional physical artifacts such as table ware, pottery, sculpture, and architecture. Traditional crafts preserve the shapes by passing them through the generations of masters in the process of permanent reproduction of the craft items.

In general, the historical heritage of traditional crafts such as pottery, embroidery or lacquer ware has specific features from the digital preservation point of view. First of all, any craft is a living tradition, not a fixed set of inherited items. It includes masters with their knowledge of the essential craft technology, which is often not presented in written form. This gives opportunity to preserve the technology or even enhance it using computers. On the other hand, it brings up psychological and economical problems, when computer-based technology is considered as not support, but a rival to traditional crafts. The necessity of computer-based preservation is validated by decreasing number of masters, fading technologies, and crafts loosing economical grounds.

In this paper, we describe practical experience in using computers to model, presenting on the Web, and fabrication of traditional Japanese lacquer ware called "shikki" as well as design and experimental manufacturing of new types of lacquer ware.

2. Project overview

Parts of a shikki item are produced manually using thin pieces of wood, and then they are assembled, painted in different colours, and covered by the natural lacquer called "urushi". There are many different types of shikki items: boxes, small drawers, stands, bowls, sake cups and pots, spoons, chopsticks, notebooks, and even ball pens and pencils. These items are quite different in their topology, geometry, and texture. All mentioned above problems of traditional crafts stand for shikki. Moreover, cheap plastic production makes additional economical pressure on this craft industry, thus making the necessity of the craft preservation even more actual.

The purposes of our project are reflected in the following directions of research and development activity:

- Modeling shapes and making parametric families of models of representative shikki items. A parametric family of models will allow us to generate samples of a specific model with different size, width/height ratio, and so on, without repetition of the entire modeling process.
- Producing 3D virtual lacquer ware objects and presenting them on the Web.
- Documenting traditional materials and technology. This documentation can also be presented in multimedia format including video, graphics, and virtual models.
- Development of interactive design tools for modeling new items. This is a radical step of developing special computer-aided design (CAD) tools for modeling shapes and material properties of lacquer ware.
- Applying existing rapid prototyping machines to produce 3D physical objects from computer models.
- Adaptation or design of new personal fabrication tools for desktop manufacturing of lacquer ware.
- Creation of an Internet-based community and e-commerce activity using interactive computer-aided design, virtual objects presentation, and fabrication of selected or designed items by user request.

3. Lacquer ware modeling and Web presentation

The function representation (FRep) was selected as the primary geometric model in our project [PAS*95, PA04]. In FRep, a 3D object is represented by a continuous function of point coordinates as $F(x,y,z) \geq 0$. A point belongs to the object if the function is non-negative at the point. The function is zero on the entire surface (called usually an *implicit surface*) of the object and is negative at any point outside the object. The function can be easily parameterized to support modeling of a parametric family of objects. The HyperFun language [ACF*99, CAP*05] was introduced for teaching and practical use of FRep modeling. The open and simple textual format of HyperFun, its clearly defined mathematical basis, its support of constructive, parameterized and multidimensional models, its support by free and open source modeling and visualization software, and its ease of use make it a good candidate as a tool for the digital preservation of cultural heritage objects. Additional discussion on the shape representation for cultural heritage preservation can be found in [VPP*04].

Figure 1: *Japanese lacquer ware spoons (top) and a spoon modeled in HyperFun (bottom)*

Modeling shapes of typical lacquer ware items and presentation of them as virtual objects on the Web was implemented as follows. First, several 3D computer models of traditional Japanese lacquer ware items were created in HyperFun (see an example in Fig. 1). Then, polygonal approximation of object surfaces was made using the HyperFun Polygonizer software and the generated mesh was exported to the VRML (Virtual Reality Modeling Language) format. We scanned colour textures directly from lacquer ware objects with planar surfaces and from photographs. The obtained polygonal models have been textured using traditional tools like 3D Studio Max. Finally, the Web site [VS] was created with the models of textured lacquer ware box, tray, cup, stand, sake pot, and a full sake set. A HyperFun model is available for each object at the Web site. Each image at the Web site is hyperlinked to the corresponding VRML model, which can be downloaded and visualized using any VRML viewer such as CosmoPlayer. The purpose of the created Virtual Shikki presentation on the Web is to allow people to remotely appreciate the beauty of shapes and textures. This is important from cultural and commercial points of view.

Selection of the VRML format for the Web presentation of 3D virtual objects seemed to be quite natural recently. However, VRML has well-known drawbacks such as huge data files and long downloading time. Other and more compact Web3D formats should be considered in future. The average size of a VRML file is 100-500 Kb. However, the size of the full sake set file is 4.5 Mb. On the other hand, HyperFun models for all lacquer ware items do not exceed 5 Kb. In this sense, we can conclude that HyperFun provides a high level of compression and should be considered as a lightweight network protocol. The radical solution would be to transfer small HyperFun models to the user's computer and provide a specialized browser able to unfold a polygonal or other representation suitable for interactive visualization.

4. Lacquer ware design and digital fabrication

Digital fabrication means creation of physical objects using special equipment under computer control. It includes two major classes of technologies: rapid prototyping and personal fabrication.

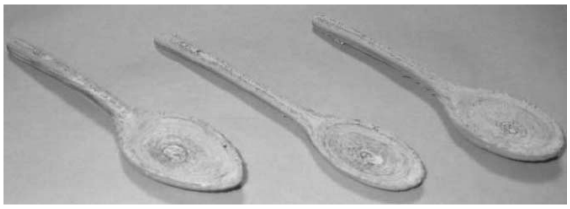

Figure 2: *Spoon models fabricated by a rapid prototyping KIRA Solid Center machine using the paper laminating process.*

Rapid prototyping was the first generation of these technologies based on heavy, expensive industrial machines often using toxic materials. The prototypes fabricated by these machines can be used mainly for visual inspection purposes, not for practical use. For example, in Fig. 2 spoon models are shown, which have been fabricated using a paper laminating KIRA Solid Center rapid prototyping machine.

Figure 3: *Desktop "3D plotter" Modela by Roland DG (Japan)..*

Personal fabrication is an alternative emerging technology based on compact desktop 3D plotters and 3D printers. These are low cost machines, which are simple in operation, do not use toxic materials, and suitable for home use. For example, a desktop milling machine or a 3D plotter Modela (Roland DG, Japan) is shown in Fig.3. The spoon model shown in Fig. 1 and produced of wood using a Modela machine is shown in Fig. 4.

Figure 4: *A spoon model fabricated using a Modela machine.*

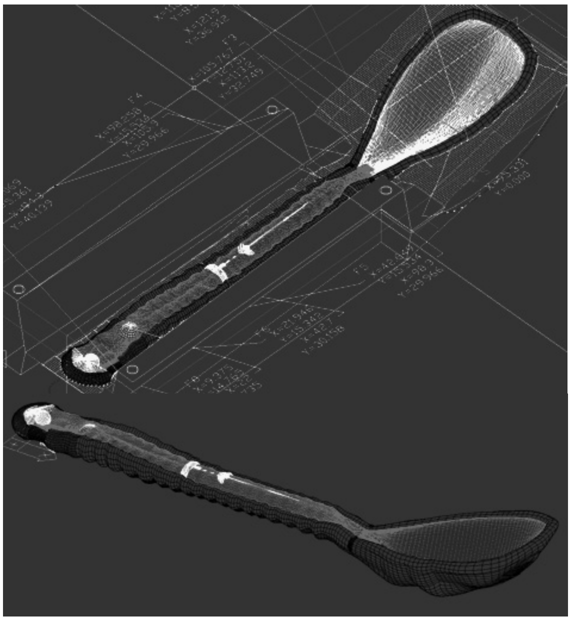

Figure 5: *New "organic" spoon design.*

Figure 6: *New spoon designs fabricated of wood using a Modela machine.*

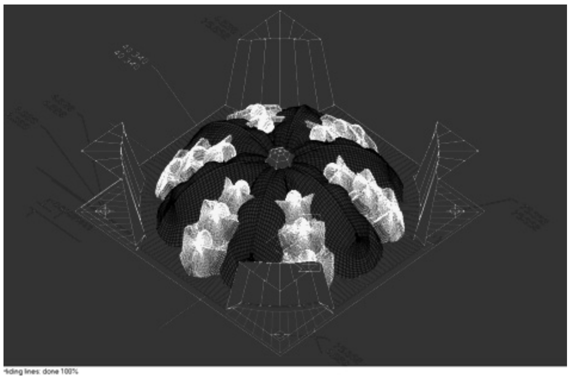

Figure 7: *New bonbonniere design.*

In addition to modeling and fabrication of traditional lacquer ware items in the project, we are trying to expand the variety of designed objects. New designs of spoons and bonbonnieres were proposed (Figs. 5 and 7) and experimental fabrication technique was tested (Figs. 6 and 8). An important part of the fabrication process is tooling, i.e., the technique for holding the piece during the fabrication. It can be seen in Fig. 8 that the top and the bottom of the bonbonniere lid were fabricated using wax for holding the piece.

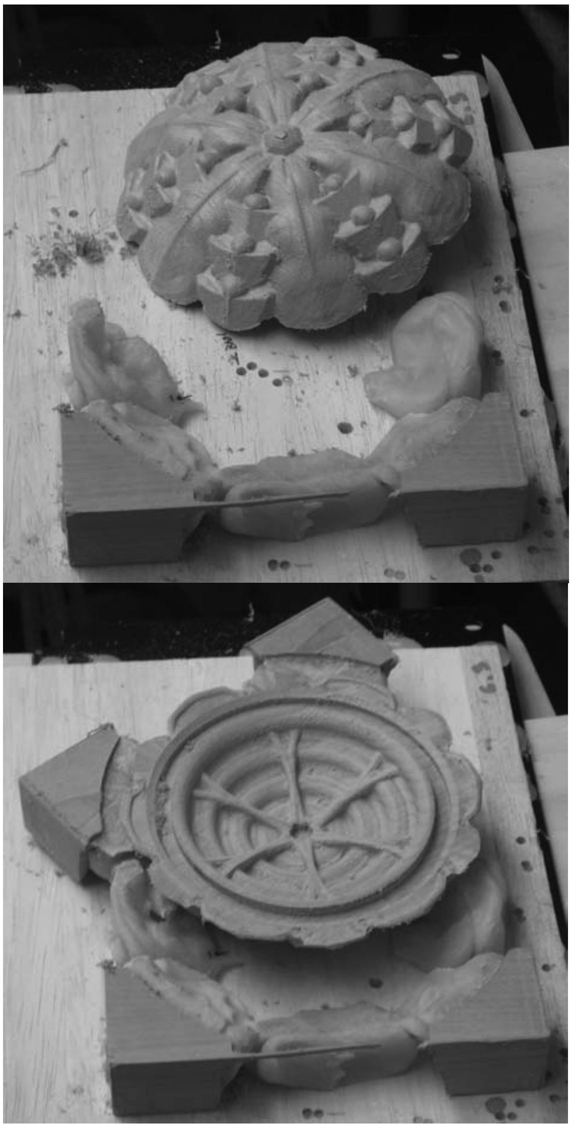

Figure 8: *A fabricated wooden bonbonniere lid with tooling for a Modela machine*

5. Conclusion

We presented a long-term project currently funded by the Japan Society for the Promotion of Science (JSPS). The main objective of the project is development of personal fabrication technology and its application in traditional crafts such as Japanese lacquer ware design and production. Our experience shows that inexpensive desktop fabrication equipment with appropriate software can give ground for the preservation and support of existing craftsmen techniques as well as for new approaches to design and fabrication.

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Project Presentations

Digital Preservation and Promotion of the Architectural Heritage of Attica

A. Pechlivanidou – Liakata, S. Mikrou, S. C. Zerefos

Faculty of Architecture, National Technical University of Athens, Greece

Abstract
The promotion of the architectural heritage of Attica and the islands of Argosaronikos and Kythera is the subject of a joint research program undertaken by the Simulation Laboratory and the laboratory of Morphologia" (Morphology) of the School of Architecture at the National Technical University of Athens. The Archives of the Morphology Lab which consists of sketches, scaled ink drawings, images and text, comprises many surveyed neoclassical buildings, byzantine and ancient monuments as well as entire traditional settlements. All this material accumulated during the past 50 years–is being constantly enriched with new architectural surveys - the outcome of student assignments, projects and research within the School. For its most part the material is original and has not yet been published. The research project aims to produce a database, which will be easily available and accessible through the World Wide Web. To do so, all the archival material is to be digitized. Sketches, drawings and photographs will be scanned and selected buildings will be represented with 3D models. The idea is on one hand to present the archival material itself, enhance and organize it into an efficient database, while on the other hand to make this database as attractive and educative as possible using dynamic ways of communication, such as animations, real time walkthroughs and interactive presentations. A basic concept in all cases will be the integration of the monument into its context thus a part of the research will explore possible ways of reconstructing the surrounding buildings and environment.

Categories and Subject Descriptors (according to ACM CCS): J.5 [Arts and Humanities]: Architecture

1. Introduction

This paper presents details and the methodology of a research project that aims to promote buildings representative of the architectural character of Attica and the islands of Argosaronikos and Kythera. This research project is undertaken by the Simulation Laboratory and the "Morphologia" (Morphology) Laboratory (the scientific field studying architectural forms and styles) of the school of architecture at the National Technical University of Athens.

The Archives of the laboratory of Morphology comprise many surveyed neoclassical buildings, byzantine and ancient monuments as well as entire traditional settlements. These surveys consist of sketches, scaled ink drawings, images and text, and they are being constantly enriched with new architectural surveys, thus forming a massive Archive which has material dated back to 1947. Due to its nature the material is original and has for the most part not been published. Yet, parts of it are occasionally being used by individuals or other bodies for scientific or research purposes.

On the cultural level, the archive is extremely valuable since architectural elements and other information can be found on existing buildings, as well as on buildings that no longer exist, have collapsed, have been demolished, or have suffered major transformations and have been significantly altered. The archival material is exceptional for it constitutes a documented and visual registration of an important part of the cultural heritage of the area and could therefore be used for the presentation and evaluation of the architectural character of the Attica region. However, the material is also in danger. Because of its present paper-based form in 1991 a small part of it was destroyed by fire and since then the need to be preserved is eminent. This can be partly achieved by its digitization, documentation and communication to the broad public.

2. Aims of the research program

The research project aims to the protection of an important part of the architectural heritage of the Attica region that has been recorded and forms part of the Archives of the National Technical University of Athens (NTUA).

The primary outcome will be a database, easily available and accessible through the World Wide Web. To do so, all the archival material is to be digitized. Sketches, drawings and photographs will be scanned and selected buildings will be modeled.

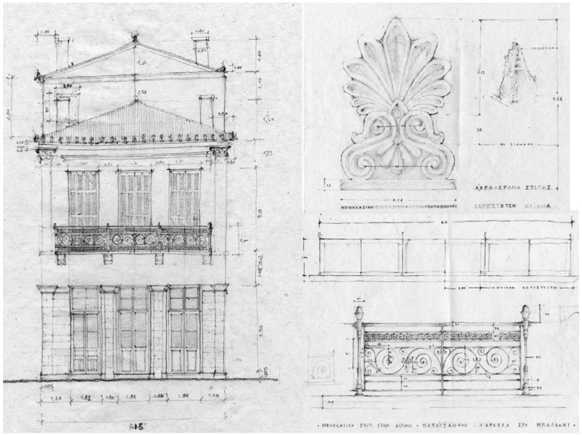

Fig 1: *An example with sketches of a neoclassical building*

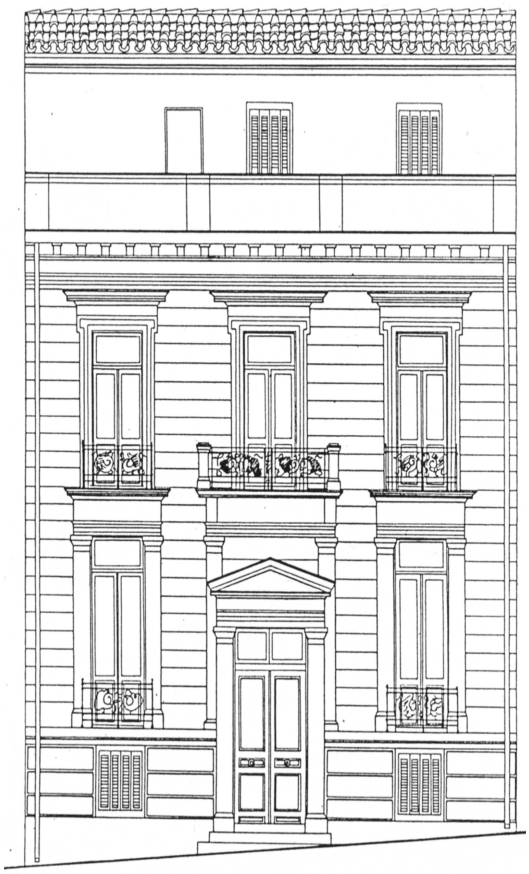

Fig 2: *An example of an ink- scaled drawings*

Databases are commonly used to handle data and allow users to easily find what they seek. As far as the sector of cultural and architectural heritage is concerned their importance is no doubt of a great value and in recent years several relevant projects have been undertaken. Yet a main concern for this particular database has been the creation of a sophisticated system that integrates multimedia and as many interactive features as possible and goes beyond a catalogue-like approach. The idea is on one hand to present the archival material itself, enhance and organize it into an efficient database, while, on the other hand, make this database as attractive and educative as possible using dynamic ways of communication and dissemination of information, such as animations, real time walkthroughs and interactive presentations.

A basic concept in all cases will be the integration of solitary buildings into their context considered in a broad sense as not only the physical but also the historical, social and cultural framework in which the building has been created and has existed or still exists. Thus a part of the research will explore possible ways of reconstructing the surrounding buildings and environment. Past theories concern with the study of the building as a single unit. However, nowadays the placement of the building in its context is more important for more complex factors concerning a holistic approach to cultural heritage. Therefore, information about the sitescape is considered imperative to be included in this project, as well as the promotion of the results.

3. Methodology

The above can be achieved by adopting a methodology that comprises three distinct phases:

- First Phase: Digitization and editing of the original material
- Second Phase: Development of the database
- Third Phase: Promotion of the material

3.1. First phase: Digitization and editing of the original material

An important and time consuming part of the first phase deals with the selection of the material to be digitized and then its organization on the basis of specific criteria such as typological, morphological, chronological, geographical or qualitative characteristics of the building.

Another part regards scanning. The original format of the ink drawings is 50 x 70 cm thus the plans, sections and elevations in scale 1/50, 1/100 and the details of the building in scale 1/20, 1/10, 1/5, scanned as grayscale images with a resolution of 200 dpi result in files with approximately 3900x5500 pixels and 20,000 kb image size. The sketches and photographs are scanned in actual format with a resolution of 200 dpi. (Usually 35x50cm for the sketches, 9x13cm or 10x15cm for the photographs that result in 3,000 kb image size). In any case the scanned images are initially saved as tiff files. These high resolution original scans are meant to serve as digital copies for the protection and the reproduction of the original material. For the purposes of the internet database the original scans are then saved as jpg (or gif) files with three different resolutions described as low, medium and high. The process of the conversion of the tiff files into jpgs and the creation of three different resolutions is facilitated by the creation of the appropriate "actions" and using the file/automate/batch command in photoshop.

The modeling of selected case studies constitutes the third part of the first phase. Conventional plane representations (plans and sections) capture much of the information of the building and may be sufficient for recording and documenting. Yet coloured rendered views taken from a complete 3D CAD model are particularly valuable since they offer to the broad public a better understanding of the building. In addition to that, a 3D CAD model can be even more exploited for the production of animations, QuickTime VR panoramas and real time walkthroughs inside or around the building that furthermore favor its perception .

Fig 3: *An example of three dimensional models created.*

Nowadays most of the still standing neoclassical buildings in Attica constitute solitary examples scattered around the region. In other words it is usually difficult to visualize what the site would have looked like as an ensemble. There are rather few neighborhoods left that retain the architectural character and the scale of the past. Thus a primary concern has been to make the 3d computer models of those buildings that stand adjascent or relatively close one to another and then produce rendered views and walkthroughs of a whole complex so that the "sense" of a neoclassical street or the fronts of a neoclassical square can be reconstructed and perceived.

3.2. Second phase: Development of the database

The second phase deals with the production of the database core, certain fields of which regard the building while others refer to the archival material itself.

Based on the recommendations of UNESCO and the Council of Europe as summarized in the Core Data Index to Historic Buildings and Monuments of the Architectural Heritage the following headings are included in the database.

1. Names and References: Name of the building –if known-, Unique reference number, Date of compilation of the data, Recording team (students and supervisor).
2. Location: Administrative Location, Address (name of street, number in the street, quarter - neighborhood, town, Cartographic Reference, GPS coordinates, Cadastral Reference
3. Functional type: Building type defined by function, date – to which the specific function is assigned. Original and current use
4. Dating - date of construction
5. Physical condition of the building at the time of the compilation of data and currently.
6. Main materials and structural techniques, Covering materials, Main morphological elements, doors and windows, staircases, railings and balconies.
7. Persons and Organizations Associated with the History of the Building: Architect(s), original proprietors, commissioner, institutions accommodated or associated with the building over a period of time.
8. Possible legislative protection of the building

As far as the archival material itself is concerned the following information is included:

- Number and type of drawings (plans, sections, elevations, perspective and/or axonometric views, details), scaled ink drawings and sketches.
- Existence or not of other visual material (photographs, maps, iconographical sources)
- Existence of text and / or any bibliographical references
- Evaluation of the thoroughness of the assignment.

3.3. Third Phase: Promotion of the material

The third phase deals with the presentation and management of the archival material and the promotion of the historical buildings using the potential of the world wide web in combination with an attractive way of hyper-textual and visual communication. The aim is to produce an innovative interface that will have the following as its main components:

- 2D drawings (plans, elevations, sections, and details)
- 3D views, Quick Time VR panoramas, animations and real time interior walkthroughs and exterior walk-arounds
- Interpretative text analyzing the building, its type, principles, form, style and history. Bibliographical references.
- Links with Google Earth locating each building at the GPS coordinates on the aerial photograph. (Thus increased possibility to access the site also through the site of Google earth).
- Glossary of key terms with links to hotspots that refer to the details of the 2D drawings and the 3D

representations highlighting the respective morphological elements and typologies.

The user of the database can select one or more buildings and then access the respective record(s) and view a detailed and analytical presentation. The search is possible in the followings ways:

- Selection from a list of all the buildings included in the database
- Selection on the basis of specific criteria (name of the building, location, building type, date). One can check one or more among different fields and then get a list of those buildings that respond to the specific criteria.
- Selection of a neighborhood. In this way one can search those buildings that form part of a complex (whole street, square, quarter), find more specific information on the complex and then if he wishes proceed to the individual records.

Each record consists of different pages entitled Introduction, Location, Use, Drawings, 3d Model, Photographs and each of the pages includes the relative information with either textual or graphical material.

4. Conclusions

This research project aims to the presentation and protection of an important archive of buildings that constitute the architectural heritage of the region of Attica and the islands of Argosaronikos and Kythera, which is dates back to 1947. The archive will be digitized and presented through the World Wide Web through a database that will be categorized by using several layers of information, as well as the missing information of the context (sitescape) that each building was situated in.

The primary benefits of the project can be categorized into five distinct areas as follows:

- Presentation of an exceptional archival material through the World Wide Web.
- Contribution to the broader cultural and social task of educating people to become conscious of the importance and values of their historic and traditional environment.
- Possibility to use this material for scientific purposes (e.g. historical research, documentation, visualization of the major changes and the evolution of the urban fabric).
- Contribution to the promotion of the architectural heritage of the Attica region for tourist purposes.
- Preservation, management of the data and systematic organization of an important architectural archive in Greece.

Finally, a documentation of the proposed type can be indispensable, for the purposes of identification, protection, interpretation and the preservation of this historical archive.

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Close-range Laser Scanning Applied to Archaeological Artifacts Documentation. Virtual Reconstruction of an XVIth Century Ceramic Pot.

H. Pires [1], P. Ortiz [2], P. Marques [1] H. Sanchez [2]

[1] Superfície- Soluções Geográficas, Maia, Portugal - mail@superficie-geo.com
[2] University of Extremadura, Centro Universitario de Mérida, Espanha – pedrotop3d@yahoo.es, sasah@unex.es

Abstract

In this paper we present an experimental study of ceramic pottery reconstruction from sherds, using close-range laser scanning. The main objective of this study was the geometric analysis and the 3D reconstruction of the pot's morphology aiming to contribute to the understanding of the constructive ceramic process. The fragments belong to a small XVIth century ceramic pot found in an archaeological excavation at the Convent of Santo António de Ferreirim in Lamego, Portugal. The existing fragments reconstitute approximately 1/3 of the entire pot along with a piece of one of the handles and two decorative medallions. The contiguous fragments were glued together by the archaeology team remaining, at the end of this process, five loose pieces.

All sherds were scanned with a Konica-Minolta Vivid 9i 3D non-contact digitizer. Some mathematical computations were necessary for the final reconstruction: the reconstituted fragments were geometrically analysed in order to determinate the axis and revolution profile. The position estimation of the five loose fragments was accomplished through geometric analysis of the decorative patterns and allowed us to propose a hypothetical 3D model of the entire pot.

Categories and Subject Descriptors (according to ACM CCS): I.3 [Computer Graphics]: I.3.3 Picture/Image generation - Digitizing and scanning; I.3.7 Three-dimensional graphics and realism – Virtual reality I.3.8 Applications.

1. Introduction

Laser scanner technology is increasingly being applied to cultural heritage. Among other advantages, the accuracy and the enormous amount of collected data contributes to the development of fields like registry and heritage documentation, conservation, archaeology, cultural tourism, among others.

This project was thought and carried out in the perspective of "bridging the gaps between conservation experts and heritage recorders so as to raise the level of conservation practices" [LG02], joining together both actors, providers and users, through collaborative work.

1.1. Geographical and historical context

In 2003 in an archaeological excavation, promoted by the Portuguese Architectural Heritage Institute (IPPAR) at the Monastery of Santo António de Ferreirim in Lamego, a significant amount of sherds belonging to a very fine and exquisite ceramic pot were found in the middle of rough ceramic fragments.

This monastery was built at the end of medieval age and was completely reformed in the first half of the XVIth century.

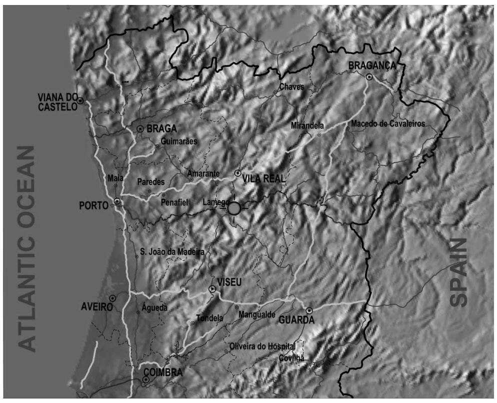

Figure 1 – *Map of the northern region of Portugal with location of Monastery of Santo António de Ferreirim (red spot).*

1.2. Object description

At the end of the archaeological analysis process almost all the sherds were glued in one big reconstructed fragment remaining five loose sherds: three single pieces; one medium size fragment and a part of a handle. Our study began with these six elements.

This pot is classified in the group of non-vitrified fine reddish ceramic and has a height of 9.7 cm and a maximum diameter of 9.8 cm at the rim. Apart from the main body, decorated with vegetable ornaments made through small incisions, the pot has two medallions representing the bust of a knight with long hair and moustache, built by mould techniques, and one handle, although archaeologists suppose that the original pot had a second handle in a symmetrical position [Lar06].

Figure 2 – *Ceramic pot fragments after archaeological reconstruction.*

1.3. Constructive techniques

The initial analysis of the ceramic pot constructive process shows, at least, two different techniques. In one hand the moulding processes used in the medallions and also in the wreaths (in the top and bottom of the existing handle) led archaeologists to consider a semi-industrial fabrication process. In another hand, the main body indicates the probable use of a potter's wheel along with the decorative hand drawings showing a handicraft process.

Figure 3 – *Photograph of the pot's medallion.*

1.4. Scope of the work

The main objective of this study was to help archaeologists with the morphological analysis of this odd ceramic artifact aiming to understand its constructive process, to provide accurate dimensioning and to reconstruct a hypothetical 3D model supported by the existing fragments.

In terms of morphology the initial hypothesis was that this pot had a bi-symmetrical construction defined by two axes: the centres of the medallions and the axes of the handles [Lar06].

Some of the initial considerations could be checked through visual inspection but others needed a more thorough analysis: the geometric symmetry; the constructive process of the pot's main body; the thickness of the clay in respect to the deepness of the incisions and the possible position of the loose fragments. This study aims to answer these questions, or at least to contribute to strengthen the archaeological interpretation providing accurate data.

2. Data collection and processing

The need for high level of detail and accuracy was one of the main criteria in the choice of the technology to use, along with a limited amount of time that we had to survey this archaeological artifact. All sherds of the ceramic pot were scanned with a Konica-Minolta Vivid 9i 3D non-contact digitizer with an accuracy of +/-0.050mm and a precision of 0,008mm. The fragments were placed on a black velvet cloth, normally used to photograph archaeological artifacts, which turned out to be an excellent choice because no points from the supporting platform were capture by the laser scanner, providing, in this way, a clear scan. Some acrylic supports were also used to place the fragments in favourable positions in order to capture its entire shape.

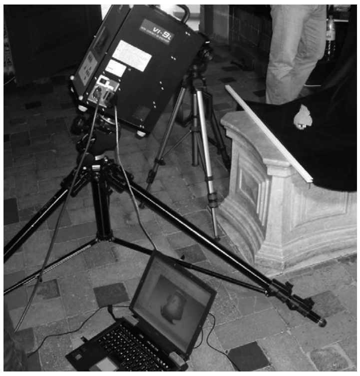

Figure 4 - *Laser Scanner System Konica-Minolta Vivid 9i 3D non-contact digitizer.*

Point cloud acquisition, as well as all the tasks mentioned in this paper were done using *RapidForm 2006* (INNUS Tech., 2006), with the built-in interface for *Vivid* digitizers. Scans of interior and exterior sides of the fragments were captured separately, creating two different point clouds for each fragment. The biggest sherd needed four extra scans to complete the survey.

