The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
VAST (2006)
M. Ioannides, D. Arnold, F. Niccolucci, K. Mania (Editors)

Photogrammetric Potential of Digital Cameras in Handheld Gadgets for Digital Close Range Applications

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Abstract:
In recent years a large number of new low cost digital consumer cameras have appeared in the market. The aim of this paper is to describe a research undertaken to examine and evaluate the geometric stability of these cameras and their potential for photogrammetric use. For this purpose, three gadgets with cameras were chosen: two mobile phones and a personal digital assistant (PDA), all of them with built-in camera.
Their geometric stability is examined using a test field, and the calibration parameters are determined. The calibration parameters' results, such as the principal distance, principal point, radial and tangential distortion and their accuracies are given. The next step of the research was focused in the exterior orientation and the accuracies which can be achieved using stereopairs of the test field. The results were not discouraging at all and some important conclusions, for these three different types of cameras, are mentioned in the paper.
Experimental research has been carried out using two study sites. The first is the fountain "Krini Priouli" at Heraklion of Crete and the second is the marble iconostasis of Saint Apostles in the Ancient Market of Athens. In both cases close-range photographs taken from the PDA were used.
Results indicate that such cameras may be used in simple close – range photogrammetric applications, with relatively low accuracy requirements.

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1. Introduction

During the last years, the manufacturers of mobile phones, decided to exploit the possibilities of digital technology, and to offer the opportunity of image recording using digital cameras via mobile phones. The collaboration of information technology and telecommunication companies constitutes the next step of mobile telephony development. In the near future rapid developments are expected. Already, mobile phone's companies produced mobile phones, with embedded cameras, with resolutions over 3.5 and 5 megapixels (Mp). Also, since mobile phones tend to incorporate the characteristics of PDAs and vice verca, these gadgets are expected to replace all the others.

Using them in this way is promising, due to the fact that they are within reach of everyday's user and also they are widely available. As a consequence a large number of images exists, taken with these handheld gadgets, not for photogrammetric purpose including and of course, monuments and archaeological sites. However, only few investigations of their metric ability exist (e.g. AB04).

In order to examine the potential of such handheld gadgets with build-in cameras, a performance evaluation of two different types of mobile phones and one PDA was carried out by the authors.

An important aspect of the usability of these cameras for photogrammetric purposes is their geometric stability and accuracy. Therefore the interior orientation parameters where determined using an accurately measured test field. Consequently, for evaluating the gadget's accuracy and applicability, their cameras are put to test in everyday close-range photogrammetric applications.

2. Methodology

2.1 The handheld gadgets used

Three types of handheld gadgets were used for this study. The first was a Nokia 5140 mobile phone and the second was a Sony Ericsson K700i mobile phone both with built-in cameras. These mobile phone cameras work at a resolution of 640 x 480 pixels. The third gadget was an HP iPaq 3700 PDA, with effective number of pixels 1.2, i.e. a resolution of 1280 x 960 pixels.

Figure 1: *The handheld gadgets used*

2.2 Description of the calibration process

From geometric point of view, a photograph is considered to be a central projection and more specifically a perspective one. This is actually the mathematical model that is used in Photogrammetry to represent the inverse process of the photography [P00].

The procedure of the determination of this mathematical model's parameters, or generally what is called in the photogrammetric literature as interior orientation of a photograph, is called calibration of the camera [G98].

Generally, the accuracy of a camera's performance depends on many and different factors, the most significant of which are: the resolution of the camera, the number of the photographs which are taken and use in the photogrammetric procedure, the geometry of the camera and the object and, last but not least, the geometry of the object itself.

Calibration parameters can be evaluated using many methods. Usually, when no-metric cameras are used, the calibration procedure is carried out with a test field [MFC*04]. For digital cameras the self-calibration method (using e.g. bundle adjustment) can be easily programmed to include any other errors from the CCD array sensor of the camera [S04].

The collinearity equations, including distortions and sensor errors, can be formed as [D95]:

$$x = x_o - c\frac{A_1}{\Pi N} + Vx$$

$$y = y_o - c\frac{A_2}{\Pi N} + Vy$$

Errors of the observed image coordinates can be analyzed further to:

$$Vx = \Delta x_r + \Delta x_d + \Delta x_{af}$$

$$Vy = \Delta y_r + \Delta y_d + \Delta y_{af}$$

Where:

x_o, y_o: are for principal point
c: is for principal distance
Δx_r, Δy_r: are for radial distortion
Δx_d, Δy_d: are for decentering distortion
$\Delta x_{\alpha f}$, $\Delta y_{\alpha f}$: are for affine distortion

The extended collinearity equations, which are used in the bundle adjustment with self-calibration, may be formed as [R00]:

$$\Delta x = \Delta x_p - \frac{\overline{x}}{c}.\Delta c - \overline{x}Scx + \overline{y}.A + \overline{x}.r^2.K_1 + \overline{x}r^4.K_2 + (r^2 + 2.\overline{x}^2).P_1 + 2.\overline{x}.\overline{y}.P_2$$

$$\Delta y = \Delta y_p - \frac{\overline{y}}{c}.\Delta c + \overline{x}.A + \overline{y}.r^2.K_1 + \overline{y}r^4.K_2 + 2.\overline{x}.\overline{y}.P_1 + (r^2 + 2.\overline{y}^2).P_2$$

Where:

$r = \sqrt{x^2 + y^2}$
K_1, K_2: are the radial lens distortion parameters,
P_1, P_2: are the tangential lens distortion parameters,
S: is the scale parameter
A: is the affine distortion parameter

For calibrating the handheld gadgets the software "Calibration CCD" was employed, which was developed by the Lab. of Photogrammetry. Also, a test field consisting from 36 points with varying heights and a flat board containing 276 points, all of which were accurately measured a priori was used.

Figure 2: *The test field used for calibration*

The cameras settings such as zoom factor, focus, white balance etc. were kept constant during the calibration procedure. The calibration of each camera was performed up to 3 times. Also, in order to accomplish the maximum accuracy and to have favourable intersection angles, handheld gadgets were set so that the Base-to-Height ratio was equal approximately to 0.25 (where H is the taking distance and B is the base distance between the two gadget stations). Figure 3 shows the handheld gadgets configuration for the camera calibration procedure.

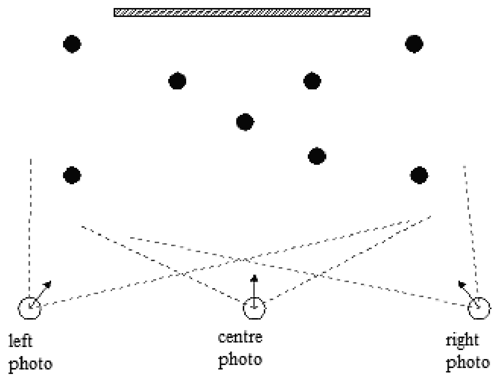

Figure 3: *Handheld gadgets configuration*

2.3 Results of the calibration process

RMSEs of all performances carried out at the calibration process, were less than 0.5 pixels. Therefore image coordinates of calibration points were measure precisely. Mobile phone's (resolution 640 x 480 pixels) and PDA's (resolution 1280 x 960 pixels) photographs seem to have common characteristics at the calibration procedure.

No systematic variation of the calibration parameters were observed but only random variation has been recorded.

Evaluating the results, regarding to the principal distance, it was found out that Nokia 5140 mobile phone had the best performance and stability. Also PDA HP iPaq 3700 shows a good stability. Table 1 shows the results for the principal distance as calculated from the calibration procedure, and figure 4 the normalized range (with the image width) of changes of principal distance for each case.

Handheld Gadget	Av. Principal Distance (pixels)
Nokia 5140	750.37
Sony Ericsson K700i	734.25
HP iPaq 3700	1590.79

Table 1: *Average principal distance*

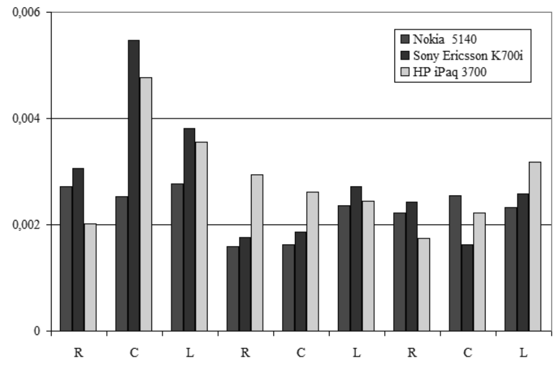

Figure 4: *Normalized range of changes in principal distance*

The changes of the principal point (referring to the image width) are shown in figure 5. Again Nokia 5140 mobile phone had the best results. Sony Ericsson's camera shows random variation and instability.

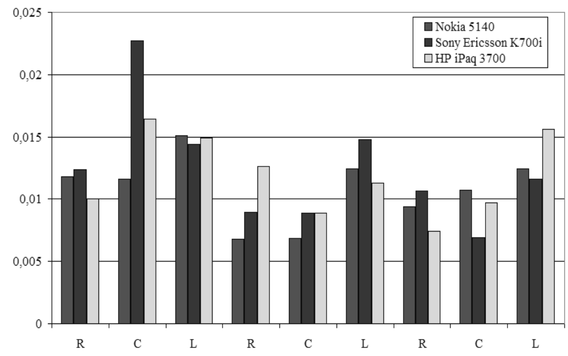

Figure 5: *Changes of principal point (normalized to the image width)*

Principal point at xx´ direction has larger distributed offsets from the center of the image, contrary to yy´ direction. This is recorded for all the photographs taken by handheld gadgets. Furthermore, standard deviations σy´ are smaller than σx´ as shown in table 2.

Handheld Gadget	Standard deviations (pixels)	
	σχ	σy
Nokia 5140	4.49	1.91
Sony Ericsson K700i	21.58	3.03
HP iPaq 3700	19.55	6.14

Table 2: *Standard deviations of principal point*

The results of radial distortion for the two mobile phones used and the distortion curve of the PDA are shown in figure 6 and 7 respectively.

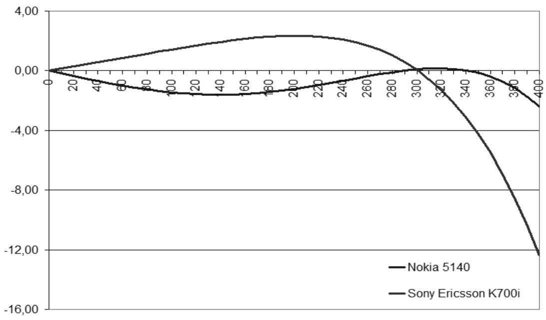

Figure 6: *Balanced radial distortion curves form Nokia 5140 and Sony Ericsson K700i mobile phones*

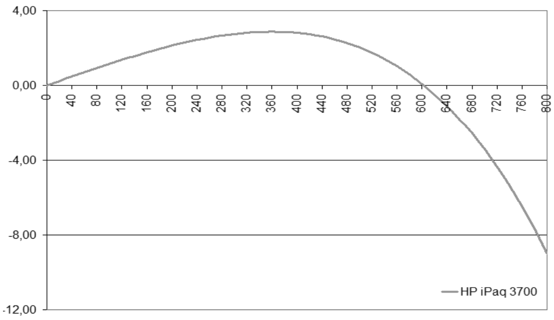

Figure 7: *Balance radial distortion curve from PDA HP iPaq 3700*

Tangential and affine distortions were evaluated from the calibration procedure, but they did not seem to have any important influence. So these, were consider not to be significant.

2.4 Accuracy with check measurements

The accuracy of the cameras may be evaluated comparing the photogrammetric results from the cameras with results which are more accurate [AB04]. Two stereopairs from each gadget were used in order to evaluate their accuracy.

Each photograph was imported at the Z/I SSK Image Station software. The relative orientation of each stereopair was determined. Several repetitions were carried out, in order to achieve the optimum accuracy.

With the removal of the y-parallax a stereo matching can be performed. For each stereopair more than 5 points were used and measured. The acceptance or not, of the results of relative orientation, depends on the remaining errors of the y-parallax. One should also consider the resolution of the images, the size of the measuring mark and the final accuracy desired [G98]. Table 3 shows relative orientation's results for each stereopair.

Handheld Gadget	Stereopair	Py (μm)	Max Py (μm)
Nokia 5140	1st	1.15	1.3
	2nd	1.09	1.2
Sony Ericsson K700i	1st	1.22	1.9
	2nd	0.31	0.6
HP iPaq 3700	1st	4.20	6.3
	2nd	5.33	7.8

Table 3: *Results of the relative orientation*

Absolute orientation is achieved within 4cm accuracy. This accuracy is not discouraging for simple close-range photogrammetric applications, with relatively low accuracy requirements. Table 4 shows the absolute orientation accuracy achieved for each stereopair.

Handheld Gadget	Stereopair	RMS (in m)		
		x	y	z
Nokia 5140	1st	0.030	0.019	0.038
	2nd	0.018	0.012	0.027
Sony Ericsson K700i	1st	0.016	0.008	0.029
	2nd	0.051	0.012	0.086
HP iPaq 3700	1st	0.021	0.017	0.028
	2nd	0.015	0.016	0.016

Table 4: *Absolute orientation results*

PDA HP iPaq 3700 presents the best results. This may be due to the highest resolution of the PDA. A similar accuracy was achieved from Nokia 5140 mobile phone, despite its low resolution. Large differences of the accuracy were recorded only from Sony Ericsson K700i mobile phone.

Moreover, 3D space coordinates of check points of the test field, were measured from stereoscopic observation for each stereopairs. These results were tabulated, and RMS of the difference in the measured coordinates, from stereoscopic observation and geodetic coordinates were calculated. Table 5 shows these results.

Handheld Gadget	Stere-opair	RMS (in m)		
		x	y	z
Nokia 5140	1st	0.025	0.013	0.041
	2nd	0.026	0.010	0.035
Sony Ericsson K700i	1st	0.016	0.007	0.051
	2nd	0.051	0.075	0.149
HP iPaq 3700	1st	0.030	0.021	0.048
	2nd	0.019	0.052	0.128

Table 5: *RMS for the 3D coordinates*

As it is shown, a relative accuracy of 1/400 in planimetry and 1/250 in heights may be easily achieved from Nokia 5140 mobile phone. However, Sony Ericsson K700i has the lowest relative accuracy, i.e. 1/150 in planimetry and 1/70 in heights. Higher resolution photographs taken from the PDA had a relative accuracy of 1/100 in planimetry and 1/50 in heights. Table 5, also indicates that it is possible to have a higher relative accuracy from the PDA's camera.

The loss of accuracy, especially at distant objects from the camera is acceptable because of the low resolution of the cameras. This is also the main reason why good stereoscopic observation can be performed only in close range applications.

3. Experimental Results

After defining the calibration parameters and the accuracy of the handheld gadgets, experimental research had been carried out using two study sites. The first is the fountain "Krini Priouli" at Heraklion of Crete and the second is the marble iconostasis of Saint Apostles in the Ancient Market of Athens.

3.1 Fountain "Krini Priouli"

The fountain "Krini Priouli" was built in 1666 when general intendant of the area was Antonio Priouli. It is also known as "Krini Delimarkou".

Figure 8: *A photo of the fountain"Krini Priouli"*

Two photos taken from the PDA HP iPaq 3700 were used. Again both interior and exterior orientation of the stereopair was prepared from SSK software. The results obtained, were similar to those from the test field for the specific camera. The exterior orientation's RMS calculated was 0.033, 0.022 and 0.060 m for X,Y and Z respectively.

The 2D facade plan derived from the above stereopair, after digital stereoplotting, is shown at figure 9. Some problems occurred during stereoplotting at the detailed sections of the fountain such as the chapiters (drawn with dark lilac) due to the low resolution of the photographs.

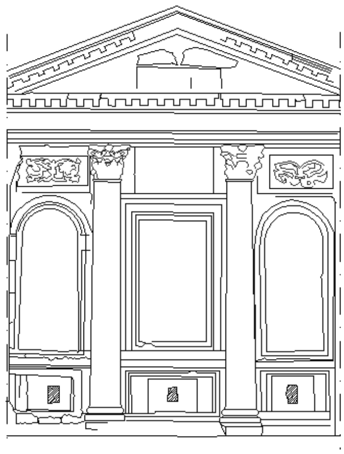

Figure 9: *The 2D façade of "Krini Priouli"*

3.2 Marble iconostasis of Saint Apostles in the Ancient Market of Athens

The second study site chosen was the marble iconostasis of the Byzantine church of Saint Apostles in the Ancient Market of Athens. The iconostasis, which separates the holy altar and the main church, is decorated with marble reliefs [B94].

Figure 10: *The church of Saint Apostles (left) and the marble iconostasis (right)*

A stereopair of photos from the PDA were used. The same procedure, as "Krini Priouli" was applied for the marble iconostasis. A slightly better accuracy was achieved for the exterior orientation. The RMS calculated for X,Y and Z was 0.019, 0.022 and 0.021 m respectively. This may be due to the almost planar surface of the marble object. However stereoplotting problems occurred at the two parapets of the iconostasis, due to low resolution.

In figure 11 the 2D facade plan from the above stereoplotting (drawn with black) is shown and also a more accurate plan of the marble iconostasis, which was carried out combining both photogrammetric and surveying measurements (drawn with blue).

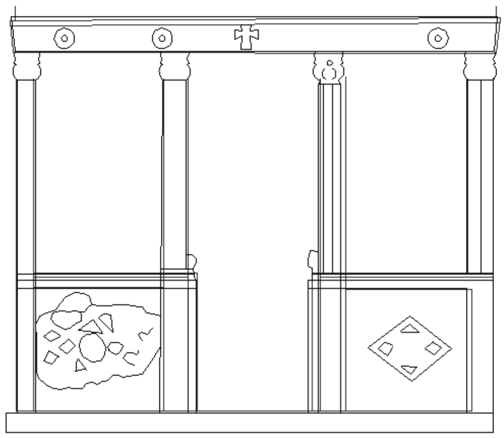

Figure 11: *The 2D facade plan of the iconostasis.*

4. Conclusions

The practical results for close range photogrammetric applications from three different models of handheld gadgets have been presented. Their geometric stability was examined using a test field, and the calibration parameters were determined. The determination of the interior orientation parameters, such as the principal distance, principal point and radial distortion showed that calibration must precede any photogrammetric procedure for these types of cameras. Also calibration, for these no metric cameras, must be regularly performed in order to minimize any possible errors.

Although a rather limited accuracy was achieved, at the test field, these cameras may be used in simple close range photogrammetric applications, with relatively low accuracy requirements. Such results from stereoplotting using PDA's photographs at "Krini Priouli" and at the marble iconostasis of Saint Apostles are given in the paper.

The low resolution of the cameras is the main reason of the low accuracy. Better results are expected in the near future from the next handheld gadgets generations, using higher resolution. Of course, a more conclusive evaluation requires further investigations, especially at the calibration process.

Reference

[AB04] ABDEL-BARY M.E., Using Mobile Phone Digital Cameras in Digital Close Range Photogrammetry, The Fotogrammetric Journal of Finland, Vol. 19, No. 1, 2004.

[B94] BOURAS C., History of Architecture, Architecture at Byzantium, Islam and Western Europe in the Middle Ages, 1994.

[D95] DERMANIS A., Analytical Photogrammetry, 1995

[G98] GEORGOPOULOS A., Notes of Digital Photogrammetry, 1998.

[MFC*04] MATSUOKA R., FUKUE K., CHO K., SHIMODA H., MATSUMAE Y., HONGOB K., FUJIWARAB S., A Study on Calibration of Digital Cameras, ISPRS Commission III, WG III/5, 2004.

[P00] PETSA E., Fundamental concepts and problems of Photogrammetry, 2000.

[R00] REMONDINO F., Investigation and Calibration of Digital Camera Sony DSC – F505 Cybershot, 2000.

[S04] SAMARA A., Calibration of Digital Cameras, Research Thesis (unpublished), Lab. Of Photogrammetry, NTUA (in Greek), 2004.

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Terrestrial laser scanner and high-resolution camera registration through single image-based modeling

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Abstract

This paper deals with an important topic: the automatic co-registration of terrestrial laser scanner data and high-resolution digital images. Our approach harnesses the power of a single image-based modeling method developed focusing on obtaining a spatial dimensional analysis from a single image. Particularly, the problem of image registration is solved automatically through a camera calibration method which takes 2d and 3d points correspondences as input data based on a search of spatial invariants: two distances and one angle.

1. Introduction

1.1 Context

The technological development in the last years has made possible the improvement of systems for geometry and colour object's measurements. From a sensorial point of view, active and passive techniques based on terrestrial laser scanners and high-resolution cameras have monopolized this leadership respectively. Thus, the demand of 3D models for objects documentation and visualization has drastically increased. 3D modeling of close-range objects is required in manifold applications, like cultural heritage, industry, cartography, architecture, archaeology, civil engineering, medicine, and last but not least, tourism and can be accomplished with traditional image-based modeling approaches or with scanning instruments.

Particularly, the image-based modeling pipeline constitutes a very portable and low-cost technique which consists on the 3D reconstruction of objects from one or more images. In this sense, several assumptions have to be solved: from camera self-calibration and image point measurements, to 3D points cloud generation, surface extraction and texturing. In this way, image-based modeling is a technique that has undergone a big growth in the last years. This promising evolution could be portrayed by the following issues:

• New technological neighbors and new relations among these: Photogrammetry, Image Processing, Computer Graphics, Computer Vision, etc.