The first step in data process was to create a mesh from each point cloud set; this operation included triangulation of the point clouds and noise removal. After, the several meshes from each sherd were registered in one single coordinate system. This alignment was done in two stages: rough and fine alignment. The first one is a semi-manual process where common points from overlapping areas on each mesh are manually selected providing rough rotation and translation values. The fine alignment tool provides an automatic alignment based on the Iterative Closest Point (ICP) algorithm [HCMV05]. This alignment can be refined by changing the numbers of iterations or the target alignment error. The average distance between the alignments was 0.042mm and the standard deviation 0.064mm.

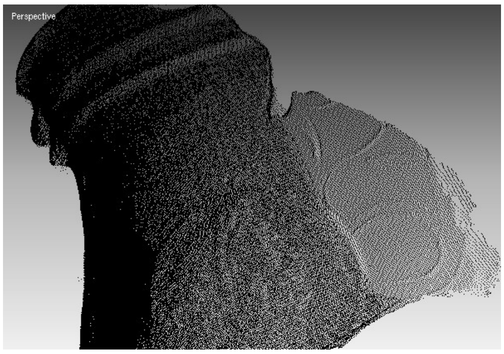

Figure 5 – *Point cloud from the biggest fragment.*

Next step was merging the aligned scans in to one single model; R*apidForm* provides two kinds of merge tools, one based on the surface zippering [TL94] and the other on the volumetric approach [GVP05]. Once the surface zippering operates directly on triangle meshes it as a better behaviour on relatively smooth surface than in regions of high curvature, thus in our case we used the volumetric approach, which was more appropriate for our work, showing better performance with respect to noise reduction and hole filling.

Figure 6 – *3D mesh from the major fragment.*

The alignment stage presented some problems; part of the scanned fragments had a very small overlapping area between interior and exterior faces, in the worst case just the thickness of the edge. To solve this problem a flat mirror was used in order to collect in a single scan both interior and exterior faces. Some opaque targets were placed in the mirror and scanned at the same time as the fragments providing the coordinates for the subsequent symmetry transformation of the point clouds.

Finally, all the point clouds were meshed, aligned and merged into separate 3d models for each fragment.

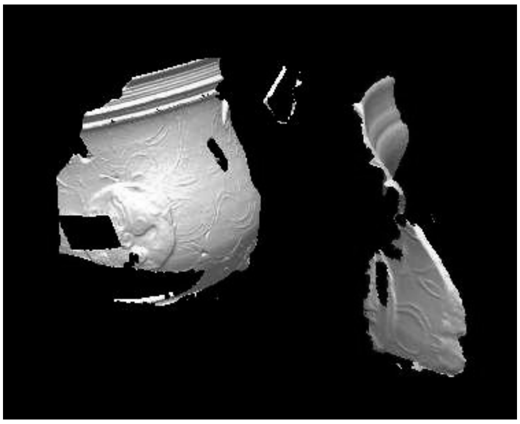

Figure 7 – *Resulting meshes from scanning with a flat mirror.*

3. Geometrical analysis

In this section we describe the methodology used to analyse the geometric characteristics of the biggest fragment. The initial hypothesis was that the ceramic pot to which this fragment belongs was inscribed in a revolution solid. The correspondent revolution axis and the generatrix profile were defined through a sequence of operations described bellow.

3.1. Revolution axis estimation

The proposed method is based on the geometric properties of a revolution solid, which defines that any horizontal section is a circle with centre contained in the rotation axis. The rim's well defined morphology of pottery biggest sherd, allowed the estimation of a horizontal plan of the object. In this case we have defined a circle passing through one of the flutes.

Making the plan that contains this circle our horizontal reference we have sliced the fragment in several parts obtaining horizontal sections that, theoretically, should describe concentric circles, defining our rotation axis.

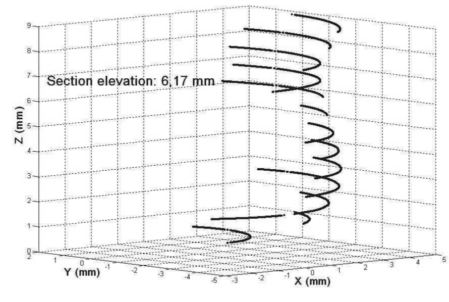

Figure 8 – *Horizontal sections.*

The sections obtained from the model were imported to Matlab (The MathWorks, Inc., USA), in order to calculate their best fit circle. Due to the fact that the exterior sections of the model reflected all the irregularities of decorations, we decide to use only the interior sections of the fragment.

The sections that intercept the medallion and handle regions also revealed a deformation to the interior of the pot (some considerations on this subject are presented in the conclusions at the end of this article). The parts where this kind of deformation was identified were excluded from the data set to avoid erroneous results in the average centre calculation.

Because the obtained sections were not completely inscribed in circles, we have calculated the best fit circle for each section data using Least Squares Method (LSM), the ordinary version once it was not given any weight to data observations [Abd03]. The rotation axis, perpendicular to the previously defined horizontal plan, was defined from the average centre of all the circles.

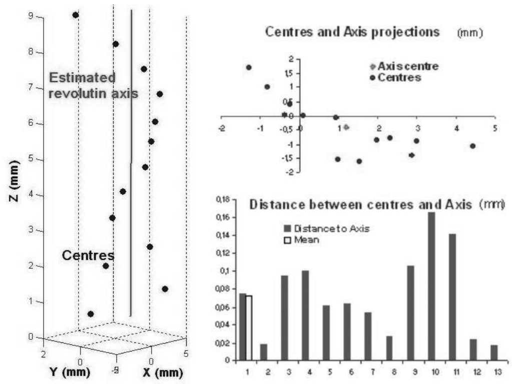

Figure 9 – *Axonometric representation of all the centres of the adjusted circles and the calculated rotation axis (left); centres and rotation axis horizontal projection (top right); distance from centres to the rotation axis and the respective mean distance (0.072 mm) (bottom right).*

3.2. Profile

The generatrix profile was defined from vertical radial sections of the model, calculated from the intersection of a vertical plan containing the previously defined revolution axis and the model.

Analysing the overlay of all the sections some irregularities were identified and excluded: ornamental features in the outside of the pot and inside deformations.

After removing patches and redundant data a simplified profile was manually estimated.

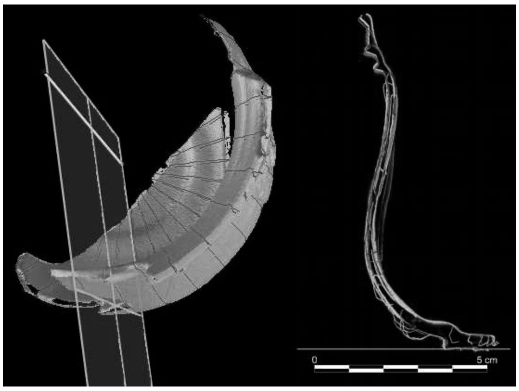

Figure 10 – *3D model radial sections (left) and overlay of sections (right).*

3.3. Symmetry plans

To corroborate the archaeologist's hypothesis of a bi-symmetrical scheme from the handles and medallions positioning two vertical plans were defined, one through the centre of the medallion and the other through the vertical axis of the handle. The intersection angle of these plans was 89.25º.

4. Virtual Reconstruction

The definition of the profile and rotation axis provided the basic elements to rebuild the virtual ceramic pot.

Figure 11 - ***Revolution solid.***

Next stage in virtual reconstruction process was the placement of the loose fragments. The fragment that contains the second medallion was placed in the symmetrical position of the first one using the previously defined symmetry plan.

The position estimation of the three smallest fragments was not so easy. Because they do not present any singular feature that could allow a direct interpretation a new methodology was developed based on decoration pattern that use the same symmetry plans centred on the medallion and handle position. The first step was to draw the existing pattern on the major fragment.

Figure 12 - ***Decorative elements restitution.***

Using the symmetry plans defined by the medallion and handle this pattern was reproduced to the inexistent areas of the model. This drawing was the key to find the possible places of each small fragment. From the visual analysis of the decorative pattern we were able to find the unique place for each fragment, in this way they were placed in their original positions.

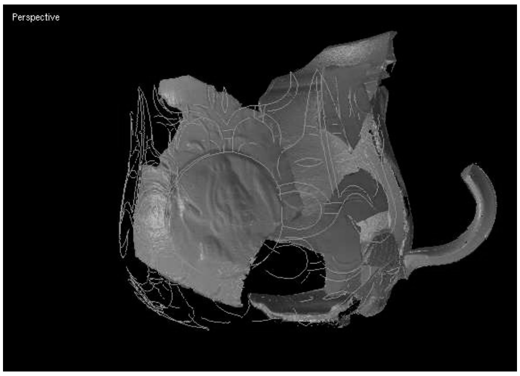

Figure 13 – *Fragments placement and decorative pattern restitution.*

The last step was the placement of a probable second handle, according to archaeological interpretation, in a symmetric position to the first one. This concluded the virtual reconstruction process and provided a hybrid model merging existing fragments with the geometric shape construction.

Figure 14 – *Hypothetical virtual reconstruction model with overlay of existing fragments***.**

5. Conclusions

The extreme quality of this ceramic pot, in a morphologic and decorative point of view, led to an unanswered question: for what purpose was this small ceramic pot made?

Some of the results of this study are very intriguing: the thickness of the pot's walls (2mm) reveals an extreme perfection in the manufacturing process and, if we think on the handmade decorative incisions (1mm deep), one can conclude that this piece of art was made by a very skilled craftsman. Another aspect is the geometric regularity of all the sections, both horizontal and radial (in the first ones the biggest value of centre dispersion is less than 2 mm).

The knowledge acquired in this work along with the archaeologists contribution and collaboration in all the phases of this study allows us to propose a step-by-step constructive process. The first operation was the construction of the main body, probably in a potter's wheel, although some questions arise when we think on the perfection of some geometric features. After the moulded elements (medallion and wreaths) were placed in the main body along with the handles (there is also the possibility that the rim could have been made by mould techniques, again because of its geometric perfection). The almost perfect symmetry, verified in this study, between the two moulded elements is another intriguing issue; were they placed with any special tool that could guarantee this geometric condition? One of the contributions of this work to the understanding of the constructive process was the detection of two small depressions on the inside of the pot's major fragment, due to the pressure made to attach the moulded elements. From here we can deduce that the clay was still fresh by the time of moulds placement. After, the decoration was engraved with a sharp tool by, has we said before, a very skilled craftsman. The finishing was a thin layer of watered clay, slightly darker than the original clay.

The incredible amount of effort and technical complexity to accomplish this small piece of pottery is more close to jewellery than to ceramic production. Just after we concluded this study two identical medallions were found in two different monasteries in the north of Portugal.

Maybe these artifacts were produced in a semi-industrial process, what could explain some of the singular geometric characteristics analysed in this study.

Acknowledgments

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Marketing the Past: Ethics and Values in the Archaeological Heritage Management of Greece

E. Anesti[1] and A. Polyzoudi[2]

[1]Ministry of Culture, 3rd Ephorate of Prehistoric and Classical Antiquities, Greece
[2]Ministry of Culture, 10th Ephorate of Byzantine Antiquities, Greece

Abstract

The cultural marketing in digital or non digital forms constitues a fundamental element of the management of cultural agencies and its main aim is to improve the communication between the cultural institutions and the public and also making access to the knowledge. When heritage is viewed in marketing terms it is presented as a "product" and the visitor to a museum or to the ancient monument becomes a "customer". The commodification of the heritage products automatically implies their exchange/economic values in order to be competive in the market world. But what are the interpretive tools of that process and who controls them? Who sets the agenda? What are the theoretical and practical implications? What is the legislative and the administrative framework in which the cultural marketing is expressed or what should it be? What are the ethical implications of the e-marketing of the heritage products?

Based on the definitions derived from sociolgy, anthropology and archaeology theories and our personal experience we will first attempt to explore and define the relations between the cultural "exchange products", the e-marketing process and the public by evaluating the pros and cons of that kind of access to knowledge, setting in that way the theoretical background. We will then focus on discussing the necessity of professional and ethical guidelines expressed in a legislative and administrative network which will control and confirm scientifically the quality of the provided knowledge. We will use two case studies from Greece, that of ARF (Archaeological Receipts Fund) and that of the Hellenic Culture Organization S.A. (e-museum shop) and through their promotion mechanisms, whether traditional or modern, we will discuss the practical implications of their activity.

1. Introduction

The cultural marketing in digital forms might offer new opportunities for supporting improvements on the communication between the cultural institutions and the public, making access to the knowledge. This paper particularly seeks to highlight the role of the cultural marketing process in the context of theoretical and practical background of heritage interpretation.

2. Related social-anthropological theories

In order to explore and define the relations between the cultural "exchange products", the e-marketing process and the public through the valuing ancient things, it is usefull to have in mind some social-anthropological theories.

2.1 Rubbish Theory: The Creation and Destruction of Value.

According to Thompson's theory there are three categories of value into which any material may be placed: transient things are those of which the value is decreasing over time; durable things are those of which the value is increasing over time; things with no value are rubbish [Tho79].

2.2 The Political Economy of the Sign

According to Jean Baudrillard there are four contemporary 'codes of values' which occupy spaces in the different socio-economic realms of production and consumption. Use value and economic exchange value represent values operative in the realm of production and also the realm of traditional political economy, where 'objects are primarily a function of needs and take on their meaning in the economic relation man to his environment' [Bau 81].

Also, sign exchange value and symbolic exchange value, represent values operative in the realm of what he calls 'the political economy of the sign' representing 'the value of social prestation of rivarly' which he distinguishes from that of economic competition [Bau 81].

Two conversions from one value to another, according to Baudrillard, represent the processes of political economy – the conversion from use value to exchange value and back which is the equivalent of the 'commodity phase' in an object's life cycle [App86]. A further conversion represent the promotion of material to the symbolic realm.

2.3 Distinction

Last, what Pierre Bourdieu suggests is that 'the sacred sphere of culture implies an affirmation of those who can be satisfied with the …distinguished pleasures forever closed to the profane; that is why art and cultural consumption are predisposed … to fulfil a social function of legitimating social differences [Bou84].

Based on the above theories it is getting clear that notions of value are central to the consideration of the purpose of creating, maintaining and promoting a set aside as 'heritage' and its 'products'. Differences in understanding the purpose of heritage result in differing schemes of value, each of which draws upon a founding principle of heritage management, derives from a source discipline outside archaeology and offers a particular value scheme resulting in specific types of value; a financial value may be placed on a heritage object, as measured by its market value, if any, its replacement cost or how much people are prepared to pay to maintain it or aquire it.

3. Cultural Marketing in the "digital market"

In our attempt to explore the practical implications of cultural marketing we will focus on discussing the necessity of professional and ethical guidelines expressed in a legislative and administrative network.

The use of cultural marketing in the digital world and in the internet, provide the ability of promoting effectively the cultural goods, and developing Cultural Markets in local and in world level. These markets, working in an independent base, will establish the new «Digital Economy», which will support, strengthen and promote the cultural action , at the same time with the government´s financial support.

Of course, for more effective results we need a suitable regulating and legislative frame. This will prohibit the transformation of the projection and promotion of cultural goods in a profitable enterprise of sale, which support the system of an illicit and uncontrolled competition.

It becomes, therefore, explicit that in the "digital world", each government must have an intervention, through the configuration of regulating frame, which will represent the public interest for the protection of the cultural heritage.

4. Cultural Marketing "in action"

We will use two case studies from Greece, that of Archaeological Receipts Fund (ARF) and that of the Hellenic Culture Organization S.A. (e-museum shop) and through their promotion mechanisms, whether traditional or modern, we will try to shed light to the legislative and administrative guidelines of their activity.

The *Archaeological Receipts Fund (ARF)* is a Public Corporate Body under the Ministry of Culture in Greece. It is the main body responsible for allocating the income deriving from various forms of exploitation of the Greek cultural heritage, which it makes available for the projection, protection and promotion of the archeological sites and monuments of Greece, and in general, to support the work of the archeological service.

It is based in Athens, and has facilities (offices, laboratories, storerooms) in various other cities. The personnel of the ARF are engaged both in supporting the aims of the organization, and in covering the needs of the services of the Ministry of Culture, especially those in the provinces. The ARF strives continually to upgrade its role, by modernizing its operations, extending the area of its productive activities, and developing the range of services it provides.

The administration and personnel of the ARF play an active part in this endeavour and make a decisive contribution to the new institutional framework.

Today, ARF is the most important institution through which the Greek cultural heritage promoted, while at the same time are economised also the essential resources that will help the viability of the Ministry of Culture. It is, moreover, known that in Greece the government owned sums that are given for the culture are particularly small and do not cover the needs. This situation strengthens more the importance of ARF, which, through its activities ensured moreover financial sums for the culture with parallel distribution and promotion of cultural goods in the public.

The strategy of marketing in this particular institution includes the publication and the distribution of specialised archaeological studies and periodicals and publications of wider archaeological interest, the production and distribution of visual aids of an archaeological character, the creation and running of laboratories to produce casts and authentic copies of items in museums, the production and distribution of authentic copies and applications of archaeological motifs produced by the ARF (casts, wall-paintings, Byzantine icons, jewellery, etc.) and items produced by third parties for sale on consignment. Also, it includes the organisation of displays and shops in museums and archaeological sites in Greece for the distribution of items produced by the ARF, the organisation of exhibitions of an archaeological character, with copies of ancient works of art, in cooperation with the Ministry of Culture and other bodies, the collection of duties and the legal safeguarding of the copyrights of the ARF, the inspection of private companies and individuals who make and sell copies of ancient objects and finally, the administration and economic management of regular contracts.

In this point, it will be necessary to emphasize that the process of promotion and marketing should be consistent with the rules of the Public Interest and they must protect the cultural heritage from the cheap commercialisation and economic exploitation. For this reason, it would be necessary the existence of regulating legislative frame which would prohibit the industrialisation and protect the basic and fundamental meaning of culture.

The context for all the activities of ARF is determined by the renewed, being in force, Archaeological Law (N3028/2002), which is presented very strict in topics and subjects that are related to the protection of cultural heritage. The activity of ARF that is related with the multi-production and distribution of authentic copies and applications of archaeological motifs, presents a particular interest, because it still exists the opinion that a work of art, when it is copied and multiplied, loses his uniqueness and does not belong more in the High Art.

The regulating frame in this case is also determined by ARF which characteristically says «…. . Our fundamental objective constitutes the, as possible, exact copy of the original museum exhibit, whether this is a big statue of classical antiquity or a small bead of necklace. Thus, we choose the objects in our collections, taking into consideration the aesthetic effect on the contemporary art, in connection with the state of maintenance of the original masterpieces in the museums. The entire process of re-production is overseen in all stages by the archaeologists of ARF, and have been made by specialised craftsmen and artists…. »

The second case-study is the *Hellenic Culture Organization S.A.* The company was founded by the 1997 "Institutions, Measures and Actions for Cultural Development" law of the Hellenic State, which was enriched by relevant amendments in 2000.

The aim of the company is to promote the cultural heritage and resources of the country, as well as to organize and endorse the Cultural Olympiada. To achieve these aims, the company started being active placing emphasis on two key areas:

a.The field of organizing complete programs of cultural activities, as part of the Cultural Olympiada.

b.The field of the promotion and endorsement of the Hellenic Heritage and the cultural potential of the country, emphasizing on digital applications and taking advantage of the opportunities offered by the Information Society in the frame of rules of conduct and the currents of the New Economy.

More specifically, the activities of the Company include the following:

- The production, publication and distribution of books, journals and other printed literature, audio-visual material, photographs, games or related items associated with the promotion of our cultural heritage, of contemporary Greek culture and the Cultural Olympiada, as well as the organisation of conferences and other similar events.
- The administration of the rights of the Greek state over the various features of our cultural heritage, in sofar as these are, individually or in thematic areas, made the responsibility of the Company by decision of the Ministry of Culture, with the approval of the Central Archaeological Council, where necessary.
- The preparation of feasibility studies and the commissioning of studies associated with the Cultural Olympiada.
- The planning and implementation of programmes and activities concerning the Cultural Olympiada
- The promotion of the Cultural Olympiada in Greece and abroad.
- The drawing up of contracts with the state or with any other natural or legal person, in public or private law, concerning the Cultural Olympiada.

In his well designed web page, Hellenic Culture Organization presents the activities and at the same time, through the *e - museum shop* gives anybody the opportunity to buy authentic copies from museum exhibits . The e-museum shop is the the ninth and the largest branch among HCO’s museums shops. There, you simply select the products you desire and the EMS (Electronic Museum Shop) will deliver them to you.

The legislative frame, as it is expressed in various forms, when is harmonised with the Public Interest, has the ability of preventing the uncontrolled and illicit competition which is unfortunately encouraged by the free market. It has also the possibility of rescuing the prestige of the identity of cultural goods, which are, nowadays, trading into the environment of the World Web.

5. Conclusion

The cultural marketing constitutes one of the basic operations of administration and cultural management. The basic aim of a complete marketing strategy, which includes market research, publicity, promotion and projection of the «competitive advantage» of specific cultural goods and cultural services, is to gain the disposal of the consumers precious "free time", which for them is translated in personal and economic cost.

However, what is totally required is, on one hand, a specialised personnel with scientific knowledge making use of accurate interpretive tools and methodology and, on the other, an organised legislative and administrative frame of regulating rules which will protect the cultural heritage and the maintenance of cultural identity.

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E-Historical Site. Documenting and Protecting Sharing 3d Geodbase

Raffaella Brumana, Federico Prandi

DIIAR - Polytechnic of Milan P.za Leonardo da Vinci, 32 – 20133 Milan
Laboratorio di Rilievo Cartografia numerica GIS

Abstract

This work is part of the research project developed to build an information system that can improve the level of protection and raise the value of historical sites: consequently it has to be used and shared outside the closed perimeter in which it was built.
The e-historical site aims to draw attention to the relationship between the evolution of data typologies to be collected and the web sharing methods to the maximum number of users.
There are three topics of research carried out from the research group through the studies on different kinds of historical centres (from the famous Genoa's one executed some years ago, to the three smaller studies in Cantù conducted over the past three years and today still in progress) attempting to improve the 3D data published and shared in particular urban contexts.
The issues this study aims to address are as follows. Which types of 3D models can be implemented in order to minimize costs and maximize benefits? Which type of E-3D sharing levels can bridge GIS technology and Virtual Reality through the web?
Different solutions may include a base level such as VRML model generated by GIS (ArcGIS) system to the more suitable .skp 3D model to be shared between the web and local station by professionals in the more common software such us CAD, SketchUp, 3D Studio,…). Publishing 3D geodata built in a GIS on the web on Google Earth allows users to independently download and implement 3D data according to the scope of their own project. Alternatively, full E-3DGIS systems are most often realized and are usable by external users at the state of the art; they offer opportunities but also problems that need to be studied.

1. E-sharing geo-info inside the risk map: an opportunity to improve cultural heritage protection policies and historical sites in residential areas

Collection and organized management of the knowledge acquired is essential to arriving at correct policies of integrated conservation of the cultural heritage as a situation in constant change. GIS, viewed in an open and updated form, can become a support to the processes of city planning of 'historical sites'.
Georeferencing, as a collection of space-time data, is developing thanks to the contribution of archeometric disciplines. The co-relationship between 2D-3D historical and current cartographies can contribute to augmenting the knowledge of the history of small sites – ostensibly anonymous and without ancient characteristics - , interpreted in the state of art through the material traces of the changes taking place over centuries, like in the case study here described. It can contribute to guiding contemporary transformation, supporting sustainable development and a programmed maintenance policy – with the active participated protection of the resident community - and transparent sharing of geo-information in public institutions and the scientific community extended to professionals.
The starting point of this research[1] is evolution of the cataloguing concept[2], which is addressed to the drafting project of Risk Map[3], conducted at a regional scale by the Region of Lombardy, starting with technical specifications of georeferencing cultural heritage with GIS technology.
It opens up many considerations and is closely related with parallel studies on complex themes of scheduled maintenance, conservation and identification of suitable methods of analysis and intervention policies, developed on an architectonic scale but strictly related to the context scale.
Today "a new role for environmental context[4] in the Risk Map is taking shape, which can emphasize the risks, but also point out the opportunities for use and development that cultural heritage offers, constitutive factor of territorial identities."

1 The Lab group of research involved in this work is composed by young researcher, PhD students in Geodesy and Geomatic (Prandi F., Fassi F.) on 3D Laser Scanner modelling and 3DGIS specifications, Uggeri G. on sharing 3Dmodel on the Web, Alessandro Rampin developing WEBGIS interface, Achille C. (junior researcher) for developing GIS 3D on Historical site, Oreni D. PhD on Historical Site Protecting

2 www.iccd.beniculturali.it; www.regionibeniculturali.it/leggi/altro/dwd/cat_bbcc.doc;

3 AA.VV., 1987. La carta del rischio del patrimonio culturale. Ministero BB.CC.AA., Ufficio Centrale per i beni archeologici, artistici e storici – Istituto Centrale per il Restauro, ICR – Bonifica P; Brumana R., Monti C., 2004. La Carta del Rischio del patrimonio culturale in Lombardia. Guida per la georeferenziazione dei beni storico-architettonici. Guerini e Associati, Milano

4 CulturAlp project, approved within UE community Interreg III B program (one of the leader project is Lombardy Region), is finalized to the valorization of historical alpine centers

Research into georeferencing methods for localization and value enhancement of cultural heritage in Italy has increased over the years, conducted in well-known historical centres as well as in 'minor centres,' as part of the risk map of cultural heritage. The interest in their conservation focuses on attention to the territorial scale of the historical-documentary-environmental stratified values and has several goals - artistic heritage protection and rediscovery of identity and collective cultural roots, in the conviction that the building heritage is not only an economic and social resource, but can become an opportunity to improve the quality of 'urban living'. The key purpose of georeferencing is the creation of geographic visualization of territorial distribution, with a view to creating a map of architectural heritage.

Moving from the mentioned specification guide towards an advanced concept of georeferencing through the use of historical maps and historical 3D views in a GIS, in the specific case of historical sites, the issue remains: how can the three-dimensional perspective involve, in a GIS, the historic 3D view map in reading and protecting the state of the art of a complex system of objects? How can the Topographic DBase be improved to support 3D views from *bottom to top* at a human scale?

2. From geodbase -- >>> to the WEB GIS e-Historical site (the Cantù sites)

Using the experience of a WEB GIS prototype realized for the historical centre of Genoa five years ago[5], the starting point is the e-sharing Dbase documentation of historical data - state of the art, state of decay, and municipality data - georeferenced on each building. To share useful information, the first requirement is the inquiring level and WEB GIS agile access.

The first topic has been to make available GIS data through the web (e-historical site of Cantù) to use the work done by the municipality and public administration (PA) in all documentation phases, in all the informative data processing and in construction of the GIS (Fig.1).

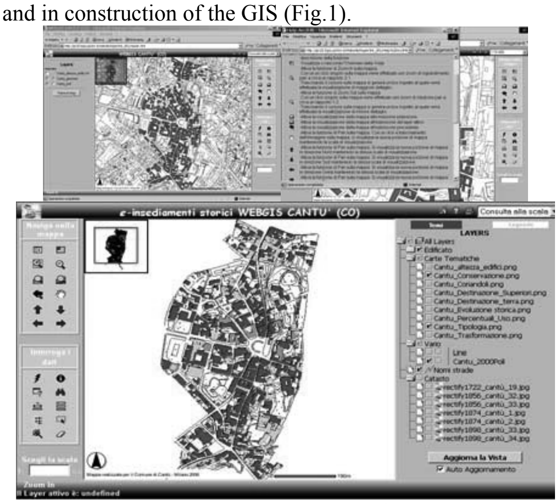


Figure 1: *E-**Historical** site of Cantu*'.
HOME page, HELP Menù (Zooming, Info,…), Legend description of the thematic raster map published.
The SHEMA GUIDE of the possible functions structured on different levels of access: from the easier built on raster thematic map with sensitive area for local and global info about the GeoDbase, to the complex ones on the published shp file to support advanced query. Functions available:

- *info-consulting*
- *geographic thematic map consulting*
- *consulting historical georeferenced cadastral map*
- *sql query by remote server querying*
- *downloading (hierarchical access PWD)*
- *3D advanced information sharing*

Obviously, the consulting level, like a reference glossary, is only the first step and we must continue.

The second issue is how to improve the knowledge, and consequently, the protection of minor historical sites distributed on the territory – many of which are considered anonymous and have been destroyed by transformation and re-use processes, eliminating all historical evidence - to raise the consciousness of the local community and professionals.

As part of the "guide of georeferencing cultural heritage for map of risk", the research has carried out some creases aspects connected to the spread diffusion of data to be georeferenced in case of historical sites in generation of flat GeoDBASE and in rising requirement analyses management.

The research looks for joining GIS with historical maps relating Archaeometric database collection. The result is the Web-GIS thematic map of the historic evolution and the levels of transformation of the historical centre, read on the historic cadastral map georeferenced to the technical map (Fig. 2). From SQL Querying GEODBASE on the E-web (Fig.1) → to the Downloading service of Ancient Cadastral Maps to the professionals and community, easy info related to the ancient and actual maps are shared to citizen till to professionals through downloading services (Fig.3a).

The third issue. Structural 2D georeferenced data collection and material-technological construction in a GIS are not enough in the project phases. The perspective must be changed from the flat planimetric geo-relation perspective to the 3Dview, to have a look at the elevation elements and the façades. Perhaps it is the case of archaeometric research about the chrono-typological analysis of the building volume and of its elements (such as window dimensions, accesses, shape of the arc) and finish analysis (stratigraphic, physical perception colorimetric analysis of the plaster). Interpretation of such data requires a shared 3Dview, orthogonal view along the frontal plane, and along different directions of the ancient roads and staircases, in order to be used by the professional in the project, implementing own data on a single building but using the 3D geo-data collected all over the historical context (Fig.3b).

In the same way, implementation of 3D models, to allow the reconstruction of the historic panoramic view of the perspectives and the 3D view of the particular landscape cone to be protected, may be disregarded unless we improve the level of e-sharing of this data constructed in a GIS environment, by promoting migration in an agile environment for the professional.

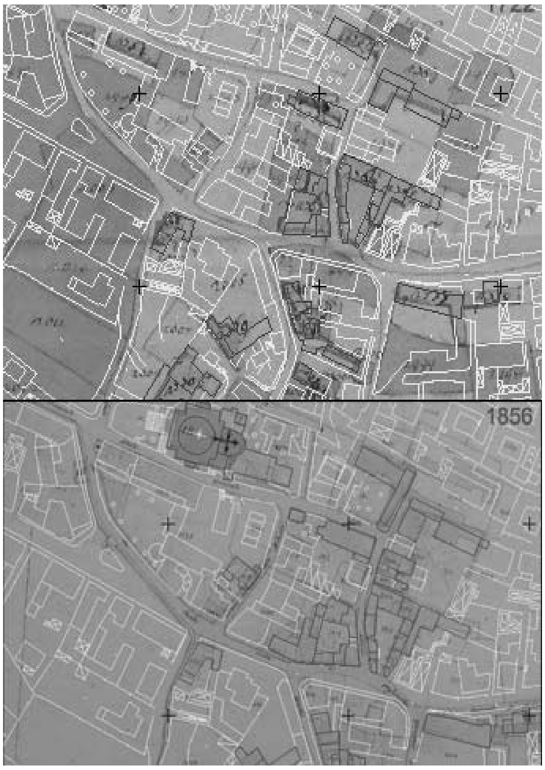
Inside the third issue, it is developed this problem: which type of 3D cartographic data is necessary in order to implement geodata from technical maps at a scale of 1.1000/1:2000, to 3D automatic plano-volumetric representation on the terrain model to allow mapping of georeferenced images (like rectified images or 3D orthophotos), to support the decay condition and finish analysis?.

Reconstruction of the shape of the urban characteristic element, such as staircases and containment wall of staircases, will allow 3D visualization supporting the analysis of the ancient façades.

A interesting new field of application is generation of a 3D view of the historical site in GIS constructed on the

[5] Brumana R., Savi C., Fregonese L., Achille C., 2001. Mapping on the internet and world wide centres: a web GIS on line prototype for the historical centre of Genoa, Int. Arch. ICC2001, Beijing, China

topographic database which can be implemented with photogrammetric-laser scanner survey.
The research wants to begin focus the definition of the 3D data specific requirement the development of 3D visualizer allows the navigation and three-dimensional analysis of the site.



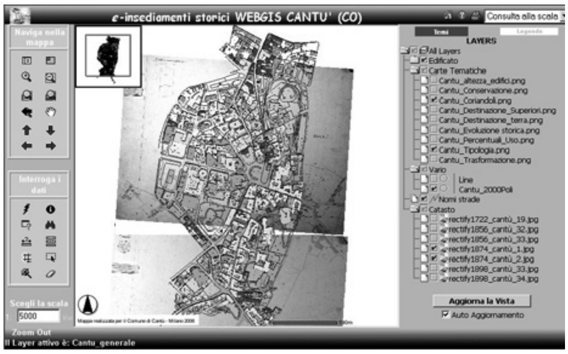


Figure 2: *The cadastral ancient map are georeferenced inside the GIS map of the historical site.*
E-sharing Geo-Information function to the resident community (easy info related to the ancient and actual maps) and to professionals through downloading services and GeoDbase querying (first, second, third pictures).
From SQL Querying GEODBASE on the E-web → to the Downloading service of Ancient Cadastral Maps to the professionals and community (fourth picture)

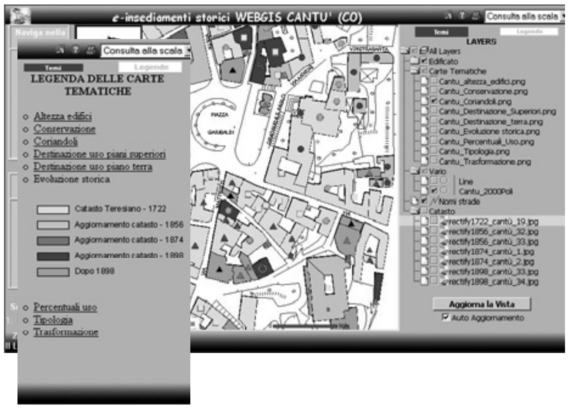


Figure 3a: *Web-GIS of the historic centre of Cantù, the thematic map of historic evolution and transformation of the historic centre read on the historic cadastral pre-existence map.*
Here is the legend related to the GIS thematic table.
The polygonal empty hatch colour refers to the period threshold value of the differing pre-existence in each cadastral map series of each building.

The coloured punctual symbols indicate the different levels of conservation and transformation obtained from the point-by-point reading of the survey campaign in each building, recorded in the Dbase and co-related to the historical cadastral series (from 1722 to the other maps):

- *analyzing demolition over the different centuries, with reconstruction on the same historical area on the shape of the historical map (black triangle);*
- *new build (magenta triangle);*
- *structural changes without respect for the original characteristics (blue triangle);*
- *changes to surface finish without respect for the original characteristics (yellow square);*
- *structural changes with respect for the original characteristics (green square);*
- *changes to surface finish with respect for the original characteristics (blue circle);*
- *remaining original characteristics (red circle).*

Figure 3b: *The evolution of the centre over the centuries is analyzed using the historical cadastral maps. The simultaneous reading of CTC scale 1:2000, of georeferenced cadastral maps (1722-1856-1874-1898) and of Dbase surveyed on site was related with transformation level of the buildings. Here is the staircases ancient system georeferenced to the technical map.*

3. Toward 3d-structured cartographic systems to support 3d view analysis relating past to future

In comparing historical views with current views extracted from the 3Dmodel, we find the most recurrent problems of geoinfo-lack in order to support advanced 3Dview obtained from pre-selected historical views positioned from the bottom, rather than the classical 'bird flight' (Fig.4-5).

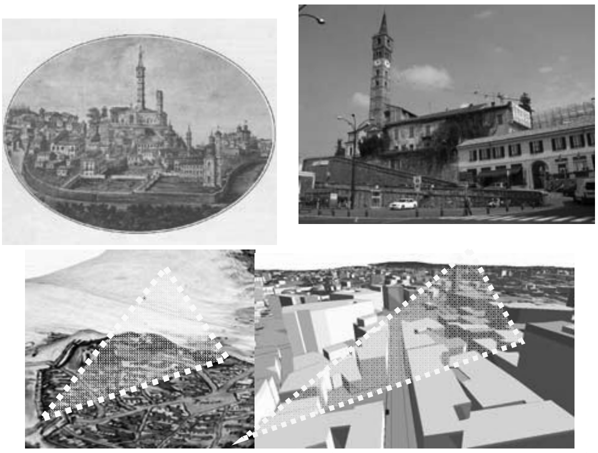


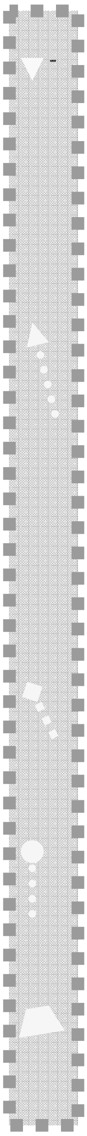
Figure 4: *An ancient 3D view of the historical walled site of Cantù, seen from the west (circa 1800) to the east. It is the View of the Basilica of S. Pauli, constructed in the late 11th century, which became in 1584 the 'Head church of the Cantù'. Relating and comparing the historic and the actual (lower side), acquired from the historic perspective of the Borromeo pastoral visit map XVI, the permanence of this preferential panoramic perspective from west to east of the Design of the Pieve of Cantù (bottom side) is recognized.*

International research on the advanced structures of 3D-cartography specification is making great efforts to supply the geographic info lacking as automatically as possible, with the minimum effort of survey and costs, through *integrated* steps:

- minimal integration of data survey
- identifying semantic feature classes
- identifying correspondent geographic entities
- improving logical-topological relations
- improving semi-automatic procedures to build 3D objects.

Here is a simplified sample of problems of 3D geographic information, in technical cartography 1:2000[6], in order to support an advanced model extracted from the selected historical perspective view: the point of view is positioned from the bottom up, instead of the classical '*bird flight'*. The problem samples are related to the different symbols to be represented on the different images and maps (Fig.4).

4. Geographic information lack to support 3DGIS data management



Semantic Feature Classes >>> Geographic Entities Through Topological Relation

(triangle) -- >*Lack of Ground Altimetric Point*

At the intersection of different sloping plan directions, as in case of the complex staircases branching off from the central point, the *ground points* are totally absent and need to be acquired to define 3D elements necessary to built up a 3D view with *unevenness* (Fig.5)

Points have been surveyed with Geodetic GPS Leica 1200 to build the flight steps beginning from the altimetric starting and ending point (Fig. 6)

(dotted line arrow) - - > *Wall containment*

The yellow dotted line arrow indicates the *wall containment (such as the scarp wall or the escarpment*), in this case the *staircase* wall was erroneously represented (Fig.5-6) due to the lack of geographic entities. Data is semi-automatically managed in the 3DGIS through a triangular, trapezoid shape. An easy automatic Lisp procedure was created to generate a 3DPoly from which to obtain a 3DPolygon beginning from the 2 upper points of the wall-head (starting and ending points) and from the ground points (horizontal projection in case of single point, sloping intersection in case of double points or of DTM enable. (Fig. 6)

(dotted line square) - - > *sloping road surface (ancient staircases)*

3D GIS management begins from the upper edge of the staircases, or previous slope road, through 3Dpoly, and than transforms them in 3DPolyg with discontinuous lines (Fig.5-10)

(dotted line circle) - - > *front view building (the case of mapping 3D urban view)*

3D GIS management of orthophotos, rectified images, or simple digital images acquired and mapped of the 3Dmodel has been implemented in ArcGIS (Fig.9)

(trapezoid) - - > *sloping surface - - > 3D pitch*

GIS modelling of historic site pitch. 3D GIS management of semi-automatic 3D pitch is obtained from the upper edge of the sloping roof and from the eaves line (Fig. 5-8-9)

---

[6] The Technical Map of the Municipality of Cantù (1995) is 2D with few 3D information, polygon auto-consistency, and 3D entities. In complex areas such as historic sites, the lacking info to generate 3D views from the bottom and front views requires advanced solutions

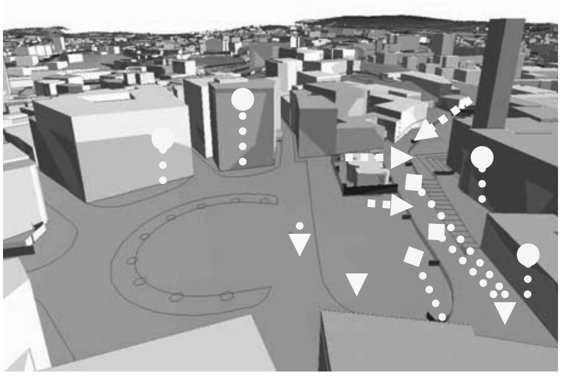


Figure 5: *Lacking 3DGeo-info sample. The skyline is reconstructed within the 3DGIS Map from the historical perspective. The 3D model return back 'flat' for less information if zoomed from a lower point of observation.*

5. 'Flat 3d model' > > > towards advanced 3d model developed from 3d historical view map

The starting point is represented by the 3D model built on the transformation thematic map (Figg. 5-6)[7]. The 'flat' attribute is not a paradox, if we consider the real potential of information which could be implemented.
This 3D flat model can contribute to some basic analyses, but it isn't enough with respect to the opportunities.
The result is not enough respect to the potential of 3dgis models could develop if better directed to support policies of safeguarding, sustainable transformation and re-use of historical sites: one of the future possibilities to support such complex policies would be to move beyond the '*flat 3D model*' towards an *'advanced 3D model'* beginning with the example of 3D historical view map directly involved in the knowledge process and in the conservation process to be shared.
Ongoing international and national research into management of the environment in more extensive ways (disaster prevention, risk analysis, VIA, urban policies, simulation, ecosystem analysis of complex problem) is involved in the generation of advanced standard 3DGEOdatabase, a sign of its recognized role.
Development of modern technologies, based on GML3-SVG standards for 3D geographic database and web publication, is addressed to ensure interoperability between data, subjects and exchangeable systems, free access and remote sharing between different platforms and geodatabase distributed *on line*. The actions promoted in international and national legislative reference points is particularly interesting, such as: internationally, the ISO TC/211 normative for the standardization criteria, documents about the use of XML/GML and the Open GIS Consortium (OGC). In Italy, these documents supply detailed information of the resolutions taken by the Technical Committee of "Intesa Stato-Regioni"[8] for the contents of the GeoDatabase (Topographic Database Technical and Content specifications, 2004).
Below are the preliminary results of research carried out by the research group,[9] especially regarding façades, roofs, and wall containments integration (Fig.6-9). The next step will be the 3D-congruence validation of topological adjacency in a 3Dspace of the staircases along the fronts and wall containments.

Key missing 3D information reconstructed in 3DGIS (Fig. 6 and sequences):
- *ground points* to define the 3D elements of a 3D view with lot of *unevenness* were totally absent
Below are some of the points to be surveyed by GPS to build the flight steps (triangle) beginning from the altimetric position of starting and ending point of each one, on which develop the 3D model.
- *wall escarpment* . The yellow arrow dot line indicates the *wall escarpment* erroneously represented due to the previous absence and managed inside 3DGIS development in order to represent it semi-automatically in the shaped elevation model (triangular, trapezoid,…).
- Respect to reality, one of the two existent perron is missing, the one parallel to the large one along the church.

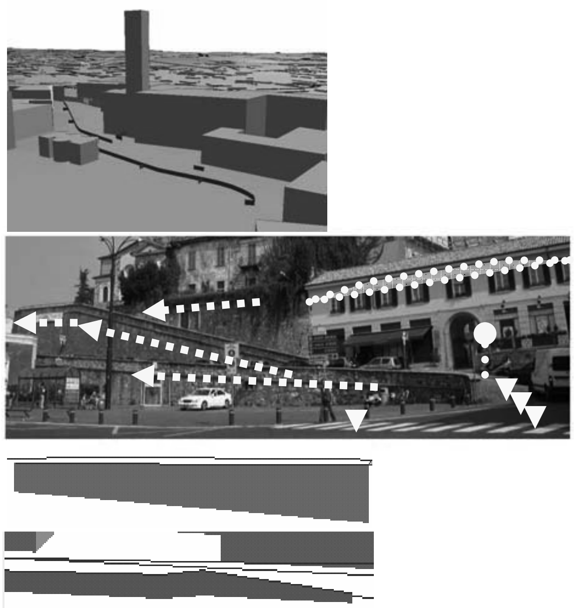


Figure 6: *Sequences of building 3DGIS object. From the flat 3D model to the advanced 3D model implemented in SketchUp (r.5.0) with technical map data integrated by absent data as explained (GPS survey, 3D ring poly – Complex surface). Here it is the case of the reconstruction of the staircases system with 3DPolygon*

[7] cfr. Brumana R., Achille C., E-historical sites. Georeferencing as availability of space-time data: historical cartography towards advanced 3Dview, in e-perimetron, it will be published in the International web journal on sciences and technologies affined to history of cartography and maps "e-Perimetron" in 2006 (Vol. 1-4), www.maplibrary.gr/e_perimetron and in Digital approaches to cartographic heritage ISBN 960-7999-18-5 Int.WS ICA WG on Digital Technologies in Cartographic Heritage

[8] "Intesa GIS" is an Agreement State-Region-Local Site for the realization of Geographical Information System, approved by State Region conferences. Topographic Database Technical and Content (DGR 18964 08 Oct. 2004 and modifications April 2006)

[9] Achille C., Oreni D., Prandi F., 2006, 3D data model for representing an historical center site, Part IV, 9.IV.1 UDMS 06, 25Th Urban Data Management Symposium, Aalborg, 2006;
Brumana R., Fassi F., Prandi F., 2006, Definition of the 3D content and geometric level of congruence of numeric cartography, International Symposium and Exhibition on Geoinformation, Kuala Lumpur, Malaysia, August 2006

Feature	Entity	Problem	Troubleshooting
Building	3D Complex Ring	Acquisition only of the boundary of the base of the features	Introduction of multipatch structure that allows wall generation
Wall	3D Polyline	Geometry does not allow complete definition of the object	Automatic generation of the vertical 3D Complex Ring starting of the 3D polyline
Staircase	???	Complex object, undefined geometry	Use of tools for manual modeling of the features
Scarp	3D Complex Ring	Geometry of features is not correctly acquired	Definition of a series of rules for Data acquisition

The 3D structured geodata is exported from ArcGIS (Esri) to the SketchUp environment for the modelling phase: the result is the model in Fig.7 (bottom side). This allows the public administration to construct interactive plan-volumetric representations more easily than only in a ArcGIS environment. It is also more shareable with respect to the external users beginning from the professionals, to minimize the costs of building 3D context and maximize the investment of the public economic resources with maximum of benefit.
Once exported and constructed, the 3D model (.skp format) can be re-imported into the ArcGIS environment through a free plug-in made by SketchUp according to Esri ArcGIS. In the U.S. these two environments are frequently interoperated to improve the geoinformation conjugated as best as possible in detailed contextualization views. The re-imported 3D model based on multipatch technology then becomes 3D geodata where it is possible to query and map thematic data (such us the level of conservations and transformations, in this case a part of the historic site, Fig. 7).
The actual possibility of quick generation of metric images obtained from photogrammetric processing (rectified images, orthophoto images obtained from 3D Laser Scanner clouds, etc.) requires a more integrated sharing solution to this kind of data[10]. The next step is texture mapping of these different kinds of images (including non-metric images) in SketchUp software (Figure 8, details). The information can be re-imported into ArcGIS

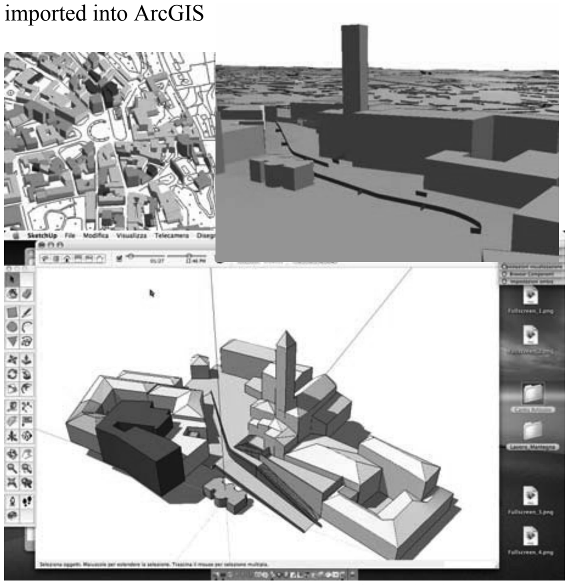


Figure 7: *The3D model implemented from the base technical map(bottom side): the Geo3D model can be integrated with the other GIS data, perhaps the historical analysis: it is constructed in SketchUp, and re-imported into ArcGIS*

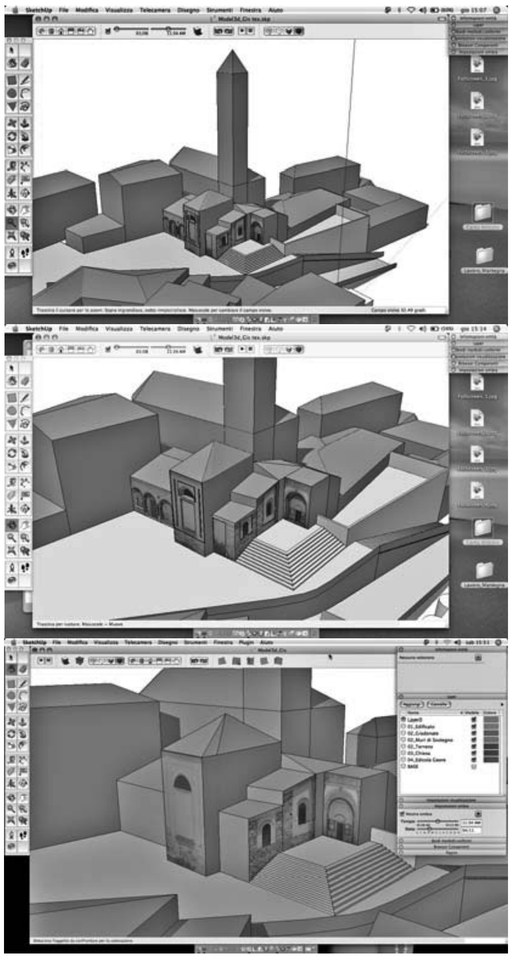


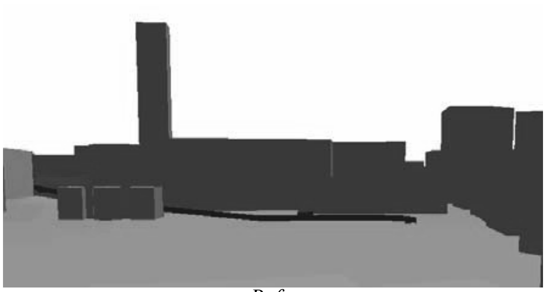
Figure 8: *Texture mapping of the 3D GEOModel inside SketchUp can be re-imported into ArcGIS*

10 Various Authors, 2004. Geography Markup Language (GML) 3.1.0 OpenGIS® Implementation Specification, OpenGIS® Consortium http://www.opengis.net/gml/3.1.0
www.intesagis.it and particularly:
Cfr. Intesa GIS-WG01, 2004 'Topographic Database Technical and Content of general interest'
ISO 19125-1 2004, Geographic information/Geomatics
ISO 19107 Geographic information – Spatial Schema
ISO 19118 Geographic information – Encoding
ISO 19136 GI- Geography MarkupLanguage (GML)
Cfr. www.regione.lombardia.it particularly:
"Intesa GIS" Agreement State-Region-Local Site for the realization of Geographical Information System, approved by State Region conferences. Topographic Database Technical and Content (DGR 18964 08 October 2004 and modifications 3 April 2006)
Regional Law for the Government of the Territory n. 12/2005 "*Legge per il Governo del Territorio*": the actions for the realization of Database Topographic to support the Integrated Informative System of the Lombardy Region are promoted through co-financed economic measures and DGR n.8/2323, 5 April 2006: criteria to assign financial resources to the Local Institutions

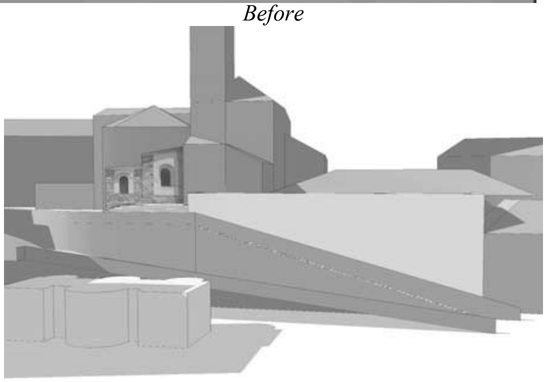
6. E-sharing 3dgeo-info world wide web on-Google Earth

The model as described can be accessed locally, in ArcGIS. The problem is that we need more information and need to improve the following functionalities:
- promote more agile Internet user access of 3D Geodata;
- maximize distribution of the 3DGoedata, as constructed, to the scientific, professional and resident community to optimize the costs and benefits of using data;
- allow specialists and professionals to maximize systematic integration of point and global data, images, Geo-data, et al, beginning with the model published by the public administration at different levels (municipality, region,…).

Which e-3Dsharing levels can act as a bridge between GIS technology and virtual reality through the web?
- one solution may be a base level, such as models generated by more common software (CAD, SketchUp, rhino, 3D studio..) shared on the web and imported/managed in GIS systems, while another might be full 3DGIS systems aligned with standard geometry models for computer graphics (X3D geospatial technologies, GML3).
  This solution appears to be most often realized and is used by external users at the state of the art; it offers opportunities but also problems that need to be studied.
  Here the proposed schema solutions:
- A base level, such as a VRML model generated by GIS system, allows navigation through the Web, it cannot be shared and imported into common environments dedicated to 3D implementation and contextualization, such us SketchUp: information such as raster info textures are only external files; the downloading process is split in two groups - models and textures. Consequently, the more compressed the texture, the faster the downloading will be. However, if we need high resolution, the integration becomes un-sustainable (VRML technology is not carried out).
- An agile user level based on other technology systems to be shared between the web and local stations by professionals in more common software such us CAD, SketchUp, 3D Studio,…). One example is the ability to export the 3Dgeo model from ArcGIS into SketchUp and then directly on Google Earth, in order to publish the GEOmodel (Fig.10) on the web. The model is archived in a Global Dbase that allows the user community to:
- visualize and navigate on Google Earth the 3Dmodel implemented in other published maps (satellite orthoimages at variable resolutions available), integrated with other 3D simplified models published by P.A.,… (Fig.10, first and second pictures);
- download locally the 3DGeodata model and other info in the .skp format (Fig.10, third picture);
- to extract 2D orthogonal façades along different directions, staircases, ancient roads (Fig. 9, the second one);
- implement the .skp model with other data collected by professionals to support the project phases (simulation, contextualization, VIA analysis,…) within commonly used software dedicated to these functionalities (Fig.10, details at the bottom side, with the downloaded model). SketchUp-Google Earth is freeware, while for importing–exporting into other software, it is possible to export other 3D formats (.obj interchange standard format for 3D Studio, Maya, Rhino) by acquiring a low-cost licence for SketchUp;
- to extract low-cost 3Dviews according to the ancient panoramic views to be protected as part of cultural heritage protection policies of historical sites, promoted by the public administration;
- to support planning of colour map of the façades in historical sites in a modern conservative way through integration of the information collected about the material characteristics (mortar of lime, sand, …) with the context and the historical use of the colour (Fig.9 lower right).



Before



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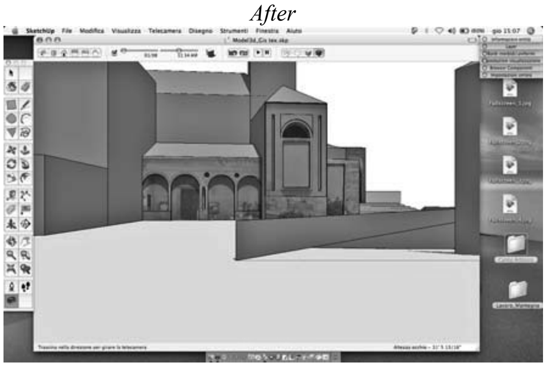

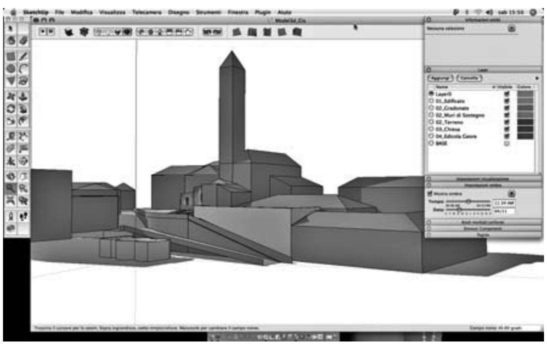

Figure 9: *E-3Dsharing GEO-info.*
Implementing 3d base model coming from technical large scale map is possible to relate paste to the future with historical info, ancient map views, state of the art of the fronts, staircases ancient systems, and so on.
This allows to improve the level of protection of monuments and context

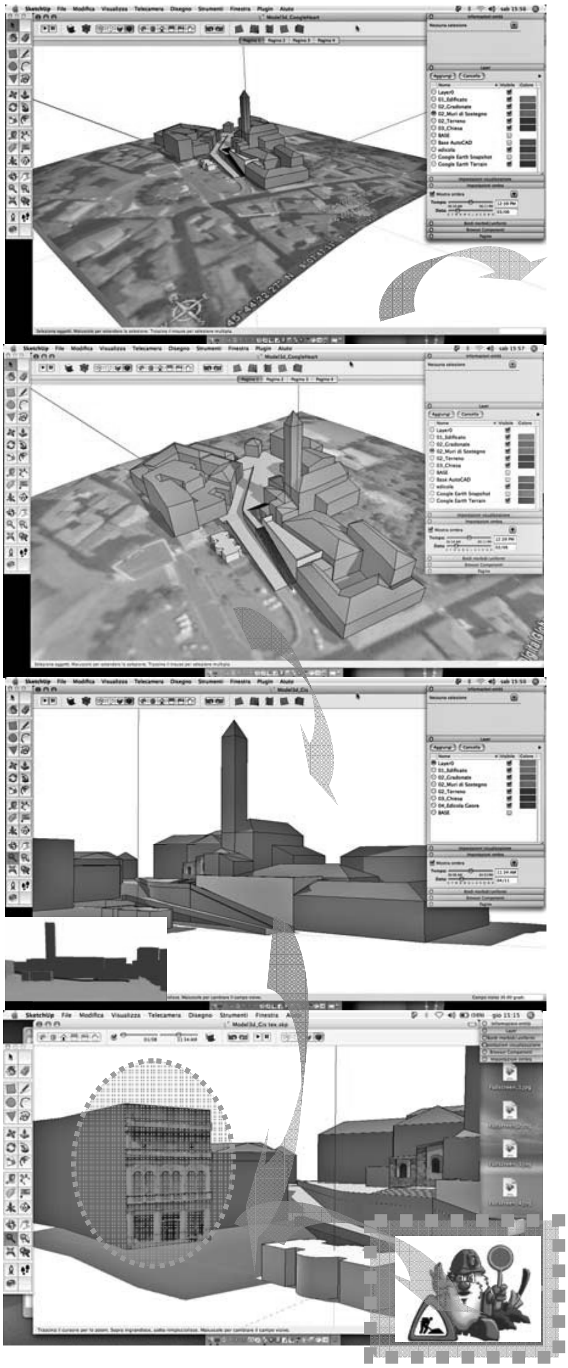

Figure 10: From *Public Administration (P.A.) to the citizens and to the professionals. E-3Dsharing Historical sites on Google Earth: Navigating, Downloading, Implementing Geo3d by external user, by the community of specialists, professionals and citizen. Interoperability between P.A. and professionals in sharing 3D technical map allows to grow up the knowledge of the historical site and to implement it inside the 3d model itself. Perhaps in this case the rectified image of the front of the palace in the last picture can be implemented by the professional inside the 3D model in order valuate the colour the lime and plaster in the context. On the traces of sample lime find out on the manufacts, it has been made chemical-physical analysis in order to support the new intervention and the project of restoration*

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Orthophoto production of non-developable surfaces. Case study implementation for documenting an early Mycenaean kipseloides tomb in N.Ionia Volos, Hellas

Efstratios Stambouloglou[1], Efthymios Stambouloglou[2], Elias Frentzos[3]

[1]PhD Candidate NTUA, [2]FOTOPO LTD, [3]PhD Candidate University Of Piraeus

Abstract

Creating two dimensional plans of three dimensional non developable objects is one of the fundamental problems that cartographers and geodesists have to face.
Choosing the best developable geometry (cone, cylinder, plane) to perform the projection in order to minimize distortions and make the plan comprehensible is another major problem.
In this case study a subterranean tomb was surveyed, using a combination of Photogrammetric and Geodetic techniques. The very nature of the tomb's construction, limited space and the undergoing excavation, made surveying the tomb a challenging task.
A three dimensional model of the inside of the tomb was created combining the results of two distinct methods. A georeferenced 3d point cloud was acquired via a robotized total station, and merged with the photogrammetric restitution from analytic and digital stereoplotters consisting of outlines and details of building elements in this case rough non-carved stones. To overcome the limitations of classic TIN creating algorithms, the 3D surface was divided in four separate parts and then merged in one.
The combined 3D TIN model created was then stored in a 3D R-Tree index.
Specially developed software was required to create the orthophotos. The R-Tree was used to perform line of sight (LOS) queries to determine the XYZ values.
The modus operandi to create the orthophotos is:
Image space, Space-resection, LOS, DSM xyz interpolation, projected normal to specified developable surface (cone), plan projection.
On the developed orthophotos the vector data of the photogrammetric restitution was superimposed.