• New algorithms and methods have emerged in order to achieve automatization and provide new products.

On the other hand, terrestrial laser scanning methods allow to recover directly 3D measurements of the scanned scene in a few seconds, providing a high level of geometric details together with a good metric accuracy. However, up to now the 3D reconstruction of precise and reliable large objects and scenes from unorganized points clouds derived from laser scanner is a very hard problem, not completely solved and problematic in case of incomplete, noisy and sparse data. As a result, nowadays none scanner can fulfill all demands in 3D modelization projects. Although the measuring process is very fast and simple, users should be well aware that, in addition to an appropriate software, time and patience are needed to get a final result in the form of a CAD drawing or a surface representation based on a topological triangulated mesh. The high complexity of 3D modelization requires a flexible multi-input and multi-output approach able to support the information arising from different sensors/techniques and to provide different levels of information to users with different requirements [FIM*05]. In this way, the key pass through taking advance of the opportunities open by the new communication and information technologies, as well as exploit the synergies with other disciplines in order to establish specific tools.

To reinforce this need, next table (Table 1) illustrates a comparison based on the most important features with relation to laser scanning and image-based modeling methods.

Laser Scanning	Image-based modeling
↓ Inaccurate lines and joints	↑ Accurate lines and joints
↓ Poor colour information	↑Good colour information
↑ Prompt and accurate metric information	↓ Hard-working and slow metric information
↑ Excellent technique for the description of complex and irregular surfaces	↓ Time-consuming technique for the description of complex and irregular surfaces
↓ High-cost technique	↑ Low-cost technique
↓ The 3D model is an entity disorganized and without topology	↑The 3D model is an entity organized and with topology
↑ Light is not required to work	↓ Light is required to work

Table 1: *Comparison of features: Laser scanning vs. Image-based modeling.*

The question, which technique is 'better' than the other, cannot be answered across the board. As we can see (Table 1), each technique owns its advantages at different working fields. In many cases, a combination of both techniques might be a useful solution.

1.2 Related work

In this integration of techniques, where a 3D scanner is used to acquire precise geometry and a digital camera captures appearance information, the 3D model and images must be registered together in order to connect geometry and texture information.

This problem of image to model registration is closely related to the problem of camera calibration, which finds a mapping between the 3D world (object space) and a 2D image. This mapping is characterized by a rigid transformation and a camera model, also referred to as the camera's extrinsic and intrinsic parameters. This rigid body transformation takes 3D points from object space to 2D points in the camera's reference frame, and the camera model describes how these are projected onto the image plane.

The camera calibration problem is solved by matching features in the 3D model with features in the image. These features are usually points, lines or special designed objects that are placed in the scene. The matching process can be automatic or user driven, and the number of feature pairs required will depend on whether we are solving for the intrinsic, extrinsic or both parameters sets.

In the context of image registration for 3D modeling using dense laser scanner data, several approaches have been developed up to now.

A pre-calibration of camera which allows to integrate geometry and texture avoiding any user post-processing used for the Digital Michelangelo project [LPC*00], or the approach described by [RCM*99] where the image to model registration is done manually by a user who selects corresponding pairs of points. Both approaches are applied in a context of small object modeling.

In search of an automatic method, [LHS01] develop an image registration approach based on silhouette matching, where the contour of a rendered version of the object is matched against the silhouette of the object in the image. No user intervention is required, but their method is limited to cases where a single image completely captures the object.
In other scale of methods applied to large distances, dealing with outdoor scenes and based on locating invariant image features, [MNP*99] suggest correlating edges common to the color image and the range map's intensity component. [Els98] aligns images by matching up the corners of planar surfaces. More recently, [SA01] present an automatic method for image to model registration of urban scenes, where 3D lines are extracted from the point clouds of buildings and matched against edges extracted from the images. [INN*03] in their Great Buddha work, use reflectance edges obtained form the 3D points and match them against edges in the image to obtain the camera position. Finally, [ATS*03] present a novel method for 2D to 3D texture mapping using shadows as cues. They pose registration of 2D images with the 3D model as an optimization problem that uses knowledge of the Sun's position to estimate shadows in a scene, and use the shadows produced as a cue to refine the registration parameters.

In a similar context, our approach harnesses the power of a single image-based modeling method developed in [Agu05] focusing on obtaining a spatial dimensional analysis from a single image. Particularly, the problem of image registration is solved automatically through Tsai calibration algorithm [Tsa89] which takes 2D and 3D points correspondences as input data based on a search of spatial invariants: two distances and one angle.

2. Multi-sensor description

The Trimble GS200 laser scanner (Figure 1) was employed for the scanning process. This scanning system is provided with a rotating head and two inner high speed rotating mirrors that allow to acquire a scene with a large enough field of view, i.e. 360º H x 60º V, reducing the need of using lots of scan stations. The sensor accuracy is below 1.5mm at 50m of distance with a beam diameter of 3mm. Furthermore, the laser allows to acquire reflected beam intensity and RGB colours.

Figure 1: *Terrestrial Laser scanner: Trimble GS200.*

A high-resolution camera, Nikon D70 (Figure 2), was used to overcome the poor colour information obtained from terrestrial laser scanner.

Figure 2: *Digital camera: Nikon D70 (www.nikon.com).*

3. Multi-sensor registration through single image-based modeling

A hierarchical process supported by single image-based modeling has been developed in order to register high-resolution images with laser scanner models. Nevertheless, before a 3D model can be texture mapped with a colour image, the transformation that aligns the two datasets must be estimated, which is not an easy task. The registration process is difficult to automate because image and laser points cloud are dataset which arise from sensors with different features: from its own intrinsic characteristics to features like its resolution and field of view.

The main contribution of this paper is the adaptation of a single image-based modeling approach in order to obtain geometrical constraints and a spatial dimensional analysis, which allow performing image to laser model registration automatically.
Our approach exploits vanishing points geometry inherent in oblique images as well as some geometrical constraints typical in architectural scenes. Particularly, four main steps are resolved sequentially: the first step involves an image analysis procedure based on recognition, extraction and labeling of features (special targets and vanishing lines); the second step involves the estimation of camera calibration exploiting vanishing points geometry; the third step carries out a dimensional analysis derived from a single image. This step uses the estimation of camera calibration, as well as some geometrical constraints used in single image-based modeling. Finally, the fourth step involves a search of correspondences between both dataset (3D points cloud and 2D image points) based on analyzing spatial invariants between special targets. This last step provides image to model registration together with a camera calibration tuning.
Nevertheless, this approach is only successful in a given domain where the following assumptions have to be considered:

a) The method is applicable in scenes with strong geometric contents such as architectural scenes.

b) The images acquired by digital camera have to be oblique with at least two vanishing points.

c) Special planar targets (Figure 4) are used as landmarks and have to be fixed to the building facades.

d) In order to have a primary camera pose estimation from a single view, user must know some priori information about the object (i.e. a distance) which performs as the reference frame.

The following scheme (Figure 3) aims to illustrate the methodology that we have developed in order to obtain multi-sensor registration through single image-based modeling automatically.

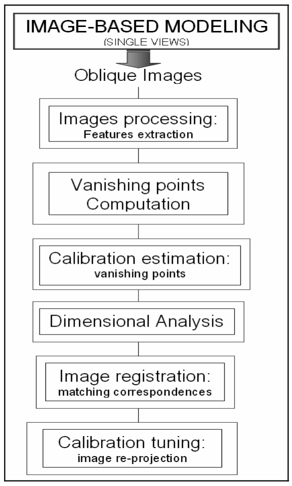

Figure 3: *Multi-sensor registration through single image-based modeling.*

3.1 Image processing: Features extraction

A hybrid image processing step which integrates lines (vanishing lines) and interest points (special planar targets) extraction is accomplished.

With relation to vanishing lines extraction, a hierarchical method divided into two levels is applied. In the first level, linear segments are detected applying Canny filter [Can68] and a linear regression based on least square which combines RANSAC estimator [FB81]; in the second level, segments are clustered through an iterative process based on their colinearity, taking an orthogonal distance as input parameter or threshold. Nevertheless, the presence of mini-segments could carry some problems in the clustering process, i.e. leaving unclassified vanishing lines. In this sense, a weight factor for the line coverage has been considered, which depends on the number of collinear segments as well as their length.

Regarding to the extraction of special planar targets, a seed of the planar target will be required in order to perform a cross-correlation template matching method [Kra93]. The probable target candidates are searched all over the high resolution image using a cross-correlation template matching method. A sub-sampled version of the high resolution image is used to decrease the computational expense. The window size is selected as 10x10 pixels. Only those pixels that have cross-correlation values greater than a predefined threshold value are defined as the target candidates.

The algorithm starts searching the most probable target candidates all over the image using cross-correlation values. The seed used in the cross-correlation procedure is generated artificially according to the real target shape (Figure 4). Obviously, the presence of outliers will carry that more targets than the real number will be detected. In this sense, the own radiometric and geometric characteristics of the targets such as green background and circular shape allow filtering some of these anomalies. Finally, with the filtered candidates circular shapes will be extracted through the Generalized Hough Transform (GHT) [Bal81]. This method is a generalization of the traditional Hough transform [Hou62] and allows detecting basic shapes independently of the rotation and scale of the image, event pretty common when we work with oblique images.

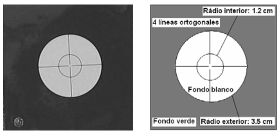

Figure 4: *Special planar targets.*

3.2 Vanishing points computation

The motivation and usefulness of precise and reliable determination of vanishing points, among other structural elements belonging to oblique images, has been demonstrated based on their correspondence with the three main orthogonal directions. Particularly, in architectural environments vanishing points provide three independent geometrical constraints which can be exploited in several ways: from the camera self-calibration and a dimensional analysis of the object to its partial 3D reconstruction.

Our vanishing points method takes a scientific approach which combines several proven methods supported by robust and statistical techniques. In this sense, the key differences of this method in relation with others approaches [Bri86], [BV99], [Shu99], [LML98], [TVP*98], [Rot00], [Heu98] and [ADV03] are reflected in the following steps:

- A *Clustering step*, which cluster the mini-segments in vanishing lines.
- An *Estimation step*, which applies a modification of the Gaussian sphere method [Bar83], in order to obtain an estimation of vanishing points and reject possible erroneous vanishing lines.
- A *Computation step*, which applies a re-weighted least square adjustment support by M-estimators [Dom00].

More details about this new vanishing points method are described in [AGF05].

3.3 Calibration estimation: vanishing points

Our approach is similar to another approach [CT90] who exploiting vanishing points geometry recovers the projection matrices directly. However, in our case the method developed, uses simple properties of vanishing points adding some geometrical constraints derived from image processing step.
The camera model can be recovered following two steps, in which internal and external parameters are estimated separately. In the first step, the intrinsic parameters, that is, the focal length, the location of the intersection between the optical axis and the image plane and the radial lens distortion, are recovered automatically based on vanishing points geometry and image processing. In the second step, the extrinsic parameters, that is, the rotation matrix and the translation vector which describe the rigid motion of the coordinate system fixed in the camera are estimated in a double process. Firstly, the rotation matrix, that is, camera orientation is obtained directly based on the correspondence between the vanishing points and the three main object directions. This relationship allows to extract the cosine vectors of optical axis, obtaining directly the three angles (axis, tilt, swing). Then, the translation vector, that is, the relative camera pose is estimated based on some priori object information, i.e. a distance, together with a geometric constraint defined by the user. Thus, the reference frame for the camera pose estimation is defined with relation to the object geometry arbitrarily.

The robustness of the method depends on the reliability and accuracy of vanishing points computation, so the incorporation of robust M-estimators in the step before is crucial.

3.4 Dimensional analysis

With the estimation of camera model and with the geometrical constraints defined by the user, an automatic dimensional spatial analysis based on distances and angles is performed between all possible targets combinations. Thus, for each target extracted in image processing step we compute the distances and angles with the remainder targets.

This approach is supported by constrained colinearity condition (3.1) (3.2) and trigonometric functions (3.3), which allow to obtain spatial distances and angles between whatever detected target:

$$\boxed{\begin{aligned} w(1) &= r_{11}(x_1 - x_{PP}) + r_{21}(y_1 - y_{PP}) - r_{31}(f) \\ w(2) &= r_{12}(x_1 - x_{PP}) + r_{22}(y_1 - y_{PP}) - r_{32}(f) \\ w(3) &= r_{13}(x_1 - x_{PP}) + r_{23}(y_1 - y_{PP}) - r_{33}(f) \\ w(4) &= r_{11}(x_2 - x_{PP}) + r_{21}(y_2 - y_{PP}) - r_{31}(f) \\ w(5) &= r_{12}(x_2 - x_{PP}) + r_{22}(y_2 - y_{PP}) - r_{32}(f) \\ w(6) &= r_{13}(x_2 - x_{PP}) + r_{23}(y_2 - y_{PP}) - r_{33}(f) \end{aligned}} \tag{3.1}$$

where, *w(1)..w(6)* are auxiliary functions derived from colinearity condition, $r_{11}...r_{33}$ is the rotation matrix coefficients, *x,y* are image coordinates, x_{pp}, y_{pp} are principal point coordinates and *f* is the focal length.

$$\boxed{\begin{aligned} X_S &= X - \left(\frac{w(2)}{w(1)} \cdot \left(\frac{DT_{XZ}}{\sqrt{\left(\frac{w(5)}{w(4)} - \frac{w(2)}{w(1)}\right)^2 + \left(\frac{w(6)}{w(4)} - \frac{w(3)}{w(1)}\right)^2}}\right)\right) \\ Y_S &= Y - \left(\left(\frac{DT_{XZ}}{\sqrt{\left(\frac{w(5)}{w(4)} - \frac{w(2)}{w(1)}\right)^2 + \left(\frac{w(6)}{w(4)} - \frac{w(3)}{w(1)}\right)^2}}\right)\right) \\ Z_S &= Z - \left(\frac{w(3)}{w(1)} \cdot \left(\frac{DT_{XZ}}{\sqrt{\left(\frac{w(5)}{w(4)} - \frac{w(2)}{w(1)}\right)^2 + \left(\frac{w(6)}{w(4)} - \frac{w(3)}{w(1)}\right)^2}}\right)\right) \end{aligned}} \tag{3.2}$$

where, X_S, Y_S, Z_S are the viewpoint coordinates, X, Y, Z are the ground point coordinates and DT is the spatial distance that we want to compute.

With relation to trigonometric functions, for a triangle in the Euclidean plane with edges a, b, c and opposite angles α, β, γ, the following holds:

$$\boxed{\begin{array}{l} a^2 = b^2 + c^2 - 2bc\cos\alpha; b^2 = a^2 + c^2 - 2ac\cos\beta \\ c^2 = a^2 + b^2 - 2ab\cos\gamma \end{array}} \quad (3.3)$$

The accuracy of the method taking into account the inherent conditions in a single image-based modeling approach is around ±10 cm. Nevertheless, this is not especially crucial since we consider that special targets are enough separate each others. So, in most of the cases, a global approximation is usually enough for a search of correspondences.

3.5 Image registration: matching correspondences

This step presents a technique to perform an automatic matching between 3D and 2D points (special targets) belonging to laser model and high-resolution images respectively.

The solution that we propose is based on the invariants properties of two distances and one angle, which are translational and rotational invariant parameters independently of the sensor viewpoint. Furthermore, three of the angle/distance elements, in which at least one of them must be distance, can exactly define a triangle. Therefore, the presented search scheme is the same as to find the equal 3D triangles in both point sets. This search will serve also for rejecting possible outliers. Those points whose correspondence of invariants or triangles is not found of will not be considered. In the end, a final list with the correspondences of target points will be obtained which will constitute the input data in the calibration tuning process.

The method developed for establishing correspondences between both datasets relies on the approach developed by [Akc03], who in order to materialize the correspondence between two laser scanner datasets develops a search of invariants supported by two distances and one angle. Nevertheless, Acka works directly with two homogeneous datasets, which proceed to the same sensor, and with a previous measurement of the invariants obtained through surveying techniques. In the approach presented here, a correspondence between two heterogeneous datasets (2D image points and 3D laser points) is established.

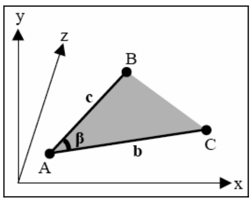

Figure 5: *Search scheme.*

In order to search homologous points, all possible space angles and distances are calculated in both datasets, one through the single image-based modelling approach proposed before and the other directly through 3D coordinates extracted from laser points cloud. The total computational cost for the distances and angles is given below (3.4):

$$\boxed{C\binom{Ni}{2} + C\binom{Nc}{2} + Ni \cdot C\binom{Ni-1}{2} + Nc \cdot C\binom{Nc-1}{2}} \quad (3.4)$$

where, Ni is the number of points in the candidate image target list and Nc is the number of points in the laser target list, and C stands for the combination operator.

Every space angle and two distance combinations for each point in the image target candidate list is searched in the target laser list with a predefined angle/distance threshold values (i.e. angle <0.5º, distance <15cm). Three of the angle/distance elements, in which at least one of them must be distance, can exactly define a triangle. Therefore, the presented search scheme is the same as to find the equal 3D triangles in the both point sets. If a point does not have a compatible 3D triangle in the invariants list, this point does not have a label, namely this point as a wrong target candidate, and must be discarded from the candidate target image list.

3.6 Calibration tuning: image re-projection

A Tsai camera calibration technique [Tsa89] is used to obtain a calibration tuning, especially the image registration with relation to laser scanner. Its implementation needs correspondences between both datasets: 3D laser points and 2D image points. Tsai's technique uses a two-stage approach to compute: first, the position and orientation and, second, the internal parameters of the camera. Thus, Tsai's approach offers the possibility to calibrate internal and external parameters separately. This option is particularly useful in our case, since the single image-based modeling method developed allows us to known these parameters with a similar strategy.

Depending on internal parameters accuracy, we carry out one or two stage approach of Tsai's camera calibration. So, if good accuracy has been achieved through single image-based modeling method, a minimal number of 5 points will be used to compute the camera pose. Furthermore, the three known rotations angles perform as initial approximations in the algorithm.

Due to the different nature of the sensors, as well as the own characteristics of the single image-based modeling approach, a single run of the algorithm can lead to a camera registration that is not fully satisfactory. To improve the accuracy and reliability of the calibration process, an iterative procedure has been introduced. In this sense, each 3D point detected as special target in the points cloud will be re-projected over the image based on colinearity condition principles and the computed camera parameters. Small discrepancies remain between the projected 3D points and the original extracted image points. The 3D coordinates of the laser scanner and the re-projected corresponding image points constitute the input to compute a new calibration. This iterative process follow until the Euclidean distance between the re-projected points and the original image targets points will be minimized (threshold distance). The general idea is that at each iteration the distance between the two datasets is reduced, allowing a better computation of camera parameters.

To ensure the convergence of the algorithm and the improvement of the initial camera model estimation, the calibration error of each correspondence is computed and recorded. In each new iteration, only matching pairs for which the calibration error decreases are updated, and the other are kept unchanged. In this stage, no robust estimation is used since the step before ensures that no outliers are present within the correspondences.

After the calibration tuning procedure based on this technique, a full model for the camera with relation to laser scanner is available and ready to map textures.

4. Experimental results

We have validated our approach on several different datasets, but we only present the experimental results tested over an emblematic romanic church situated in Avila (Spain), San Pedro's church (Figure 6).

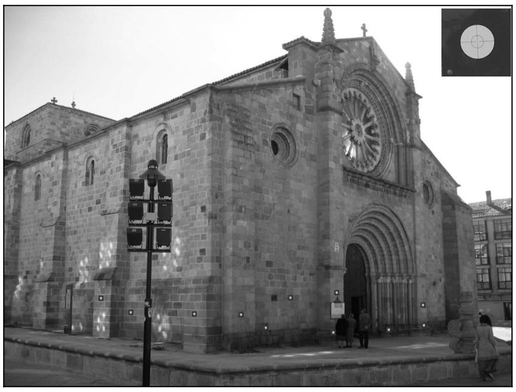

Figure 6: *Original image with special targets (3008x2000 pixels)*

After applying the image processing step, we obtain the different features extracted with sub-pixel accuracy (Figure 7).

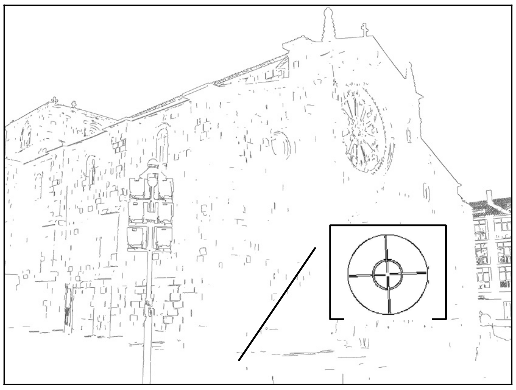

Figure 7: *Image features extraction: vanishing lines and targets.*

With relation to the features statistics (Table 2):

Vanishing Lines	231 segments were clustered in X direction 274 segments were clustered in Y direction 35 segments were clustered in Z direction 91 segments were clustered as outliers
Special Targets	20 targets were detected 2 targets were not detected 7 targets were detected as outliers
Accuracy (σ)	0.5 pixels

Table 2: *Statistics in features extraction.*

Next, a robust method for vanishing points computation which combines Danish M-estimator together with Gaussian Sphere was applied iteratively (Table 3).