Categories and Subject Descriptors: Architectural Photogrammetry, Non-Photorealistic Visualization, Orthophotos, Non-Developable Surfaces.

1. Introduction

Early Mycenaean Kipseloides Tombs are scattered around Hellas, but not many have been preserved in a state that scientists can draw safe conclusions on the techniques used in building them, or the People buried in them. All of the tombs found until now were either looted or in a semi-destroyed condition. This particular tomb was discovered by accident when earthworks for the construction of the ring road of Volos in N.Ionia Hellas were taking place. The excavator hit the "Keystone" of the tomb, which is the last stone to be placed when building the construction thus closing the last opening and supposedly contributing to the tomb's structural integrity. According to the archaeologist in charge of the excavations, Mrs. Vasiliki Adrimi, the construction of the tomb is placed in 1500 BC. Excavations to date have unearthed the entrance of the tomb with a small causeway. The real entrance was blocked by carefully laid rocks, making entering and exiting the tomb only possible from the relief triangle over the horizontal slab of rock bridging the top of the entrance. The relief triangle was large enough for a person to crawl inside. This made carrying measuring equipment harder than usual. Unlike the well known tomb of Atreas in Mycenae, this tomb was not built with well finished carved stones of cyclopean size. Instead it was built with rough non-carved stones which presented a very irregular non uniform surface. This led us to decide on using classic photogrammetry techniques together with topography methods to document the monument.

2. Surveying the Tomb. Problem Solving and merging of techniques

The tomb's base diameter is at 6.6 m, the floor of the tomb (laying at 6.1 m below ground) had four grave pits, which at the time of the surveying were still being excavated.

As shown in **figure 1** placing a tripod inside the tomb was not an easy task due to lack of space. A robotized Leica Total Station TCRA 1103 Plus was used to automatically measure control points as well as 3D points to form a georeferenced point cloud. In total about 5968 points where measured from 3 stations inside the tomb. All pre-marked control points were measured from at least 2 stations. The complete network was solved with control points treated as unknown stations.

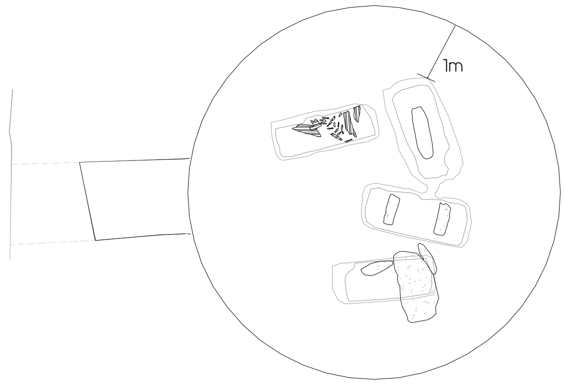

Figure 1: *Space restrictions inside the tomb*

3. Coordinate Systems/Control Network

20 premarked Control points were placed on the inside of the tomb. Because the use of a ladder to place control points on the upper half of the tomb was impossible, control points were established using the Total Station's laser pointer to identify the point that was then measured by the total station and photographed using a HP DX7440 4MP digital non-metric camera. (**Figure 2**). 20 non-marked control points were measured.

Figure 2: *Laser on a control point*

The control network was referenced to the Hellenic Geodetic Network.

Connecting the inside network of 3 stations to the outside network was made possible through the 40 cm diameter hole left by the now absent "Keystone" on the ceiling of the tomb.

Station network internal accuracy was at a mean of 2mm RMS XYZ, and control points at 3mm RMS XYZ.

An UMK 10/1318 metric camera was used for picture taking, because of its large format reducing total pictures needed dramatically. Five stereo models were needed to completely cover the inside of the tomb, using the UMK's large format. Four facing the points of the horizon, one facing the top. Accordingly and because of the tomb's shape, five coordinate systems were created for fotogrammetric restitution, which followed the general orientation of the stereomodels. Four of these where on vertical planes, one was horizontal with Z of the model parallel to the plumb line, for the ceiling of the tomb.

4. Restitution

Pictures taken with the UMK where in B/W, and were scanned at 2000dpi on a photogrammetric scanner.

Photogrammetric restitution was done in a Galileo Siscam Digicart 40 analytical stereplotter as well as on a digital photogrammetric workstation Siscam Stereometric Pro.

Result of the restitution was 3D brake lines of the outlines and details of building elements (rocks). The vector data was exported to CAD and merged with the measured point cloud in the global coordinate system

5. Surface construction

The vector data from the restitution was merged with the 3D point cloud to create a Digital Surface Model (DSM) of the inside of the tomb. Because of limitations of the Triangulated Irregular Network (TIN) algorithm, creating the DSM in commercial Computer Aided Design (CAD) software, required the surface to be broken down in four subsurfaces for creation and then merged back together. Blunder detection (i.e. identifying erroneous points in the point cloud) was a painstaking procedure because of the very nature of the surface making irregularities even harder to spot and remove. Automatic blunder detection was used and rejected. Blundered cloud points seemed to be occurring mostly because of humidity on the rocks as well as texture and dark color as is often the case with reflectorless laser distance measurement.

6. Shape Determination - Projection selection

Creating the model of the tomb, we were faced with the problem of deciding how we would make plans of the restitution and finally the orthophotos. The shape of the tomb, resembles that of a beehive (Kipseli). This surface does not necessarily have a deterministic mathematical representation. One cannot use one single geometry to approximate the entire surface without considerable error. Besides that and in order to create plan views and develop the surface we were bound to using developable shapes like the cylinder and the cone. For simple section representations, projections on planes running east-to-west and north-to-south were created (**figure 3**). The photorealistic visualizations of the 3D surface are renderings made in AutoCAD.

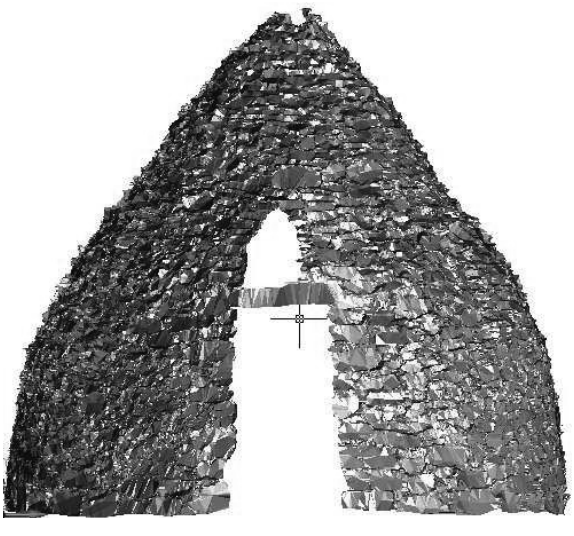

Figure 3: *Photorealistic plan of the west (entrance)*

According to *W.G.Cavanagh and R.R.Laxton*, these tombs were built in layers on circles of reducing radius. The actual curvature was such that allowed the construction to remain stable by weight/friction forces between the building elements and not because of the arch like construction. In investigating the shape we made 16 vertical sections (roughly every 20 degrees) and 10 horizontal sections (roughly every 60 cm). Least-squares fitting was used for the horizontal sections to determine the best fit circle. Data from the vertical as well as the horizontal sections show that the tomb has an axis of symmetry, even though deformation from earth settlement has occurred in the top part of the tomb. As such the axis used for subsequent operations, was the best fit axis that resulted from the bottom 7 levels. For these levels the center of the fitted circle had an RMS of 4cm from the mean value that was used. The axis is considered to be vertical and common for all cones/cylinders for ease of further calculations. Cone and cylinder fitting was then done using least squares. What we found out was that the Kipseloides shape could be approximated with good precision, using four distinct cones. More would not enhance precision, but instead make the plan harder to comprehend.

Following table shows the cones data.

	Cone I	Cone II	Cone III	Cone IV
Apex	106.59	107.35	111.05	133.62
Cone Opening (c=tan(ω/2))	0.779381	0.614958	0.342912	0.101034
Highest H	-	103.584	102.584	101.584
Lowest H	103.584	102.584	101.584	-

Where ω is the cone opening angle (see **figure 5**). As one can see the lowest cone (cone IV) is very close to being a cylinder and in fact our tests showed that a cylinder could be fitted in the lower part with around the same RMS figures, but to preserve uniformity we opted for a cone.

7. Projection

The final restitution was projected to the corresponding cone using simple mathematical functions and then developed on the plane. (**figure 7**)

The mathematical workflow was the following:

From Xg, Yg, Zg (global) to Xc,Yc,Zc (projected on the cone) to x, y (plan).

$$X_c = X_0 + rc \cdot \sin\left(Az_g\right)$$
$$Y_c = Y_0 + rc \cdot \cos\left(Az_g\right)$$
$$Z_c = \frac{-Z_0 \cdot c^2 - Z_g + rg \cdot c}{-\left(c^2 + 1\right)}$$

Figure 4: *Cone projected Coordinates*

Where:

$$rc = \frac{Z_0 \cdot c - Z_g \cdot c + rg \cdot c^2}{c^2 + 1}$$

$$rg = \sqrt{\left(X_g - X_0\right)^2 + \left(Y_g - Y_0\right)^2}$$

$$Az_g = \tan^{-1}\left(\frac{X_g - X_0}{Y_g - Y_0}\right)$$

$$c = \tan \omega$$

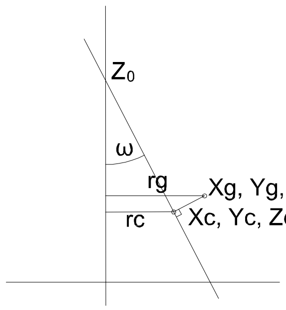

Figure 5: *Geometry of Cone Projection*

And X_0, Y_0, Z_0 are the calculated center and apex of the cone.

$$x = \rho_0 \cdot \sin \theta$$
$$y = \rho_0 \cdot \cos \theta$$

Figure 6: *Plan projected coordinates*

Where:

$$\theta = Az_g \cdot \sin \omega$$

$$\rho_0 = \frac{R}{c}$$

$$R = \frac{\sqrt{\left(X_c - X_0\right)^2 + \left(Y_c - Y_0\right)^2}}{\cos \omega}$$

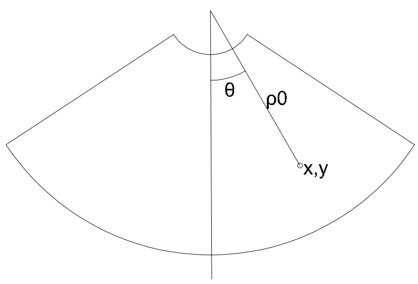

Figure 7: *Developed cone*

The end result is shown in **figure 8**.

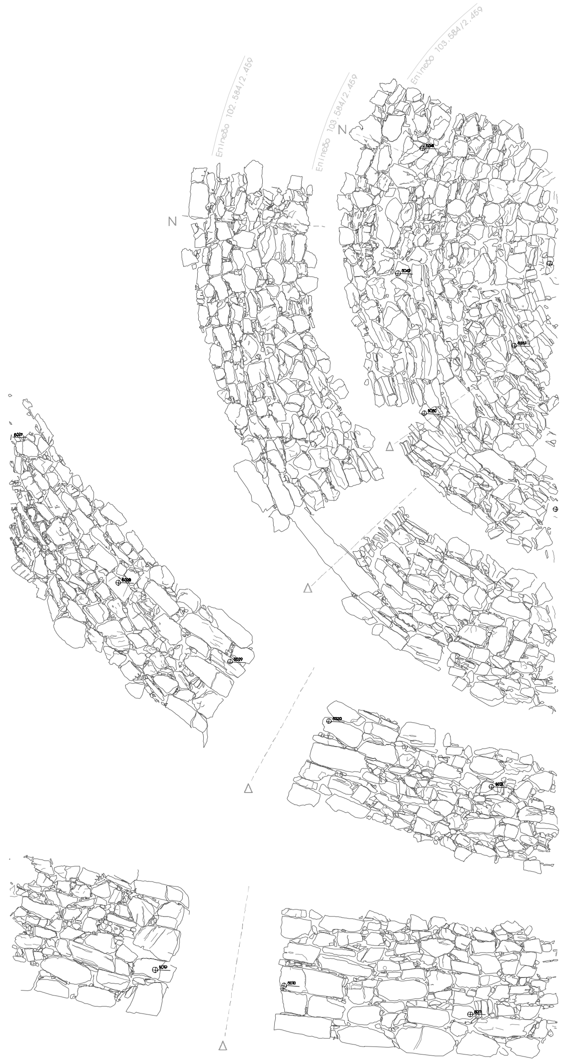

Figure 8: *Part of the final plan depicting 4 distinct cones*

8. Orthophoto Creation

The biggest challenge of this project was the creation of orthophotos for this non-developable surface. With external orientations of each photo known, the colinearity equation was used to determine the projective ray for each pixel of the photo. The projective ray was then intersected with the surface to determine Xg, Yg, Zg coordinates. The rest of the procedure is described in the previous step.

9. Determining The Line Of Sight – Surface intersection

The main problem we had to deal with was to develop an efficient technique in order to determine the *z*-value of each line of sight, given the object's surface as a set of 3*D* faces.

As mentioned before Traditional commercial TIN algorithms do not provide such unusual operations. As such, we developed specialized software based on the well-known R-tree [Gut84].

R-trees [Gut84, BKSS90, SRF87] are widely used in multidimensional databases in order to index such kind of data. R-trees can be considered as a multidimensional equivalent of the B^{+}-tree usually employed in commercial DBMS (Data Base Management System) to index typical data as numbers and texts. More specifically, the R-tree is a height-balanced tree with the index records in its leaf nodes containing pointers to the actual data objects. Leaf node entries are of the form (*id*, *MBR*), where *id* is an identifier that points to the actual object and *MBR (Minimum Bounding Rectangle)* is a *n*-dimensional (hyper-) rectangle approximation of the actual object. Non-leaf node entries are of the form (*ptr*, *MBR*), where *ptr* is a pointer to a child node, and *MBR* is the minimum bounding rectangle that covers all entries in the child node. A node in the tree corresponds to a disk page and contains between *m* and *M* entries (*M* is the node capacity and *m* is a tuning parameter – usually $m = M/2$). On the other hand, the structure of leaf node entries used in this paper are slightly different, since we replaced the pointer by the actual object (e.g.. the three 3*d* points composing each 3d face).

In order to achieve our objective, we need to define the Line-of-Sight query (LoS query), having as arguments two points (Base and Reference point), returning the first object with respect to the base point lying on the line connecting the base and the reference point. A Group Line-of-Sight query (GLoS query) is a generalization of the first query, using one base and many reference points, returning the first objects with respect to the base point lying on each one of the lines connecting the base and the reference points. However, to the best of our knowledge, there is no previous work on how to process a LoS and GLoS queries using R-trees.

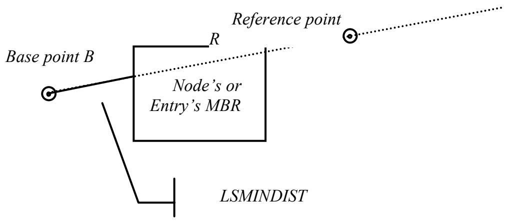

Figure 9: *LSMINDIST Definition.*

```
Algorithm LoS_ Search(node N, line_of_sight
LS, struct Visible)
 1.  IF N Is Leaf
 2.    FOR each leaf Entry in leaf node N
 3.      Q = Intersection(Entry, LS)
 4.      IF Q Exists
 5.        IF Q.Dist < Visible.Dist
 6.          Visible.Entry = Entry:
             Visible.Dist = Q.Dist
 7.        END IF
 8.      END IF
 9.    NEXT
10.  ELSE
11.    BranchList = GenLoSBranchList(LS, N)
12.    SortBranchList(BranchList)
13.    FOR Each Entry in BranchList
14.      LoS_DF_Search (Entry.ChildNode,
                        LS, Visible)
15.      PruneBranchList(BranchList,
                         Visible.Dist)
16.    NEXT
17.  END IF
```

Figure 10: *LoS_Search algorithm.*

Nevertheless, in this work we developed several efficient algorithms for the processing of LoS and GLoS queries. Particularly *LoS_Search* algorithm traverses the tree structure accessing tree nodes recursively as also shown in [RKV95]. The algorithm discards tree nodes according to the line of sight *LS* rejecting those who do not intersect it at all. At leaf level, the algorithm iterates through leaf entries checking whether an entry intersects *LS* and if so, the algorithm calculates the actual Euclidean distance between the *LS* base point and the resulted point of intersection (line 3) both returned as items of the *Q* structure; then, if necessary, the *Visible* structure is updated (lines 5-7). At non-leaf levels, the algorithm calculates *the active branch list* containing the child nodes intersecting *LS* along with their *minimum distance on the line of sight LSMINST* (shown in 2*d* in **Figure 9** – easily extended on the three dimensional space) and sorts them with the increasing order of their distance (lines 11-12). When a candidate *Visible* is selected, the algorithm, backtracking to the upper level, prunes the nodes in the active branch list: any object intersecting a line of sight *LS* inside an *MBR* has greater distance than the respective *LSMINDIST* between the *LS* and the *MBR* (see also **figure 9**). Finally, the algorithm returns the "winner" (e.g. the visible 3*d* face), along with the coordinates of the point intersecting the line of sight. The GLoS_Search algorithm exploits several lists in order to process the query in a single tree traversal; however the illustration of this algorithm deviates from the scope of this paper.

10. Conclusions

Current technology gives surveyors, architects and archaeologists alike, the ability to document monuments more efficiently and with greater detail.

Use of more adequate commercial software to create the surface would speed things up considerably and facilitate many operations like blundered points detection, erroneous restitution etc.

Automatic DSM mensuration was unusable because of the great differences in scale and perspective in the stereo models. The repetitive nature of the tomb's stone construction, made automatic matching even more problematic.

We are not convinced that using a Laser scanner would help considerably. It would be of help in creating the DSM but important brake line information on such a surface is almost impossible to extract. With stone sizes ranging from 2-3cm to a maximum of 30-40cm, and most outlines of rocks being irregular the point cloud should be very dense (at least every 4mm) and even then existing commercial packages have slim to none chances of automatically identifying outlines. Thus even if it is time consuming, the recommended method to document the monument was photogrammetric restitution. Because of space restrictions, the use of a Laser scanner was also troublesome. The weight and bulk of commercial laser scanners available, made using one objectionable.

If the only result would be orthophotographs, then a Laser Scanner would be a viable option.

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Quick And Accurate Digital Recording Of Archaeological Findings Using Photogrammetry And Laser Scanning

E. Stylianidis† and P. Patias

The Aristotle University of Thessaloniki, Department of Cadastre, Photogrammetry & Cartography, Thessaloniki, Greece

Abstract

In this paper we present and examine the involvement of Photogrammetry, Laser Scanning and 3D Reconstruction in the digital recording of archaeological findings (i.e. within the parcel of the Nicosia Sewerage Board) in the old city centre of the Capital of Cyprus, Nicosia.

The archaeological findings have been found during reconstructions works, while the diggers where trying to open a big hole on the ground to build the underground parking station. Archaeological excavations have taken place for a small period of time to the parcel and the results highlight a part of the long history of the city of Nicosia. In the paper we present the digital recording of the archaeological findings and give an overview of the introduction of Photogrammetry and laser scanning for a quick and accurate mapping. The results such as digital drawings and orthoimages of the entire excavation area had to be completed in short time otherwise the cost of the construction rises a lot.

Categories and Subject Descriptors (according to ACM CCS): I.3.5 [Computer Graphics]: Computational Geometry and Object Modeling I.4.5 [Image Processing and Computer Vision]: Reconstruction

1. Introduction

1.1. General

The digital recording, 3D reconstruction and visualization in the area of culture heritage are issues that were taken considerably into concern by the scientific community in the last few years and continue to be discussed in order to establish new methods and techniques. The various scientific issues that are involved in these cases are basically Photogrammetry, Computer Graphics and Archaeology, providing at the same time the opportunity for a multidimensional approach in the area of digital recording and archiving the different components of cultural heritage [BPH*03, Hak02, KFK*03].

The paper describes the role of Photogrammetry, 3D reconstruction and visualization within the framework of the digital recording and 3D reconstruction of archaeological findings that have been found during reconstruction works, at the parcel of Nicosia Sewerage Board at the city centre of the Capital of Cyprus, Nicosia.

The history of Nicosia begins with its initial occupation in the Neolithic period and continues through to the Chalcolithic (6th-3rd M.B. C.), a period also verified by the finds on the Hill of Agios Georgios, PA.SY.DY [Pil00, SCIP04]. In the Bronze Age there seems to have been a shift in the settlement but the limited evidence from rescue excavations at the earlier part of the 20th century indicate the presence of a prosperous settlement.

Traditionally the area of Nicosia was regarded as the site of one of the kingdoms of Cyprus, Ledroi, in which it was divided during the Iron Age. Little was known of the history of the city from this period, the 8th century to the Medieval, when Nicosia was the capital of the kingdom of the Lusignan and later of Venetian Cyprus.

The parcel of the Nicosia Sewerage Board is located at the heart of the old city of Nicosia (Figure 1). At the parcel a neo-classical building of the 20th century already exists and nowadays is reconstructed so as to host the new offices of the Nicosia Sewerage Board. During the reconstruction works, at the backyard of the parcel the construction company discovered the archaeological findings. After that, the responsible Department of Antiquities undertook the archaeological excavations to examine the entire area at the parcel and ventilate the findings. One of the major jobs of the project was

† stratos@geoimaging.com.cy

Figure 1: *The location of the excavation site within the old city centre of Nicosia*

the documentation of the archaeological findings in a quick and accurate way.

The paper presents the digital recording of the section of the referred parcel that archaeological had been found as well as an introduction of Photogrammetry, Laser Scanning, 3D reconstruction and visualization techniques for the documentation of cultural heritage.

1.2. Motivation and Aims

The decision for the recording of the archaeological findings within the parcel of the Nicosia Sewerage Board was taken by the relevant authorities, i.e. the Department of Antiquities. In order to proceed with the reconstruction of the building and the surrounding area, a detailed digital recording of all the findings came to light was necessary due to the existing legislation and relevant procedures.

The primary aim of the project concerned the photogrammetric mapping of the entire area that archaeological findings exist. The 3D reconstruction and visualization of the surrounding area and the accurate representation of the "archaeological excavation" through high resolution digital orthoimages provided the appropriate and substantial information for the documentation of the findings. Furthermore, it was necessary to provide a detailed vector map of the findings for archiving and documentation reasons.

2. Instruments

The Trimble GS200 (Figure 2) laser scanner was used for the laser scanning campaign. The Trimble GS200 scanning system has a rotating head and two internal high speed rotating mirrors that allow the acquisition of a scene with a wide field of view, i.e. 360˚ H x 60˚ V, reducing the need for a large number of scanning stations. The accuracy of this scanning system can reach down to 1.5mm at a distance of 50m with a beam diameter of 3mm at at a distance of 50m as well. Furthermore, the laser, expect X, Y and Z coordinates is able to capture the reflected beam intensity and RGB colors.

Figure 2: *GS200 laser scanner (www.mensi.com)*

Supplementary technical and other features of the Trimble GS200 laser scanner are illustrated on Table 1.

Manufacturer	Trimble	
Product	GS200	
Range	optimized to 200m, with 350m OverScan^{TM} capability	
Resolution	down to 32μrad (3mm at 100m)	
Accuracy	down to 1.5mm @ 50m (typical)	
Speed	up to 5000 pts/s	
Field of View	Horizontal	360˚
	Vertical	60˚
Weight	13.6 kg	
Size	340mm D x 270mm W x 420mm H	
Minimum Resolution	3mm @ 100m (32μrad)	

Table 1: *GS200 laser scanner specifications*

The Trimble GS200 (Figure 2) laser scanner has an on board video camera with low resolution characteristics, i.e. the video camera can capture colour images at a resolution of 768 x 576 pixels. Such resolution is extremely low for the production of high accuracy photogrammetric products. That is why a high resolution camera, the Cannon EOS 300D SLR (Figure 3, Table 2) was used to overcome the low resolution on board video products captured by the Trimble GS200 laser scanning system.

Canon EOS 300D SLR	
Sensor Resolution	6.3 Megapixel
Image Size	3072 x 2048
Lens	50 mm
Body	Cannon

Table 2: *Camera system specifications*

Figure 3: *Canon EOS 300D SLR (www.canon.com)*

3. Field campaign

The 3D reconstruction of the backside of the parcel where archaeological findings had been found was generally based on a rapid photogrammetric campaign. Once that the archaeological findings came into the light the Department of Antiquities undertook the excavations to study the interest area at the parcel and ventilate the findings.

Image acquisition has been realized using a crab from free spaces that the access to the excavation area was practicable. In Figure 4 indicative illustrations from the image acquisition campaign crab are given. Around 30 images have been obtained but only 4 were selected for further photogrammetric processing.

Laser scanning campaign led to the production of a dense cloud of point which by the appropriate processing led to the production of a detailed DTM as shown on Figure 5. Six 3D scans were enough to cover the whole excavation and provide the necessary 3D information for the surface model.The DTM was used to make possible the creation of the excavation site's orthoimages.

(a) South part

(b) North part

Figure 4: *Image acquisition facilitated by a crab on the south (a) and north part (b) of the excavation site*

Figure 5: *High dense DTM of the excavation site*

4. 3D reconstruction & visualization

4.1. General

The archaeologists are familiar with the documentation of the excavation and findings, either by means of traditional techniques, i.e. the hand surveys, or collaborate with professionals that are using edge-technology and novel techniques like the ones provided by Photogrammetry or GPS. They usually document the excavation's findings with the appropriate accuracy with the aim to restructure the established conditions as far as possible hundreds or thousands of years ago.

On the other hand, the visualization techniques offer the equipment for the creation of a "true" representation of the ancient scenes, i.e. how the situation was or is, and consequently the archaeologists may be more comprehensible to other professionals and to the public. Many different visualization processes exist; from simple hand drawings, to CAD drawings, GIS systems, 3D representations, animations and fly/walkthroughs or even stereoscopic representations in virtual reality applications.

The representation of the archaeological or excavation site must make available sufficient geometry and effectively detailed textures for the archaeologists to be able to work on them. On the other hand, it must be "light" enough, so as to allow for interactive viewing by the users. This initially was an issue, since the procedurally created geometry had a very large number of polygons, so it was processed to produce a lower resolution model which kept the overall appearance.

The addition of realistic textures hides any visible errors introduced by the simplification.

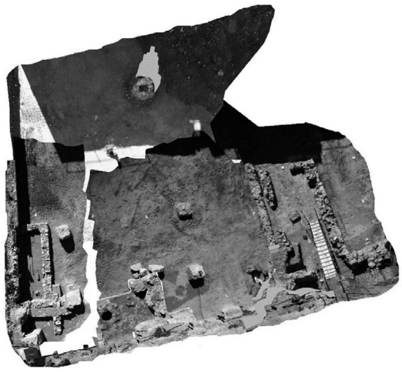
In the following four figures (Figure 6) indicative orthoimages and CAD drawings from the excavation site are shown to give the actual situation.

5. Conclusions

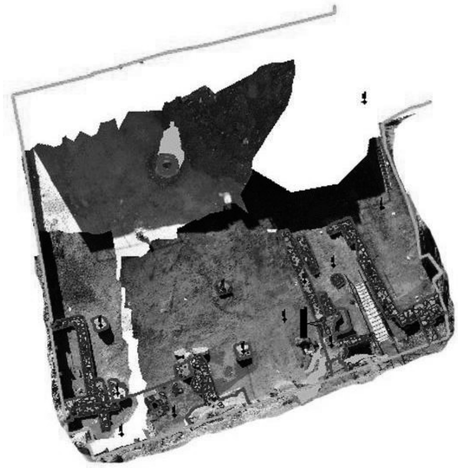
In this paper the application of a 3D recording, modelling and visualization technique with the use of laser scanning and photogrammetry, for quick mapping and documentation of archaeological findings have been presented. A laser scanning model was combined with high resolution images and photogrammetric measurements to produce an accurate 3D model of the object in a short period of time.

The paper describes a complete photogrammetric framework where the key prohibitive parameter is time. Due to the fact that the delay in reconstruction works is equivalent to multiple amount of money, the proposed technique and the expected results have to be accurately enough and quickly ready.

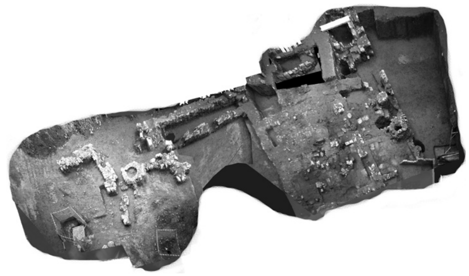
During the implementation of the project, the main difficulty faced was the processing of the dense point cloud in the area of the walls' edges. This is crucial in the orthoimage production because weak 3D model at the abrupt changes point to the blurring of the orthoimage at this area during processing. This problem was faced with manual editing of the model points at the edges.