Vanishing points computation (4^{th} iteration)

M. Gauss Sphere + Danish estimator (Unit: pixels)	**VPX**	**VPY**	**VPZ**
x	3761.981	-1483.73	1054.882
y	1432.395	1255.766	-2378.66
σ_{xx}	0.13	0.35	0.38
σ_{yy}	0.18	0.40	0.57

Table 3: *Vanishing points computation.*

With the structural support provided by vanishing points an estimation of camera calibration parameters was obtained (Table 4):

Camera calibration estimation: vanishing points

Internal Parameters (Unit: millimetres)		**External Parameters** (Unit: degrees, metres)	
PP [x] (mm)	11.83	**Axis**: 38.0025	**X**: -14.956
PP [y] (mm)	7.76	**Tilt**: 95.8034	**Y**: -12.037
Focal (mm)	18.10	**Swing**: 181.4477	**Z**: 1.7
K_1	0.003245		
K_2	-0.000012		

Internal Parameters (Unit: millimetres)		**External Parameters** (Unit: radian, metres)	
σ_{PP} [x]	0.032	σ_{Axis}: 0.00175	σ_X: -0.034
σ_{PP} [y]	0.036	σ_{Tilt}: 0.00213	σ_Y: 0.039
σ_F	0.044	σ_{Swing}: 0.00127	σ_Z: -0.048
σ_{K1}	0.000134		
σ_{K2}	0.00000123		

Table 4: *Camera calibration estimation.*

Dimensional analysis: single image-based modeling

Taking into account the threshold fixed to distances and angles: 15cm and 0.5º respectively, every space angle and two distances combinations for each point in the image target candidate list was searched in the target laser list, obtaining the following:

- 7 correspondences were located between both datasets and added to the target image list.
- 6 especial targets were detected as outliers or wrong targets being discarded from the candidate target image list.

In the laser scanning context, all special targets were correctly extracted by laser scanner software, so eleven 3D points were added to the laser points list (Figure 8).

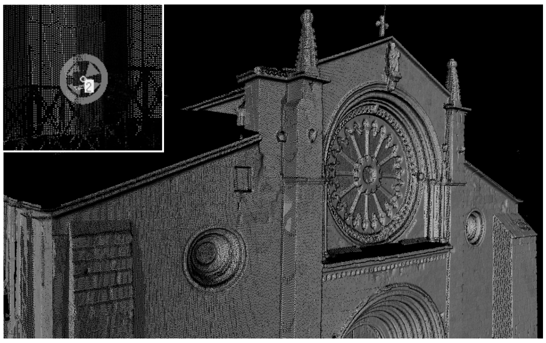

Figure 8: *Laser model and the special targets extracted.*

Finally, once both datasets were matched each other in image and laser list, a camera calibration tuning with seven correspondences was performed in order to provide an image to laser model registration (Table 5).

Camera calibration tuning: image to laser model registration

Image to laser model registration (5th iteration) (Units: degrees, radian and metres)	
Axis: 38.6257; σ_A: 0.00065	**X**: 8.138; σ_X: -0.009
Tilt: 95.667; σ_T: 0.00023	**Y**: -3.307; σ_Y: 0.012
Swing: 181.9487; σ_S: 0.00077	**Z**: 1.094; σ_Z: -0.021

Table 5: *Calibration tuning: image registration.*

A re-projection strategy (section 3.6) based on five iterations was necessary to minimize the Euclidean distance between matched points, obtaining good results in mapping textures.

Figure 9: *Multi-sensor registration: mapping textures.*

5. Conclusions and future perspectives

We have developed a method for registering high-resolution images to laser models. Our technique uses a single image-based modeling approach which provides relevant data: from camera calibration and geometrical constraints to a metric dimensional analysis. Particularly, in the automatic co-registration of terrestrial laser scanner data and single digital images, our approach performs a dimensional analysis from a single image based on a search of spatial invariants: two distances and one angle. This approach works very well for outdoors scenes in which the geometry of the building is easy to modeling. Nevertheless, some ill aspects have been assessed:

- In the search of correspondences step, maybe applying an adaptative threshold supported by a RANSAC estimator could be a good idea to reject fewer points.

- Obviously, a large sensor's baseline does not contribute in a good way to map textures, obtaining some anomalies in upper parts of the building.

With relation to future perspectives, the research could be extend to exploit the single image-based modeling towards applications related with the improvement and refinement of the laser model, adding metric and semantic information in missing areas (non reflective material, occlusions, shadows, etc). Furthermore, in the context of texture mapping, develop algorithms that allow to handle the resulting problem of occlusions, illumination properties and transition between junctions, would let to achieve a realistic and integral representation of the object.

References

[AGF05] AGUILERA D. G, GOMEZ LAHOZ J, FINAT CODES J., 2005. A new method for vanishing points detection in 3D reconstruction from a single view. ISPRS International Workshop. Mestre (Italy).

[Agu05] AGUILERA D. G., 2005: 3D Reconstruction from a single view. Doctoral Thesis. University of Salamanca.

[Akc03] AKCA DEVRIM, 2003: Full automatic registration of laser scanner point clouds. Institute of Geodesy and Photogrammetry, ETH Zurich, Switzerland.

[ATS*03] P. K. ALLEN, A. TROCCOLI, B. SMITH, S. MURRAY, I. STAMOS, and M. LEORDEANU. New methods for digital modeling of historic sites. IEEE CG, 2003.

[ADV03] ANDRÉS ALMANSA, AGNÈS DESOLNEUX, and SÉBASTIEN VAMECH, 2003. Vanishing points detection without any a priori information. IEEE Trans. on Pattern Analysis and Machine Intelligence.

[Bal81] BALLARD D. Generalized Hough transform to detect arbitrary patterns, 1981. IEEE Transactions on Pattern Analysis and Machine Intelligence, 13(2):111-122.

[Bar83] BARNARD S. 1983. Interpreting perspective images. Artificial Intelligence, vol. 21.

[Bri86] B. BRILLAULT-O'MAHONEY, 1986. New method for vanishing point detection. Computer Vision, Graphics, and Image Processing. Image Understanding, 54(2):289-300.

[Can86] CANNY J.F. 1986. A computational approach to edge detection. IEEE Trans. Pattern Analysis and Machine Intelligence.

[CT90] CAPRILE B. and TORRE V. 1990. Using vanishing points for camera calibration. IJCV 4 (29).

[Dom00] DOMINGO PRECIADO ANA, 2000. Tesis Doctoral. Universidad de Cantabria.

[Els98] M. D. ELSTROM. A stereo-based technique for the registration of color and laser images. Master's thesis, University of Tennessee, Knoxville, Aug. 1998.

[FIM*05] FINAT CODÉS F., M.A.DE LA IGLESIA SANTAMARÍA, J.MARTÍNEZ RUBIO, J.J.FERNÁNDEZ MARTÍN, 2005: The roman theatre of Clvnia: hybrid strategies for applying virtual reality on laser scanning 3d files. ISPRS Workshop Commission V, WG 4. Mestre (Venice).

[FB81] FISCHLER, M. A., and R. C. BOLLES, 1981. Random sample consensus: a paradigm for model fitting with applications to image analysis and automated cartography. Communications of the Association for Computing Machinery.

[Heu98] HEUVEL F.A., 1998. Vanishing point detection for architectural photogrammetry. In ISPRS archives Vol. XXXII part 5, pages 652-659.

[Hou62] HOUGH P.V.C., 1962. Methods and Means for Recognising Complex Patterns, U.S. Pattern.

[INN*03] K. IKEUCHI, A. NAKAZAWA, K. NISHINO, and T. OISHI, Creating virtual buddha statues through observation, in IEEE Workshop, Conference on Computer Vision and Pattern Recognition, vol. 1, 2003.

[Kra93] KRAUS, K. 1993. Advanced Methods and Applications. Vol.2. Fundamentals and Standard Processes. *Vol.1*. Institute for Photogrammetry Vienna University of Technology. Ferd. Dummler Verlag. Bonn.

[LHS01] H. P. LENSCH, W. HEIDRICH, and H.-P. SEIDEL. A silhouette-based algorithm for texture registration and stitching, Graphical Models, vol. 63, no. 4, pp. 245–262, 2001.

[LPC*00] M. LEVOY, K. PULLI, B. CURLESS, S. RUSINKIEWICZ, D. KOLLER, L. PEREIRA, M. GINZTON, S. ANDERSON, J. DAVIS, J. GINSBERG, J. SHADE, and D. FULK, The digital Michelangelo project: 3D scanning of large statues, in Siggraph 2000, Computer Graphics Proceedings, 2000, pp. 131–144.

[LML98] LUTTON E., MAITRE H., LOPEZ-KRAHE J., 1998. Contribution to the determination of vanishing points using Hough transform. IEEE Trans. PAMI.

[MNP*99] MCALLISTER, L. NYLAND, V. POPESCU, A. LASTRA, and C. MC-CUE. Real-time rendering of real world environments. In Proceedings of the 10th Eurographics Rendering Workshop, pages 145–160, 1999.

[RCM*99] C. ROCCHINI, P. CIGNOMI, C. MONTANI, and R. SCOPIGNO, "Multiple textures stitching and blending on 3D objects," in Rendering Techniques'99, ser. Eurographics. Springer-Verlag Wien New York, 1999, pp. 119–130.

[Rot00] Rother C., 2000. A new approach for vanishing point detection in architectural environments. Proceedings of the 11th British Machine Vision Conference (BMVC'00), 1:382-391.

[Shu99] SHUFELT J.A., 1999. Performance evaluation and analysis of vanishing point detection techniques. In ARPA Image Understanding Workshop, pages 1113-1132. Morgan Kaufmann Publishers, Palm Springs.

[SA01] I. STAMOS and P. K. ALLEN. Automatic registration of 2-D with 3-D imagery in urban environments. In Proceedings of the ICCV-01, pages 731–737, July 2001.

[Tsa89] TSAI Y., 1989. Synopsis of recent progress on camera calibration for 3d machine vision. The Robotics Review, pages 147–159.

[TVP*98] TUYTELAARS T. VAN GOOL L. PROESMANS M. MOONS T., 1998. The cascaded Hough transform as an aid in aerial image interpretation. Proceedings of ICCV.

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
VAST (2006)
M. Ioannides, D. Arnold, F. Niccolucci, K. Mania (Editors)

The Alcazar of Seville in the 14th Century. An Integrated Project of Documentation, Research and Dissemination

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Abstract

The Alcazar of Seville is one of the monuments included in the World Heritage List for the city of Seville (Spain). It is an especially relevant complex both from an artistic and an historical point of view. Its buildings reflect over ten centuries of History of Spain and the city itself, as it has always functioned as a royal residence. This complex includes some of the most important Islamic and Mudejar buildings in Spain, and its long History has allowed the succession of numerous transformations, which can cause the original shape of buildings in each phase to be difficult to perceive. Based on a complete and detailed photogrammetric survey of the whole complex and on throughout historical and architectonical research, the School of Arabic Studies (CSIC) has carried out a number of studies on the most outstanding phases of creation for the Alcazar, and especially in the 14th Century, when it reached its brightest moment. Not only as a way to further research, but also in order to disseminate scientific knowledge reached, a digital model has been made, showing how it should have looked like in the 14th Century. This model has been used to develop an audiovisual piece in which the most important parts of the complex are shown, and their main characteristics are explained.

Categories and Subject Descriptors: I.3.8 [Computer Graphics]: Applications

1. Introduction

The Alcazar of Seville is a monument with such historical and artistic value that it was included in the World Heritage List in 1987. The Alcazar dates back to the 10th Century, and is the oldest still in use royal palace in Europe. Its most interesting structures stretch from those corresponding to de Almohad period (12th Century) to the Baroque of the 18th Century, and including its Mudejar ones, built in the 14th Century with clear Islamic influences. This palace complex also suffered from important transformations during Renaissance and Baroque periods, which turned it into a wonderful example of cultural hybridization.

Defended by a number of military enclosures, the inside of the complex was occupied in the Islamic period by a number of palaces and residential houses which, from the moment the city was conquered by the Christians in 1248, were gradually adapted to the needs of the Castillian kings who established their residence there. In the 14th Century the complex reached a moment of splendour to which other residences of the time cannot be compared. After the works carried out by Peter I, by the middle of the 14th Century, the Alcazar became for that age the most sumptuous mansion that could be conceived by a Christian king, and was a worthy rival to the very famous Alhambra, which could not be surpassed for its privileged natural setting, although it could be compared as regards its beauty and splendour.

The basis of the new arrangement was the opening of a visual axis which began in the Gate of the Lion, which was opened up for this purpose, and reached as far as the impressive façade of the new royal residence, passing through another doorway which gave on to the central courtyard of the palace, known as the *Patio de la Montería*. This new complex complemented the older residences situated inside the Old Alcazar, in which the *Patio del Yeso* and another courtyard, known as the *Patio del Crucero* were set. The latter was an original Almohad building which had a garden at more than four metres below the level of the rooms. In the 13th Century the halls along the South side were reconstructed in Gothic style and arranged some raised paths over the garden in the shape of a cross to communicate with both ends of the courtyard. This palace

Figure 1: *Actual section of the palace of Peter I.*

was much altered in Baroque time, when its present appearance was achieved, and it had been in its time one of the most singular complexes in Spanish Islamic architecture.

Outside the Old Alcazar, with Peter I's new project, a large porticoed courtyard was planned outside the Old Alcazar. The original plan of this complex, known as the *Cuarto de la* Montería, included the construction of a *qubba* intended as the throne room that was started, but was left unfinished due to the king's death. On the South side, a new royal residence was built following the model of Islamic palaces. The building has an impressive façade, with a double turn entrance designed to preserve the owner's privacy, and is organized around a courtyard with a sunken garden surrounded by richly decorated porticoes. It had a reception hall on one of its sides.

Next to the *Cuarto de la Montería* there was another Almohad palace set around a courtyard with gardens, with sunken planted areas and with walkways in the shape of a cross. In the 14th Century, this building was subjected to considerable modifications, maybe as to adapt it to become a residence for important guests: the halls were enlarged, and the courtyard and the garden were re-laid. It was in this palace where the Catholic Kings, at the beginning of the 16th Century, established the *Casa de Contratación,* to regulate and control trade with the newly discovered America.

2. The survey

From 1997 to 1999 a complete survey of the Royal Alcazar was carried out, made possible by a number of agreements for scientific collaboration between the Patronage of the Alcazar and the School of Arabic Studies. The School of Arabic Studies had already been developing some documentation works, more specifically roof surveys including the whole area between the Cathedral and the Alcazar, using aerial photogrammetry. For three campaigns, elevations, sections and detail surveys of the different parts of the Alcazar were accomplished, most of them made using photogrammetric systems. They were considered the most suitable ones for this kind of task, as they can be carried out with barely any auxiliary means (scaffolding, cranes, and so on), take very short field-work time and provide great homogeneity in both accuracy and quantity of information to be included in the drawings. This is especially important in cases such as this, in which decoration shows very special characteristics and importance.

Complexes such as the *Patio de las Doncellas*, with its extensive lozenge decorated plaster surfaces, or the Ambassadors' Hall, with its semicircular woodwork cover can difficultly be measured and drawn without the use of photogrammetric techniques and computer aided design systems. These systems even allow the creation of three-dimensional models that can be visualized from different points of view and at different scales.

Figure 2: *Hypothetical cross section of the original palace of Peter I.*

The plans already made did not include every section and elevation of the Alcazar, but it was restricted to the most outstanding areas and elements, both architectonical and artistically. It allows better knowledge and accurate information of the most important structures, and it can be used as a basis for a possible future development of complementary documentation works that should be linked to ordinary conservation and maintenance works on the monumental complex.

These works have been carried out using the semi-metric Rollei 6006 Metric camera and a Hasselblad SWC that had been converted into a semi-metric one in the School of Arabic Studies. To measure control points Wild T1000 and TCR303 theodolites have been used, the later one with a laser distance-metre. Plotting has been done with Leica SD2000 and Adam MPS2 stereo-plotter. For some detailed works a Kodak DC200 calibrated digital camera and VSD digital stereo plotter system from the AGH Cracow University have been used. All drawings have been digitally drawn using AutoCAD. The survey has been published in a special edition of a portfolio with 40 plates, 40x60 cm in size.

3. Historical and archaeological research

It has already been noted that the Alcazar suffered from a great number of transformations in the course of its history. Such changes have caused older phases to be masked or to disappear. The knowledge on the appearance of this monument in each of its phases is among the main aims of our research, as it shows History, not only on a local scale or referred only to the monument, but also at a national level, as the detailed analysis of the building works of each time can be used in many cases to infer from them the underlying political objectives these constructive enterprises usually have. This research labour has a number of phases, among which photogrammetric survey is doubtlessly one of the most important ones.

After that, a extensive research on documents is needed. Fortunately, the Alcazar owns an historical archive that is well preserved, and also a number of monographs devoted to documentation related to different times, that allow us to follow quite in detail the works and interventions carried out along its History. Data provided by research in the archives is to be confronted to the physical reality of the building, with the objective of identifying each work and intervention included in the written sources. This task is mainly an archaeological one, and must be supported by other techniques such as the archaeology of architecture and the stratigraphic analysis of build-works or even dating using dendrochronology or any other suitable techniques. Furthermore, it must be completed with archaeological digs under ground level that ought to provide information on structures or disappeared elements, and on previous uses of the site.

These last few years, this kind of research has been carried out in the Alcazar, and the School of Arabic Studies has been participating through agreements with the Patronage of the Royal Alcazar and through a research Project of the Spanish National Research and Development Plan. The objective of our research is centred on Peter I

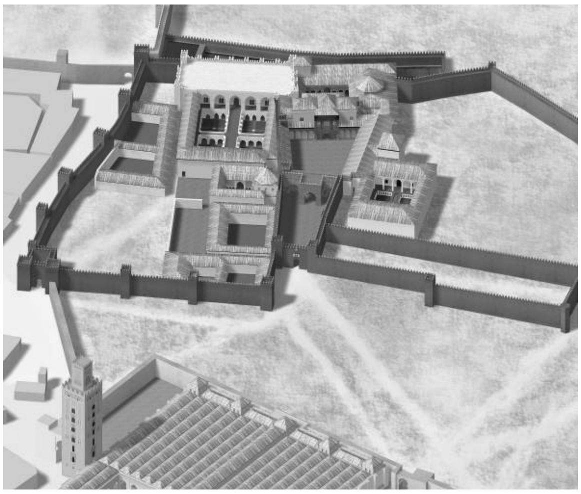

Figure 3: *Aerial vew of the Alcazar in the 14th Century*

time, as the project's aim is the study of the palaces built by this king, of which the Alcazar is the most important one. Research works have been related to the recuperation of covered or disappeared structures which, because of their relevance have been considered worth of being made visible again. In other cases, tasks have consisted on simple conservation and maintenance works that, because of the dismantlement of fixed elements or the clearance of previously inaccessible areas have provided new data on the life and evolution of the monument. In some cases, archaeological surveys have been made in the walls, by partially removing plasters in order to see the inside structure of the walls.

The union of all these tasks have allowed us to know with some certainty the appearance the palace had in the time of its construction, and even parts of the project that were never finished. All of this information, logically has been represented through the necessary plans and drawings, and has been published in academic and dissemination spheres. However, many of these documents are difficult to comprehend by people who are not used to working with plans, and we thought that the results of our research were of interest to the public that visit the monument and to scientists and experts that develop their research in this field. Thus, we have been developing a number of dissemination activities using digital models that doubtlessly allow the public to have a better understanding on the past.

4. Modelling Methodology

4.1. Modelling in AutoCad

The starting point for the modelling is always graphic information from .dwg archives (plans, sections and elevations) generated using photogrammetric surveys. After removing unnecessary information in these drawings, the next step is to standardize the design of plans and elevations, trying, whenever it is possible, to use symmetries and the repetition of geometrically similar elements. All these drawings are then referenced to a new coordinate system origin, which is set at the intersection of the general symmetry axes of the complex, and to an UCS that is orthogonal to this axes.

The so obtained .dwg archive is the interchange base with 3DStudio, that is to say, every element sited in the space of this drawing will be present in this three-dimensional model. The generation of 3D entities in AutoCAD is made thought the *extrusion* command of a solid object created from a flat polyline drawn over each element, to which a certain height or an extrusion axe is assigned. Other operations with solid objects are also used, according to the spatial complexity of the object to be modelled and the suitability of the different AutoCAD commands: *revolution solids, solids' union, solids' subtraction, solids' intersection…*

4.2. Creation of textures using ASRix and Adobe Photoshop

One of the initial plans in our work was the achievement of a model as realist as possible, and, in order to do so, real and high quality textures and materials were used on the model, taking advantage from the possibilities offered by digital photography.

Using images taken in situ and photographic manipulation software such as Photoshop, we generated tileable textures (textures in which no transition is perceived when repeated continuously) that where applied to elements with big surfaces and a continuous finish, such as covers, walls or the mortar of walls.