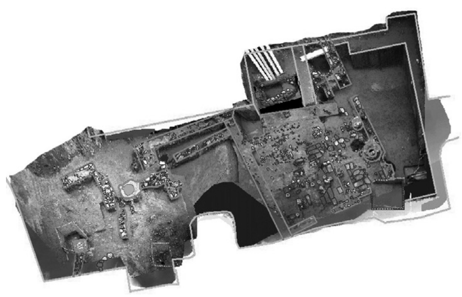
Orthoimage of the north part of the excavation site



Orthoimage overlay to a CAD drawing (north part of the excavation site)



Orthoimage of the south part of the excavation site



Orthoimage overlay to a CAD drawing (south part of the excavation site)

Figure 6: *Selective photogrammetric products from the excavation site*

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Visualization of Historical City Kyoto by Applying VR and Web3D-GIS Technologies

Y. Takase[1,2], K. Yano[1], T. Nakaya[1], Y. Isoda[1''], T. Kawasumi[1], K. Matsuoka[1], S. Tanaka[1'], N. Kawahara[1], M. Inoue[1], A. Tsukamoto[1], T. Kirimura[1], D. Kawahara [1,2], N. Sho[2], K. Shimiya[2], A. Sone [2] and M. Shiroki [2]

[1] Ritsumeikan University, 56-1, Tojiin-kitamachi, Kita-ku, Kyoto, Japan
[1'] Ritsumeikan University, 1-1-1, Noji-higashi, Kusatsu, Shiga, Japan
[1''] Ritsumeikan Asia Pacific University, 1-1, Jumonjibaru, Beppu, Oita, Japan
[2] CAD CENTER Corporation, 2-3-21, Kouraku, Bunkyo-ku, Tokyo, Japan

Abstract

The authors have developed techniques for automatic generation of 3D city models using LIDAR data, 2D digital map and aerial photograph, as well as a virtual reality (VR) viewer software with high-speed graphic engine which can deal with a large area of 3D city models on VR. For the recent years the authors also have developed Web3D-GIS system which can provide transmission and reception of a great amount of urban information with interactive manipulation of detailed 3D city models linked with geographic information systems (GIS), on ordinary internet infrastructure such as DSL. Using those techniques and systems the authors have been conducting a research project, "Kyoto Virtual Time-Space," which aims at 4D-GIS of Kyoto, that includes reconstruction and visualization of Kyoto at different eras on VR and on the internet, starting from the present to the past, and finally up to Heian era (8^{th} to 12^{th} century) when Kyoto was the capital of Japan.

1. Development of Techniques

1.1. Automatic generation of 3D city models

Traditional modeling method of 3D city models usually had required enormous amount of works. Especially, manual modeling with 3D CAD software used to be most time-consuming and required operators' expertise. Therefore, it had not been applicable for the production of great area of 3D city models in a short period of time.

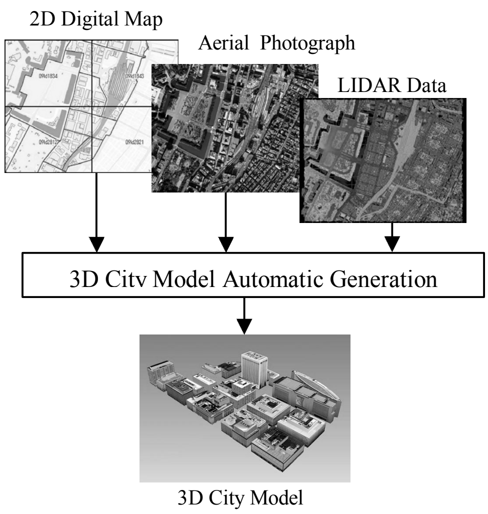

Figure 1: *Automatic generation of 3D city model*

The automatic generation system of 3D city models developed by the authors has realized surprising reduction of production time for modeling 3D city models. The material data for the automatic generation system includes LIDAR data with elevation accuracy of 15cm, aerial ortho-photo images, and 2D digital maps with precision of 1/2500. Before the automatic generation process, raw LIDAR data is filtered by software and separated to terrain data and building data. The terrain data is automatically complemented and meshed DEM (Digital Elevation Model) data is generated. With those material data, accurate 3D city models are automatically generated with newly developed software (Figure 1).

The system consists of several programs including that for 3D city model automatic generation, database management, material data input, and 3D CG/VR data output. Through the application of 3D automatic generation programs, accurate "geometry model" of terrain and buildings are automatically generated. Presently geometry models of 14 major cities of Japan are available on the market (MAPCUBE®), which are revised annually based on changes in 2D digital maps through years that are automatically extracted. The 3D models of other cities are also available on project basis (Figure 2).

Figure 2: *3D city model (MAPCUBE® of Chiba)*

In addition to geometry model, 3D models of well-known buildings/objects called “landmark models” are being produced with detailed geometry and texture manually. More than 2,000 landmark models are presently available.

Those city models and landmarks are used in various fields including car navigation as well as urban design, disaster prevention and real estate sales promotion.

1.2. VR viewer

The VR applications using wide areas of 3D city models are becoming indispensable in a variety of fields. However, VR viewer software for popular use, such as VRML, often has difficulty in terms of drawing speed when it is applied for a wide area of 3D city model. To solve the problem, the authors have developed VR viewer software that can easily deal with wide areas of 3D city models. The software is presently available on the market (UrbanViewer™) and is used in a variety of fields including urban design, real estate development, disaster prevention, tourism and navigation (Figure 3).

Not only MAPCUBE® but also those 3D model data made by users can be transferred to the viewer through intermediate formats, such as 3ds, Open Flight and OBJ.

Figure 3: *User interface of UrbanViewer™*

1.3. Web3D-GIS system

The authors also have developed a Web3D-GIS system that makes possible transmission and reception of a great amount of urban information with interactive manipulation of detailed 3D city models linked with GIS on ordinary internet infrastructure such as DSL (Figure 4).

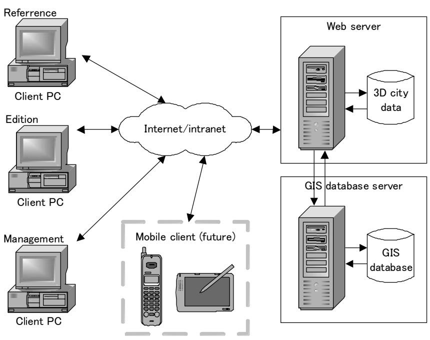

Figure 4: *System structure*

New techniques have been developed for the system, including; (a) reduction of data, (b) level of detail (LOD) and streaming, and (c) linkage between 3D city model and GIS.

The topography of cities and surrounding areas, including mountains and rivers, is a dominant element of landscapes. The system also can deal with topographical 3D data of wide area. To make this possible a technique to change density of meshed DEM according to the distance between viewpoint and viewed topography (Figure 5).

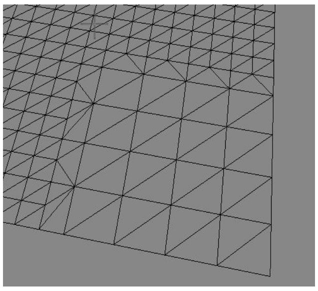

Figure 5: *Connection of DEM meshes with different density*

The system is named UrbanViewer™ for Web and is presently available on the market, and various applications including those for tourism, shopping, disaster prevention and real estate sales promotion are recently appearing. Figure 6 shows the example of an internet homepage for tourism where users of the internet can access with Internet Explorer.

Figure 6: *A tourism web site on UrbanViewer™ for Web (http://web.nta.co.jp/3dmap/)*

2. 4D-GIS of Kyoto

“Kyoto Virtual Time-Space” is a part of “Kyoto Art Entertainment Innovation Research” by Ritsumeikan University, a 21st Century COE (Center of Excellence) program funded by Ministry of Education, Culture, Sports, Science and Technology of Japan during the fiscal years from 2002 to 2006. It aims at reconstruction and visualization of “4D-GIS” of Kyoto, which means that it provides 3D-GIS of Kyoto, starting from the present going back to the past through 20th century to Heian period (12th to 8th century, when Kyoto was the capital), based on 3D city model and available historical documents and information, employing new visualization technologies including VR and Web3D-GIS. Since early stage of the research, "Kyoto Virtual Time-Space" has employed MAPCUBE® of Kyoto, and UrbanViewer™ has been employed as VR viewer for it. All 3D data and information are installed and handled on VR, and they are transferred on to Web3D-GIS in succession.

Figure 7: *3D city model of Kyoto*

2.1. 3D model of Kyoto at present

The landscape of Kyoto characteristically consists of natural elements such as the mountains surrounding the city and the rivers, as well as built elements including traditional townhouse called *machiya*, temples, shrines and modern heritage buildings. Therefore, the research firstly aimed at the construction of 2D-GIS of those elements in order to build up 3D-GIS based on it later.

In addition to automatically generated 3D city model of Kyoto, detailed VR models of major streets, buildings and cultural elements have been made so that walk-through in those spaces can be experienced.

Traditional townhouse: *machiya*

Kyo-machiyas, or *machiyas*, traditional townhouses of Kyoto, most of which had been built in between 18th century and World War II, have been decreasing rapidly in recent decades. However, they still are dominant elements of urban landscape of Kyoto (Figure 8).

Figure 8: *Machiyas in Kyoto*

Since 1995, community surveys covering the central area of Kyoto were conducted by the city of Kyoto, an NPO, and Ritsumeikan University. In the surveys, the surveyers visited all buildings within the area and identified *machiyas*, as well as recorded the types, conditions and uses of them. The surveys identified 21,820 units of *machiyas* within the area and a 2D-GIS of *machiya* was built up (Figure 9, 10).

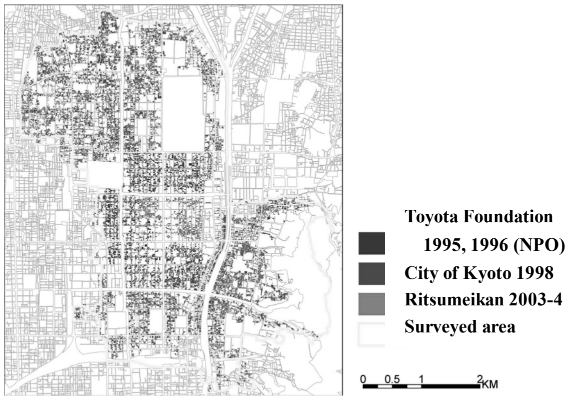

Figure 9: *Machiya surveys*

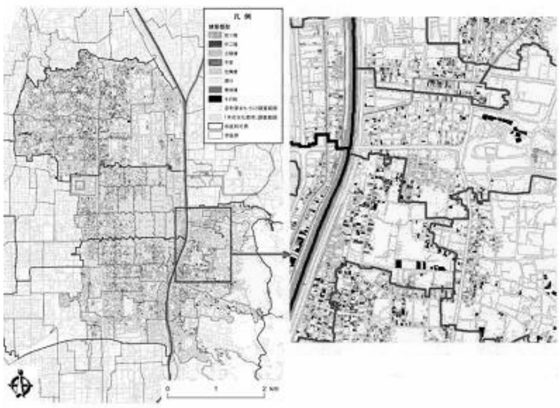

Figure 10: *Distribution of machiyas in Kyoto by types (left), and the detail of Gion area (right)*

Considering that there still are so many *machiyas* in Kyoto, a method for automatic generation of *machiya* 3D models has been developed. That is, an Excel VBA Macro has been developed for the purpose, which retrieves the coordinates and attribute data of *machiyas* from GIS database, applies one of *machiya* library models, resize the model matching to the width and depth of the building lot, and place the model in the VR space (Figure 11).

Spreadsheets are ideal for writing parametric 3D model. In our case, Excel is used to write 3D parametric model in OBJ format. In this way, we can use Excel VBA to reads the coordinates and attributes from the GIS database, substitute parameters in the 3D parametric model with the values, repeating this for the whole records in the database, and thus creating *machiyas* exactly matching the building footprint for the entire city.

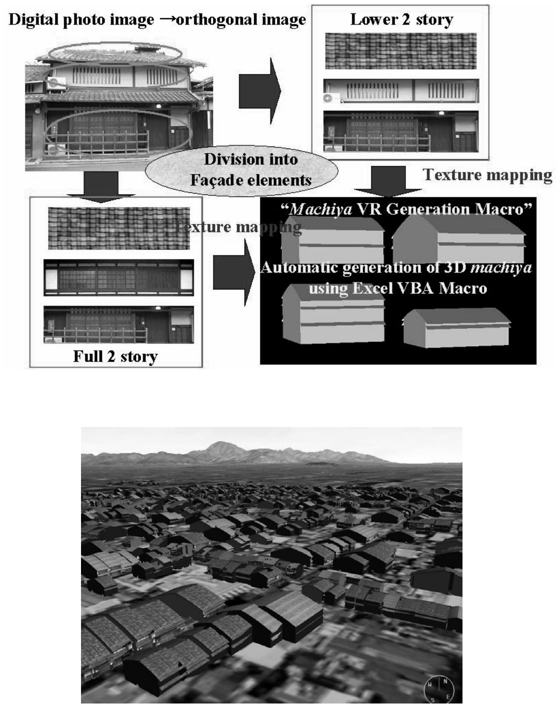

Figure 11: *Automatic generation of Machiya VR model*

Temples, shrines and western-style heritage buildeings

The authors have built up 2D-GIS of approximately 1,300 temples and 350 shrines of Kyoto based on "Digital Map 10,000" by Geographical Survey Institute (GSI) of Japan (Figure 12), as well as that of approximately 2,000 western-style heritage buildings based on the survey in 2003 by the city of Kyoto (Figure 13). Their detailed VR models of those buildings are continuously being modeled with priority using CG/VR software such as MultiGen Creator and Form.Z RenderZone (Figure 14).

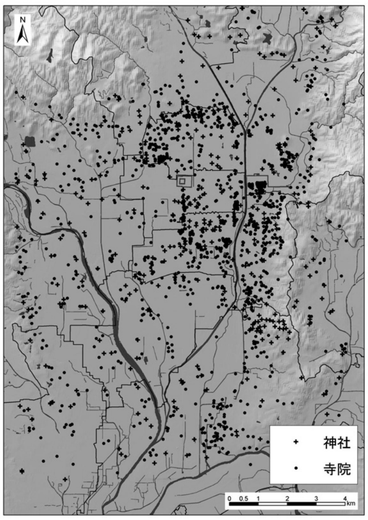

Figure 12: *Distribution of temples and shrines in Kyoto*

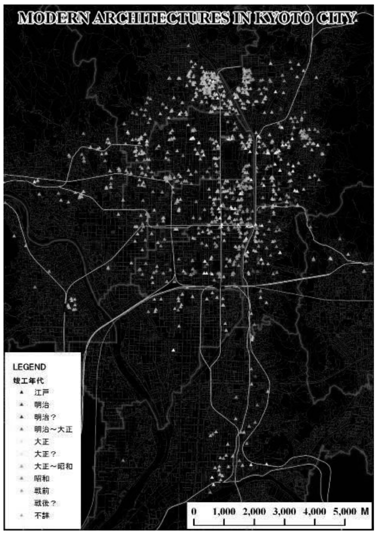

Figure 13: *Distribution of western-style heritage buildings in Kyoto*

Figure 14: *Detailed VR model examples (left) and photographs (right)*

Detailed models of streets and Minami-za theater

Textured models of existing buildings have been added to 3D city model of Kyoto, starting from those located along major streets.

Building façade textures are made by rectification of digital photos of building facades with Photoshop. Then geometry models of MAPCUBE® are mapped with the façade textures using CG/VR software such as MultiGen Creator and Form.Z RenderZone. Those textured models are transferred to OBJ format and handed to UrbanViewer™ finally. At present, detailed 3D models have been made for part of major streets of Kyoto, including Shijo, Karasuma and Oike Streets.

Minami-za theatre was originally constructed in 17th century on Shijo Street, which was close to the place where Kabuki was first performed in early 17th century. Although there were seven major theatres along Shijo

Street in 17th to 18th century, Minami-za theatre solely remains on the street today.

The detailed VR model of Shijo Street provides not only walk-through experience of the street but also that of the entrance and theater space of Minami-za (Figure 15). In the near future Kabuki or traditional dance will be performed on the stage. Motion capture technique is to be applied to those performances on VR.

Figure 15: *Shijo Street and Minami-za Theater*

Gion Festival and *yamahoko* floats

Gion Festival, held every July in Kyoto, is one of the most famous festivals in Japan. It originated in the mid 9th century, evolved to be the current form by the mid 14th century and continues until today. During the festival, 32 *Yamahoko* floats representing downtown neighborhoods parade along the streets of downtown Kyoto, including Shijo Street (Figure 16). *Yamahoko* parade of Gion Festival becomes a symbolic landscape of Kyoto during the festival period.

Figure 16: *Yamahoko parade of Gion Festival*

The authors have attempted to model Gion Festival from the beginning of the research. At present, four VR model of *Yamahoko* (*Kanko-boko*, *Fune-boko*, *Naginata-boko* and *Kita-kannonnyama*) have been created by laser scanning of detailed miniature and digital images of the real *Kanko-boko* taken by digital cameras during the festival, as well as by manual modeling (figure 17).

Figure 17: *Laser scanning of miniature Yamahoko and VR models*

2.2. 3D reconstruction of Kyoto in the past

In the research varieties of 3D reconstructions of Kyoto have been and are being done, starting from the present to the past, including times of soon after and before World War II, Taisho and Meiji eras (early 20th to late 19th century), Edo and Muromachi eras (late 19th to 16th century), and finally up to Heian era (12th to the end of 8th century).

Landscape changes in the 20th century

Machiya usually employs gable roof covered with roof tile. The observation of aerial photographs makes possible identifying *machiya* as different from other type of houses such as modern-style houses.

Five sets of aerial photographs taken after World War II at 13 years intervals have been observed. Those are photographs by: US military force in 1948, GSI in 1961, 1974 and 1987, and Naka-Nihon Koku, Co. in 2000. And it was found that those in 1928 owned by Kyoto University were available (Figure 18).

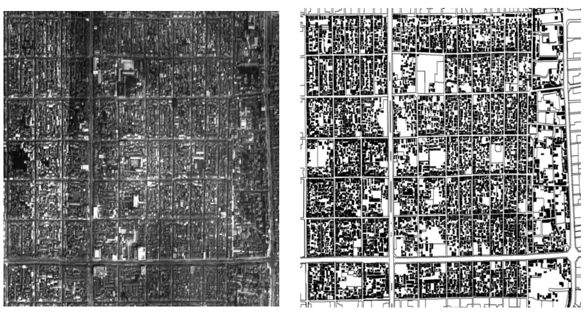

Figure 18: *Identification of machiyas in aerial photograph of 1928*

The aerial photos were scanned, and rectified to fit to the map using ArcGIS geo-referencing function. After these geometrical adjustments, gable roofs were traced to make their polygons using ArcGIS editor (Figure 19).

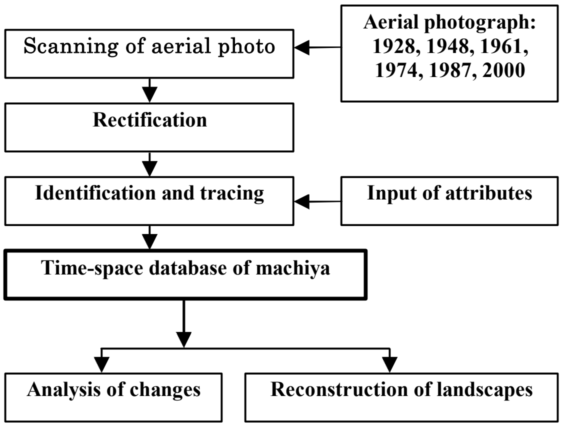

Figure 19: *Time-space database of machiya*

Based on the distribution data of *machiyas* identified by aerial photographs, VR data of *machiyas* automatically generated by "*Machiya* VR Generation Macro" were located on MAPCUBE® of Kyoto. The types of *machiya* were randomly selected.

It clearly shows that *machiyas* facing major streets disappeared first, and the disappearance gradually expanded inward the street blocks. As the result, modern high-rise buildings have become more and more dominant in urban landscapes (Figure 20).

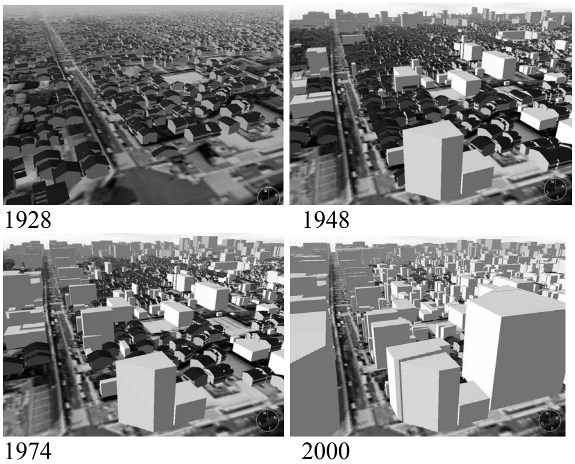

Figure 20: *Changes of landscape*

Reconstruction of Kyoto in early 20th century

Figure 21 shows landscapes of Shijo Street at present and the one in 1910's. The landscape at present has been visualized based on MAPCUBE® of Kyoto with addition of textured models of the buildings along the street. The landscape in 1910's has been visualized based on digitized cadastral maps of 1912 and "*Machiya* VR Generation Macro." Moreover, *Yamahoko* floats were placed on Shijo Street in order to reconstruct Gion Festival of different times.

The figure shows that *Yamahoko* floats look as very big objects in 1910's though they look smaller at present surrounded by high buildings. The visible ranges of mountains were much greater in older times.

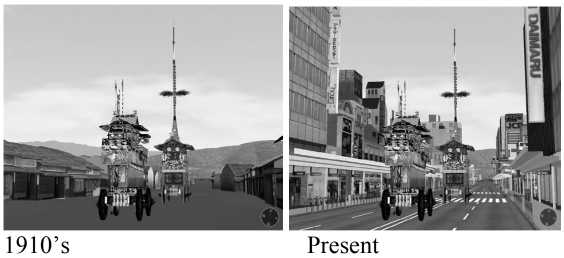

Figure 21: *Changes of Gion Festival through time*

Reconstruction of Kyoto in 17th century

Kanei-go-Manchi-zen-rakuchu-ezu, drawn in 1640's and presently owned by Kyoto University, is known as a considerably accurate map of Kyoto. It has the size of 636cm by 282cm and shows names of towns and streets, land use, widths of streets, widths and lengths of blocks and major building lots and names of landowners.

The map was scanned, and rectified to fit to the map recently published using GIS software's geo-referencing function. After these geometrical adjustments, streets, blocks and major building lots were traced, and their attribute data were input on a 2D-GIS system. Using this GIS database 3D reconstruction of Kyoto in 17th century is being conducted (Figure 21).

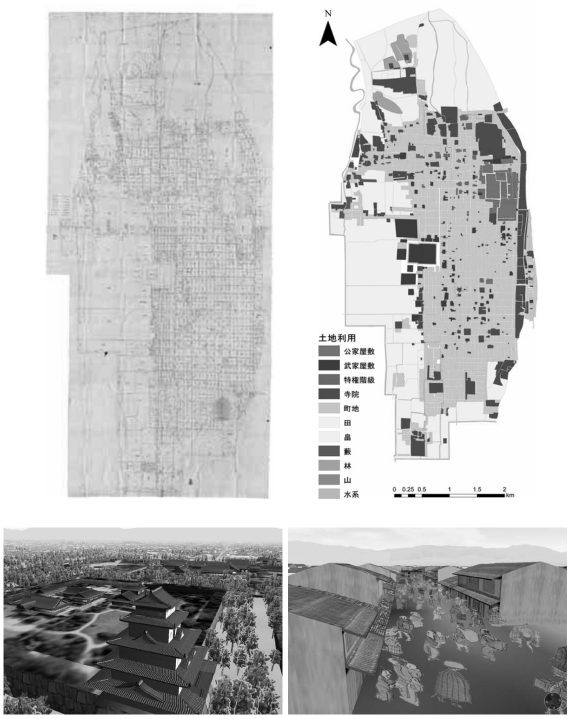

Figure 21: *Map of Kyoto in 1640's (upper left), land use map (upper right), and reconstructed Kyoto in Edo era*

Reconstruction of Heian-kyo

When Kyoto was founded in A.D. 794 as the capital of Japan, the city was called Heian-kyo. The authors have started the reconstruction of Heian-kyo, based on available historical documents and information. The topographical data has been reconstructed using excavation and geological boring results. Street blocks and buildings have been modeled using 3D CAD based on design drawings for miniature model of Heian-kyo which was made by the city of Kyoto celebrating 1200th anniversary. Those models have been automatically located according to the land use plan at that time (Figure 22).

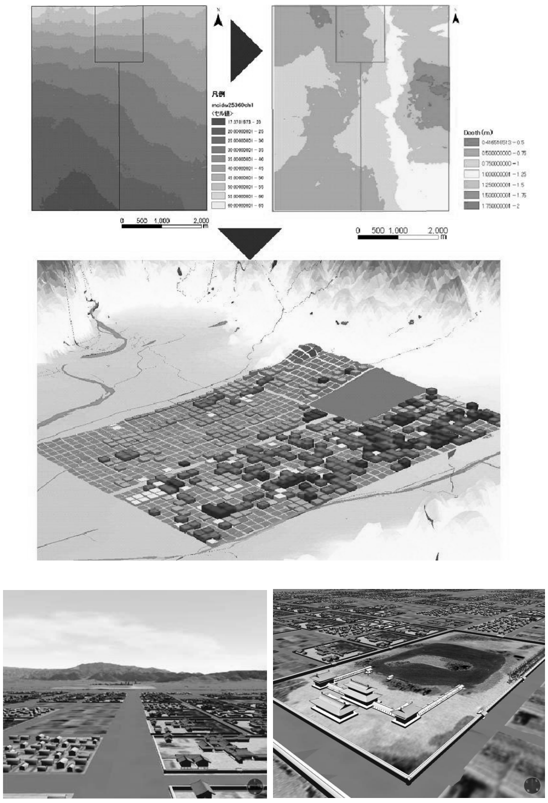

Figure22: *3D Reconstruction of Heian-kyo*

3. Concluding Remarks

The research will continue to reconstruct historical city of Kyoto starting from the present going back to the past while making varieties of digital contents which constitute the landscapes at different times. We continue adding VR models based on all available historical information and documents. At the final phase we intend to employ "Kyoto Virtual Time-Space" as a platform to integrate a large collection of digital archives of arts and entertainment in geographical context of Kyoto with its historical landscapes. And it should play a very important role in the assistance for urban planning, cultural preservation, and tourism promotion of Kyoto, as well as sending rich information on Kyoto to the world through the internet.

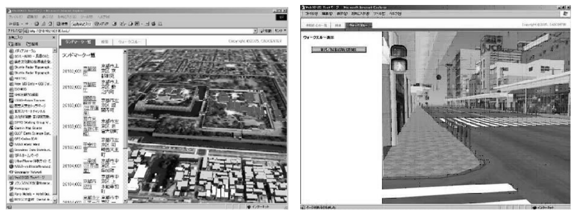

Figure 23: *"Kyoto Virtual Time-Space" on web*

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CAD CENTER Corporation
http://www.cadcenter.co.jp

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CREATIVE HISTORIES - THE JOSEFSPLATZ EXPERIENCE

Robert F. Tobler, Stefan Maierhofer, Konrad Karner, and Mario Sormann

VRVis Research Center, Vienna, Austria

Abstract

The Josefsplatz Experience is an effort to capture the development of a set of historic buildings and contained artifacts through the course of a few centuries and present the resulting 4D models (3D models over time) to the interested user. Since not all of the historic data is 3D, innovative methods are used to map the 2D input data (paintings, sketches) onto reconstructed 3D models. Artifacts (mostly statues) that are still available are reconstructed as high- quality near-realistic 3D models from photos. All of the reconstructed material as well as a significant amount of associated media (sound, text, movies, aso.) is stored in a large database with both location and time as primary methods to access all relevant data. A simple user interface on top of this database allows quick and intuitive navigation through the 4-dimensional reconstruction of a historic site.

1. Overview

The Josefsplatz Experience (official project title 'Creative Histories') has been started in order to create a digital version of a set of historic buildings and their contained artifacts. One of the challenges of the project is the digital recreation of these buildings through a number of historic epochs. As opposed to the status quo, which can be reconstructed via standard photogrammetric techniques (see figure 9), sources for some of the historic version of the buildings are limited to single 2D drawings. For this reason a number of novel techniques had to be employed , in order to obtain viable 3D models for these buildings.

Based on the reconstruction of the architecture and artifacts, the projects will present a host of additional information, such as videos, texts and audio files in the form of a virtual walkthrough. A specialized viewer application is currently being developed, that simplifies the navigation of both the 3D models and the associated media files. The second challenge of this project is the conceptual simplification of this large information space, so that it can be presented to the user in a comprehensible form that can be easily navigated.

In the following sections we will describe some background and our solution to this challenge.

2. As-Built 3D Reconstruction

In our project the 3D modeling of artifacts like statues is performed by applying an image-based modeling approach which reconstructs a virtual copy of the object under investigation using a dense set of photographs. Image-based modeling techniques are chosen due to the availability of low priced high quality digital consumer camera, a wide range of object sizes which can be reconstructed as well as the additional benefit of radiometric (texture) information.

Our overall reconstruction pipeline is illustrated in Figure 1. In our case, the input images are captured with a calibrated high quality digital consumer camera with a 11.4 megapixels CMOS sensor. The image acquisition process consists of taking hand-held photographs with short baselines resulting in high overlap. The process of camera calibration, is a well studied problem in photogrammetry and determines the internal parameters of a camera. Our method is based on work described by Heikkilä [Hei00].

The remainder of the reconstruction pipeline works as follows. An automatic orientation procedure to obtain the relative orientation of each image pair is performed. A reliable calculation of the relative orientation is based on an accurate point of interest (POI) extraction followed by an affine invariant matching approach. In addition, the reconstruction of complex objects, like statues require a segmentation pro-

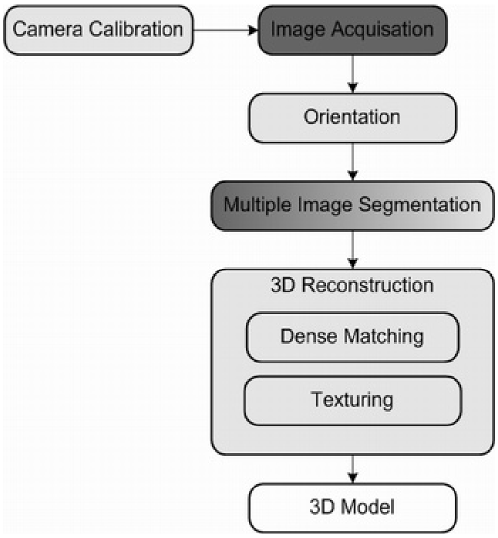


Figure 1: *Overall reconstruction pipeline. The dark grey shaded tasks are interactive whereas the light grey shaded procedures are fully automatic.*

cess to separate the relevant parts of the scene belonging to the statue from the background. Essentially, we combine a graph cut based optimization algorithm with an intuitive user interface. At first a meanshift segmentation algorithm partitions each image of the sequence into a certain number of regions. Additionally we provide an intelligent graphical user interface for easy specification of foreground as well as background regions across all images of the sequence. Within the graph cut optimization algorithm we define new energy terms to increase the robustness and to keep the segmentation of the foreground object coherent across all images of the sequence. Finally, a refined graph cut segmentation and several adjustment operations allow an accurate and effective foreground extraction. More details can be found in [SZK06].