Figure 4: *The Patio de la Montería*

Figure 5: *Facade of the Palace of Peter I in the 14th Century*

In certain elements, of relatively small size and that cannot support continuous textures, such as socles, decoration stripes, plasterworks and pavements, in the process a rectification in the original image is added, in order to prevent possible distortions when applying the texture. To do so, we use ASRix rectification software, which is easy to use and barely requires any training. It is enough to have a digital image of the flat element that is to be rectified and to know the coordinates of at least four of its points that can be obtained directly form the AutoCAD drawing itself.

4.3. Creation of images using 3DStudio

Three-dimensional elements that have been previously created in AutoCAD are now imported into 3DStudio. Each AutoCAD layer imported into 3DStudio will be interpreted in 3DStudio as a stand-alone object, and, thus, it is necessary to decide, already in the modelling phase, which objects are to be used in the model, as well as their properties and final appearance. Later, a library will be created with the materials from the model, using the maps and textures previously created, and they will be applied to each three-dimensional object, once their geometrical characteristics have been defined.

The introduction of light effects may be the most important part of the process carried out in 3DStudio. In a computer graphic reconstruction light should imitate the real solar circumstances for which the structure was built. 3DStudio can create solar light, and orientate and measure it according to the geographical position of the building and the chosen time of the day. There are also lighting systems (ray tracing and radiosity) that generate a lighting model that takes into account the reflection and refraction of light on the surface of each object in the scene, as well as their interaction, just as it happens in reality. However, the use of this type of ideal light has huge hardware requirements and, thus, an option is taken in favour of other types of lighting that have fewer requirements, and that provide an acceptable lighting final quality in its perception.

There are no limits in the possible position and orientation of the cameras, although it is advisable to choose a point of view similar to that of a real spectator,

Figure 6: *The Almohade portico of the Patio del Crucero.*

and a camera lens that distorts the visualization of the complex as little as possible, so that it imitates the human perception of reality as much as possible.

In order to achieve more realism in the final images and animations, a number of effects can be used: fog, light volumes, water reflections, and the use of real images in the surrounds… On the other hand, the use of RPC's (a system used to work with three-dimensional images) permits the introduction in the scene of vegetation, objects and people, either static or animated ones, without having to model them, but simply cutting and pasting them in the scene.

5. The use of the model: images and animations

The creation of computer-generated images from the rendering of the scenes is, in some cases, the final aim of the process. These images permit a perception of the space similar to that given by a photographic image, although in this case what is represented is not real, but virtual.

Apart from these images, factors like time and movement can also be incorporated to the virtual model, through the generation of animations that help understanding the space of the architectonic environment in a more complete way. The experience of movement and the changing image of the object that it produces, can, without any doubt, provide the best three-dimensional perception possible. In order to do so, it is fundamental to choose an adequate route according to the type of architecture and the sensations that want to be transmitted. The speed given to the movement (which depends on the number of frames that create the timeline in 3DStudio) and the control of the camera lens to visualize the animation (to where and how it is looking) are also of main importance. As a reference, it can be said that, for the average speed for a walk at 2.5 km/h the time variable to be introduced is of 35 frames per metre in the route. The lenses of the camera used in our animations were of 28 mm and 35 mm.

While the spectator moves through the scene following the designated route, any entity in the model can be animated: a geometrical element, an effect, a certain light… and, thus, the perceptive possibilities given by animation can be greatly increased.

The final stage of this process is the rendering of sequences, which can be generated following two different systems:

-In video format, directly, so that the animation can be immediately visualized in any video player that supports this type of files.

- One frame at a time, which implies the later use of some kind of software for video editing.

The first option is recommended for simple models, with continuous routes and short animations. It is faster than the second process, but it has de disadvantage of having to redo the whole animation if any kind of modification in the scene wants to be introduced, or if there is a failure in the IT system. Therefore, it can imply the loss of much time if problems arise or there are many changes in the routes or in the model itself.

5.1. Video editing with Adobe Premier

Once the animating and rendering phase is finished, it will be necessary to edit the graphic material to obtain the desired results. This is the so-called postproduction phase. In it, apart from giving shape to the production through the structuring of the different sequences according to a predefined outline, the introduction of titles, sound, special effects, fades and pauses, video and audio transitions, and so on, are also done. This group of elements permits the creation of a narrative outline for the animation using mostly a sensorial language.

The use of this software is really simple and very intuitive. Basically, it consists on the manufacture of a collage with the image files created in 3DStudio and the

Figure 7: *The Gothic portico of the Patio del Crucero*

Figure 8: *The Patio de las Doncellas in the 14th Century.*

audio files (music and voice) that are exported into video format with the chosen definition.

6. The audiovisual project "The Alcazar of Seville in the 14th Century"

Our interest in disseminating and showing the results of our research to non-specialist public has lead us to increase the use of computer-generated images. These resources allow us not only to fulfil this social demand, but also to enrich our own experience and that of our colleagues and specialists. Thus, this project is in the main line of our research, in which we gather together previous works, historical and archaeological updated researches and social needs linked to cultural events.

One of the main characteristics of this project is that all of it has been developed by the same working group, functioning at the same place and with similar criteria and training. The experience that has been gained in the School of Arabic Studies for the last few years in this type of activity has provided us with the technical ability and knowledge to develop every phase of the process, from planimetric survey to the final cut of the audiovisual product. We can say that only the voice in the audiovisual has been done on a different place and by people who are outside the group.

Our extensive experience in documentation and planimetric survey has allowed us to work taking whole benefit of the possibilities offered by three-dimensional restitution and the creation of 3D models directly from the photogrammetric plotting. We have been the principal authors of the historical research, either by developing it directly or by using data provided by some colleagues who work in the Alcazar, and reviewing it, synthesizing it, and transforming it into sufficiently based proposals of hypotheses.

The models are generated by personnel who have a long experience in the field of Islamic architecture, and who know its shapes and the characteristics of its decoration. We have an extensive database of plans and details from the different architectonic types corresponding to each phase, decorations, textures, and so on. On the other hand, these tasks have been carried out in its entirety by architects or architecture students in their last course of University, with good spatial vision and a solid knowledge on architectural principles. This has allowed us to always work on solid and well-built hypotheses.

The advantages of this way of working are clear. As we are one single working group there are no language or understanding problems concerning objects and their representation or on the definition of objectives. Each member of the workgroup shares the same interest on the problems raised throughout the whole process, and the solutions that are taken.

On the other hand, low-sophisticated and standard solutions have always been chosen, always aiming more for de diffusion of the system itself than for it to be spectacular. Results are more indebted to previous documentation and research labour than to IT work, in which advances made both in hardware and in software allow us to achieve more spectacular effects and results every day, and with less effort.

Using this baggage, we have approached this important project, which was requested by the Patronage of the Royal Alcazar and the Foundation of The Legacy of al-Andalus. The original motive was the celebration of an exhibition on “Ibn Khaldun, Rise and Fall of the Imperious”. This important person, who has been considered to be the father of historiography, first knew the Alcazar of Seville when he went to visit the court of Peter I as an ambassador of the Sultan of Granada. Our intention was to show the visitor of the exhibition the appearance of the palace at that time or, to be more precise, what the project that was being carried out was, as in the year when he was in Seville the palace was still under construction.

Figure 9: *The reception hall of the Palace of Peter I.*

The complete model of the core of the Alcazar permits a detailed visit to its different parts, led by a text read by an off-screen voice explaining what is being shown, that is to say, the palace such as it was in the mid 14^{th} Century and, in some cases, the modifications made to previous phases. This virtual visit helps to understand part of the complex reality this important monument contains.

This kind of work is to be developed in the future for other cases and monuments.

Bibliography

[Alm99] ALMAGRO, A.: El Patio del Crucero de los Reales Alcázares de Sevilla. *Al-Qantara* XX, (1999), 331-376.

[Alm00] ALMAGRO, A.: *Planimetría del Alcázar de Sevilla*, Granada, 2000.

[Alm02] ALMAGRO, Antonio, ALMAGRO, Ana: La expresión gráfica en el análisis del Patrimonio: El patio del Crucero del Alcázar de Sevilla. *Actas del IX Congreso internacional de Expresión Gráfica Arquitectónica, EGA 2002, Re-Visiones: enfoques en docencia e investigación*. La Coruña 2002, 517-522.

[Alm03] ALMAGRO, A.: Planimetría del Alcázar de Sevilla. *Loggia, Arquitectura y Restauración* 14-15, (2003), 156-161.

[Alm05] ALMAGRO, A.: La recuperación del jardín medieval del patio de las Doncellas del Alcázar de Sevilla. *Apuntes del Alcázar* 6, (2005), 45-67.

[Alm05] ALMAGRO, A. Dir.: *El Patio del Crucero*. CD-Rom, Granada, 2005.

[Bla01] BLASCO, C.: *El Palacio del Buen Retiro de Madrid. Un Proyecto Hacia El Pasado.* Madrid, 2001.

[Fer97] FERNANDEZ RUIZ, J. A., *La restauración del patrimonio por la imagen de síntesis.* PhD Thesis. Departamento de Expresión Gráfica Arquitectónica y en la Ingeniería, University of Granada, 1997.

[Ser01] SERRATO-COMBE, A.:*Aztec Templo Mayor*. University of Utah Press 2001.

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
VAST (2006)
M. Ioannides, D. Arnold, F. Niccolucci, K. Mania (Editors)

Inquiry into architectural heritage with motion graphics and hyper-media

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Abstract

This project paper describes a workshop conducted at the Harvard Design School, where students were asked to use digital media technologies to explore subjects in architectural heritage preservation. First, a brief background is presented dealing with geometric representation, sensuous systems, preservation theories and state-of-the-art digital media technologies. Once a background has been established, the paper explains the methods and tools used in the workshop; afterward, it illustrates student work and discusses the results vis-à-vis customary preservation practices. The paper addresses two main issues: first, it deals with the authorative nature of customary preservation practices; and, second, it explores the possibilities of motion graphics and hyper-media constructs as a complementary way of preserving architectural heritage.

J.5 [Computer Applications]: Arts and Humanities

1. Introduction

The development of digital media technologies has ushered rapid and sweeping changes in methods of representation. It has profound implications in architectural heritage studies; the possibilities of digital technologies "affect much more than one's scholarly output; they end up shaping one's life and, thus, probably, modify the very nature of one's actual or potential knowledge" [GRA94]. The implications are wide-ranging; digital media tools are more efficient and accurate in comparison to conventional drawing tools, and, at the same time, they introduce a new spectrum of inquiry. New types of questions arise, which, in turn, infer unprecedented information, "…even minor discrepancies can be shown to have significant and far-reaching implications…" [AEK96]. In "Experiencing the Ancient Assyrian Palace: Methods for a Reconstruction," the authors argue that, by modeling digitally, researchers have learned more efficiently about the subject than through flat plans, cross sections, or drawn perspectives. "We are learning to 'inhabit' specific interior and exterior spaces in ways not possible before" [SP01].

Motion graphics and hyper-media applications have opened new avenues for the way in which people experience, research, and learn about their built environment. These applications facilitate the human engagement with the built environment by taking into account issues of sensual experiences, e.g. perception, cognition, kinesthetics.

1.1. Goals of the Workshop

The preservation of architectural heritage is based on restoration and conservation practices, which were primarily formulated by Italian architect and historian Camillo Boito in the 19th century. Boito's principles, however, pose two main problems: first, the choice of a singular reconstruction of a cultural artifact is misleading and authorative; and, second, the procedures of physical restoration are interventionistic and ambiguous. Restoration practices depend on the executer's particular time-specific interpretation. The processes are interventionistic; despite clearly prescribed methods, the extensions and changes on old architectural structures often alter the nature of the building and its context.

Digital media technologies can help in overcoming these drawbacks. The goal of the workshop, thus, was to investigate the possibilities of emerging digital technologies and explore new ways of architectural heritage preservation. What modes of representation can capture the history of an architectural artifact? How can alternative interpretations, visions, and ideas be visualized? How can the level of evidence and ambiguity be represented?, were some of the questions the students had to cope with.

The workshop did not intend to suggest replacing customary processes of architectural heritage preservation; neither did it offer new hardware products or software programs. Rather, it sought for new ways to augment and extend conventional processes by employing and synchronizing digital media tools and making use of their optimal capacity in this particular field.

2. Background

In *The Production of Space*, philosopher Henri Lefebvre stresses the importance of the interaction of human beings with their built environment and claims that orthographic representations have reduced the richness of reality to the domain of blueprints. Levebre writes that "a spatial work attains a complexity fundamentally different from the complexity of a text, whether prose or poetry… what we are concerned … is not texts but texture" [LEV97]. The comprehension of a "spatial work" involves "sensory experience that is both the recording of stimuli and, at the same time, an intentional act of projecting images, formal exigencies, bodily scale, and spatial cognition" [ARN98]. In a nutshell, our cognizance of architecture lies in our corporeal existence and bodily movement in space. In orthographic drawings, however, the perception of sensory phenomena within a particular context and time is not only neglected but also difficult to represent and, thus, difficult to consider and evaluate.

This shortcoming of geometric conventions is best described by art historian Erwin Panofsky in his seminal work *Perspective as Symbolic Form*, in which he argues that the perspective is a "systematic abstraction" that transforms the psycho-physiological space into a mathematical space. By abstraction, Panofsky means that perspective drawings negate between front and back, right and left, between bodies and intervening space, so that "the sum of all parts of space and all its content is absorbed into a single quantum continuum" [PAN91]. He criticizes, first, that the mechanical reproduction is just a reflection of one fixed eye, whereas humans have constantly-moving two eyes that create a spheroid field of vision. Second, he claims that it falls short in reflecting the "psychologically-conditioned visual image" that actually creates our consciousness of the visible world. This visual image requires more than a perspective—it requires the cooperation of vision with other tactile senses. Finally, he claims that, even on the very basic representational level, the perspective construct cannot mimic the concave retinal image. Therefore, "marginal distortions" occur. For example, if a line were divided into three sections with subtending equal angles, the sections of the line would be represented on the retina (or on a concave surface) as equal lengths; whereas, on a flat picture plane they would appear unequal. Therefore, straight lines appear curved on our retina and curved lines straight.

This very basic fact—the distortion of objective reality—was recognized by ancient Greeks. The curvatures in the Doric temple reflect this in an exaggerated manner. In the Doric temple, columns were subjected to "entasis" so that they would not appear bent, and the epistyle and stylobate were built curved so that they would not look sinking. Optical considerations were also made with regard to spatial organizations in Greek cities. Konstantinos Doxiadis in his controversial work *Architectural Space in Ancient Greece* shows that Greek builders employed a uniform system in the disposition of buildings, based on principles of human cognition. Doxiadis's arguments reveal the basic difference between the application of geometry in antiquity and Renaissance. According to Doxiadis, ancient Greeks did not use the abstract coordinate system to design cities; each layout was developed onsite in an existing landscape. This is significant because it shows that the design was directly determined in relation to the designer on the site [DOX72]. In Doxiadis's view, the main reference point in ancient Greek architecture is the corporeal human being; and, therefore, there is no intermediate stage of orthographic representations between imagination and production.

Panofsky and Doxiadis illustrate very well that sensual qualities, experiences and architectural phenomena were the main driving forces of ancient architecture. In antiquity, geometry produced aggregate space according to the psychological and physiological realities of human vision and was used as a means for designing sensuous space. From the Renaissance onwards, however, geometry produced systematic space reflecting the mathematical theory of representation [VEL80]. Advanced computer graphics liberate us from constraints of orthographic projections and allow us to explore the possibilities of sensuous space once again.

2.1. Preservation of Architectural Heritage

According to B.M. Feilden, conservation is the act of preventing decay, i.e. the consolidation of crumbling artifacts, and restoration is the effort to make the original concept of an object legible. His definition for preservation, though, remains rather ambiguous [FEI94]. Paul Philippot, on the other hand, points to the fact that preservation is considered equivalent to conservation and restoration in certain cultures and argues that it is often confused with reconstruction, which, according to him, is a revival of past styles of art and architecture. He views preservation as "the modern way of maintaining living contact with cultural works of the past" [PHI76]. The preservation of architectural heritage encompasses a wide variety of cultural artefacts: from monuments, to vernacular architecture, to entire districts, towns, and even intangible cultural traditions, e.g. certain religious rituals, oral and musical legacies.

In the 19th century, two opposite doctrines of preservation emerged and struggled over how to reconstitute historic heritage for future generations. These were the "interventionist" and the "anti-interventionist" doctrines, epitomized, respectively, by John Ruskin and Violet le-Duc [CHO01]. Ruskin's understanding of preservation was based on the idea that the labour of past generations imprints a sacred character on buildings. Therefore, he defined the act of restoration as "the most total destruction which a building can suffer… It is impossible," he went on, "as impossible to raise the dead, to restore anything that has ever been great or beautiful in architecture" [RUS81]. According to Ruskin, we cannot "obliterate" the rights of the dead who labored for and expressed themselves in their building endeavor. Violet le-Duc, conversely, favored the restoration of the edifice to a particular point in time and based his conviction on scientific archaeology. In the late 19th century, Italian architect Camillo Boito made a synthesis of these two opposite approaches. He defined the notion of "authenticity" along the lines of Ruskin's "ethical" approach of conserving monuments, but "maintained the priority of the present over the past and affirmed the legitimacy of restoration" [CHO01]. Boito suggested restoration as a last resort, though, which can only be conducted if "all other methods of protection [i.e. maintenance, consolidation, repairs] have failed" [CHO01]. Added parts had to be clearly marked and legible. They should not blend into the original structure and not confuse with the original structure. These general rules remain more or less valid today and were constitutionalized into actual guidelines in 1931 at the First International Conference on Historic Monuments in Athens.

Digital technologies can help us to overcome the limitations of a single viewpoint, and allow for diverse reconstructions to be represented. We no longer need to restore any building according to a particular viewpoint, as Le-Duc suggested, or to differentiate literally an addition along Boito's guidelines. We can virtually reconstruct many layers of thoughts and represent a multitude of attitudes.

2.2. Early applications of digital media

An example of one of the earlier utilizations of digital technologies is a joint work by art historian Oleg Grabar and architect Muhammed Al-Asad in *The shape of the holy: early Islamic Jerusalem.* This work included computer-generated reconstructions of the Haram al-Sharif, street views and ideas of past buildings. In 1995, architectural historian Nezar Alsayyad used animation technology in a linear film format to investigate transformations of urban form in medieval Cairo. The end product in this case was a 30-minute-long VHS tape. In this more advanced use of digital media technologies, computer-generated 3D views were successfully integrated with traditional photographs, revealing novel and valuable information on the various chronological phases of ancient Cairo—its streets, landmarks, and people.

Takehiko Nagakura used digital technologies to reconstruct "Unbuilt Monuments," visualizing buildings and projects that were never realized. Nagakura produced hyper-real motion graphic. Gravity, wind, weather, sunlight, aging of material, dust, dirt, etc., just about every detail of reality, was considered and represented through motion graphics. The end product is finite and very convincing. It leaves no doubt about accuracy and no room for different interpretations of the artifact. Therefore, it bears the danger of convincingly mimicking possibly false assumptions.

Another early example is Karen Kensek's and Lynn Swartz-Dodd's research project "Study of entry: Sanctuary of the Great Aten Temple in Amarna." In this project, the authors visualized certain types of evidence levels and ambiguity, i.e. which part of the digital reconstruction is actually based on textual sources and which parts are interpolations of the authors. This certainly mimics Boito's guidelines regarding the differentiation of materiality in restoration projects.

Conventional architectural visualizations pose substantial shortcomings when it comes to the incorporation of experiential or sensual qualities. One could argue that the essence of architectural experiences lies in the more subjective interactions of humans with their architectural environments. Orthographic drawings were not able to incorporate aspects of cognizance and, therefore, in Lefebvre's words, design was imprisoned to a geometric box of blueprints and devoid of a structure which could embrace and reflect upon the more personal encounters of human beings with architecture. Russian filmmaker Sergei Eisenstein demonstrated in *Motion and Movement in Architecture* that mobility and juxtaposition of mental images enables us to be sentient to architectural phenomena. In experiencing architecture, our entire perceptual systems are actively engaging with built environments. Therefore, the challenge lies in finding a methodology that can represent the intangible qualities of architectural experience.

3. Methods and Tools

Architecture has exceptional qualities that can be only captured through the moving body. Atmospheric and lighting effects, sound effects, textures and materiality of space can only be experienced in context, and all sensual qualities holistically together make our experience of architecture complete.

The workshop consisted both of practice and theory-based sessions. In the former sessions, we introduced methods for the creative production of digital media works; in the latter sessions, we discussed ways of analyzing and evaluating existing digital media works. The tools were advanced software and hardware applications; and methods to frame and compose a narrative structure for the projects.

Figure 1: *J.K. and F.G. scanning the capital*

Figure 2: *C.L. and D.M. working on a blue-screen scene*

The digital media applications we used covered a wide range of products: we introduced audio-video editing tools for synchronizing and composing digital film sequences; we used 3D scanning equipment to digitize architectural artefacts; and we introduced applications for animations, key framing, camera movements, light simulations, and texture mapping. We also explored more advanced techniques of blue-screening to record human scale and movements, and also worked with hyper-media applications for non-linear representations.

In order to give students a vehicle to compose their work we introduced the procedures of storyboarding. Storyboarding is a creative technique to sketch, frame-by-frame, outlines of digital media works. It helps critical thinking, planning, and communicating. It is a relatively old method credited to Walt Disney Studios, as such it began in the film industry, but nowadays is widely used in advertising, video game production, TV series, multimedia and Web design. Essentially, it is in any field where sequentially and montage is in question. Storyboarding assists firstly in organizing the sequences of a narrative: What comes first, next, last? (If it is a non-linear flow, what is the structure?) Secondly, it helps in montaging components: How do audio, video, or still images interact with each other? How do transitions and effects help tie audio, video, and images together? In other words it allows us to think about and document the timing of a sequence of work, experiment with camera angles, camera movements, and explore continuity among elements.

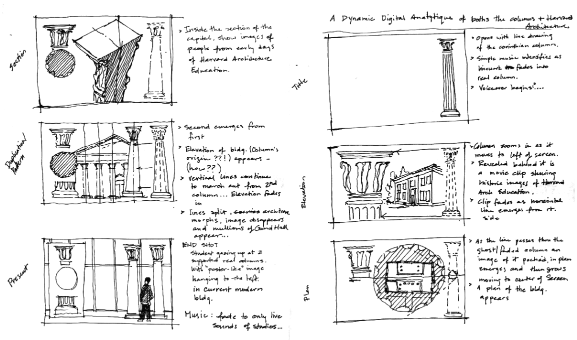

Figure 3: *Storyboard of P.J.*

The practical exercises were coupled with a more theoretical seminar. These sessions were about methods of description, analysis, interpretation, and evaluation of linear/or non-linear dynamic representations. We explored the making of aesthetic judgements for digital media work. Issues of representation, montage, motion, perception, memory and authenticity in digital media works aimed to augment the students' capacity to make quality judgements in matters of emerging technologies for cultural heritage.

4. Results

We distributed three projects. The first assignment was a one-week immersion exercise where students were asked to montage still images and audio to make a one-minute audio-video sequence. The second assignment spanned five weeks and was a trailer about a narrative around an architectural artefact. The final project, allowed each student to embark on a particular subject in architectural heritage preservation. (All animation and VR work of students can be viewed at: http://icommons.harvard.edu/~gsd-2413/REVISIONS_Student_Work.html)

4.1. Architecture at Harvard Yard: Montage and Synchronization exercise

The objective of this one-week exercise was to immerse students into techniques used in making simple montages of still images and audio. Each student was asked to prepare a brief montage sequence that communicated a point, observation or message about the built heritage at Harvard Yard. F.G. presented a short clip on figurative art and statues scattered around Harvard Yard and expressed his own emotional experiences. C.L. recorded numerous pathways in Harvard Yard, and N.P. simulated the light and shadow projections on historic buildings in the Yard, by means of the Solar Eclipse phenomenon.

Figure 4: *Project of F.G., sculptural elements at Harvard Yard*

4.2. Narrative Development: Working with light and materiality

The second project was about narrative development. Through a given architectural history theme, students were expected to develop a short movie trailer. With this exercise we wanted to explore the relevance of digital media tools in understanding and effectively conveying an aspect of an architectural artefact. The assignment provided a vehicle for a series of discussions that focused on technical issues related to materiality, texture, light and shadow, etc. It also addressed issues that are conceptually much broader—the role of context, definition, memory and ambiguity, and others—topics that were raised in the readings and which were mentioned by several guest speakers. The assignment stretched over five weeks and spanned the time of the main lab sessions. In this way, students were able to reflect directly on the 3D scanning, animation, light simulation, texture mapping, and blue-screen tutorials and apply these in their works. F.G. presented a one-minute movie clip showing the historic origins of the Corinthian columns at the GSD, their initial location in Harvard's Robinson Hall. J.K. presented the geological material origins of the same columns, and Y.K. a comparative analysis with contemporary uses of columns.

Figure 5: *Snapshots of project from F.G., illustrating the life-cycles of the Corinthian columns at the Harvard Design School*

4.3. Final Project: Revisioning Architectural Heritage

In the final projects students had the opportunity to re-visit and re-vision architectural themes of their choice through lenses of new digital technologies. The end-products were 3–5-minute-long linear or non-linear hyper-medial motion-graphic projects. With the final projects students ultimately were expected to converge theoretical and practical components of the course. Each project should present new vignettes into age-old architectural problems. Some of the questions we asked were: How can we describe transition/evolution/inversion/change in a lifecycle of a building through digital means? How can we visualize transformations that occur in many ways all over our built environment? What makes digital and dynamic representations more useful compared to conventional representational techniques? The final projects would provide different types of (if not more) information regarding the subject of inquiry. Some topics which students addressed were as follows:

i. The life cycle of a site/building; its distinct phases from its design, to later alterations to its death, basically the representation of time-based phases.

ii. An analytical work, to describe a site's/building's design, structure, and its relationship to its context. If it is non-existent, how is it comprised and what would it look like if it were "there" today?

iii. The symbolism/meaning of the site/building within a transformation of educational practices and values.

iv. The socio-cultural exploration of the site/building within its lifetime; the representation of important events, inventions etc., in/around the building (to understand and preserve events/memoirs of a building.)

v. Comparative study on aesthetic/stylistic questions.

F.G. reconstructed a significant edifice in China - a summer palace of the emperor - which was demolished by the Russian invasion. B.H. worked on "The Old Man on the Mountain" which was a series of 5 granite ledges on Franconio Notch in the White Mountains of New Hampshire and constituted its state symbol. When the ledges were viewed in profile, they formed the shape of an old man's face. This natural cultural heritage crumbled into the valley below in the spring of 2003. The premise of B.H.'s final project was to place the phenomenon of the "Old Man" and its demise into a broader socio-historical context. His work conveyed the processes of natural forces and proposed a proper tribute to this important cultural heritage. N.P. presented an analysis of the engineering techniques and a probable ritual path used at the Great Altar at the Acropolis in Baalbek, Lebanon. The engineering marvel of the construction of this excellently preserved Roman temple complex remains a mystery; especially the technology of stone cutting, transporting, as well as lifting each stone into its place. N.P. showed also how the Great Altar impacted the movement of people who visited the place in ancient times. D.M. worked on an interactive hyper-media application for Le Corbusier's Carpenter Centre building at Harvard University. While moving through the building, users could view and listen to special features, which were located at strategic points in virtual 3D space.

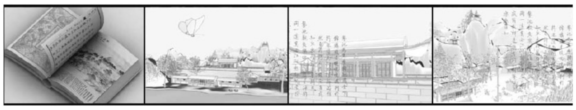

Figure 6: *Snapshots of project from F.G., reconstructing the destroyed summer palace of the Chinese emperor*

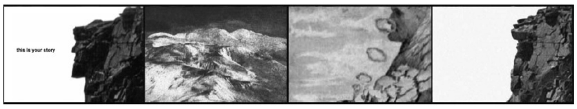

Figure 7: *Snapshots of project from B.H., recording the cultural heritage of the Old Man on the Mountain in New Hampshire*

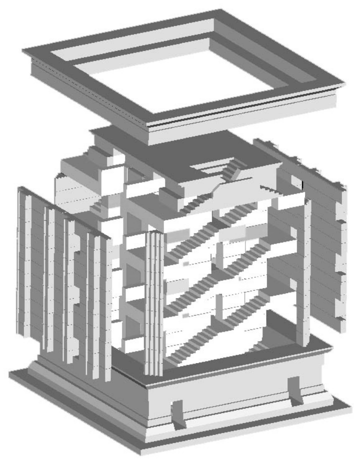

Figure 8: *Project of N.P., assembling the Great Altar*

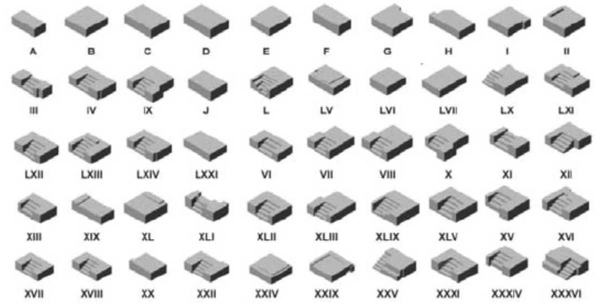

Figure 9: *Project of N.P., the individual stone components of the Great Altar*

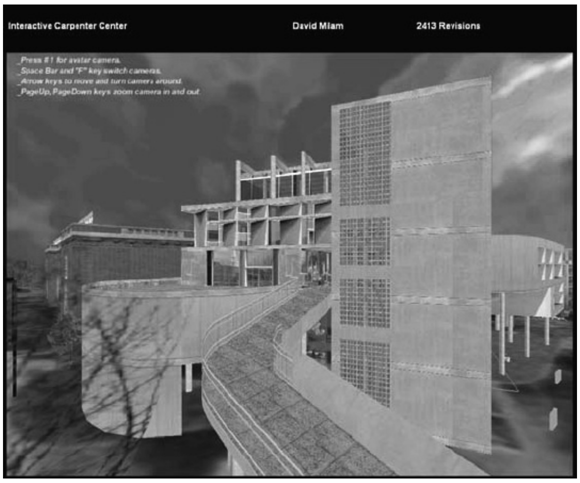

Figure 10: *Snapshot of project from D.M., interactive Carpenter center*

5. Conclusions

Digital media technologies within the proposed method can lead to new insights and new approaches through which architectural historians could inquire and research both the history of an architectural artifact and the way to convey it. The application of newer technologies in architectural preservation greatly expands the role and impact of digital media in this field. Digital technologies are not only helpful in new visualization techniques but also in accommodating human sentiency within built environments. This change of approach—the re-conceptualization of methods and representations with and within digital media technologies—addresses a significant paradigm shift in architectural heritage preservation.

The webpage for this workshop can be visited at: http://icommons.harvard.edu/~gsd-2413/

References

[AEK96] Alsayyad, N., A. Elliott and Y. Kalay., "Narrative Models: A Database Approach to Modeling Medieval Cairo," in Design Computation: Collaboration, Reasoning, Pedagogy, ACADIA Conference Proceedings, Tucson, October 31 - November 2, 1996, pp. 247-254

[ARN98] Arnheim, R., "Das Bauwerk als Anschauung," in Daidalos 1998 March, n.67, pp.26-31

[CHO01] Choay, F., The Invention of the Historic Monument, Cambridge: Cambridge University Press, 2001, p.15

[DOX72] Doxiadis, K., Architectural Space in Ancient Greece, Cambridge, Mass. : MIT Press, 1972, p. 3

[FEI94] Feilden, B.M., Conservation of Historic Buildings, Oxford: 1994, pp.3-9

[GRA94] Grabar, O., "The intellectual implications of electronic information," Leonardo, V27 N2, 1994, pp.135-142

[LEV97] Levebre, H., "The Production of Space," in Rethinking Architecture: A reader in Cultural Theory, ed. Neil Leach, London: Routledge, 1997, pp. 140

[PAN91] Panofsky, Erwin, Perspective as Symbolic Form, New York : Zone Books; Cambridge, Mass. : Distributed by the MIT Press, 1991., p.31

[PHI76] Philippot, P., Preservation and Conservation: Principles and Practices, Washington D.C., 1976, p. 368

[RUS81] Ruskin, J., The seven lamps of architecture, New York : Farrar, Straus, and Giroux [1981], p.184

[SP01] Snyder, A. and S. Paley, "Experiencing and Ancient Assyrian Palace: methods for a Reconstruction," In Reinventing the Discourse: How Digital Tools Help Bridge and Transform Research, Education and Practice in Architecture. Proceedings of the Twenty First Annual Conference of the Association for Computer-Aided Design in Architecture, Buffalo, New York, ed. W. Jabi, October 11-14, 2001, pp. 62-75.

[VEL80] Veltman, K. H., "Panofsky's Perspective: a Half Century Later," in Atti del convegno internazionale di studi: la prospettive rinascimentale, Milan 1977, ed. Marisa Dalai-Emiliani, Florence: Centro Di, 1980, pp.565-584

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
VAST (2006)
M. Ioannides, D. Arnold, F. Niccolucci, K. Mania (Editors)

Close-Range Photogrammetric Measurement and 3D Modelling for Irish Medieval Architectural Studies

Avril Behan

Abstract

In Ireland, as in much of Europe, church architecture of the late medieval era is considered by architectural historians to have been designed according to specific geometric principles and methods. Research into such structures and their design methods has traditionally involved visually-based stylistic comparison of features, primarily by visual techniques. In recent years, however, more analytical approaches to these studies have developed and these procedures require accurate documentation of buildings and features.

3D models generated by a number of close range measurement techniques (terrestrial laser scanning (TLS) and photogrammetry) are appropriate for use in such studies. However, since historical research frequently requires the comparison for large numbers of objects and/or buildings, it is essential that the methods used are easily available and are of low or medium cost, while still being appropriate in terms of accuracy, speed and usability. For the typical multi-site architectural historical study TLS is too expensive and too complex in terms of data collection, software processing and data management.

This project evaluated the suitability of a close-range measurement method for 3D modelling of medieval architecture comprising a non-metric digital camera (Nikon D70), a reflectorless total station (Leica TPS 1205) and software for stereo modelling. Stereo models suitable for the extraction of 3D details of medieval window tracery (an important stylistic and dating feature) were generated and each stage of production analysed. This paper presents preliminary results of investigations into the suitability of this method for use in Irish medieval architectural historical studies and finds that low-cost methods are capable of achieving sufficient levels of accuracy without being onerous in terms of time spent or user inputs.

Categories and Subject Descriptors (according to ACM CCS): I.4.8 [Image Processing and Computer Vision]: Stereo

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1. Introduction

The development and commercialisation of Terrestrial Laser Scanning (TLS) technology in recent years is often seen as the solution to all cultural heritage measurement problems mainly because of the speed and accuracy of the method. TLS has been shown to be extremely effective in the recording of complex and inaccessible objects; both as an individual technique [PR01] and in combination with other measurement methods [EBG*05]. The method has also been successfully used in the protection and reconstruction of damaged sites, including some at UNESCO World Heritage Sites level such as the Bam Citadel, Iran [BS04].

Many of these projects have been completed as proof-of-technology and method by instrument or software developers, or by interested academics. Others have been funded through grants from national or international cultural heritage sponsors.

Based on the positive results reported in the literature a significant number of regional and national bodies (including one in Ireland) have purchased TLS systems for use in cultural heritage applications. However, for many individuals and organisations involved in the care and study of cultural objects, measurement using TLS systems is not currently realistic for two main reasons – cost and knowledge.

[Ker06] has shown that the costs involved in the production of fully rendered 3D models of heritage objects, even when accounting only for the operators' time, would be prohibitive for all but the best-funded projects. The knowledge required by the collectors and, more importantly, users of the data is also of a different type to that required for previous measured surveys. In particular, the learning-curve involved in becoming competent in the utilisation of TLS processing software and the output of usable products from point clouds of data is excessive for many applications.

However, this project was not concerned with the production for fully rendered 3D models of complex sites but of simple objects – traceried windows. In this instance TLS could provide high quality data in a short period of time. However, for the project concerned over 100 individual sites, distributed over the island of Ireland, need to be measured and the investigators do not have access to TLS equipment for the necessary duration. Also, although the products of the measurement will be 3D models, they are models of weathered and damaged medieval stonework, and TLS-generated data would be of higher accuracy than is required.

The investigators, therefore, have evaluated the use of other less-expensive remote sensing technologies and their ability to meet the needs of cultural heritage documentation for architectural historical investigation. In the research presented here, the contribution of relatively low cost image-based measurement methods to the field of history of architecture in Ireland is evaluated.

2. Irish Medieval Architectural Historical Studies

The study of medieval architecture in Ireland, as in many places, has typically used visually-based stylistic comparison to evaluate the methods used by medieval architects and masons in the design and erection of buildings. This method also enables the historian to trace the development of architectural styles and methods over time and from place to place.

In particular a number of building elements are often used by historians as indicators for the development of techniques and fashions. These features include window tracery and moulding profiles of windows, doors and piers.

In England Morris [Mor92] has used moulding profile analysis to assist in the dating of medieval buildings where documentary evidence is absent or scant. Similar work is ongoing in Ireland [ODo06] where evidence from buildings is often the only available information source due to the severe lack of contemporary documentation relating to the foundation and usage of medieval buildings.

Window tracery has also been used as evidence for dating buildings as well as for analysis of the movement of stylistic ideas. Fawcett [Faw84] produced a catalogue of Scottish window tracery that he used to suggest the origin of design ideas as well as proposing building dates for undocumented objects.

While by the mid-16th century English and Continental European master masons (architects) were building cathedrals with vaults 50m above ground and towers up to 153m above ground [Hey95] their Irish counterparts seemed to have trouble executing window structures less than half that height. The reasons for this limitation on Irish structures are often levelled at a lack of funding from patrons and knowledge by masons. Accurate measurement of remaining structures may provide information about the methods used by masons and the failings, in design or structure, which may have contributed to the reduced size/ambition of the buildings.

For this area of study, and a number of other specific architectural historical topics, research is beginning to focus on the abilities of modern measuring instrumentation to supplement the visually-based stylistic analysis previously preferred. Comparison of 3D measurements of objects (mouldings and window tracery) from various sites is much easier and accurate in today's digital environments. To this end, this project is an evaluation of the ability of low-cost remote sensing methods to produce the types of data that can be analysed between numerous medieval sites to add to the body of knowledge about their foundation history and building and design methods.

In particular, the notion that geometric techniques were used in the design and setting out of built objects during the middle ages is suited to evaluation by accurate measurement. The geometric principles date as far back, at least, as the Roman Vitruvius of the first century BC, who wrote that architects were taught to strive for harmony in the design of their buildings through the use of proportion, symmetry and numeric systems to ensure that the parts related pleasingly to the whole [Mor60]. Many historians have shown that similar principles were used in the design of churches and cathedrals, both in their plans and in their details, in the middle ages in Europe [Zen02] and England [Fer76] and [His02]. Thus far studies of Irish buildings have only shown a little adherence to these principles [Sta90] but further measured studies could reveal either more examples of use or possible reasons for the lack of use.

3. Test Site

The site chosen for testing the image-based remote sensing methodology was St. Mary's Collegiate Church, Howth, Co. Dublin, Ireland.

The building is in ruins having no roof and with much natural and human damage having been inflicted on the walls and windows (Figure 1). This is typical of many Irish buildings of the period which were allowed to fall into disrepair due to religious changes and a lack of funds from the 16th century dissolution to the present day.

Figure 1: *Roofless and incomplete state of the interior of St. Mary's Church, Howth.*

The building, as it stands, extends to less than 30m in length and 12m in width and contains elements from the 14th, 15th and 16th centuries. The walls are mainly of rough masonry but the windows are constructed of cut stone. Most windows have segmental arches but one east and one west window have pointed arches, each containing tracery.

The tracery in the west window is badly damaged and only the cusps remain (although drawings from 1960 show the window in its intact state [LEA60]), thus the study focused on the east window (Figure 2). (In future work it is hoped that accurate measurement of tracery remains, combined with measurements taken from similar windows/sites, will be used to assist in reconstruction of objects using fallen stone retained at a number of Irish sites.)

Figure 2: *East window tracery, St. Mary's Church, Howth.*

The building material is yellow sandstone which was often used by medieval Irish masons since it is easy to work. However, it degrades over time and much of the remaining tracery is soft and not sharply defined because of this. This factor also makes sub-centimetre measurement unnecessary as often only an estimation of the intended shape can be obtained from the remains.

4. Equipment

Since the aim of the research is to evaluate a low-cost method of measuring medieval architectural features, the equipment and software used were either inexpensive or easy availability to facilitate rental without high overheads.

4.1 Reflectorless Total Station

Photo control was collected using a Leica TPS 1205 reflectorless total station with an angular accuracy of 5' and a maximum reflectorless range of 300m (accurate to 3mm + 2ppm). Weekly hire of this instrument cost in the region of €120 thus making it accessible to most research projects. For this project an instrument owned by the Dublin Institute of Technology was used.

4.2 Digital Camera

The camera used for photography was a Nikon D70 6 Megapixel camera with a Nikkor 18-70mm lens. For all photographs used in measurement the focal length was fixed at 24mm and the focus at infinity. (Both of these parameters were easily checked using the EXIF information displayed at the time of image capture.)

Camera calibration was not carried out for two reasons. Firstly the object of interest was photographed at the centre of the image to ensure that a minimum of lens distortion effects would be present. Secondly, the accuracy required for the final measurements, particularly because of the weather-damage mentioned in section 2, was deemed to be below the threshold that would require full calibration.

The Nikon D70 has a 23.7mm by 15.6mm sensor with 3008x2000 pixels resulting in a pixel size of approximately 8µm.

4.3 Photogrammetric Software

In line with the goal of low-cost analysis of data for architectural historical applications the software tested for this project was LISA FOTO developed by Wilfried Linder of the University of Duesseldorf [Lin03]. For research purposes the latest version of the software costs ~€800 which is significantly less than the costs associated with commercial photogrammetric packages.

Although mainly developed for use by non-photogrammetrists in aerial applications the software has been used for close-range applications using non-metric digital cameras [Lin03] and [Map04].