This 2D segmentation masks are important to reduce the outlier rate in the following dense matching procedure and to obtain a meaningful 3D reconstruction. Consequently, we use a high performance 3D reconstruction approach [ZSK06], which generates true 3D models from multiple views with known camera parameters. The complete pipeline from depth map generation over depth image integration to the final 3D model is performed on programmable graphics processing units (GPUs). A so called plane sweep approach with optionally employing robust similarity functions is used to generate a set of depth images. The subsequent volumetric fusion step combines these depth maps into a surface representation of the final model. Depending on the number of input views and the desired resolution of the final model the computing times range from several seconds to a few minutes.

Another important aspect to fulfill 3D reconstruction requirements is a high quality texture of the 3D model, considering the visibility, viewing angle and the base of the projection. All these requirements are incorporated in our automatic texture generation method, which is based on work proposed by [LPRM02].

Figure 2 shows all intermediate results of our high performance image-based modeling approach demonstrated on the emperor Kaiser Karl VI located in the Austrian National Library in Vienna.

3. 3D Reconstruction from Historical Data

For historical data, the image-based modeling technique mentioned so far is not suitable in terms of the unknown camera geometry and the insufficient number of overlapping images. Therefore we propose two different approaches to obtain 3D models based on historical data: geometric modeling based on historical drawings and texturing an existing 3D model from important historical events. Both approaches will be explained in more detail in the following subsections.

Geometric Modeling based on Historical Drawings

In general, historical drawings are not based on perspective projections. Therefore, we calculate a local projection model by selecting four maker points at the building of interest. Once we have determined the local projection, we are able to model the geometry of a building by drawing contours, which overlay the original image, as shown in Figure 3(b). The whole reconstruction process is supported by an intelligent user interface, which allows to combine simple contours to more complex primitives. Furthermore, an user assisted texturing step is performed which results in a fully textured 3D model of the single historical drawing. Our reconstruction pipeline is illustrated in Figure 3(a), whereas the modeling result is shown in Figure 3(c).

Texturing 3D Models from Historical Events

Texturing 3D models from historical images can be separated in three major steps. The first task consists of a preprocessing step to remove the radial lens distortion in the input image. Our approach is based on the fact that straight lines have to be straight as proposed by Devernay et. al. [DF01]. The second step includes the estimation of the camera pose, utilizing 2D-3D point correspondences. Therefore, a human operator selects 2D points in an image and the corresponding 3D points of an existing 3D model. Given at least six point correspondences the pose of the camera can be computed based on a direct linear transformation. Figure 4(a) shows the obtained camera pose for a historical photo. As soon as the camera pose is known a final texture mapping approach is performed to obtain a 3D model textured from a historical event, as shown in Figure 4(b).

(a) (b) (c) (d)

Figure 2: *Illustration of all results achieved with our 3D reconstruction approach and demonstrated on the emperor Kaiser Karl VI located in Austrian National Library in Vienna. The statue of Emperor Karl VI. is 2.3 meters high and the data-set consists of 45 images.* ***(a)*** *One original image of the data-set.* ***(b)*** *Obtained camera positions and colored 3D tie points.* ***(c)*** *Acquired depth map.* ***(d)*** *Reconstructed 3D model.*

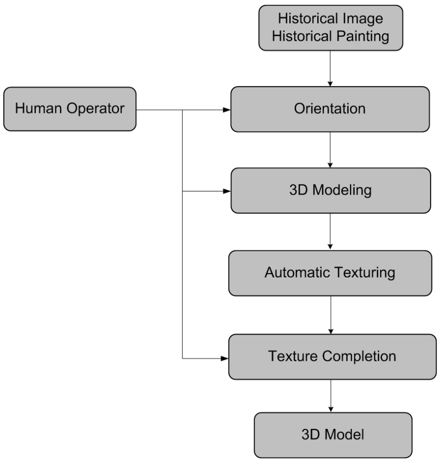
4. Navigating Creative Histories

In addition to a succession of 3D models of Josefsplatz through history, the project also provides links to a number of media files (text, video, audio) that are associated with the various artifacts (such as statues, pictures aso.) in and around Josefsplatz. In order to simplify access to all this data, each media file is tied to a location inside the 3D-model by assigning a 3D bounding box to the information item. Whenever this bounding box intersects the viewing frustum of the current view, an icon for accessing the associated media file is presented to the user. Figure 5 shows examples for the bounding boxes which are normally invisible, and for the icons that are presented to the user. Clicking on this icon will play the associated media file in a separate window (see figure 6). Thus these icons are the equivalents of HMTL anchors in the viewer application that mimics a 3D browser.

Although these simple 3D-anchors provide a nice navigation metaphor, the number of available media files is much too large to present them to the user all at the same time. In order to restrict the amount of information, that is presented to the user, we introduced two additional concepts.

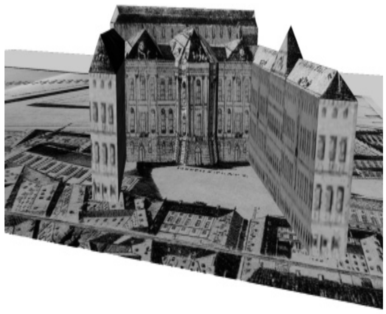
Information Categories

This represents the first of the two additional concepts. Each and every information item is categorized with respect to a selected number of information categories, which were cho-



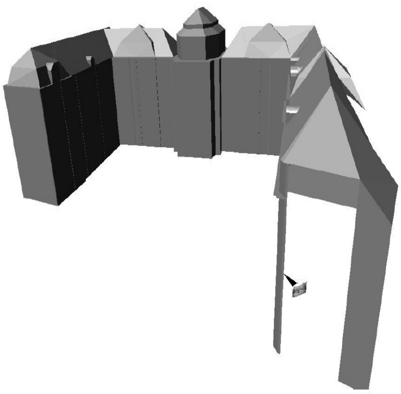
(a)

(b)

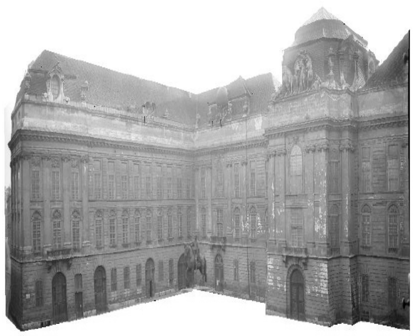


(c)

Figure 3: *Illustration of the geometric modeling procedure based on historical drawings.* ***(a)*** *Rough workflow of the reconstruction pipeline.* ***(b)*** *Intelligent graphical user interface.* ***(c)*** *Acquired reconstruction result from a single historical drawing.*



(a)



(b)

Figure 4: *Illustration of texturing 3D models from historical images.* ***(a)*** *Obtained camera pose.* ***(b)*** *Textured 3D model.*

(a) (b)

Figure 5: *Metadata links associated with the geometry via bounding boxes.* ***(a)*** *The invisible bounding boxes.* ***(b)*** *Metadata icons presented to the user.*

Figure 6: *Metadata is presented to the user in overlay windows.*

sen to somewhat evenly cover the available historical information for the Josefsplatz buildings and artifacts:

- History
- Baroque
- Historic Models
- Music
- Royal Orchestra
- Royal Library
- Literature
- Architecture

The user-interface allows the user to specify his main interest, by selecting one of these categories. The viewer application restricts the displayed anchors to mainly fall within the specified category of interest. The browser does not apply a full filtering, in order to present some important anchors of all the other categories that have not been specified. This somewhat fuzzy selection allows a more fluent navigation across different information categories.

In order to symbolize these categories for the user, each of the categories is assigned a separate color. All the anchor icons for a given category are displayed in the corresponding color, so that the user can immediately see the category of information that hides behind the displayed icon (see figure 6).

The Time-Line

The second concept is the so called *time-line*. In order to restrict the presented information in the time dimension, a scrollable and zoom-able time-line is available as a user interface-element. The time-line will be both scroll-able, to enable swift navigation through time, as well as zoom-able, in order to specify a time-range of anchors that the user is interested in. Marks on the time-line will correspond to visible anchors, with their color signifying the category of the information that can be accessed by clicking on the mark. The color of the timeline represents the selected main infor-

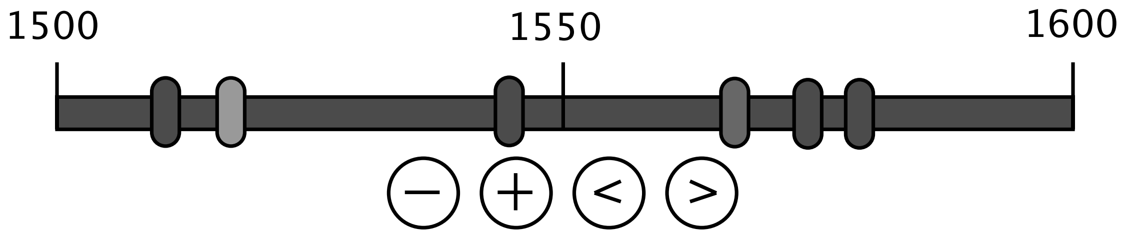


Figure 7: *Possible design for the timeline with marks for anchors and user elements for zooming and scrolling.*

mation category. A possible design for the time-line can be seen in figure 7.

Underlying Database

Based on the described concepts, each item in the underlying database (e.g. media-files, 3D geometry, aso.) has associated fields for its 3D-bounding box, its information category, and its validity range in time. All the users navigation and selection operations are translated into equivalent queries to the database: for the category and the time line this is obvious, for the 3D position, the viewing frustum of the current view is approximated with an enclosing bounding box, and the query is performed to return all items that intersect this bounding box.

The result of each query is a number of relevant items, which are displayed according to their bounding box, i.e. the final geometric selection of the items to present is performed in the viewer application.

5. Results

As of the time of writing, the user-interface for the final user has not been finalized, the current UI is targeted at the developer, and although all the restrictions on categories and time-intervals are available (see figure 8), they have to be wrapped into a well-designed layout for the final viewer application. This will be completed by the end of september.

The first of the movie files supplied with this paper shows a camera path along the reconstructed statues in the so called Prunksaal of the national library of Austria which is inside one of the buildings around Josefsplatz. The second movie shows the detail to which each of the statues are reconstructed. This second movie highlights the amount of detail that is contained in the texture which is automatically applied in the photogrammetric reconstruction process.

6. Conclusion

Within the Creative Histories Project a viable method for both reconstructing and presenting time-dependent 4D content has been presented. The reconstruction of 3D content from both multiple 3D images of various artifacts, as well as single 2D images with adequate user input has been shown. Simplifications for easy navigation through the resulting 4D data have been presented, and although the user-interface has not been finalized, a number of concepts for easy access of additional media files have been demonstrated.

7. Acknowledgments

This work is partly funded by the VRVis Research Center, Graz and Vienna/Austria (`http://www.vrvis.at`). We would also like to thank the Vienna Science and Technology Fund (WWTF) for supporting our work in the *Creative Histories – The Josefsplatz Experience* project.

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Figure 8: *The current control window for specifying restrictions. This will be replaced by a user-friendly time-line and a selection possibility for the main information category.*

Figure 9: *The Josefsplatz and its central statue, entirely reconstruced photogrammetrically.*

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From Landscape to Object: The Evolution of Digital Recording for Multi-Disciplinary Investigations and Site Management at Chersonesos in Crimea, Ukraine

Jessica Trelogan[1] and Stuart Eve[2]

[1]University of Texas at Austin, Institute of Classical Archaeology, Austin, Texas
[2]L – P : Archaeology, London, United Kingdom

Abstract

This paper presents an overview of the digital recording methods developed and implemented over the last twelve years of work by the joint expedition of the Institute of Classical Archaeology and the National Preserve of Tauric Chersoneosos at Chersonesos, in Crimea, Ukraine. Our multi-disciplinary project includes the study and preservation of an 11,000 hectare agricultural territory, conservation and research within its associated urban center, and excavations of sites within and outside the city walls. Since our first joint excavation in 1994, our recording methods and techniques have evolved to keep pace with the rapid development of digital technologies, software and hardware and that of our increasingly international and multi-faceted project.

Categories and Subject Descriptors (according to ACM CCS): H.4.m [Information Systems Applications]: Miscellaneous

1. Introduction

This paper presents an overview of the digital recording methods developed and implemented over the last twelve years of work during the joint expedition of the Institute of Classical Archaeology (ICA) and the National Preserve of Tauric Chersoneosos (NPTC) at Chersonesos, in Crimea, Ukraine. As the collaborative project has developed since its first year of excavation 1994, our recording methods have evolved to meet the changing demands of our increasingly international, interdisciplinary and multi-scale research, conservation and site management efforts. Over the last decade, we have also strived to keep pace with the rapid development of digital technologies, software and hardware while trying to adhere to an underlying philosophy that emphasizes light, practical and efficient, but robust and sustainable (both short- and long-term) methods.

Since 1998, the recording of all of our excavation, conservation and management projects have had at their core a GIS and relational database component. Our eventual goal is to combine these diverse, multi-scale datasets and present them as an integrated whole, from intra-site excavation recording to urban-scale mapping and site management, to landscape-level study and site preservation.

We briefly outline below the history of our project and highlight a number of our major GIS-based projects. We present a handful of examples of the many lessons we have learned over the years and emphasize the evolution of our methods as informed by changing technology.

2. Project Background

2.1. Site Background

Chersonesos, located near modern Sevastopol in Crimea, Ukraine (Figure 1), was settled in the 5th century BC by Greeks from Herakleia Pontika. Continuously occupied throughout Greek and Roman antiquity, the site remained a thriving Byzantine outpost and important center for Christianity until its abandonment in the 14th century AD.

Figure 1: *Site location map.*

Unoccupied since its destruction, the lack of subsequent building has left the fabric of the Byzantine city virtually intact. Still standing are large portions of the regular street plan, residential and public buildings, quarters of industrial production (including wine presses, ceramic workshops and basins for fish-salting), tombs and ecclesiastical structures small and large. Large sections of the city's defensive walls are also extant, spanning nearly the whole of the city's history from the 4th century BC (Figure 2).

Figure 2: *Aerial view of the ancient city.*

Outside the city walls, the site encompasses a vast agricultural hinterland, or *chora*, which provided the main economic basis for the city throughout its history. This rural territory is one of the best-preserved examples of ancient farmland known today. Of the original area of over 11,000 hectares of ancient fields, more than 500 hectares remain preserved. Remnants of the grid of roads that divided the territory into over four hundred roughly equal land plots are still visible, as are traces of planting walls for trees and vines, and the remains of over 140 documented Greek and Roman farmhouses and settlements (Figure 3) [SZM2000], [MC2003].

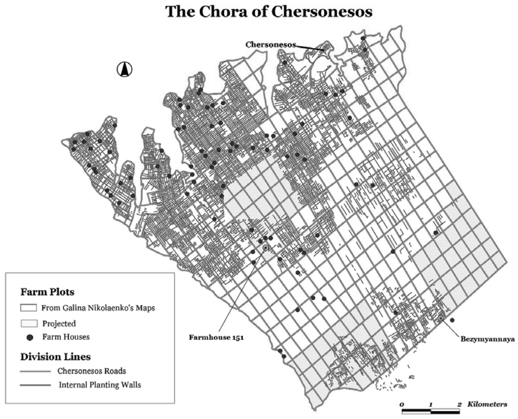

Figure 3: *The divided chora.*

The site's well-protected natural harbors and easy overland routes to the Crimean steppe have made this a strategic and heavily defended location since antiquity and through the Crimean and Second World Wars. Today Chersonesos is an important tourist destination, an important military port adjacent to the home of the Russian and Ukrainian Black Sea fleets, and a destination for religious pilgrims interested in the birthplace of Christianity in the Slavic world. Since 1996, it has been repeatedly included in the World Monuments Watch *List of 100 Most Endangered Monuments of World Cultural Significance* and application for its inclusion on the UNESCO World Heritage List is in progress.

2.3. Project History

ICA began collaborating with NPTC in 1994 with the small-scale excavation of a fortified farmhouse in the center of the divided chora [CCL*2000]. Since then, excavations have continued at a multi-phase hill fort at the edge of the chora [RYN2005] and, since 2001, in an urban residential quarter in the southern region of the ancient city.

In addition to excavations and their related investigations into the lives of the people that inhabited both the countryside and the city center, we have, since 1998, also been working together to find the best possible solutions for the preservation and conservation of the site. Among our main research questions are the interaction of human settlements with their surrounding natural landscapes, the way inhabitants of the city related to those of the surrounding countryside, and the relationship between the ancient and contemporary landscapes that comprise the site as a living monument today.

We have also been carrying out a comprehensive program of site conservation, monuments conservation and collections care. This includes landscape-level monitoring and preservation of the larger chora, structural conservation and management of the complex, open-air exhibit of the city center. On the objects level, we are carrying out conservation, digital preservation and environmental monitoring of the Museum's collection of objects, rare books, manuscripts, and original excavation reports going back to the early 19^{th} century.

2.4. History of Digital Recording

At the core of all of these projects is a commitment to integrated and practical documentation and information management of current, past and future work with a vision of long-term sustainability by the National Preserve, which is ultimately responsible for the management of the site and museum collection.

While we rely heavily on digital recording methods, we remain keenly aware of the need, especially in the post-Soviet environment of under-funded cultural heritage institutions, to keep our recording methods viable and sustainable in terms of both cost and time considerations. Our collaborative projects, though now generously funded by outside institutions, primarily the Packard Humanities Institute, began, as most do, on a tight budget with limited access to the necessary skills of professional surveyors, remote sensing specialists, and information scientists. Much of what we have learned during these last twelve years was thanks to trial and error and constant reassessment of the way we collect, manage, store and serve our digital data.

The nature of our project (surely not unlike most other large cultural heritage projects) has expanded steadily from the outset in both scale and scope. Meanwhile, as technology, software, operating systems, digital media and data acquisition systems have developed, we have experienced drastic changes in the way we record our work, sometimes as often as every year. This process has taught us an immense amount and has brought to the fore what we consider to be potentially dangerous trends in digital recording for cultural heritage. These include the reliance on high-cost, high-tech methods without practical field considerations, the proliferation of digital data (often replacing completely the paper record) with little attention to international standards for long-term preservation, readability and accessibility, and the lack of general understanding of the science, theory, and limitations of the technologies being used.

3. Project Descriptions

3.1.Mapping and Monitoring the Ancient Countryside (Landscape Scale)

ICA and NPTC, in collaboration with the University of Texas at Austin Center for Space Research, received a grant from NASA’s Solid Earth and Natural Hazards program in 1998 to investigate the use of remotely sensed data for the study and protection of Chersonesos’ rural territory. The primary goal of the project was to assess a variety of remotely sensed data types both for improving our understanding of the ancient topography of the chora and for assessing and monitoring modern urban encroachment that is threatening its preservation.

A wide range of imagery was obtained for mapping the Greek cadastral system, including Soviet historical aerial photography and CORONA imagery from the 1960s and 1970s, recent high resolution panchromatic imagery from the IKONOS II, IRS, and SPOT satellites (Figure 4). For monitoring recent landscape dynamics and for vegetation analysis, a series of Landsat scenes from the 1980s, 1990s, and 2000 were obtained and used for automated land-use/land cover mapping and change detection analysis. [TCC2001]

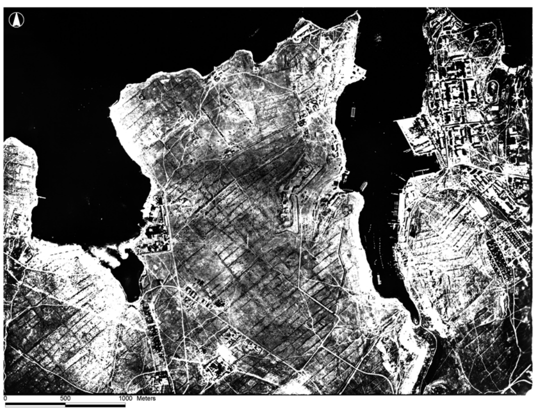

Figure 4: *Historical aerial photograph showing traces of ancient cadastral system.*

Although ICA had already been amassing a vast amount of paper and digital archives during its previous 20+ years of work in the rural territory of Metaponto in southern Italy [CAR2006], the NASA-funded project was our first experience with large digital datasets and our first major digital recording project for our work in Ukraine. The institutional experience of managing over two decades of digital data for the Metaponto survey project informed much of the way we set about managing our digital data at Chersonesos. Having experienced traumas associated with changing staff and of changing technology (which included the transfer of data from Bernouli disks to floppy disks to 8 mm tape to CD to DVDs and powerful servers), we were somewhat more prepared not to repeat our mistakes (though many of them were naturally repeated anyway).

The NASA funding for the remote sensing project is now complete, but we continue to rely on the results and the data generated by it in our ongoing projects in the Chersonesan chora. This year, for example, a team of landscape architects set out to create a plan for an archaeological park in one of the best-preserved areas of the ancient chora. The mapping base from the NASA project proved incredibly useful for their work, but reminded us about the importance of producing data about our data. The experience of making the imagery and basic GIS data for the chora accessible to new members of our larger team brought home to us the importance of documenting our data with useful and complete metadata and keeping a tight and tidy file structure.

Likewise, we continue to struggle with the challenges of making the data accessible (and versions up-to-date) for a large international team. Large datasets like satellite imagery and scanned maps quickly add up to many gigabytes of data that are nearly impossible to transfer back and forth between specialists, many of whom live in countries with unreliable or inadequate internet connections. Further complicating the issue is how to address the question of who eventually will maintain the datasets, equally the property of our two institutions. (See below, section 4.1).

One of the major challenges we have had with all of our GIS projects at Chersonesos is the lack of good coordinate data and maps. Due to the military sensitivity of the area (as a major naval base), precise locations of features and large scale, good quality topographic maps are considered a state secret and nearly impossible to obtain. While we have been waiting for permission from the local authorities (since 1998) to use GPS, we have planned all of our mapping projects so that it would eventually be relatively easy to transform our mapping base and coordinate system (from arbitrary local to real-world coordinates) without making any of our projects dependent on either GPS or quality maps. For the landscape scale GIS of the ancient chora, satellite imagery has served as our base map, providing us with spatial accuracies no better than our most accurate dataset. In terms of keeping pace with changing technologies, we have transformed our base map twice already, and will have to do so again if we get permission to use GPS. At first, all imagery was geo-referenced to our best map base, a 1:50,000 scale topographic map. All of it (plus the results of its analysis) had to be transformed when the new generation Landsat 7 ETM+ satellite (with improved ephemeris data and a 10-m panchromatic band) went operational, and again when the first 1-m resolution imagery became available (in 2000) from the IKONOS II satellite.

This level of accuracy (+/- 10 to 20 meter) is adequate for a small scale (1:10,000 or smaller) GIS, but for the medium scale mapping (1:1000) required for our work in the ancient city center, and for large scale (1:20) excavation recording, much higher accuracies are needed. For mapping the city and our excavations, we therefore use floating arbitrary coordinate systems, which we will eventually tie in to a UTM map projection so that we can navigate seamlessly from chora to city to site to object.

3.2. Mapping and Monitoring the Ancient City (Urban Scale)

In 2003 we began a GIS project in the ancient city as part of a conservation recording system developed for rapid general condition assessment and monitoring of exposed structures. It also incorporates results of detailed recording for individual structures (before and after conservation). This recording system was designed specifically to assist in the preparation of a conservation management plan, part of a general management plan required for nomination to the UNESCO World Heritage List [CTE2006].

While developing the conservation GIS for the city, we had in mind the long-standing needs of the Preserve and other researchers for an up-to-date phase plan of the ancient city. It was part of our plan from the outset that the GIS could eventually also be used to link to archival material already being digitized for a separate project of library and archive preservation (known as Megarica, and also funded by the Packard Humanities Institute). This has the potential to be a powerful tool for research as well as for site management and conservation planning (Figure 5).

As with the GIS for the chora, the lack of an adequate mapping base or permissions to use GPS required a great deal of patience and flexibility in designing the GIS for the city. What would have taken about a season's worth of field work under ideal situations (with a good paper map and/or GPS plus an aerial photograph), instead has taken us 4 seasons (with a team varying from 8 to 3 surveyors) to create a complete general plan of all standing architecture on the site.

A combination of methods was used in creation of a digital base map. After conducting a total station control survey and setting a network of permanent and temporary benchmarks throughout the site, we incorporated a variety of traditional total station survey, scanned archival plans (of varying scale and quality), a 1:500 scale map (with all coordinate/map projection information removed) from 1958, and, finally, in 2005, a color aerial photograph.

In addition to the familiar problems with mapping data and state secrecy, we were continually faced with the challenge of keeping pace with changing technology. The most drastic shift we experienced was the shift to ESRI's ArcGIS after one season using a combination of ArcView 3.2, AutoCAD, and ENVI (remote sensing software that we used for georeferencing maps and imagery). This shift, though it eventually paid off because of vast improvements in (among many other things) display capabilities, georeferencing tools and portability of the GIS data, was a painful one in terms of the learning curve and the re-design of the back-end of the GIS.

Likewise, an upgrade in the data collectors used with our two total stations in 2005 required major changes to the back-end of the GIS and related database in order to streamline the process of downloading survey data and importing it into the GIS. Eventually this was worth the extra effort, but it was definitely a difficult transition that required a lot of on-the-fly learning and major changes mid-stream to the way we worked in the field.

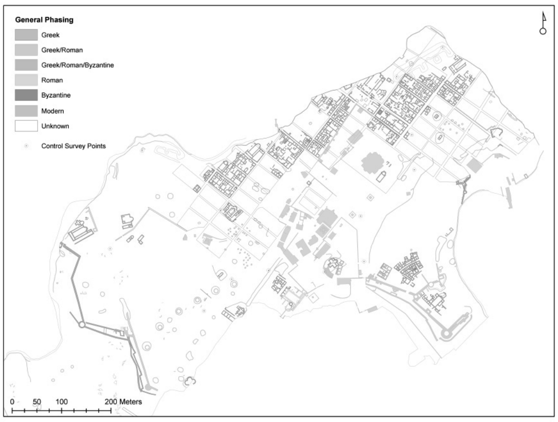

Figure 5: *General plan, the ancient city.*

3.3. Excavation (Intra-site Scale)

In terms of changing technology, recording methods for the excavation in the southern region have gone through radical changes in both the back-end and interface. As with the recording systems developed for the chora and city, our excavation data are held within a GIS and relational database [ERT2006].

The mapping base problem has been less of an issue for this intra-site scale, as we use a total station to record our spatial data within an arbitrary local coordinate system in order to maintain high accuracies required for such large-scale mapping. Changes in staff structure, as well as in software, operating systems and equipment have been especially problematic.

Our basic data collection methods (in terms of the paper forms filled out in the field) has remained almost the same throughout, but the database structure has radically changed almost every year. In the first years, a stand-alone Access database was designed by a team of collaborators from the University of Lecce. The system was originally developed for their excavations in southern Italy and was exported for use in Chersonesos.

Because of the initial participation with the Italian team, recording was originally done primarily in Italian, followed by a mix of Italian, English and Russian. From 2004, excavations were conducted under a different field director (from the University of Texas at Austin), and the inherited database was radically redesigned. This situation resulted in a large amount of legacy data (in multiple languages and formats) that had to be integrated into the new database.

The inheritance of a large amount of legacy data brought with it a number of problems, including the need to design the back-end structure in order to handle multiple context and special finds numbering systems and file naming conventions. We were tempted to ignore this legacy data and start from scratch, but this would likely have resulted in the inability to integrate the two datasets and the potential loss of information. This process was relatively time-consuming, but the two datasets can now fully integrated and can be queried and presented alongside each other in the final analysis and publication.

The problem of some of the entries being in Italian still remains, meaning that free text searches will not always give the expected results (unless one searches in English and then Italian). A fully multi-lingual database structure could have been be implemented from the start – but at the time the overhead needed in terms of design and translation was considered to be too great. For future projects, however, we would take this problem into consideration from the outset.

One of the most important things we learned from the evolution of the excavation recording system is the necessity of flexible design and extensibility so that new recording needs can be addressed as they arise without total system overhaul mid-stream. All too often, in our experience, short field seasons with their compressed time-frames lead to short-term fixes in the field that take priority over careful design considerations and thorough data documentation. The documentation then gets left to the post-excavation period and more often than not does not get fully completed. While a certain amount of this is inevitable, it is crucially important to make the time to document properly the data, its structure and processing history, especially as digital data proliferate at an exponential rate.

One other challenge we will be facing in the coming study seasons and publication phase is the issue of meeting specialized users' needs. This is particularly acute in the case of specialists with their own stand-alone data sets or with aversions to working in a digital environment. Several add-on modules to the database are currently being designed to incorporate specialist datasets from a wide range of disciplines.

4. General Considerations

4.1. Storage and Archiving

The past three years of excavations in the southern region at Chersonesos alone have produced nearly 180GB of digital data. This, combined with the chora–wide remote sensing data, conservation recording data in the city center, and general project photography, publication and presentations, we have generated well over a terabyte of data in the course of our project at Chersonesos. Data storage is becoming a major problem for all cultural heritage projects as increasing reliance on digital recording becomes the norm. Although the cost of storage devices decreases every year as they become larger and more efficient, portable hard disks are a relatively unstable medium for transport to and from the field every year. While more suitable solutions are still being investigated, we feel regular backups to more stable removable media (e.g. DVDs) is crucial.