5. Measurement

5.1 Photography

Multi-photo techniques (such as used by Photomodeler [Eos06], Shapecapture [Sha06] or iWitness [FH04]) were ruled out because they typically require the acquisition of photographs from an array of angles, including from above the object of interest [WO94]. At most of the Irish sites of interest for architectural historical studies such photographs would be difficult, if not impossible, to obtain due to issues of accessibility, safety, cost and time.

Therefore stereo close-range photogrammetric methods were used. Images were taken from either end of a stereo baseline of 1m length at a distance of ~10m to ensure a base to distance ratio of between the recommended 1:5 and 1:15 values (Figure 3).

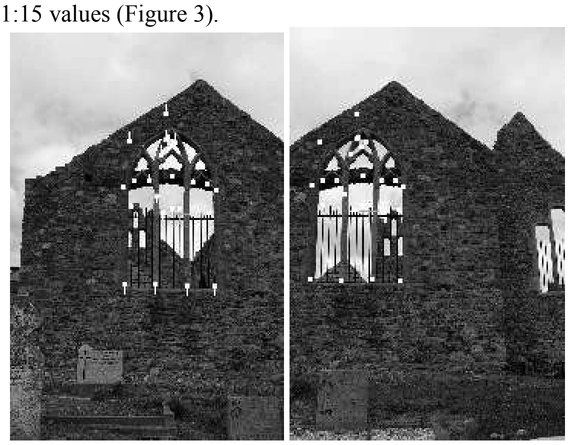

Figure 3: *Left and right stereo images*

5.2 Photo Control

Using the reflectorless total station Leica 1205 the three-dimensional co-ordinates of 42 natural control points were measured. While it is acknowledged that targeted control points would add to the overall accuracy of the restitution it was not possible to use them for this study. Typically, buildings of interest to architectural historians are protected structures and any interference, even sticking on removable targets, is discouraged. Also, as mentioned in section 5.1, building accessibility is typically very poor (even if a hoist or other platform was available) and adhesion of targets is not possible.

The 42 control points were well-distributed around the tracery of the east window and its setting in the wall. The most defined natural points were chosen, such as points on the railings.

6. Software Processing

LISA FOTO software performs Exterior Orientation (EO) in mono mode with the operator performing all measurements of control points on each image separately and the software calculating a space resection. The use of more than 3 control points invokes a least squares adjustment, as was the case in this project where 22 control points were measured per photo. The remaining control was used for validity checking.

In LISA FOTO the photos are later combined into a stereo model using the Define Model function. In this module the focal length, the co-ordinates of the photo projection centres, the $\omega\ \phi\ \kappa$ rotations and the image and real co-ordinates of the control points are transformed via an affine or polynomial transformation.

6.1 Stereo Processing Results & Analysis

For the Exterior Orientation 22 of the available 45 control points were measured in each image. Table 1 shows the results of the orientations.

Image	Average Std Deviation (mm)	Maximum Std Deviation (mm)
Left	0.010	0.031
Right	0.009	0.020

Table 1: *Exterior Orientation results*

Although the results display low relative standard deviations it is the outcome of the model definition, as given in Table 2, that is more indicative of the quality of the processing.

Approximate Pixel Size	0.0038m
Height to Base Ratio	4.9121
Approximate Maximum Attainable Accuracy in Z	0.0186m
Approximate Photo Scale	1: 471
Mean y-parallax before correlation	0.73 pixel
Mean y-parallax after correlation	0.01 pixel
Mean Correlation Coefficient	0.8809

Table 2: *Model definition results*

The mean correlation coefficient of 0.8809 taken in combination with the value of mean y-parallax after correlation (0.01) indicates that using the 22 measured control points the software was able to reliably match the two image positions and orientations calculated by the EO phase. The closer the correlation coefficient is to unity the better the result. The failing of this set of measurements may lie in the distribution of control points towards the top of the model (also the top of the window tracery). Unlike in the lower parts, at the top of the model the control points were concentrated on the central mullions and the peak of the arch. This resulted in an uneven distribution of control points throughout the model

Although the model boundaries were set with the project (the x and y extents are illustrated by the heavy lines on Figure 4) it is possible that the limited extent of the control, relative to the full photographs, may have contributed to some inaccuracies in correlation.

Figure 4: *Control point distribution and model area*

Unlike in most other stereo photogrammetric systems in LISA-FOTO there is no facility for the operator to either interactively add tie-points between the images to strengthen the match or to use a pre-defined tie-point pattern which matches images using digital image matching techniques. Thus there is more necessity for the collection of exactly the right number and distribution of control points in the field.

Another element different in this software to some commercial packages is the ability to control points in stereo for the EO phase. Without 3D visualisation, natural points that in the field are clearly distinguishable from their surroundings become difficult to identify. This again makes point selection at control measurement stage very critical.

The photo scale of 1:471 agrees well with the expected value since the photos were taken with a focal length of 24mm from a distance of 10m from the building. Using standard photogrammetric formulae (1/scale = focal length/object distance) the scale could be approximated at 1:416.

In this particular project, due mainly to issues of accessibility on site, the object of interest represents, at most, one quarter of the image. With a pixel size of only 8µm and an enforced object distance of 10m the maximum attainable z accuracy thus calculated by LISA-FOTO is just below 2cm. This figure is at the limits of what is acceptable for analysis of the envisaged products, i.e. 2D profiles of mouldings and 3D models of tracery.

It is clear, however, that in most circumstances this accuracy can be improved upon, particularly by more careful photography. For future work a number of other digital focal lengths will be available, including both 18mm and 35mm, which will expand the range of photographs that can be taken on any site. The pixel size on the object can thus be improved from 3.8mm to enable both better control point measurement for model setup and better point/profile/object extraction from the model.

7. Outputs

Traditionally the products used in architectural historical studies were 2D in nature comprising either profiles (plan views) of particular pieces of stonework (piers, mullions, window tracery) or elevation drawings of objects. In some cases perspective drawings are used but these were visually based rather than measured.

Using the type of photogrammetry presented above once the stereo model has been created via orientation procedures 2D products such as profiles and elevations can be easily produced.

However, unlike traditional methods, these products are created in a fully digital environment and can be output in ASCII format from which they can be imported into a CAD system. Once in any CAD package profiles from different objects, which are adjudged to be similar on the basis of visual comparison, can be overlaid and compared for both size and stylistic similarity.

Research in England [Mor92] has also pointed to the repeated usage of particular feature sizes, based on typical medieval units, by individual masons or schools of masonry. With all features extracted digitally such repetition will be easily recognisable. This type of information is useful to architectural historians when tracing the movement of the "free" masons of the middle ages.

Likewise, elevations of window tracery could be compared via overlays in CAD. However in line with taking full advantage of the capabilities of photogrammetry and the CAD environment these 2 elements (profiles and elevations) will be combined into a 3D model which can be compared via 3D CAD overlay, or using another modelling language.

7.1 Evaluation of Outputs

Using the remainder of the control points measured in the field by the total station but unused in the orientation procedure it was possible to carry out an evaluation of the quality of the model (Table 3).

Co-ordinate	Average Difference (mm)	Maximum Difference (mm)
X,Y	0.003	0.021
Z	0.023	0.035

Table 3: *Stereo Model Evaluation*

As would be expected the quality of the model in planimetry (elevation) was better than in depth. The magnitude of the difference in quality is too high but it is envisaged that in future work the quality of Z co-ordinates will be improved using the improvements in fieldwork and processing listed in section 6.1.

Another factor in this variation between field and stereo model co-ordinates is the human element. In line with the low-cost concept of LISA-FOTO stereo viewing is facilitated using Cyan-Red Anaglyph glasses. Seeing in 3D through these glasses requires more acclimatisation than is typically needed with polarisation or flicker technology.

8. Project Completion Aspects

Fieldwork for this method is rapid. Once there are no accessibility restrictions directly in front of the object of interest stereo photography can quickly be acquired. In the simplest cases where it can be judged that the object of interest is symmetrical between interior and exterior all control point measurements can be acquired from a single total station setup; thus very quickly even when acquiring a large number of redundant points as checks or even to field measure particularly important features. Thus fieldwork per object would typically take between 1 and 2 hours.

In more complex situations where two sides of an object occur on either sides of the wall of a building and the object is deemed not to be symmetrical it is necessary to first measure a geodetic network. Depending on accessibility aspects for the object – typically medieval churches had only one entrance – the network may require a significant number of setups to connect interior and exterior. It is not envisaged that many relevant sites will require this level of processing but those that do will probably increase fieldwork time by a factor of 4 or 5.

Orientation of the stereo model, once the operator is familiar with the software, is also rapid, requiring again only 1 to 2 hours.

Extraction of features typically comprises the bulk of the processing time. For the window tracery show in Figure 3 the extraction of points and lines sufficient to produce a 3D CAD model required approximately 4 hours.

Thus the ratio of field to orientation to feature extraction time could be given as 2:2:4. This particular object would not be considered very complex in comparison with some to the other objects that will be measured in the future. Thus the feature extraction aspects of projects could increase from representing half of the time to three-quarters or more.

9. Conclusions & Future Work

In conclusion, the photogrammetric method using low-cost software is usable for this type of architectural historical study particularly since the accuracy requirements are not very high. However, a degree of care is needed in the acquisition of control information and photography. At some sites it may be possible to use targets to increase accuracy and reduce the total numbers of control points measured.

The usage of digital image matching methods for feature extraction, rather than using an observer, may reduce processing time but these, again, must be used with care.

Further work will involve the acquisition of 3D models of tracery from a large number of sites and the creation of a digital database. Using CAD, VRML and/or GML options models can be compared in a digital environment to look for patterns of building and design. If found these patterns could assist in the dating of objects, in analysis of building methods, and in the reconstruction of objects from in-situ remains and fallen stone; all aspects of interest to architectural historians.

References

[BS04] BOUROUMAND, M., STUDNICKA, N.: The Fusion of Laser Scanning and Close Range Photogrammetry in Bam: Laser-Photogrammetric Mapping of Bam Citadel (Arg-E-Bam)/Iran. In *IAPRS Vol,* no (2004).

[EBG*05]EL-HAKIM, S.F., BERALDIN, J.-A., GONZO, L., WHITING, E., JEMTRUD, M., VALZANO, V.: A Hierarchical 3D Reconstruction Approach for Documenting Complex Heritage Sites. In *Proc. CIPA 2005 XX International Symposium, 2005, Torino, Italy.*

[Eos06] EOS SYSTEMS INC.: *Photomodeler*. (2006) http://www.photomodeler.com/.

[Faw84] FAWCETT, R.: Scottish Mediaeval Window Tracery. In *Studies in Scottish Antiquities presented to Stewart Cruden*, Edinburgh, 1984.

[Fer76] FERNIE, E.: The Ground Plan of Norwich Cathedral & the Square Root of Two. *Journal of the British Archaeological Association* 129 (1976), 77-86.

[FH04] FRASER, C. S., HANLEY, H. B.: Developments in Close-Range Photogrammetry for 3D Modelling: The *iWitness* Example. In *Proc. ISPRS Workshop on Processing and Visualization using High-Resolution Imagery, Pitsanulok, Thailand, 2004*.

[Hey95] HEYMAN, J.: *The Stone Skeleton: Structural Engineering of Masonry Architecture.* Cambridge University Press, 1995.

[His02] HISCOCK, N.: *A Schematic Plan for Norwich Cathedral.* In *Ad Quadratum: the Practical Application of Geometry in Medieval Architecture,* Ashgate Publishing Ltd., 2002.

[Ker06] KERSTEN, T.: Combination and Comparison of Digital Photogrammetry and Terrestrial Laser Scanning for the Generation of Virtual Models in Cultural Heritage Applications, *VAST 2006.*

[Lea60] LEASK, H.: *Irish Churches and Monastic Buildings.* Dundalgan Press, 1960.

[Lin03] LINDER, W.: *Digital Photogrammetry: Theory and Applications.* Springer-Verlag, 2003.

[Map04] MAPTEC PHOTOGRAMMETRY, *Photogrammetric evaluations with usual digital cameras – specified for the programme LISA* (2004) http://www.ipi.uni-hannover.de/lisa/cam_guide.pdf.

[Mor60] MORGAN, M. H.: *Viturvius: The Ten Books on Architecture*. Dover Publications Inc., 1960.

[Mor92] MORRIS, R.: An English Glossary of Medieval Mouldings: with an introduction to mouldings c. 1040-1240. *Architectural History,* 35 (1992), 1-17.

[ODo06] O'DONOVAN, D.: *Late Gothic Architecture in Ireland: The Evidence of Mouldings*. Trinity College Dublin, Unpublished PhD Thesis, 2006.

[PR01] PFEIFER, N., ROTTENSTEINER, G.: The Riegl Laser Scanner for the Survey of the Interiors of Schönbrunn Palace. In *Proc. Fifth Conference on Optical 3-D Measurement Technique,* 2001.

[Sha06] SHAPEQUEST INC.: *ShapeCapture.* (2006) http://www.shapecapture.com/.

[Sta90] STALLEY, R.: Gealic Friars and Gothic Design. In *Medieval Architecture & its Intellectual Context: Studies in Honour of Peter Kidson,* The Hambledon Press, 1990.

[WO94] WALDHÄUSL, P., OGLEBY, C. (1994) 3-by-3-Rules for Simple Photogrammetric Documentation of Architecture. In *Close Range Techniques and Machine Vision. Proceedings of the Symposium of Commission V of ISPRS in Melbourne, Australia,* (1994), 426.

[Zen02] ZENNER, M.T.: A Proposal for Constructing the Plan & Elevation of a Romanesque Church Using Three Measures. In *Ad Quadratum: the Practical Application of Geometry in Medieval Architecture,* Ashgate Publishing Ltd., 2002.

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
VAST (2006)
M. Ioannides, D. Arnold, F. Niccolucci, K. Mania (Editors)

Integration of Cultural Digital Resources in Institutional Repositories and On-line Communication through Cultural Portals. A Case Study: the Project for the Pompeii Information System and its Web Application as a Sub-Portal of the Portal of Italian Culture.

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Abstract

In September 2004 the Italian Ministry of Cultural Heritage and Activities (MiBAC) commissioned the Scuola Normale Superiore di Pisa (SNS) to create the scientific and technical project for the Italian Portal of Culture. The project was delivered in 2005, along with a prototype realised by SNS. The Portal will be fulfilled by the beginning of 2007: at the moment SNS is working as a consultant for MiBAC in order to flank the company which is carrying out the Portal.
The Italian Portal of Culture will provide unique and integrated access to digital contents created by MiBAC and its central and local departments, by public or private institutions such as research institutes, museums, libraries and by several other providers, such as regional and local portals. Metadata pertaining to different cultural resources will be harvested from various repositories, using OAI-PMH for data transfer and XML for data coding. This contents will be mapped into one metadata scheme, the PICO AP, which is a Dublin Core Application Profile designed ad hoc for the Portal domain.
In May 2005 SNS started the Project for the development of the Pompeii Information System. It is promoted and financed by ARCUS S.p.A., and developed together with the Archaeological Superintendence of Pompeii (SAP). This Project will be delivered in May 2008: at the moment the domain analysis and the design of the Information System have been completed. The main objective of the Pompeii Project is centred on the transferring of various existing resources and contents on a structured platform which will be designed for the implementation, storage, organisation, management and publishing of different kinds of contents (texts, 2D and 3D images, audio, video, geographic information, etc.).
The System will constitute the central archive of the SIAV (Archaeological Information System of Pompeii's Superintendence for the Geographic Area of Mount Vesuvius) and will be used both for internal purposes (cataloguing, documentation, preservation, management of Pompeii's archaeological heritage) and for external communication through a web interface (directed to expert users such as archaeologists and researchers in various fields, and to general users such as tourists and students).
Moreover, the Pompeii Information System and its web application will be predisposed in order to provide contents to the Portal of Italian Culture, thus it will constitute a prototype of Institutional Sub-Portal that could be used as a model by other Archaeological Superintendences and local departments of MiBAC.

Categories and Subject Descriptors (according to ACM CCS): C.0 [Computer Systems Organization]: general – E.1 [Data]: Data Structures – E.4 [Data]: Coding and Information Theory – H.2 [Information Systems]: Database Management – H.3: Information Storage and Retrieval – H.4: Information Systems Applications – H.5: Information Interfaces and Presentation, J.5 [Computer Applications]: Arts and Humanities – K.3 [Computing Milieux]: Computers and Education – K.4: Computers and Society.

1. Introduction

The Scuola Normale Superiore of Pisa (SNS – website: http://www.sns.it/) is developing the Project for the designing and fulfilment of the Pompeii Information System, in collaboration with the Archaeological Superintendence of Pompeii (SAP – website: http://www.pompeiisites.org/) and funded by ARCUS (website: http://www.arcusonline.org/), which is a company that promotes and develops Arts, Culture and Performances whose capital is entirely subscribed by the Italian Ministry of Economy and whose actions are planned by the Ministries of Cultural Heritage and of Transport and Infrastructures. The Project is regulated by an agreement amongst the three above mentioned Bodies; it started in May 2005 and will continue for a duration of three years.

The name of the Project, "The Fortuna visiva of Pompeii", is derived from the homonymous research project which was started in 2002 and is presently ongoing with the partnership of Consorzio FORMA, SNS and SAP. This is a mainly scientific project, aimed at reconstructing the present cultural identity of Pompeii and the evolution of the taste for its monuments through the analysis of digitised edited and unedited documents (texts and images) dated in the XVIII and XIX Centuries. The contents of this research, which has already been provided as a demonstrator to the EU Project BRICKS (Building Resources for Integrated Cultural Knowledge Services – website: http://www.brickscommunity.org/), will be integrated in the Pompeii Information System together with other contents owned by the SAP and by various Institutions which developed research on Pompeii's heritage.

The Information System of Pompeii that will be carried out with the ARCUS – SAP – SNS Project will manage the existing scientific contents on the archaeological site, on its monuments and on the objects found in Pompeii and in the territory administrated by the SAP, which includes Herulaneum, Stabiae, Oplontis and Boscoreale. Thus, it will recover and import different kinds of contents which presently are managed by various software and are stored in different repositories.

The contents will serve both for administrative and scientific usage within the SAP, and for a better external exploitation through a renewed website addressed to expert users and to more general users, such as tourists and students.

During recent years, many changes have taken place in this field, developing a new way for communicating the cultural resources, indications and best practices for the accessibility and the interoperability.

The technical-scientific evolution and development for the digital publishing, the interoperability and the integration and retrieval of cultural resources, offer the possibility to import, export and share documents and interactive resources from and with other repositories. They consequently give to the communication experts more material and a broader range of choice through the available contents, in order to design impressive and efficient interfaces that will be able to respond to the expectations of different kinds of users.

In this panorama numerous research, projects and discussions have recently been carried out regarding the Institutional Websites, conceived as central nodes for collecting and distributing information and data pertaining to public and private entities subordinated to the Institution. This data came especially from databases, digital libraries and other resources that have been produced in the context of research projects for the cataloguing and the organisation of different kinds of documents and information. Thus, the main objective of an Institutional Website is more and more centred on the porting and the publication of various resources and contents on one structured platform.

The main requisite of the Pompeii Information System is therefore to import various kinds of contents and to make them available to different users through specific interfaces. Moreover, the System will permit the exportation of its contents to other repositories.

In particular, it will be configured to allow the metadata harvesting from the Portal of Italian Culture, after the mapping of the metadata schemes adopted for the description of Pompeii's contents into the Application Profile which have been specifically designed for the Portal of Italian Culture.

The Portal of Italian Culture is presently under development: it was designed by SNS under the request of the Ministry of Italian Culture (MiBAC) during 2005. SNS is following up its development as the consultant of MiBAC. The fulfilment of the Portal is foreseen for the beginning of 2007.

In this scenario, the Pompeii Information System and the connected renewed website of the Superintendence, which will import its contents from different repositories, will provide metadata and contents to the Italian Portal of Culture and will constitute a case-study for the configuration of an institutional Sub-Portal, representing a model for Information Systems and Sub-Portals to be carried out by other Superintendences and Institutions subjected to MiBAC administration.

The Project offers a new case study to design a model of Institutional Website to the SNS team who will apply their acquired expertise with the Portal of the Culture Project and with other research projects.

2. Previous experience: a) The "Fortuna Visiva of Pompeii" and its Application in the BRICKS EU Project

The "Fortuna visiva of Pompeii" is an ongoing project conceived and carried out since 2002 by a scientific team from the SNS and the Consorzio FORMA, directed by Professor Paola Barocchi, supervised by Dr. Benedetto Benedetti and coordinated by Dr. M. Emilia Masci

The SAP and the Deutsches Archäologisches Institut in Rom (http://www.dainst.org/) joined the scientific staff as partners in the project. The Information System and the website have been designed by Liberologico (http://www.liberologico.com) in strict cooperation with the research group.

The research project intends to analyse the perception of the monumental and archaeological ensemble and the landscape of Pompeii, through the graphic sources and texts produced starting from the years immediately following its discovery, in 1748, until the end of the Nineteenth century. It proposes an enriched perspective through the reconstruction of different representations of Pompeii in the past, defining a wider critical approach to its present cultural identity. The main objective of the research is therefore the examination of the different perceptions and representations of Pompeii, in its several shapes and variations in space and time, in order to obtain an overall view, based on a historical and critical synthesis.

The project produced a Digital Archive containing an interrelated database of the Iconographic, Bibliographic and Unedited Sources, on which the research is based. This Archive is related to a Digital Library, that permits the final user to consult the complete collection of digitised books and manuscripts, and to a GIS (Geographic Information System), which allows the final user to perform research in the Archive starting from the houses and monuments of Pompeii that are visualised on a map.

The results of this ongoing research and its contents, which are progressively growing, are published in the website http://pompei.sns.it.

Since 2005, the contents of the "Fortuna Visiva" Project have been provided in the Digital Library created by the European Project BRICKS, into the work-package 'Archaeology', in order to contribute to the definition of the user requirements and scenarios and to build up a specific application as a demonstrator, using BRICKS' Technical Platform and testing it on data pertaining both to the database and to the GIS.

BRICKS is an Integrated Project of the 6th Framework Program of the European Commission, involving 24 partners selected amongst Institutions devoted to the Cultural Heritage preservation, universities and research Organisations, Information Technologies Enterprises. The core of the project is the building of a distributed platform for cultural resources, in a peer-to-peer network, within which each database, legacy system or repository could be physically stored by the single promoting institution and, at the same time, could support queries as in a whole. The retrieval of the resources is based on the descriptive metadata harvesting, using the codification in XML of documents and the metadata porting with OAI-PMH; besides the adoption of metadata codified by Dublin Core Metadata Initiative, the BRICKS retrieval System can identify other metadata sets and the related ontology.

Moreover, the BRICKS System provides some web services, distributed on single nodes of the net and available for each partner, such as the automatic indexing, the protection with Digital Rights Management System, and tools for the editing of new collections and of annotations on the existing resources.

For the demonstrator shown in the occasion of the first review of the project (March 2005), the metadata related to the contents of the "Fortuna visiva of Pompeii" have been transposed in XML, mapped in Dublin Core standard and harvested through OAI-PMH into BRICKS System, in order to allow inter-operability with other contents provided by other organisations to the BRICKS Community. For the second review (March 2006), the functionalities of BRICKS System have been demonstrated through the installation of a B-Node (BRICKS Node of the P2P System) in real time, showing Pompeii's contents and other resources directly drawn from their own OAI Servers.

During the second year of the project, an XML schema of the "Fortuna Visiva of Pompeii" metadata schema has been provided for BRICKS. On the basis of this schema, it will be possible to make Pompeii's contents in its own schema available on BRICKS platform and also to support schemas other than Simple Dublin Core Element Set. From this perspective, Pompeii's schema has been mapped into different metadata standard schemas: Categories for the Description of Works of Art (CDWA); VRA Core Categories and the possibility of providing a mapping into the CIDOC Conceptual Reference Model is under evaluation.

The archaeological domain and the specific case study of Pompeii, brought forth the need to also manage geographical data into the BRICKS Community. Therefore, the "Fortuna visiva" application is being used as a grounds for experimentation, in order to find the way to integrate a GIS into BRICKS.

Pompeii's GIS original application, which is based on a proprietary system, has been transposed into Web Services and connected with the contents pertaining to the database using BRICKS services at the level of the interface: the System Architecture has been integrated joining a Map Server, which is compatible with OGC (Open Geospatial Consortium) standard. The integration of contents from B-Node and Map Server has been implemented at the Application level.

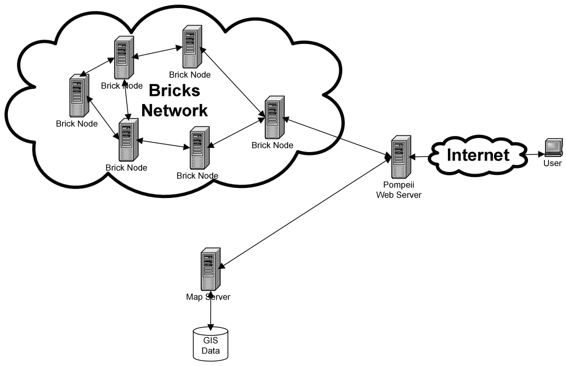

Figure 6: *the "Fortuna visiva of Pompeii" BRICKS Application. Architecture.*

Future activity will consider the development of the interface for Pompeii Application in BRICKS, which will be targeted for different kinds of users and will allow various solutions for the data retrieval on texts, images and geographic data.

3. Previous experience: b) The scientific and technical Project for the Portal of Italian Culture

The scientific and technical project for the Italian Portal of Culture was promoted by the Italian Ministry of Cultural Heritage and Activities (MiBAC) and delivered by SNS during 2005, together with a prototype which had the function of testing the project itself and will serve as a sample and reference for the implementation of the Portal, due to be published for the beginning of 2007. At the moment SNS is working as a consultant for MiBAC in order to flank the company which is carrying out the Portal.

The main mission of the Italian Portal of Culture is to communicate to different kinds of users the whole ensemble of Italian culture, comprehensive of tangible and intangible patrimony, such as media conceived for the diffusion of knowledge, promotion and enhancement of Cultural Heritage. Thus, the Portal will offer access to the existing resources on cultural contents, and at the same time will give more exposure to the vast amount of websites pertaining to museums, libraries, archives, universities and other research institutions: through the Portal, users will access resources stored in various repositories browsing by subjects, places, people and time. It will be possible to visualise information and contents from the resources and to further deepen the knowledge directly connecting to the websites of each single Institution.

Resources originating from various data-sources will remain under the control of Institutions responsible for their creation, approval, management and maintenance: data will not be duplicated into the Portal's repository and will be retrievable through a unified and interoperable system, which will manage contents by harvesting metadata pertaining to those data.

After being harvested, metadata coming from various data-sources will be imported in a specifically designed metadata scheme, which will permit the index, browse and query functions on the whole ensemble of harvested contents. Metadata will be harvested using OAI-PMH: this protocol allows the metadata migration from content providers to one or more harvesters, adding services such as indexing system or automatic classification.

As the Portal will join different kinds of contents pertaining to the complex domain of Italian culture, it seemed unsuitable to use a data model with predefined entity types. This solution would have been not aligned with the requisite of system's scalability.

Therefore, a flexible solution has been preferred, which consists in the designing of a unique metadata scheme: in order to respect world-wide standards, the Italian Portal will adopt a metadata set based on Dublin Core standard.

A DC Application Profile (PICO AP) has been designed for the Portal on the basis of recommendations, documents and samples recently published by Dublin Core Metadata Initiative (DCMI), in order to define further extensions to the Qualified DC elements and encoding schemes, specially conceived to retrieve information pertaining to Italian culture. This application profile could be further expanded, if necessary for the harvesting of eventually unexpected contents in the future.

The PICO AP was designed by Irene Buonazia, M. Emilia Masci and Davide Merlitti (SNS working group on metadata supervised by Umberto Parrini and Benedetto Benedetti). It is exposed in the table below. An official publication inclusive of an updated version of the PICO AP and the related schemas is under development.

Extensions to Qualified DC are written in bold. Some Element Refinements and Encoding Schemes have been added in order to describe roles of persons and institutions involved in the creation, execution, publishing of a resource and to better specify relations trough resources, coverage parameters and format.

In addition, resource types have been further extended with the PICO Type Vocabulary, which joins the types 'Institution', 'Physical Person' and 'Project' to the types foreseen in the DCMI Type Vocabulary.

METADATA SCHEME OF THE PORTAL OF ITALIAN CULTURE - DC APPLICATION PROFILE		
DCMES ELEMENTS	**ELEMENT REFINEMENTS**	**ENCODING SCHEMES**
Title <dc:title>	Alternative <dcterms:alternative>	
Creator <dc:creator>	**Author <pico:author>** **Cataloguer <pico:cataloguer>** **Inventor <pico:inventor>** **Commissioner <pico:commisioner>**	**ULAN <pico:ULAN>** **MIAN <pico:MIAN>** **ICCD – Archivio Controllato dell'Autore <pico:iccdACA>** **SBN – Archivio Autori <pico:sbnAA>**
Subject <dc:subject>		DDC <dcterms:DDC> LCC <dcterms:LCC> LCSH <dcterms:LCSH> MESH <dcterms:MESH> UDC <dcterms:UDC> **PICO Thesaurus <pico:PICO>** **UNESCO Thesaurus <pico:UNESCO>** **AAT <pico:AAT>** **MIT <pico:MIT>** **ICCD - Ambito culturale ATBD <pico:iccdATBD>** **ICCD - Descrizione Iconografica DESS <pico:iccdDESS>** **ICONCLASS IN ITALIAN <pico:iconclass>**

METADATA SCHEME OF THE PORTAL OF ITALIAN CULTURE - DC APPLICATION PROFILE		
DCMES ELEMENTS	**ELEMENT REFINEMENTS**	**ENCODING SCHEMES**
Description <dc:description>	Abstract <dcterms:abstract> Table of contents <dcterms:tableOfContents> **Contact <pico:Contact>** **Related Service <pico:relatedService>** **Preview <pico:preview>**	URI <dcterms:URI>
Publisher <dc:publisher>	**Publisher <pico:publisher>** **Distributor <pico:distributor>** **Printer <pico:printer>**	
Contributor <dc:contributor>	**Collaborator <pico:collaborator>** **Editor <pico:editor>** **Performer <pico:performer>** **Producer <pico:producer>** **Responsible<pico:responsible>** **Translator <pico:translator>**	**ULAN <pico:ULAN>** **MIAN <pico:MIAN>** **ICCD – Archivio Controllato dell'Autore <pico:iccdACA>** **SBN – Archivio Autori <pico:sbnAA>**
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METADATA SCHEME OF THE PORTAL OF ITALIAN CULTURE - DC APPLICATION PROFILE		
DCMES ELEMENTS	**ELEMENT REFINEMENTS**	**ENCODING SCHEMES**
	Promotes <pico:promotes> **Is Promoted by <pico:isPromotedBy>** **Manages <pico:manages>** **Is Managed by <pico:isManagedBy>** **Is owner of <pico:isOwnerOf>** **Is owned by <pico:isOwnedBy>** **Produces <pico:produces>** **Is Produced by <pico:isProducedBy>** **Performs <pico:performs>** **Is Performed by <pico:isPerformedBy>** **Is Responsible for <pico:isResponsibleFor>** **Has as responsible <pico:hasAsResponsible>** **Contributes to <pico:contributesTo>** **Has as Contributor <pico:hasAsContributor>**	
Coverage <dc:coverage>	Spatial <dcterms:spatial> Temporal <dcterms:temporal> **Place of birth <pico:placeOfBirth>** **Place of death <pico:placeOfDeath>** **Date of birth <pico:dateOfBirth>** **Date of death <pico:dateOfBirth>**	Box <dcterms:box> ISO3166 <dcterms:ISO3166> Point <dcterms:point> TGN <dcterms:TGN> Period <dcterms:period> W3CDTF <dcterms:W3CDTF> **ISTAT <pico:ISTAT>**
Rights <dc:rights>	Access Rights <dcterms:accessRights> License <dcterms:license>	
Audience <dc:audience>	Education level <dcterms:educationLevel> Mediator <dcterms:mediator>	**PICO User Level <pico:PICOuserlevel>**
Provenance <dc:provenance>		
Rights Holder <dc:rightsHolder>		

The Portal will not only publish resources stored in the catalogue, which will be imported from external repositories, but will also produce new contents: a publishing office will prepare and manage new contents specifically created for the Portal in order to provide interesting relations between resources, to fidelize the user and make him discover them through the links created among different kinds of resources, suggesting more specialised queries.

The interface of the Portal will allow data retrieval on the contents through different possibilities for searching and browsing, using facettes for progressively deepen the retrieval of contents.

4. The ARCUS – SAP – SNS Project for the Pompeii Information System

The expertise acquired with the development of the “Fortuna visiva” Application for BRICKS Project and with the Project of the Portal of Italian Culture will constitute the basis for designing and carrying out the Pompeii Information System. The three projects are also hierarchically linked because Pompeii’s System will include, amongst other data, the contents pertaining to the “Fortuna visiva” and because its metadata will be harvested by the Portal of Italian Culture.

The Pompeii Information System will be conceived to import data from various content providers, in order to make their contents interoperable and to publish them in different forms, depending on the various kinds of users, that will have different rights.

The contents to be imported in the System consists of data pertaining to Geographic Information Systems, of the Digitised Cataloguing Archive of the SIAV (Archaeological Information System of the Pompeii’s Superintendence for the geographic area around Mount Vesuvius) and of other digital resources produced by the SAP, by its internal departments and by other research projects carried out by different Institutions and research groups in connection with the SAP:

- The already concluded analysis of existing contents to be managed by the System revealed that the SAP owns three different GIS that manage different types of information: 1) The “Neapolis” GIS manages different themes, levels related to the date of the excavated structures, indexes of different kinds of architectonical structures and links to the databases; it comprehends the cartography of the whole Vesuvian area and a detailed cartography of the Pompeii archaeological site; 2) The GIS “Un piano per Pompei” utilizes the vector digitalization of the Rica Map as a cartographical basis; it manages data about findings situated at, or originating from, the various buildings, and data related to the conservation conditions of specific monuments, to the various degrees of risk , to the restoration work carried out, to the necessary maintenance, taking into consideration priority and cost; 3) The GIS of the “Vesuvian Area” contains data for the monitoring of the volcanic risk and is based on an aero-photographic campaign of the territory pertaining to 18 Administrations comprised in the Vesuvian area. Its usage is mainly directed to the territorial action-planning.

- The Cataloguing Archive of the SIAV consists of various kinds of digitised resources that have been ordered and catalogued by the SAP: it's built up of various databases that are presently managed by different proprietary softwares. It contains mainly cataloguing charts on the Archaeological Objects (mostly paintings and mosaics from Pompeii) and Monuments (private houses and public buildings from all over the Vesuvian area), conceived on the standard metadata scheme of the ICCD (Italian Central Institute for the Unified Catalogue – website: http://www.iccd.beniculturali.it/). It moreover contains graphic and photographic documents, digitised texts pertaining to the excavation diaries and reports and inventorial charts on the books stored in the SAP library.
- Other digital resources will be integrated in the SAP Information System, on the basis of a census that will be concluded next year for their selection: they will pertain to different kinds of resources (databases, digital libraries, hypertexts, 2D and 3D digital images, audio-video, etc.) and will contain various contents, targeted for different kinds of users (experts and researchers, amateurs and tourists with a high level of preparation, general users and simple tourists, young people and students). This class of contents comprehends for instance, amongst others, data pertaining to the previously exposed "Fortuna visiva" Project.

The System will manage information of different types, formats and structures. Moreover, the Pompeii Information System will be needed to manage complex events together with the concerning documentation, as projects for restoration or excavation, exhibitions, etc., through a workflow platform.

At the moment, the scientific and technical project of the Information System has been delivered and the second phase of the project, which foresees the creation of the System, has just started. In the meanwhile, the cataloguing digitised contents owned by the SAP and stored in different formats with various software has been transposed into XML.

The architecture of the System has been designed in order to respect the pre-requisites of scalability, joining different modules specialised for the managing of specific areas.

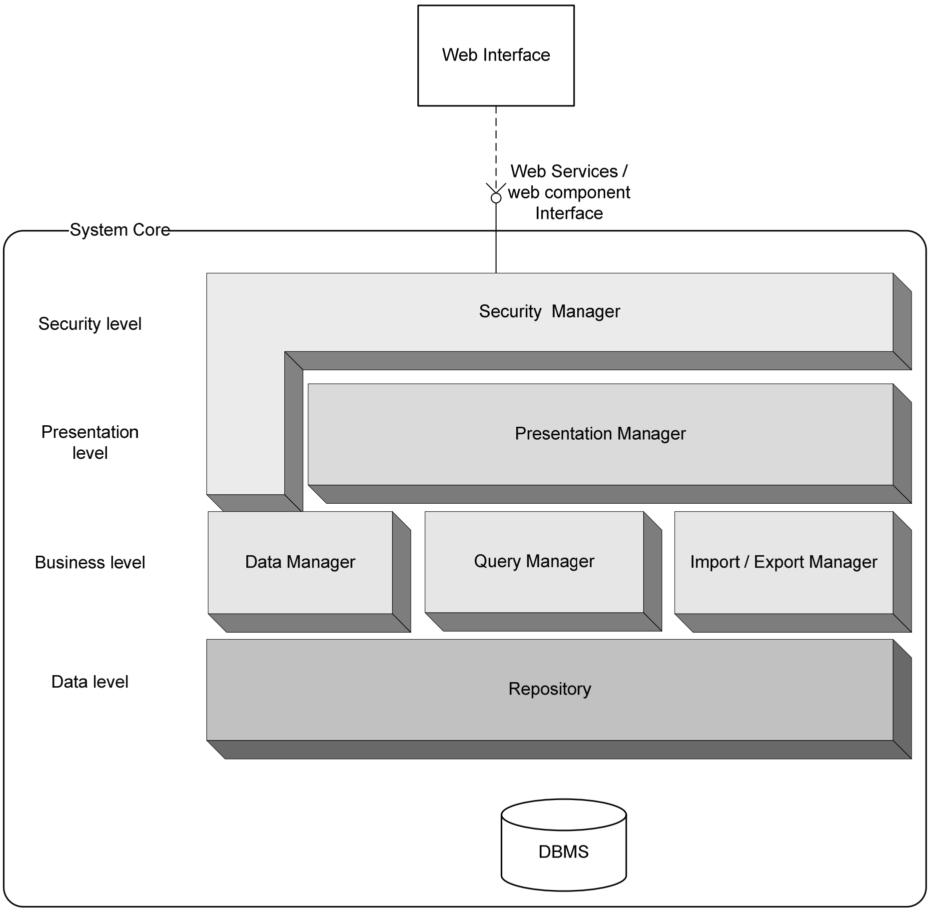

Fig. 2: *Architecture of the Pompeii Information System. Overall view.*

The System joins a specific module for the data managing; a module for the management of the query functionalities; a module for the security management; another module for the import and export of data; a module for the repository management and another one for the presentation and communication of information.

The System will expose an interface based on Web Services and Web Components, that will permit the access to the System from external systems, as websites and various technological media (GSM, GPRS, Palmtops) for the communication of the contents stored in the System.

The Repository Module plays a central role in the whole System: in fact, every other module interacts with it for viewing, modifying or entering data. In addition, the Security Manager is used by all the other modules for controlling the authorisations pertaining to specific operations.

In order to obtain a highly scalable System, the functional dependences amongst the different modules have been reduced as much as possible: the Business Level Modules are linked only with the interface of the Data Level Modules; the Presentation Manager is connected to the interface for the implementation of the Business level; the Security Manager is related to the interface of the Presentation Level Module.

The Web Interface Component is external to the Core of the System, as visualised in the diagram. This module joins the user interfaces directed both to the broad public (website) and to the internal staff of the SAP (limited access interface for authorised users, with different rights).

The detail of each Module is illustrated in the following diagram.

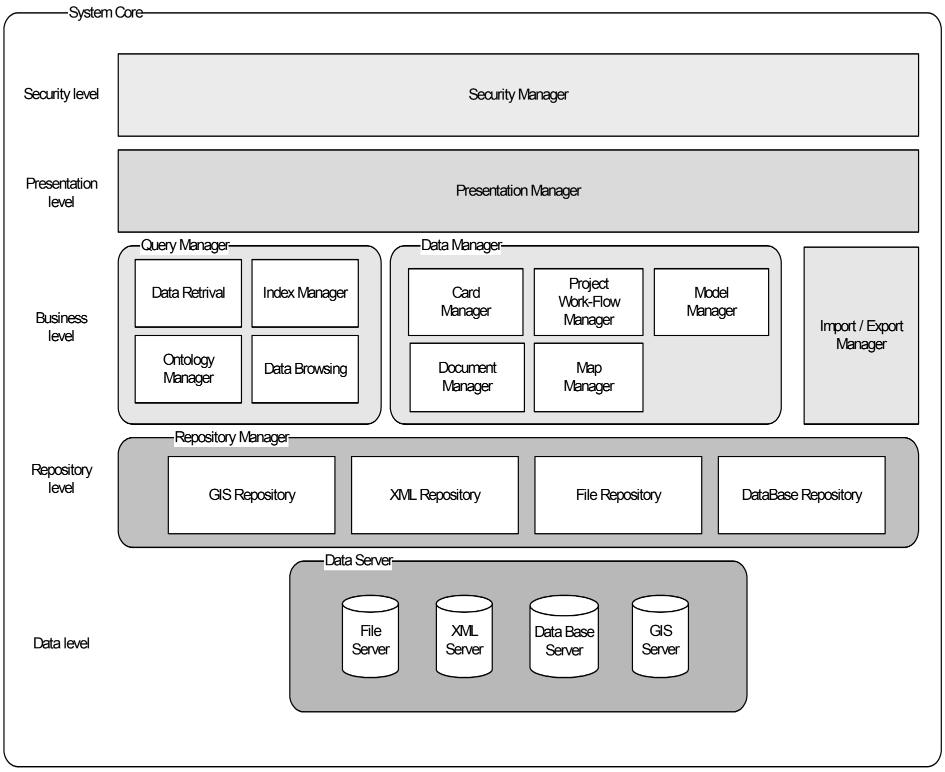

Fig. 3: *Architecture of the Pompeii Information System: detail of the integrated Modules.*

The fulfilment of the Pompeii Information System will be carried out simultaneously with the development of some tasks concerning the contents management and treatment, as the mapping of different metadata schema into one or more standardised schemas, the uniforming of existing vocabularies and thesauri, the creation of specific ontologies, etc.