4.2. Data Integrity

With the exception of photographs, we have attempted to avoid solely digital data capture wherever possible, to ensure that the information can be completely reconstructed even if the digital record becomes obsolete, inaccessible or corrupted. In terms of the paper record, we have striven to ensure that the paper documentation is not just considered a medium to transfer data into the database (for updates later), but can stand alone as a complete record of the work undertaken. A full set of all paper forms, illustrations, plans and sections is photocopied at the end of each season and stored along side the digital data. One complete set is left in Ukraine, while the other travels back to Texas.

The fact that our huge database of site and objects photography is solely preserved at the moment in digital form is a serious problem that we hope to address in the coming year, as funding permits.

4.3. Long-term Support and Maintenance

Of major concern to us is the long-term fate of the primary data [ERT2006]. A number of data-warehouses, such as the Archaeological Data Service (ADS) in the UK, have been specifically designed to store and serve heritage datasets. Their main objective, however, tends to be the preservation of the primary data, with little or no consideration of the interface developed for accessing it. While data preservation is absolutely crucial, some form of the interface originally intended to view it should be housed, served and maintained. We view this as important as a print publication's cover, figures, index and typesetting.

Clearly this brings its own problems, as currently websites are rich with JavaScript, Flash animations and other server- or client-side programs that bring the website to life and make navigating and using the content possible. Storage of data is cheap and reasonably low-maintenance, however, if the interface has to be continually updated and re-designed to keep abreast of the latest changes, it becomes a much less sustainable solution.

5. Future Work

The next step for these digital projects is publication and dissemination to the wider public. It is our eventual plan to publish the full set of primary data, at least for excavations in the southern region of the city. We will produce a traditional paper publication as well, but plan to publish, as a companion to the print publication, a web-based database and GIS that will allow others to query and search all of our primary data. Our main aim is to present the data with an intuitive interface that will permit users to access the data without prior knowledge of our recording system. This will not only allow our audience access to information that would normally be too cumbersome and costly to reproduce in the print publication (such as all finds photographs and stratigraphic documentation), but will also allow re-interpretation of our results and integration with other datasets from other similar sites.

Acknowledgements

This work is the result of a huge number of extremely capable hands. None of it would be possible without the generous support of the Packard Humanities Institute, NASA, and a large number of other private foundations and individuals who have helped support ICA's projects since 1974. Special thanks go to Prof. Joseph Coleman Carter, who has been the mentor, inspiration and source of support of so many of the people who have worked on this project over the years. Prof.s Melba Crawford and Adam Rabinowitz from the University of Texas at Austin and Chris Cleere of Cleere Conservation Ltd. also made major contributions, as did Larissa Sedikova and Galina Nikolaenko from the National Preserve of Tauric Chersonesos.

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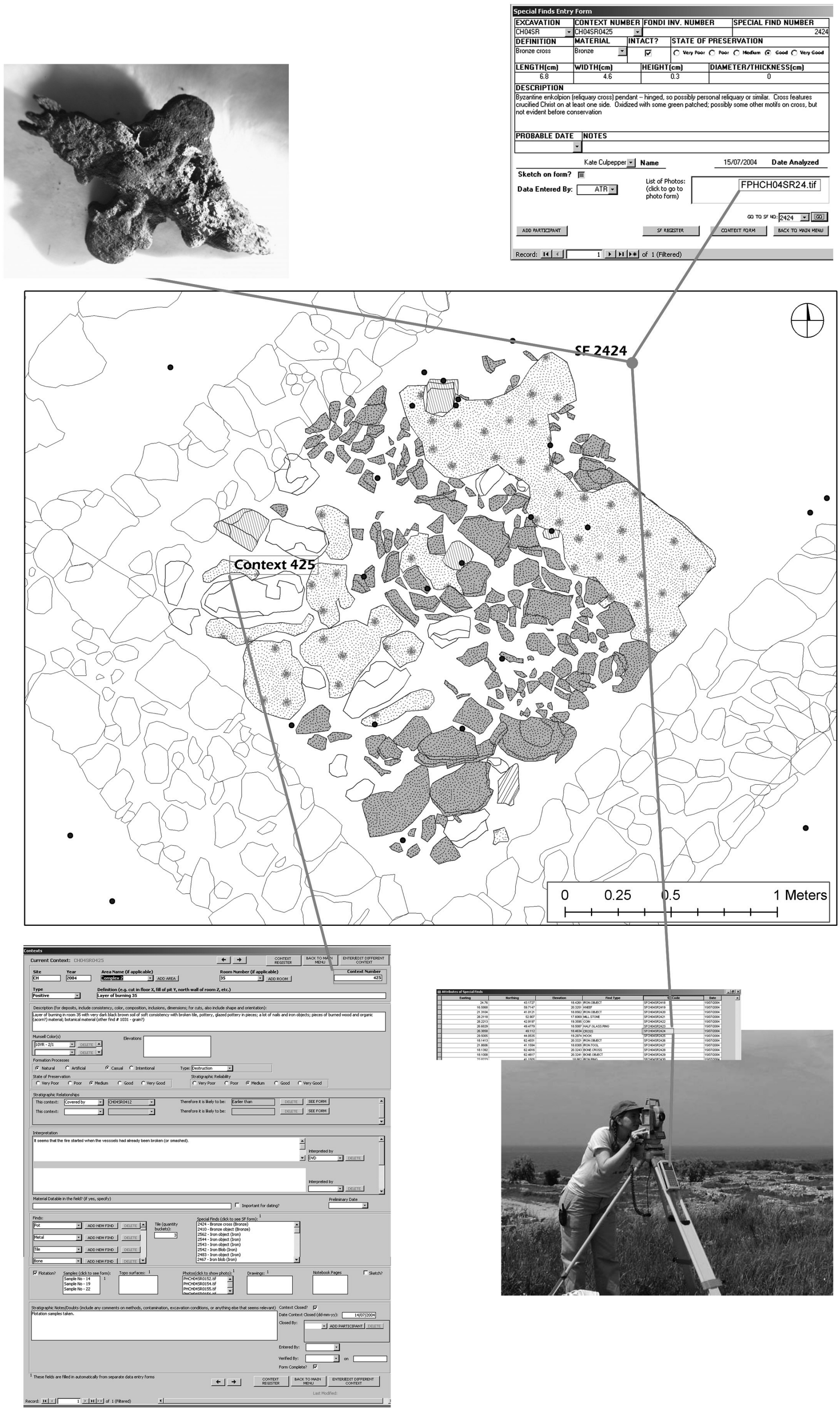

Figure 6: *Special find from field to conservation lab.*

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
VAST (2006)
M. Ioannides, D. Arnold, F. Niccolucci, K. Mania (Editors)

Interactive and Real-Time Interpretation: New Boundaries for Cultural Heritage

Patrícia Valinho, Catarina Cerdeira, Ivan Franco and Bruno Serras

YDreams

Abstract

Over the last years we've watched the emergence of new technologies and communication systems that have, in their own way, changed the way people live. Technologies have invaded daily routines, from LCD screens to biometric costumes. The use of emerging technologies in cultural services is also becoming a challenge and can perform, itself, a major revolution transforming the way monuments and landscapes can communicate with visitors.

The Portuguese Institute for Heritage and Patrimony (IPPAR) has implemented the first Virtual SightSeeing®® unit, an innovative interpretative tool that allows visitors to access information about the landscape, in real-time; in Pinhel Castle, in September 2005.

In this paper we'll analyze the impact of this technological tool in Cultural Sites namely at the Pinhel Castle, and its capabilities to improve the communication between visitors and monuments worldwide.

Categories and Subject Descriptors (according to ACM CCS): I34 [computer graphics]: image processing and computer vision.

1. Introduction

Cultural places - such as museums, archaeological sites and monuments - hold several narratives and stories, related with their historical, social and economical backgrounds. Presenting these stories to the public has always been a hard task mainly due to the peculiarities of each place, the particularities of the exhibited objects, and the diversity of visitors: foreigners, special needed, elders, children and others.

The 21st century's main challenge for cultural institutions is telling these stories to each public in particular, getting them involved with the cultural space, establishing new communication channels between them and the institution's assets. The development of new technologies brought new possibilities to this challenge, allowing the implementation of innovative interactive systems that reinforce the relationship between technology, culture, heritage and the public.

Emerging technological concepts like ubiquitous computing, micro geography and augmented reality offer a brand new approach for cultural institutions in general, museums and monuments in particular. These systems enable visitor's access to contextual information offering multimedia contents to the public that can know have a more personal and customized visit. Interactive systems can bridge the gap between visitors, cultural sites and institutions. It can allow an autonomous to tour to cultural spaces to everyone, with no exclusions. This paper presents a tool that uses augmented reality in a see-through system that widens the horizons regarding to the use of technology in cultural sites.

2. State of the Art

The use of augmented or virtual reality systems in cultural sites is not a novelty. In the late 90's appeared the first technological systems that, using virtual or mixed reality, offered innovative services to cultural sites' visitors.

We'll briefly introduce some of these technological systems, before introducing the Virtual SightSeeing® scenic viewer:

- **TimeScope**. This tool uses a see-through approach to provide contextual information to Ename Archaeological site visitors. Using two monitors and a static structure (integrated in a kiosk house), visitors can understand the labyrinth of the archaeological remains and see how the original structures were.

- **Archeoguide**. This is a research project that seeks to build a system that provides new ways of accessing information at cultural heritage sites. Using IT including augmented reality, 3D-visualization, mobile computing and multi-modal interaction, this research group is developing a head-mounted display that will allow visitors to walk freely through the cultural site, receiving more information according to their location.

- **XC-01** (Fraunhofer IGD). This system uses a video see-through approach; it is implemented at the Grube Messel, near Darmstadt Germany, a large fossil storage. The system can be used to augment views of sites where the intention is to explore the landscape, allowing visitors to access additional information about some of the referred objects in the landscape. This work doesn't use real-time image but pre-recorded videos.

The main difference between these systems and the Virtual SightSeeing® relies on structure's characteristics and design approach. Using the same kind of technology (real-time image capture and augmented reality), and similar content exploitation as the referred projects, the Virtual SightSeeing® is a structure that rotates 360 degrees, allowing user to fully explore the surrounding landscape. Besides, it integrates a large screen that allows visitors to widely explore the landscape.

The Virtual SightSeeing® is the result of a two-year result project, and it is now under final stage of industrialization. The beta version is already implemented in a Portuguese Castle in the city of Pinhel, near the Spanish frontier. At the moment, we are already preparing new interactive interfaces, in order to offer an easy interaction to all users, no matter what their physical characteristics are – by the end of 2006 it will be launched the first inclusive Virtual SightSeeing® unit, at the sensorial blind park called Pia do Urso (in the centre of Portugal, near Batalha). This project is being funded by the European Commission.

3. The Virtual SightSeeing®: Cultural and Tourist Revolution

Figure 1. *The Virtual SightSeeing® unit.*

The Virtual SightSeeing® is a visualization device that works by superimposing in real-time images generated by a computer on a real image captured by a lens as in a telescope. It can be used for cultural, entertaining, educational or commercial purposes. This device replaces and adds innovative functionalities to existing telescopes, commonly located in historic or scenic places. It allows adding multimedia elements to the real scenery by composing them in the image that is presented to the user. The multimedia elements can be defined and maintained using a simple Web page interface.

This particular interpretation tool takes advantage of the physical characteristics of a standard telescope, namely ease of use and 360 º rotations, to build an innovative system that can be used by anyone, anywhere. The multimedia information and virtual elements that are displayed are sensitive to the orientation and position of the device. They change as the user manually changes the orientation by moving the device. All the information presented in the device is geographically referenced.

The physical structure supporting the Virtual SightSeeing® is similar to a standard sightseeing telescope; however it includes distinct components for its new functionalities. The main components are a system to capture the real image (typically a video camera), a computer to process the real image and superimpose the virtual elements, and a screen to display the composed image. Sensors or image processing techniques are used to determine the orientation of the device. The user can interact with the device with a touch screen, buttons or simply by moving the device.

The position of the different components of the device was designed such that it can be as most user friendly as possible. The touch screen is incorporated in a mobile structure for better view and easy access. The handle is placed in front of the device for simple and intuitive user grip. In this handle there are two pressure buttons similar to those used in computer mouse devices. Besides, resulting from a long industrial design process, the structure is robust (anti-vandalism and weather conditions resistant) and water-proof.

From the user's viewpoint, the steps to run the system are:

- The first step is initialization, where the system collects all the contextual information from the server. When all the information is downloaded from the server, the system is ready to use and starts the Demonstration mode (optional) or the Application mode;
- When the system is in the Demonstration mode, a video is presented. The video can include advertisements,

credits or other generic information. Depending on how it is set (optionally the system can be used by paying), the system starts the Application mode, which is when the Virtual SightSeeing® actually works. In this mode, the user can interact with the elements in sight (real or virtual), play games, or use any other functionalities provided by the system.

- Finally, when time ends (according to the amount paid or by user's selection), a message of goodbye is displayed and the system returns to the Demonstration mode (optional) or turns inactive.

At the moment, the system allows two kinds of users. The common user, who uses the Virtual SightSeeing®, and the administrator, who has the permission to change, add or clear virtual information. These changes can be done locally or remotely. The administrator can execute changes without going physically to where the Virtual SightSeeing® is located. This is done using an internet connection and Web pages for configuration or onsite.

By the end of 2006, the system will include another type of user, allowing blind people to use the device and take advantage of a customized audio interface that describes the landscape to the user, allowing them to experience differently.

3.1 The Virtual SightSeeing®: Main Functionalities

Using a basic system, users can interact with the following features:

- Identification of points of interest
- Detailed contextual information
- Photographic Album
- Map with tourist paths
- Search of points of interest
- Language selection

Besides these features, the system can be incorporating other functionalities, taking advantage of augmented reality but also structure' characteristics:

- Paths to, and virtual flights over designated points of interest
- Fun and educational games (ex: interactive quizzes)
- 360º panoramic videos (QuickTime VR´s)
- Possibility to photograph the terrain, print images and/or send them to third parties via MMS/e-mail.

3.2 The Prototype

Pinhel Castle was the site that received the first Virtual SightSeeing® scenic viewer; a prototype version till the product is tested and the industrial design process concluded. This castle, dating back to the XII century, is a Portuguese classified national monument located near Guarda, in northern Portugal and was subjected to conservation works in 1999.

The Portuguese Institute for Heritage and Patrimony (IPPAR) decided to implement the Virtual SightSeeing® in this castle to promote the net of monuments in the surroundings (representing an ancient castle defensive line, near the Spanish frontiers).

Figure 2. *The Virtual SightSeeing® interface.*

Since September 2005, visitors can explore the surrounding landscape with the guidance of system's interactive interface, which indicates nearby points of interest over the landscape, in real-time. If the user wants more information about a particular reference, he just has to press the label on the touchscreen. Then, he'll have detailed contents like maps, pictures, descriptions and videos. Besides this feature, users can search for a particular element in the landscape, using the search tool; an arrow emerges, indicating the location on the screen. Other functionality is the language selection.

The number of visits to the castle has increased significantly during the last year. According to monument staff, people go to the castle just to explore the guided tour. Visitor's feedback has been quite enthusiastic, contributing to the improvement of some elements in the machine. The prototype will be replaced by the end of 2006.

IPPAR has already started a new project, in a nearby Castle: Trancoso that is also a part of the ancient defensive barrier. It will be implemented till June 2007. This new Virtual SightSeeing® unit will include an additional feature: the reconstruction of an important battle that occurred about 700 hundred years ago. The idea will be simulating troops movements in real-time, over the landscape. Allowing visitors to understand better the way the battle occurred and the how the landscape was in that time.

4. Conclusion

Technology has assumed an important role in the communication process with visitors to cultural sites, but also with their involvement with culture itself. Cultural sites have to be innovative in order to attract new sectors of the public, namely those unfortunately set aside by society. Implementing interactive services in cultural sites is a special task that cannot be neglected; we have to carefully analyse the fusion between technology and the space in order to bring the right service to the public.

How to involve the public with cultural sites has always been a delicate question for curators; is it possible to give information about the site itself and the surroundings to everyone, according to users' needs? And how can they be rentable?

The devices described earlier can answer these questions; regarding the contents, these systems can enhance:

- **Links to the past**. Integrating the monument in its old environment, changing the landscape in real-time (taking use of augmented reality).

- **Storytelling.** Multimedia applications telling stories in real-time over the landscape, making use of video and audio devices; for instance, performing the simulation of a battle that occurred long time ago.

- **Replacing absent elements.** 3D graphics allowing the insertion of 3D elements like buildings, roads, railways, others.

- **Guiding the visitor through the landscape.** Using an intuitive interface that guides visitors through the landscape, showing information according to user's needs.

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Analysis – reconstruction – design: case studies on ongoing projects

Dr. Zs. Vasáros[1]

[1]Budapest University of Technology and Economics, Faculty of Architecture, Hungary
Narmer Architecture Studio, Budapest, Hungary

Abstract

The perceptual and theoretical reconstruction of architectural structures resulting from archaeological excavations goes hand-in-hand with scientific publications and presentations. However, the majority of the issues and problems lie in the algorithm of the process. The layout of the structure that is to be reconstructed emerges on the basis of the thorough analysis of archaeological remains. Even during this phase, a number of considerations and decisions need to be made in order to clarify the coherence of the ground plan. Are we allowed to create the overall extension of a structure that is problematic even from the point of view of its ground plan, let alone create its photorealistic reconstruction? These questions are definitely justified. The issues at hand are both practical and ethical. Further, there are the expectations of those who view the product: visitors demand high-quality interpretations, and professionals are also curious concerning a possible reconstruction. The suggestions presented below offer alternative solutions, in line with the concepts based on analysis of the primary data. In the majority of the cases, these presentation methods enable us to give an account of the validity – or the doubtful validity – of the reconstruction in question only through the applied graphics. In this presentation I will give an overview of the above issues through the virtual reconstruction of Roman Age villa complexes, tombs, Early Middle Age churches, and Egyptian temples.

Categories and Subject Descriptors (according to ACM CCS): I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism – Virtual Reality; J.2 [Physical Sciences and Engineering]: Archaeology; I.3.6 [Computer Graphics]: Methodology and Techniques – Interaction Techniques; I.3.3 [Virtual Heritage]: Computer Graphics Animation

1. Introduction

Conceptualization with virtual modelling still has not become a generally accepted and generally used method among archaeologists [Vit04]. The experts of this field are participants in conferences and pioneer developers of applications, but still can not always be participants in projects offering long range results. Some consider 3D visualization and modelling a curiosity or even a luxury, others think them superfluous, not scientific or simply incomprehensible [Bar00]. Nevertheless, there are refreshing examples, some of which will be cited here.
It must be admitted that the visual world of recent years has resulted in enormous development in applications [Red02], but the anachronistic and inaccurate reconstruction of many historical films has generated dislike among scholars. The application of computers and rendering software is on a wide range - just think of the database systems developed for archaeological purpose or modelling software [NC03].

2. Methodology

During the process of a project and the evaluation of architectural data, it is possible to define the following points – and also the level of process - from the fieldwork documentation to the photorealistic presentation [BFS00]:

A. Digital database of the in situ remains: the source can either be a digitalized survey executed with traditional methods, or a digital data recording consisting of mainly geodesic methods. Uncertainty can only be in the precision of the survey or the misinterpretation of the data.

B. Preparation before the reconstruction: This includes the definition of the wall foundations, the synchronization of levelling data and the presentation of main information. The level of uncertainty is low, and the decisive factor is the accuracy of the survey.

C. The reconstruction of the ground plan: the rendering of the ground plan based on survey data, the definition of the floor-levels and the fall. In many cases analogies can help to clarify the spatial structure – but that may result in some inaccuracy. It is important to note that the ground plan should not be considered as a two-dimensional surface – the falls, supporting walls, and steps can fundamentally influence the theoretical reconstruction.

D. The analysis of the spatial organization: roofed structures, opened areas, drainage, roof structures etc. On this level the observations of the fieldwork can be crucial: the character and position of the ruins, observations of the floors, the thickness and foundations of the walls, and the archaeological object indicating the use must be considered. The incomplete documentation or the limited or destructed structure – a lost floor level, for example – that is detected during the fieldwork can raise the level of uncertainty.

E. Architectural reconstruction: the rendering of the architectural concept with the required details according to 1) previously set needs and 2) possible analogies. On this level it is very important to consider the archaeological finds which are connected with the architecture, such as statue and moulding fragments, structural elements, fresco fragments, etc.

1. Simple axonometric reconstruction of the ground plan for better understanding.
2. Reconstruction with the rendering of those parts which can be completed.
3. Reconstruction of the whole structure without details and indicating the materials.
4. Reconstruction with the indication of the materials and rendering the parts which can be completed.
5. Photorealistic reconstruction.

3. Visualization

Often archaeological data is visualized at a specific time in the past. This can be categorized as a reconstruction, which when using 3D models and computer graphics is called a virtual reconstruction. This methodology can even be extended into the future for illustrating models of restoration or deterioration [Rya01].

4.0 Case studies

Some examples will be presented below which mainly show the differences of full reconstructions as per requirements of the target group and also show aesthetic points.

4.1 Case study – Egypt-Eastern Desert, Bir Minih

The site of Bir Minih, situated in the Eastern Desert of Egypt south of Wadi Hammamat, has been under exploration by the Hungarian Mission since 1998 [Luf01]. The finds include ruins of a settlement with an adjacent cemetery, a vast amount of rock drawings and rock inscriptions, areas of mining activity and more, possibly Palaeolithic and/or Neolithic camps. The documented rock drawings and inscriptions cover a remarkably long period extending up to recent times. The ruins of the settlement are situated on cliffs that rise above the current surface of the Wadi. The fieldwork took place in the Eastern Desert where the architectural-geodesic survey of a late antique gold-mining settlement had to be executed with the documentation of hundreds of pharaonic inscriptions and rock-carvings. The remains of the settlement cover some acres of land in the area; the ruins of almost 500 buildings and 150 tumuli were detected.

The extreme circumstances demanded very fast fieldwork whereas the scientific analysis and interpretation of the data called for special methods. The Survey Project at Bir Minih (1998-2003) involves applications of advanced digital technologies for a detailed reconstruction of the archaeological landscape: analysis and classification by remote sensing and GIS, as well as interpretation and presentation of the results through virtual reality and visual information systems. The most relevant aspect of the research is a multidisciplinary approach, starting with the acquisition of the data during the fieldwork, and then creating predictive classified maps and databases, including 3D models [VLB04]. The compilation of the data surveyed and that of the level models served different purposes: on the one hand, they offered impressive, comprehensible visual representation of the particularities of the segmented surface, and on the other hand, arranging the individual objects in this virtual space revealed their spatial connections. On the screenshots we show the attempts to visualize and model the terrain using the simplified surface-model (not trying to create a naturalistic rendering). The 3D rendering of the contour lines proved to be an interesting problem – we tried different variations. The model built from flat surfaces is suitable for a virtual ground on which to insert the building and surface ruins. The terrain model of vertical surfaces offered a good opportunity to place the rock-carving and inscriptions. The surface covered with polygons gives both a naturalistic image of the terrain and an impression of the original surface.

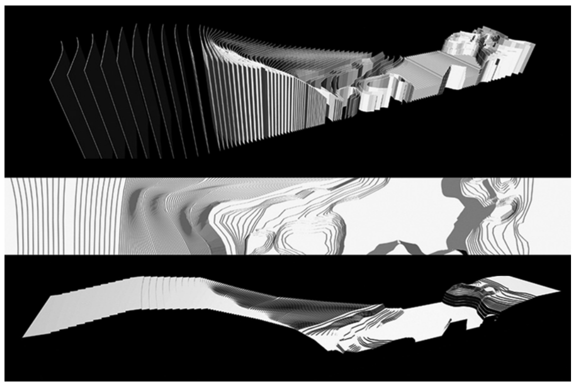

Figure 2: *The terrain model of vertical and horizontal layers*

3D modelling creates a highly detailed and versatile record of the site, a much better one than what could have been achieved previously. Traditional methods greatly relied on the surveyor's skill and the ability to convey the understanding of the site through graphical methods. This area needs more consideration in the modelling process or the development of new visualization techniques and virtual models. In the future, attention will be paid primarily to recreating the virtual landscape in which the rock art sites and the architectural and archaeological objects are embedded. The following short example illustrates the latest results.

4.2 Case study- Syria-Qanawat

It was possible to reconstruct a part of the Roman burial structures surveyed and documented during the fieldwork with the help of computers [Oen00]. Following the digitalization of the drawings made in the course of the fieldwork, we were able to model the buildings using edited simple geometric forms. We made sections of them and we could set the view port to an angle from which these became easily comprehensible.

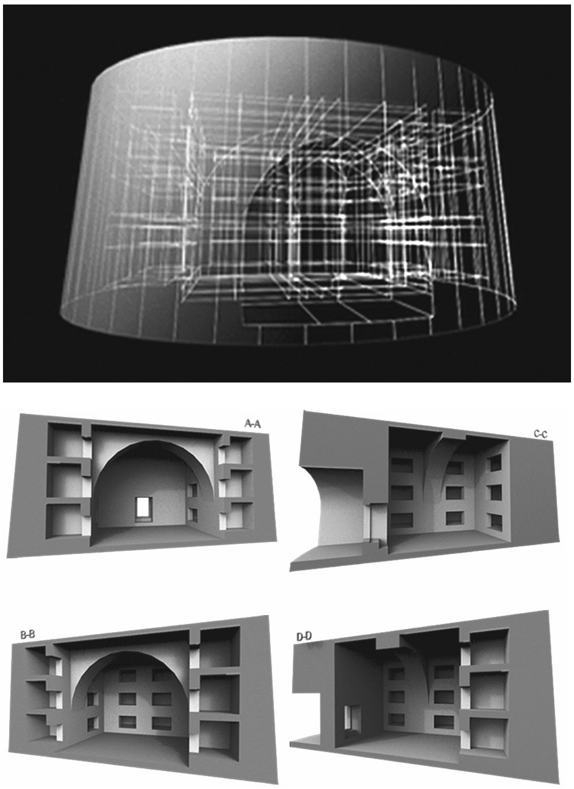

Figure 2: *3D view and sections of a Roman tomb structure*

4.3 Case study – Egypt-Thebes-West Bank, Tomb of Djehutymes

In the last 20 years the Hungarian Archaeological Mission in Thebes has unearthed a huge structure of the courts and chambers of a noble's tomb from the period of Rameses II. together with a huge amount of archaeological material [KBB*04]. I will show some of the computer reconstructions already presented at a number of conferences [VD04]. These are results of completed project phases. Considering the generally typical character of the architecture and the detailed information available, it seemed practical to aim at an almost photorealistic reconstruction. Years of research provided excellent ground for a detailed understanding the particular finds – statues, architectural parts, furniture -- and as full a reconstruction of them as possible.

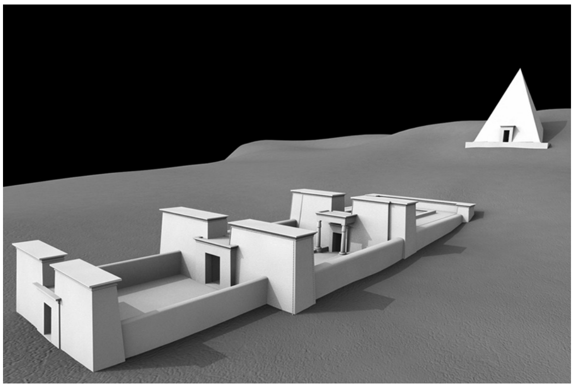

Figure 3: *3D view of the forecourts and the pyramid of the tomb of Djehutymes*

The material to be presented here is the architectural and archaeological reconstruction and virtual modelling of the spatial structure of Theban tomb No. 32 and its surroundings. Apart from representing the architectural units, we also wished to give an account of the chronology, that is, to present the periods the area in question was used - through the course of thousands of years.

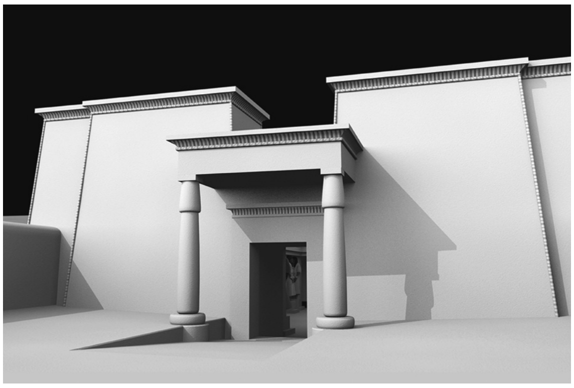

Figure 4: *Reconstructed portico of the third forecourt*

Digital processing started after the surveying and the architectural reconstruction had been completed. The survey drawings, the aerial and site photographs, the find assemblage and its analogies were our points of departure. The structure of the model was determined by the software which was chosen; in this case this is a surface model created by bitmap-based shading, mapped onto a wire frame. The multifunctional application of the computer for the assessment of archaeological data provided novel results from a scientific perspective as well.

4.4 Case study – Egypt-Thebes-West Bank, Tomb B

In the following example computer modelling served various purposes during the excavation itself. Tomb B occupies a large area on the southern slope of el-Khokha that partly overlies the first and second forecourts of TT32 [SV05]. A late burial complex was found in the forecourt of and partly under the great tomb mentioned above.

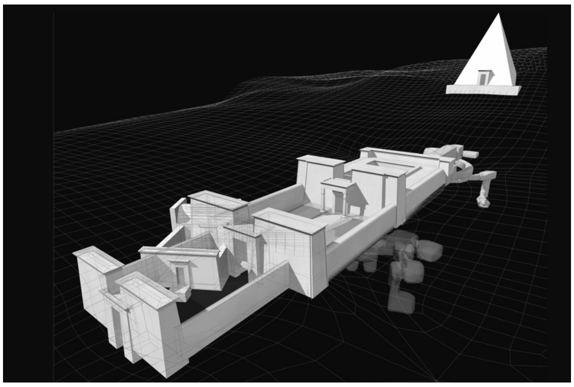

Figure 5: *3D reconstruction of the architectural superposition of Tomb 32 and Tomb B*

Already during the excavation we made a number of 3D rendering to help define the location of certain underground and higher structures. Following the final phase of the excavation it became clear that this tomb, with its unique ground plan has remarkably high walls which can be preserved only by conservation and partial reconstruction. To achieve our goal we made further models partly focusing on the conceptual reconstruction of the structure, and partly helping to make decisions regarding the rebuilding on the site. The screenshots show the most important structural elements via the work versions and the final models, and also show the reconstructed phase.

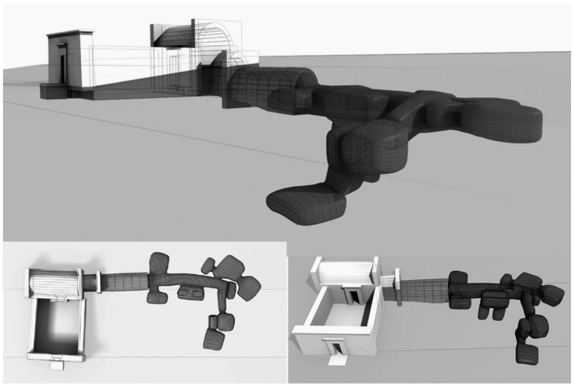

Figure 6: *Tomb B and its reconstructed architectural features*

4.5 Case study – Cologne Dome project

We started to survey the medieval forerunners of the Cologne Dome with Dr. Sebastian Ristow many years ago [Ris02]. Using traditional 2D drawings more and more impressive and scientifically accurate 3D renderings were built in each subsequent year. We present here some samples of this process also showing the different approaches of graphical representation. The following screenshots are designed for the temporary exhibition "Frühes Christentum im Rheinland" in Bonn, opening in December this year. Because of the representational nature of an exhibition the visual elements and animations had great importance. Although the surfaces and lights we chose give a naturalistic impression the perspectives, angles and camera motion are entering a different world, the world of motion pictures.

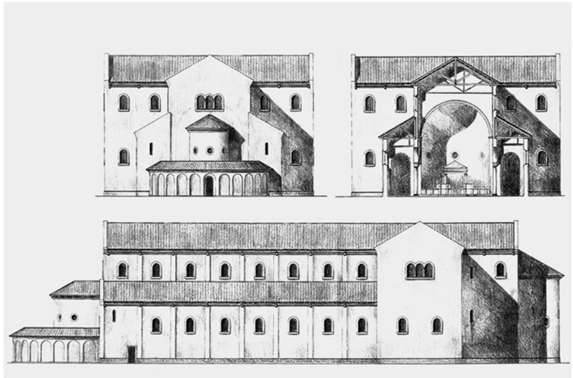

Figure 7: *Reconstructed views of the Cologne Dome - pencil drawings by the author*

Through this double character of the representation, we tried to compensate for the lack of imaginable elements, thus balancing creativity and scientific accuracy. Even the architectural concept of a particular phase can be problematic down to the outline of the ground plan, so it is advisable to be careful with very detailed models. The screenshots show the work versions of this process.

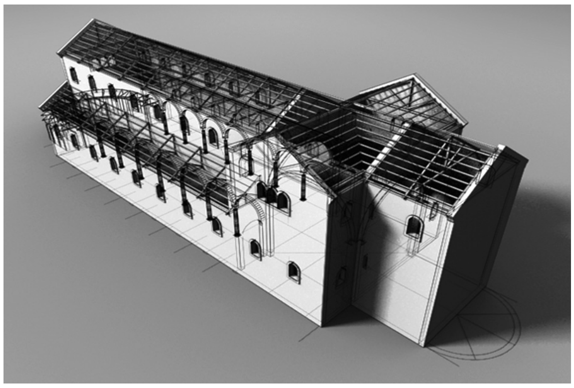

Figure 8: *3D view of the 7th century phase of the Dome*

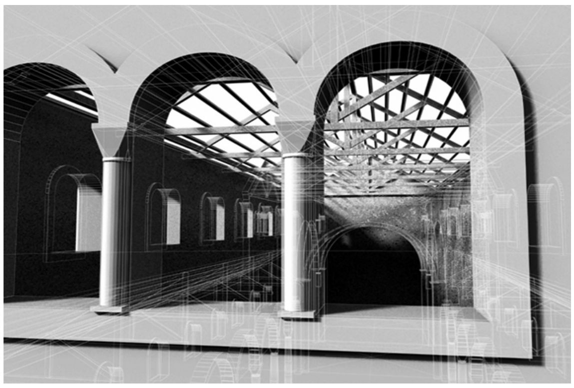

Figure 9: *Detail of the 3D model*

4.6 Case study – Roman forts: Campona, Haus Bürgel

These examples show the results of a comprehensive study on of Roman auxiliary forts. The Campona model made 10 years ago gives a good example that on the technological level of the day it was possible to make impressive models.

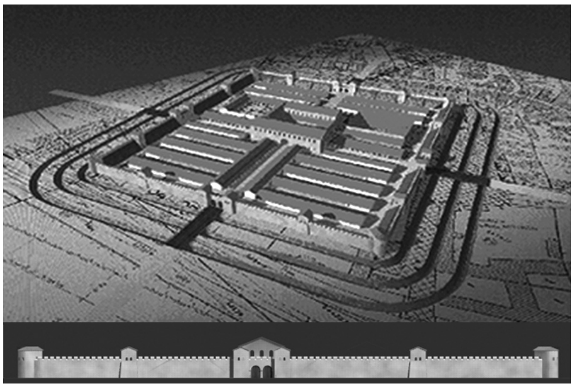

Figure 10: *3D reconstruction of the Roman cavalry fort Campona/Budapest Nagytétény*

The Roman architecture, especially the military buildings, with their typified character and variability, are cooperative subjects of 3D modellers. The easily constructed virtual models can serve as a better background for the scholars' disputes on the vertical dimensions conceptualizing the architectural mass. The example from Germany – Hausa Bürgel – were built with model-like rendering assuming the particularities of late Roman architecture due to the limited available data.

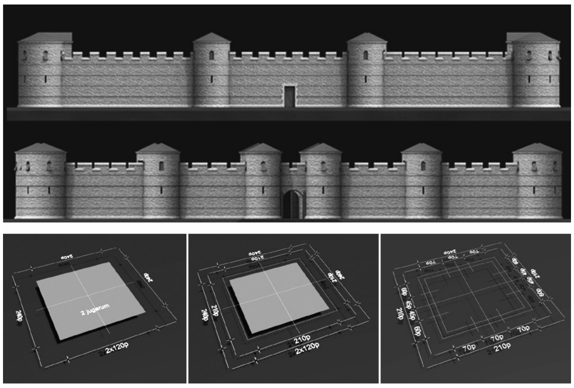

Figure 11: *Reconstruction of the Roman fort Haus Bürgel/Monheim, Germany*

4.7 Case study – Szabadbattyán, late Roman architectural complex

The modelling of the huge complex also identified as Sevso-villa was done under by different circumstances. During the excavation the most extensive building complex was unearthed. It is outstanding on the level of its "contemporaries" with its unique features and size. The fieldwork revealed hundreds of m^2 of fresco fragments which give patterns that help the reconstruction of the wall-surfaces and thus the heights.

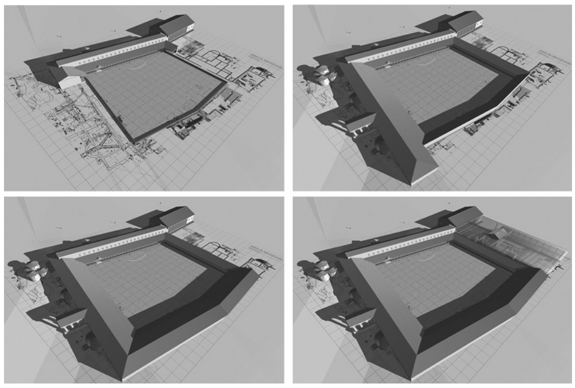

Figure 12: *3D reconstructions of the proposed restoration phases of the late Roman building complex*

The relatively simple but generous spatial organization, executed on a sloping terrain, raised interesting questions about the original architectural work. After digitalizing the data of the ground plan we tried to build the 3D model as close to the possible original as we could but it still could not solve the problem arising from the monotone impression of the huge buildings. Of course, since there is no data available about the unique superstructures and roof-forms, we can only rely on the ground plan, archaeological finds, and to some extent on analogies. The screenshots represented here are showing work phases, because in the course of the excavation newer and newer monumental structures are being observed, which will surely change our picture of the 4th century Pannonia province.

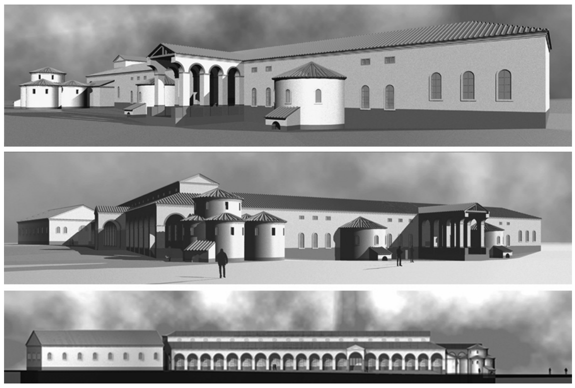

Figure 13: *3D views of the building complex*

5. Conclusion

Nowadays, computerized representation of architectural structures and historical relics is nothing new within the field of archaeology [Rou02]. The aim of computer-aided planning and modelling is to expose people to and acquaint them with contemporary professional skills and creativity and innovative thinking, besides creating virtual reality displays. Thanks to ongoing software developments, modelling is increasingly successful in capturing the richness of surface detail and the texture of the applied materials. The photo-realistic representation of virtual reality can be considered as a general expectation.

The 3D reconstruction of superstructures which have only fragmentally survived sheds light on the contemporary master strokes of design and at the same time gives away the awkward, less-successful solutions - which otherwise would not have been visible in a 2D model. Using 3D modelling, we can visualize alternative suggestions for details that either cannot be decided straightforwardly or cannot be deduced from the ground plan structure. Hence 3D modelling presents the best possible solution.

6. Acknowledgements

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The Use of 3D Reconstruction Applied to the Study and Spatial Analysis of Architectural Heritage: The Palace of the Aljafería in Zaragoza, Spain.

A. Almagro Vidal, M. González
Escuela de Estudios Árabes – CSIC, Granada (Spain)

Abstract

Computer graphics has a solid area of application in the field of cultural heritage if it is approached as an instrument to facilitate debate on the study of architectural heritage that has disappeared or been transformed. There is no doubt that the possibilities opening up, once the model has been generated, will provide interesting ways of conducting spatial analysis and its evolution in time, approaching this architecture in a way that is unthinkable using traditional means. Supported by the huge potential offered by the possibilities to change scene and model parameters, we can focus the use of this technique on comparing different states in time as well as various reconstruction possibilities.

Based on a rigorous and scientific working method, digital perception through the 3D model, is used as a procedure for study, analysis and establishing hypotheses, helping the avoidance of errors that are difficult or a least costly to correct later, because it does not affect the building itself.

One of the architectural episodes analysed in this project of 3D reconstruction developed at the Escuela de Estudios Arabes-CSIC in Granada, is the Palace of the Aljafería in Zaragoza (Spain). The events of History have deeply transformed what this 11th century palace originally was. Despite this fact, it is still so worthy of being visited today that this study, apart from the interest of the already developed research, stresses the importance of facilitating the perception of the palace's original form through a synthetic image and virtual animation as well as to discover and understand through the 3D model some cultural features that could have inspired its original design.

Categories and Subject Descriptors: I.3.8 [Computer Graphics]: Applications.

1. Introduction

The graphic field that is nowadays at our disposal using computer graphics is a tool of undoubted value and potential for studying, analysing and discovering Cultural Heritage. For a long time the scientific research field has been using traditional techniques, whose results were most of the time only at the disposal of the scientific community because of the need of some basic knowledge about the different graphic languages and codes used to be able to interpret the information contained, as well as the significance and value of that information.

At the same time, the increasing interest of nowadays society about cultural remains, their origin and evolution throughout time has promoted the development of new techniques applied to this field, in order to present the results through didactic multimedia environments and 3D representations. These means permit the user to understand the contents in a very intuitive way, and to deepen, as far as they may decide, a better knowledge of the monument or site.

In this context, there is no doubt that the influence of Islamic culture in Spain throughout almost eight centuries of presence in the Iberian Peninsula delivered outstanding architectural episodes. Unfortunately, the events of History have in most cases transformed or even destroyed what they originally were, so that nowadays it is rather difficult to understand and interpret the remains without the help of a qualified expert's explanation.

Thanks to computer graphics, specially 3D modeling obtained through different techniques, it is now possible to easily visualize 3D hypotheses of reconstruction and to enlarge the field of study according to the different steps that the modeling process entails. That implies new possibilities to learn more about different features such as the quality of the 3D space, the use of light and colour, and internal spatial relations. The fact that these features cannot be analysed through flat designs emphasize the importance of the use of 3D representations so, in this case, this technique turns up to be retained as absolutely essential to understand the concept of Spanish-Muslim space developed through History.

2. The historical evolution of the Palace

The origins of the Palace of the Aljafería (Fig. 1) can be traced back up to the 11th century, during the so-called Taifa petty kingdoms' period that followed the collapse of the Great Caliphate of Cordoba. All these little kingdoms tried in some way or another to ensure continuity to their Arab and Umayyad past by trying to reproduce the magnificence and the intricate architectural programme of Madinat al-Zahra', the fabulous royal city of the Caliphate. Of course, none of them had the power attained by Abd al-Rahman III and al-Hakam II during the 10th century, so there therefore followed a period of highly-elaborated theatricality. They tried, through decoration, and using few resources, to maintain the grandiosity and a kinship with the world of the Caliphate.

Figure 1: *Aerial view of the Aljaferia in Zaragoza*

The palace of the Aljafería, built by the Banu Hud family at a certain distance from the city of Caesaraugusta –Zaragoza– was originally a rectangular shaped construction surrounded by a fortified enclosure with ultrasemicircular towers (Fig. 2). The geographical position of the palace was probably established by the previous existence of a military tower of the 9th century that was subsequently included as part of the external walls. The palace itself occupies the central part of the enclosure as a detached building leaving two empty areas at the East and the West that could have been used as gardens (this is a hypothesis that has no archaeological confirmation at the moment) being protected by the high walls of the external enclosure.

The palace inside had a typological plan that followed a defined North-South composition axe. The building gathered a series of rooms around a central courtyard (Fig. 3), and was oriented according to the axe defining the palace main area in the Northern part of the residence. The throne room was a rectangular-shaped space with two small bedrooms in both sides. This main room was preceded by a U-shaped portico with a huge decoration programme of crisscrossing arches that surrounded in three of its sides a rectangular pool. On the opposite side of the courtyard, the main room with lateral bedrooms was preceded by a flat portico that was more massive than the North one (Fig. 4). This portico repeats a similar composition of crisscrossing arches that will be analysed when we will talk about the space and its study through the 3D model.

The central space of the residence was the patio, a constant feature around which the whole of residential life hinged in Al-Andalus –name given to Spain during the Islamic period. It was around this point that all the areas comprising the residence revolved and the zone relating to the house. The patio was structured with gardened squares. Accordingly, the longitudinal pathways interplayed with secondary transversal circulations nearby the two pools in front of the porticos.

Apart from its original function as an Islamic *alcazar* – Arab word that means fortified palace – this complex also contained through the centuries a Christian royal palace between the 12th and the 15th century; the Inquisition headquarters and a prison, during the 16th and 17th century, a fortress and military barracks from the 18th to the 20th century, and, finally, the headquarters of the Government of Aragon since the 1980s. Just enumerating the different temporary uses of this building permits to understand its morphological complexity nowadays, and the different historical lectures that can be done depending on the existing documentation about the building, the remains preserved in different museums, the traces still visible in the on-site structures and the results of the archaeological excavations [Alm98].

3. The project methodology

In this kind of projects methodology is a key concept. From the survey phase to the modeling process and final presentation, it is imperative to maintain a rigorous procedure in order to keep under control the different steps of this long process. Specially in this case, where decorative programme has an outstanding role, data management and codification was essential in order to keep information easily identifiable.

Another key aspect apart from methodology and directly linked to it, was to understand what was the aim of the process. In this case the aim was to tackle the reconstruction of the main spaces of the ancient Islamic palace that lies underneath the actual building.

The first step consisted of gathering all the information available about the building, specially historical sources, plans, the results of the archaeological excavations and to find out if there existed a good survey to be used as a base for the work. In principle the best solution would have been to produce the survey ourselves as this process entails a constant contact with the building, its structures, construction solutions and decorative elements on-site that permits to acquire a better knowledge of the building itself. But in this case survey was not carried out by the authors because there already existed CAD-based documentation coming from the team that had been in charge of the restoration of the complex.

Based on the analysis and the study of all the documentation available the plans of the hypothetical reconstruction were elaborated in 2D following a rigorous and scientific method, identifying which elements were real and which were hypothetical. Once this documentation was ready, the proper 3D modeling process started defining the space through 3D geometry elaborated in AutoCAD. All the decoration has been elaborated through 3D geometry due to the extreme importance of this aspect in the overall project.

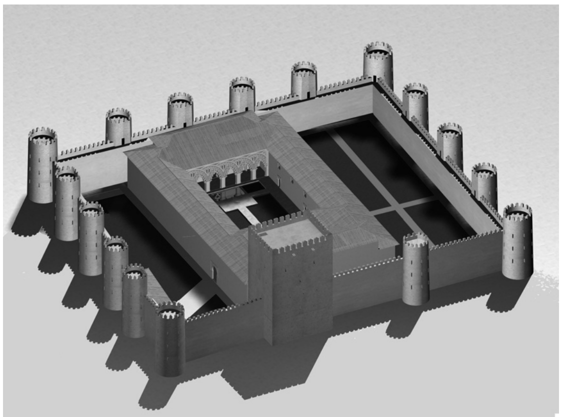

Figure 2: *View of the 3D reconstruction of the whole fortified palace*

The next step was to start studying light effects in the space and to apply mapping textures to the objects in order to characterise and analyse the ambience. At this point starts a backward-forward process between geometry and surface study from AutoCAD to 3Dstudio, and the contrary, that lasted the rest of the process. This constant checking is key in this kind of projects as it permits to understand spatial features over geometrical aspects which are not visible through 2D documentation, such as light effects, shadows, textures on the different surfaces, the use of vegetation and water, human presence. That means to understand how does the space work with all its intrinsic elements and values.

Once the model is corroborated and accepted, final results are presented through images and video production, selecting the means depending on what is going to be explained.

4. The 3D reconstruction process

As it has been mentioned previously, the aim of this project was to face the problem of how throughout History, time is a dimension that can be shared meanwhile the space is not [AA02]. Following this statement, it is possible to understand how difficult it can be to understand and transmit the complexity of a monument that can be considered as an alive organism throughout the time, such as it happens to the palace of the Aljafería.

At this point, 3D modeling comes up to demonstrate how this tool can be of great help for researchers at a first stage of study and, in consequence, to the general public later. It permits to understand the process of creation, aggregation, transformation or even destruction of architectural heritage according to historical events, as well as possible cultural values, symbolisms and significance underlying the *materia* that have stamped the natural evolution of the monument or site.

On the one hand, the modeling process helps the researcher to re-build architecture in 3D. This process entails to solve a large amount of geometrical difficulties that would have probably never been raised up defining the hypothetical reconstruction only through a plan and an elevation, as the modeling process entails to fit both kinds of information in 3D coordinates. During this matching process it is common that many errors come to light, showing up details and features which were not identifiable through flat representations. This point is one of the first and most important contributions to the research process as it permits to corroborate the accuracy of the information available.

On the other hand, computer graphics has introduced a revolution in the architectural analysis through the spatial perception in 3D thanks to the possibility of generating lighting conditions similar to reality as well as coloured material textures. It permits to give the 3D model a similar appearance to real conditions. At this point, it is important to outline that the elaboration of this model aims to a final result that should be far away from photo-realistic effects which are not the goal of this reconstruction because what we reconstruct is not reality but an hypothesis of an ancient state of the building or site. Therefore, we should always maintain the difference between reality and virtuality.

Another important issue in the reconstruction of this palace was the extreme importance of decoration, as it has been mentioned before, which has made the modeling process quite more complicated from the geometrical point of view, due to the level of detail of this decoration. However, the study through a 3D model of the intricate system of crisscrossing arches has finally provided interesting results when the geometry represented in the porticos has been developed and analysed, specially when the results have been related to cultural and religious values and symbolisms.

Furthermore, this project has gone one further step forward in the understanding process of this palace, trying to graphically support and demonstrate some hypotheses already pointed out by outstanding experts in Islamic Architecture, such as Prof. Christian Ewert, that have been discussed in international congresses since the 1970s [Ewe77]. Due to the lack of computer technology applied to this field in the past, the hypotheses defended had never been graphically represented in order to confirm through a 3D reconstruction the transformation that this palace's morphology meant in the overall context of the Islamic residence, specially in Al-Andalus, where a new way of understanding the space was being generated since the construction of the royal city of Madinat al-Zahra' in Cordoba.

5. The spatial analysis of the ancient Palace

The original construction follows the plan scheme that would be used in the following centuries in Al-Andalus: a domestic type of residence to be used for a life of pleasure, with the enjoyment of the patios and gardens.

Figure 3: *View of the palace from the patio*

An outstanding aspect that can be observed in the Aljafería is that there is a radical change in the building composition itself that would continue in the next centuries, which is the reduction of the depth of the spaces, tradition that came from the palaces in the Middle East. Thus, the plan of the palace arranges the main rooms transversally to the composition axe, therefore emphasising the relationship between the rooms and the courtyard, and developing consequently the porticos as a delicate filter space between the inside and the outside.

Perhaps this change is the consequence of a space constraint, due to the fact that the economy of the kingdom sovereigns in the 11th century was unable to consistently produce a sufficiently strong power structure to put across the continuity of the Caliph's power under these dynasties. This is when the response was made, based on a decoration programme of a very marked baroque-style with highly theatrical effect, seeking to stage ornamentally what it was unable to bring to actual fruition. Thus it is that we find in the Aljafería a genuine simulation of the Great Mosque of Cordoba through numerous decorative devices, specially represented in the porticos, that might have suggested and archaic *trompe l'oeil.*

If we take a look to the South portico (Fig. 4) we can see a series of crisscrossing arches – exactly 7 arches – overlapped in a certain direction. The reconstruction model permitted to find out further information about the composition rules and how they interact to create the whole portico. For the complete model of the palace, a first portico was generated following the shape of the real one so as to consider its real deformations (Fig. 4 & 6). Meanwhile, a second "ideal" portico was created according to the composition rules in order to investigate what was the real purpose behind the system of overlapped arches represented (Fig. 5 & 7). The result was that behind the complex ornamentation of that portico, as well as in the one in the North side, there is the intention of representing a transition space that does not exist in the plan of the palace.

However, this ideal space is represented in the elevation as a walk through a succession of arches in order to reach the throne room were the sovereign gave audience to his subjects (Fig. 5). And it is thanks to computer graphics that this space of transition can be observed through an ideal 3D reconstruction of the portico, in order to understand the perceptual significance of this spatial suggestion represented as a flat decoration on the portico's surface (Fig. 6 & 7).

The perception of this virtual space allows the observer to understand the relationship between this idea and the typology of the most important building in the Islam: the mosque, understood in most of the cases as a succession of naves that must be walked through to reach the *qibla* and the *mihrab.*

Another fact related to this overlapped arches is the symbolism of the exact number of arches represented: 7. This number is mentioned in the Koran, Sura LXVII, as the number of skies created by Allah. So this number is not a coincidence and it would be an explanation to the question of why to use an odd number in the composition of a portico when that creates such an interruption of the viewing axe of the palace.

The same facts can be observed in the North portico, but in this case it is in the front part where there are only five arches represented. The other two missing properly are the side wings of the U-shaped portico. It is our opinion that this analysis confirms the error committed by the restorers of this portico in the 1970s when they decided to reproduce the overlapping arches (Fig. 8) also in the right side of the U instead of one single arch (Fig. 9) as it was on the opposite side. Perhaps this decision was due only to the intention of making the restoration work understandable in order to clearly identify which part was the original. However, the result creates a misunderstanding of the significance and the symbolism behind the exact number of arches of the U-shaped portico.

6. Future project development

This project has been developed in the framework of the activity carried out by the Research Group of the Escuela de Estudios Árabes – CSIC in Granada, Spain specially focused on the study of Palatine Islamic Architecture in Spain. In the future, the intention of this group would be, based on the work already carried out, to tackle the reconstruction of the following periods that successively transformed this complex in time.

In our opinion, this outstanding building, already included in the World Heritage List because of the *mudejar* palace of the 14th century, deserves a better way to transmit and explain its different historical transformations. It is therefore in our minds to keep on going with this process and permit the visitors and the society in general to observe and learn more about its history and complexity through computer graphic reconstructions and multimedia interactive presentations.

7. General conclusions

This theme is certainly a challenge and a risk by supporting the study of a series of hypotheses, some of which can only be corroborated in very general terms. However, the tip of an iceberg can be seen in the novelty of an understanding of the Palatine architecture in Al-Andalus, in terms of a computer graphic perceptive interpretation, because recreating and simulating the spaces open up new ways of seeing and analysing things, when digital reconstruction is possible. Therefore this could be the starting point for possible future researches into this issue, which is certainly one of great interest, not only in the scientific community but also in general. It is an attempt, through computer graphic documentation, to achieve a better understanding of the hypothetical architectural reality of the past at a level of perception so that anyone wishing to do so, can find out about and better understand the palatine architectural heritage which has been handed down to us by Andalusian culture.

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Figure 4: *View of the South portico*

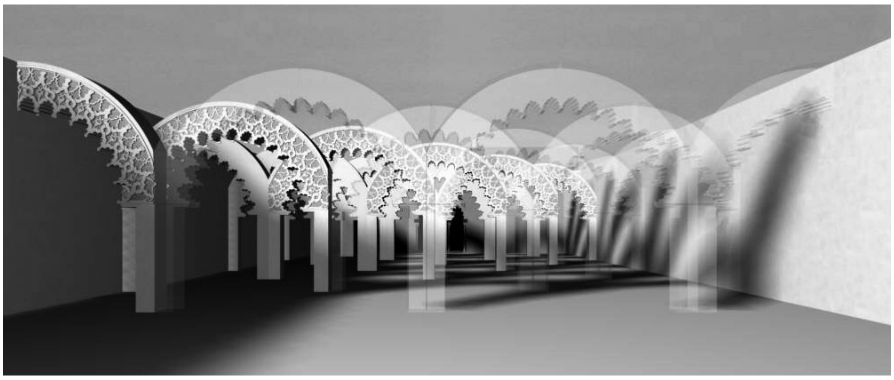

Figure 5: *Ideal front view of the space created by the superposition of porticos*

Figure 6: *View of the South portico and the decorative programme there represented*

Figure 7: *Ideal oblique view of the represented space*

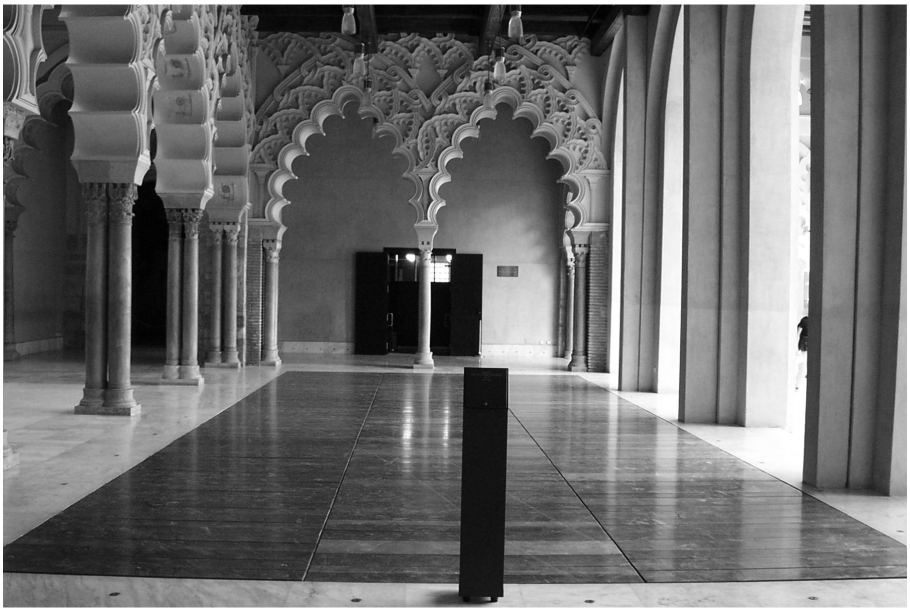

Figure 8: *The right side of the U-shaped portico nowadays. Reconstruction work made in the 1970s*

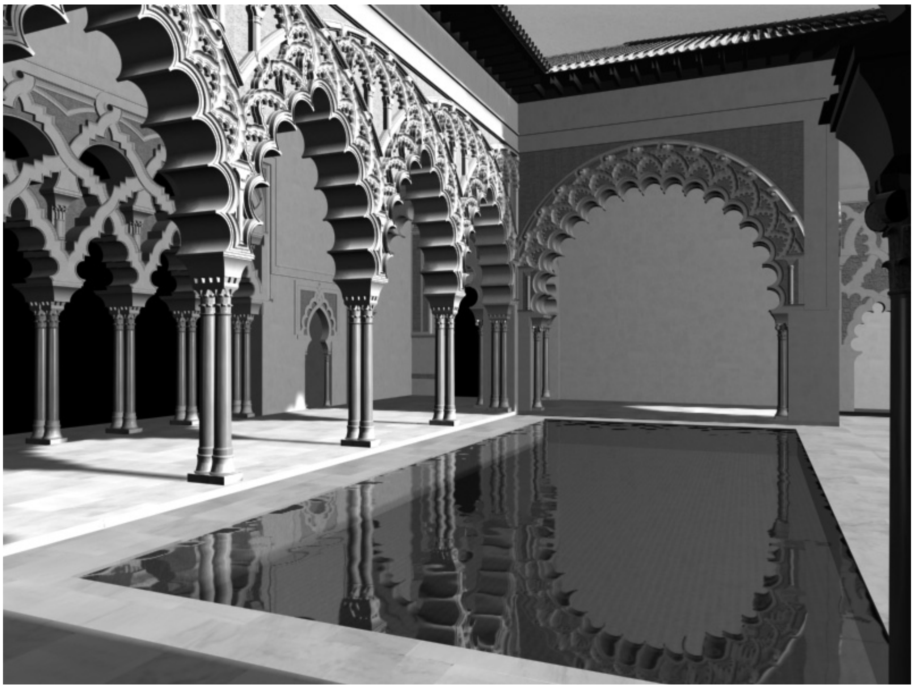

Figure 9: *The U-shaped portico following the reconstruction hypothesis of the 3D model*

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