The second phase of the Project will concentrate its research on the design of the web interface and on the experimentation of various technological applications and communication devices, such as palmtops, GSM, GPRS, etc. The "communication plan", which has been gradually evolving from the beginning of the Project, will also be the core of the research in order to conceive and test prototypes for new strategies for the exploitation of cultural heritage resources through interactive users' experience.

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
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CHIMS: The Cultural Heritage Inventory Management System for the Maltese Islands

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Abstract

The Cultural Heritage Act of 2002 identified the Superintendence of Cultural Heritage as the statutory body responsible for the development and management of a national inventory of cultural heritage in Malta. To this end, the Superintendence launched the CHIMS (Cultural Heritage Inventory Management System) Project. The main objective of CHIMS is to create a new knowledge-based context for understanding, managing and disseminating data concerning cultural heritage. CHIMS aims at enabling access to cultural heritage as a requirement for protection as well as a fundamental human right. Increasingly, it is becoming clear that speed and accuracy in data capture and retrieval are critical to heritage management and protection. Public access to data-storage is similarly becoming an increasingly important issue. It is acknowledged that these objectives should be addressed and are to be achieved through the use of advanced IT technologies. For the first time in Malta, an internet-based core for heritage data management is being created, providing an effective platform for improved public heritage management as well as improved contact between government and society at large. Following a thorough systems analysis, needs assessment and design exercise – which took a holistic and integrated approach to cultural heritage data management, addressing such diverse resources as museum collections, archives, archaeological and geological deposits, architectural resources, rural and urban landscapes and marine resources – a specific, custom-built internet and GIS based system was designed to cater for all the requirements identified by the Superintendence of Cultural Heritage as necessary for the management of Malta's vast and varied cultural heritage data. CHIMS is not merely an electronic inventory of cultural assets, but is principally a heritage data management tool, also including the automation of some of the Superintendence's functions. The System is currently being developed and will be launched by the end of 2006. It is envisaged that the experience gained through the development of the CHIMS Project can also be beneficial to an international audience in that it can serve as a focal point for training and for promoting standards and best practice.

Novel Internet-based Cultural Heritage Applications: H.2 Database Management

1.0 Background

The cultural heritage sector in the Maltese Islands underwent a radical reform through the enactment of the Cultural Heritage Act in 2002. This Act set up a number of entities working in cultural heritage and also established their respective functions. The Superintendence of Cultural Heritage was established as the regulatory body in the heritage sector, having as its main mission the fulfilment of the duties of the State in ensuring the protection and accessibility of Malta's cultural heritage. The Cultural Heritage Act also identified the Superintendence as the statutory body responsible for the development and management of a national inventory of cultural property.

The Cultural Heritage Act has also provided a very broad definition of "cultural heritage", incorporating movable, immovable, as well as intangible cultural assets. As such, the national inventory required by law is aimed at storing and managing data pertaining to all sectors of cultural heritage, including archaeological, palaeontological, geological sites and deposits, landscapes, historical buildings and monuments, scientific collections, collections of art objects, manuscripts, books, published material, archives, audio-visual material and reproductions, as well as intangible cultural assets which have a historical, artistic and ethnographic value. As defined by the Cultural Heritage Act, the national inventory will include data pertaining to cultural property belonging to the State, to the Catholic Church and to other religious denominations, and data relating to privately owned cultural assets which are made accessible to the public.

2.0 The Maltese Context

For the first time in Malta, a national inventory of cultural property has become a legal requirement. Prior to the enactment of the Cultural Heritage Act 2002, only a few selected sectors of cultural heritage were inventoried according to legal obligations. For example, an inventory of the national fine arts collection has been regulated through Government Circulars issued in 1977 and 1999 respectively. The Development Planning Act of 1992 established a Planning Authority which is legally bound to prepare and periodically review a list of areas, buildings, structures and remains of geological, palaeonotological, cultural, archaeological, architectural, historical, antiquarian, or artistic or landscape importance, which the Authority would schedule for conservation purposes. The Authority is also legally responsible to keep an electronic index of notices of conservation orders given in order to regulate scheduled properties.

Inventories of a number of cultural heritage collections have been kept in some cases, very often depending on personal initiatives in maintaining a list of items within a collection. As such, existing inventories are often sporadic, inconsistent, incomplete, limited, and of different formats. Only very few inventories exist in simple electronic version. Most other sectors of cultural heritage have often been neglected with regard to inventories, and therefore, inventories of several important collections, as well as of most major categories of cultural heritage property, are unfortunately non-existent.

This situation has been appropriately addressed by the Cultural Heritage Act. The comprehensive inventory required by the same Act does not only include all categories of cultural heritage as broadly defined by the Act itself, but is also aimed at covering the cultural heritage property of the whole Maltese archipelago on a national level, including Malta's territorial waters. This has led into a very specific and unique scenario, in which data pertaining to a rich, vast and varied amount of cultural property belonging to an entire country is being managed in a single inventory. Although the amount and variety of data is remarkably extensive, the limited size of the Maltese Islands allows for the implementation of such a challenging initiative as the creation of an all-inclusive national inventory.

3.0 The Project

3.1 Aims and Objectives

Upon its establishment, the Superintendence of Cultural Heritage launched the CHIMS (Cultural Heritage Inventory Management System) Project. The Superintendence views CHIMS as an opportunity to create for the first time in Malta a national core for heritage data management.

The main objective of CHIMS is to create a new knowledge-based context for understanding, managing and disseminating data concerning Malta's cultural heritage through the creation and maintenance of an electronic database. CHIMS aims at enabling access to cultural heritage as a requirement for protection as well as a fundamental human right. CHIMS will therefore aim to have a social vision that can bridge the gap between academic and technical necessities and public concerns. This development will also provide an effective platform for improved public heritage management as well as improved contact between government and society at large.

Cultural heritage is steadily gaining importance as one of Malta's most important assets. Because of its bearing on cultural identity, cultural heritage is fast becoming an element that gives strength to Maltese cultural identity in the context of globalisation. In addition, cultural heritage is of intrinsic value to tourism in Malta, and is therefore defining the country's position in international economic markets.

Experience, locally and internationally, is showing that it is no longer sufficient to simply create lists of cultural heritage assets. It is simply not enough to develop ever more lengthy and fragmented lists, schedules or catalogues of heritage resources without concurrently addressing public needs and expectations.

Increasingly it is becoming clear that speed and accuracy in data capture and retrieval are critical to heritage management and protection. Public accessibility to data storage is similarly becoming an increasingly important requirement, both for the local public and for extra-national audiences. It is also generally acknowledged that these objectives should be achieved in a unified format, through the use of advanced IT technologies.

CHIMS is aiming at developing these values with a view to making heritage data management a pro-active tool for the use of contemporary society in Malta. This is one tangible way in which cultural heritage management can extend its contribution to the improvement of the quality of life enjoyed by today's society.

On a technical level, CHIMS aims at recording details of immovable and movable heritage as defined by the Cultural Heritage Act, as well as recording details of historical events, sources of information, and heritage consultation and management histories. CHIMS will provide real-time capture, validation, processing and recording of cultural property data. All the data will be stored in a relational database, which is also GIS and internet-based. The indexing of the records will be done according to international standards. The System will provide flexible, end-user oriented querying and reporting facilities. Up-to-date cultural heritage information will be available for online query and reporting based on defined user security levels. Cultural heritage information will be maintained as close to the source as possible, and data integrity will be enhanced by the elimination of data entry redundancy and extensive data reconciliation. Accuracy of data input is acknowledged as of paramount importance and CHIMS will therefore incorporate a mechanism of data validation and edits throughout the software to ensure such accuracy.

The Superintendence envisions a dynamic system that will grow, change, and remain current with available technology, changing philosophy of data management, changing regulations, and reporting requirements. All information will be accessible to all authorised users and the information shall be as current as possible. CHIMS should also enable the Superintendence to be more customer focused and to provide employees with the required tools to make informed, competent decisions and appropriate responses to customer requirements. CHIMS will not simply be an electronic inventory, but a number of functions of the Superintendence are also being automated through the use of the System. The System shall also provide increased flexibility for all users to have their needs met, especially since CHIMS will be internet-based.

3.2 Implementation

The Superintendence of Cultural Heritage has conducted a Systems Analysis and Needs Assessment of the current situation in Malta with respect to heritage data management. This analysis took a holistic and integrated approach to cultural heritage data management, addressing such diverse resources as museum collections, archives, archaeological and geological deposits, architectural resources, rural and urban landscapes and marine resources. During this process, the Superintendence identified a large number of stakeholders, who will have a direct role in the establishment and updating of CHIMS. Stakeholders include both regulators and operators within the heritage sector. The latter include public entities, ecclesiastical entities, NGO's, bodies within the public sector, as well universities and organisations related to heritage, which are operating in Malta. Partners include e-Government, Government agencies and departments, schools, international and regional partners, as well as international organisations, institutions and universities. The CHIMS Project is intended to dovetail with broader nation-wide e-Government initiatives. Such a link will allow the data management system to be easily accessed by all interested audiences, locally and internationally.

Following the Systems Analysis phase, work continued on the drafting and publication of a Request for Proposal for the development or purchase of the CHIMS software. This process entailed the analysis of the eventual System's content in terms of metadata, images, descriptive metadata, etc. Analysis was also carried out in respect to the means for the management of the System content, such as databases, user interface, GIS, and other technical specifications. The means of long-term data storage and conservation, both in electronic and in archival formats, were also investigated.

Following the publication of a Request for Proposals by the Superintendence, through the Department of Contracts, for the purchase or the development of a software system for the operation of CHIMS in 2003, and subsequent to the adjudication of submissions made to the RFP, Datatrak Solutions International Ltd was identified as the company providing the best solution, and was subsequently awarded a contract for the development, maintenance and support of CHIMS in September 2005.

According to this contract, the Project was divided into three phases, namely an initial phase for conducting an analysis of the CHIMS requirements and to design the System, a second phase for data migration of already existing heritage data in electronic format, and a third phase during which the System will be developed, implemented, and tested.

Phase 1, which included the creation of a new data model and all the relevant tables and data fields, as well as analysis of the Superintendence business processes, was completed in May 2006. Work on Phase 2 commenced in April 2006, with the migration of data pertaining to the fine arts inventory and with the GIS mapping of the items within the same inventory.

The completion of the CHIMS Project is expected by December 2006, including the full development and implementation of the System, as well as the training of the Superintendence staff to administer and use the System.

The national inventory Project will inevitably be an ongoing process. Following the development and installation of CHIMS, the Superintendence will be conducting various exercises of data capture and data input. Since existing inventories are of a highly sporadic nature, and since data capture for most categories of cultural heritage assets still has to be initiated, the next phase of the inventory Project following the implementation of the System, will certainly be an extensive undertaking. However, in order for the System to start functioning, the Superintendence has identified and prioritised sets of core data which require capturing, digitising, and/or inputting into the System. These include the national collections (pertaining to archaeology, fine arts, history, natural history, and ethnography), known archaeological sites and threatened archaeological sites, built heritage, cultural assets which are in transit, and threatened intangible cultural heritage.

4.0 The Technical Solution

CHIMS development is based on web mapping technology providing a powerful information technology tool whereby spatial data can be accessed and analysed from anywhere in the world providing a common access for all users. On implementing CHIMS, up-to-date cultural heritage information will be accessible for online querying and viewing to all. CHIMS is aiming to provide significant benefits to Maltese cultural heritage by providing a tangible way in which cultural heritage management can extend its contribution to the improvement of the quality of life enjoyed by today's society.

CHIMS is developed using the latest Microsoft technology .NET framework. Its back-end map server is ArcIMS – a solution for distributing mapping and GIS data and services over the Web. ArcIMS works seamlessly with ArcGIS, ESRI's comprehensive, integrated GIS solution. ArcGIS Desktop software, which includes ArcView, ArcEditor and ArcInfo, can connect to the map and feature services provided by ArcIMS and uses ArcIMS as a data source to publish data over the internet. This technical e-tool solution will be based on the current technologies and all development will be .NET oriented to generate XML web services and web application pages based on ASP.NET and VB.NET.

CHIMS deployment will make use of a spatial database engine to store spatial objects within the database. This combines spatial and aspatial information with data being stored in a relational database management system. This results is an efficient way to manipulate, store and analyse large amounts of complex data while inherently enforcing data security and data integrity. In fact, all spatial data changes can be saved in the database to keep an audit trail and history of the manipulations of the spatial object's extent. In addition, the use of a spatial database engine implicitly includes an efficient spatial indexing system thus eliminating the need to chop the data into discrete tiles or chunks as usually required in a file based system for large coverages.

4.01 CHIMS Datasets

As part of a hosting agreement between Datatrak Solutions International Ltd and the Superintendence of Cultural Heritage, CHIMS will be making use of Datatrak's national mapping datasets including the raster and vector basemap, street centrelines and the altimetry data. The coordinate system of these datasets is LatLong WGS 84. A detailed description of these datasets is given below:

- Ortho Imagery – Orthophotos are an excellent cartographic base on which to overlay and add-on any number of layers for displaying, generating, and modifying planimetric data or associated data files. The maps are available at a scale of 1:2500 with a ground resolution of 25 cm and a RMSE (root mean square error) of ± 50 cm. Each orthophoto represents 1 km by 1 km of terrain and can be delivered in a number of formats, including TIFF, Grid and MapInfo TAB formats.

- Street Gazetteer – A comprehensive street gazetteer referencing streets throughout Malta and Gozo will be used for CHIMS as street finder. This dataset is an intelligent street network where all the street segments are identified, captured and displayed as an object over the orthophotos or basemap of Malta and Gozo. The gazetteer provides a complete list of all streets by their names and classification and is provided with a unique reference number of the Maltese Islands.

- Vector Datasets – The Vector dataset is a coordinate-based data structure commonly used to represent map features. This divides space into discrete features, usually points, lines or polygons. Each linear feature is represented as a list of ordered x, y coordinates. Datatrak Solutions International Ltd provides two vector-based spatial datasets, describing building outlines and field delimitations for the Maltese Islands.

4.02 genGIS.NET Toolbox

The CHIMS solution development is being jump-started through the deployment of the genGIS.NET toolkit which is developed and licensed by Datatrak Solutions International Ltd and which is today a core component of most of the web GIS solutions that Datatrak deploys both locally and overseas.

In summary, genGIS.NET embraces .NET, ASP, VB.NET, IIS, arcSDE, SQL Server and arcIMS technologies to provide a configurable web GIS toolkit affording advanced web GIS functionalities out-of-the-box. The deployment of the genGIS.NET toolkit will be particularly effective to achieve shorter solution development periods, and to break down system requirements into manageable building blocks, thus rendering the development less complex and easier to support and maintain.

4.03 CHIMS Functionality

Apart from using genGIS.NET toolbox and developing the Superintendence of Cultural Heritage's normal business processes, CHIMS deployment will include the following functionality:

- Provide an easy to use interface to allow users to query simple or complex spatial data making use of the standard query language;

- Provide a generic Report Generator where adhoc reports can be generated, edited and printed;

- Provide a Layer component where a spatial object's style such as colour, style and fill can be directly edited online. CHIMS Datasets will be stacked on top of each other, and all aspects of the map can be seen at the same time as it makes use of different superimposed layers;

- Provide a highly specialised image and document management tool having version control mechanism together with uploading facility of documents and images;

- Provide a Data Importer tool to facilitate data import and export from standard formats;

- Provide a mechanism to digitise, select and edit spatial and aspatial data (that will include tangible and intangible cultural heritage data) directly on the image.

The mechanism to manipulate spatial objects in a web environment is normally classified as advanced functionality in web GIS terms. Spatial object editing and creation in a web environment requires more than just the generation of a raster map image and dictates an exact coordinate geometry data capture mechanism where reference to existing spatial object geometry is usually essential

Such requirements will be handled by the IFS (Internet Feature Server) Module within the genGIS.NET toolkit. The IFS, which runs as a server-side NT service, supports and allows the extraction of feature object geometry from the spatial database to be downloaded to the client. This client side intelligence is required to edit spatial features and enables functionalities such as coordinate snapping to existing nodes. The IFS module also handles feature object editing and creation and is also responsible for handling attribute, spatial and also combined queries.

All edits to a spatial database table or layer can be executed interactively by the user in an online manner. However, for security purposes, versioned table mode is used for editing capability which essentially confines all the edits to a different version of the published table with the facility to update the main table with the edits as an off-line back-end administrative process.

4.04 Technology Benefits

- Unparalleled data security which allows specific access rights to be easily assigned to individual users and user groups for each data layer. In contrast, a file-based system would be prone to uncontrolled access and would thus require keeping both local and published copies of the ArcInfo coverages or shapefiles while also entailing a publishing approval process;

- Greatly enhanced data integrity where the spatial and attribute data are always in-sync with each other since they are stored in a single database and are updated through a single database transaction. In addition, multi-user edits on the data are also possible through the enforcement of the check-out/check-in data access mechanisms available in SDE;

- Audit trails on spatial data – All spatial data changes can be saved in the database to keep an audit trail and history of the manipulations of the spatial object's geometry and extents;

- Enhanced management of large GIS datasets – The use of a spatial database engine implicitly includes an efficient spatial indexing system thus eliminating complex processes usually required in a file based system for large coverages.

5.0 Conclusion

It is hoped that any lessons learnt in Malta – both on a conceptual and on a practical/managerial level – will be of interest and utility to a broad international audience. It is envisaged that the experience gained through the development of the CHIMS Project can be beneficial to neighbouring countries in that it can serve as a focal point for training and promoting standards and best practice. The aims of the CHIMS Project are on a scale that can attract interest among neighbouring micro-regions. In these areas one finds countless small-scale territories (national, regional or communal) that share identical concerns in cultural heritage management. The application of a system incorporating a vast and varied cultural heritage as that of the Maltese Islands on a national level can be readily adopted and adapted for the inventorisation and management of cultural heritage within regional spheres.

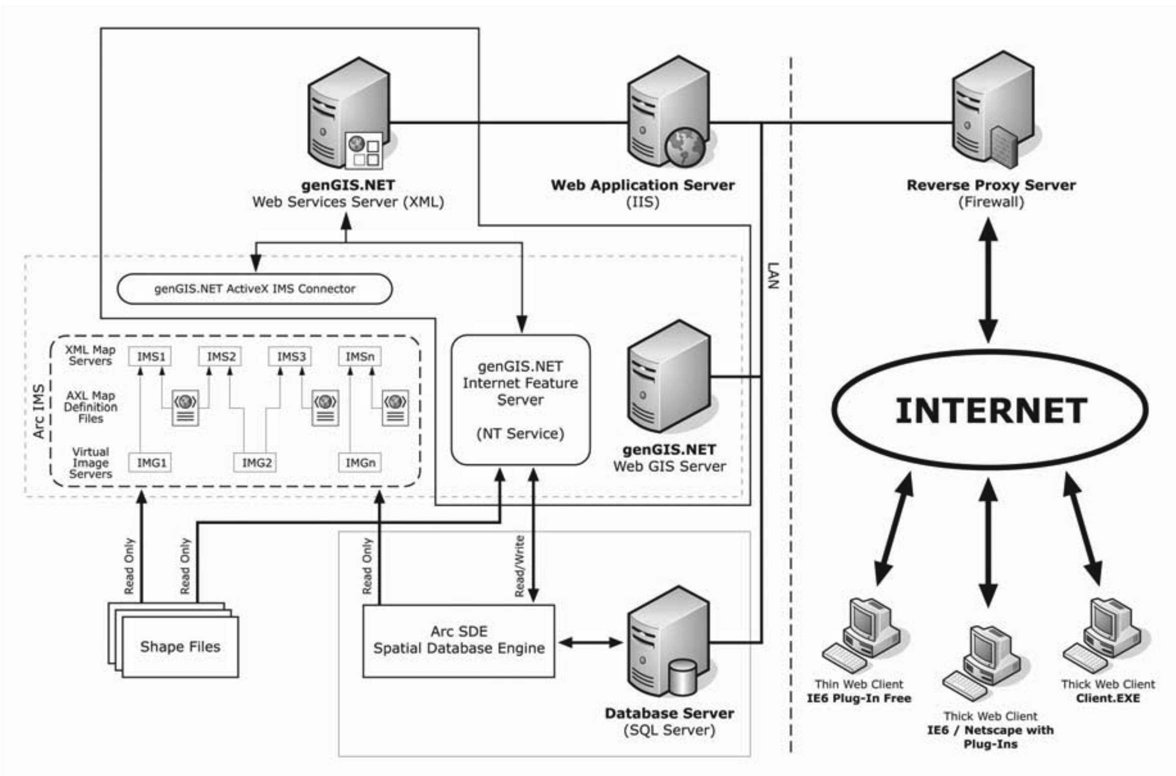

Figure 1: *Web GIS Architecture Model*

References

[Aqu03] AQUILINA C.: *Report: The Cultural Heritage Management Systems – A project by the Superintendence of Cultural Heritage*. Unpublished, 2003

[Fen03] FENECH CONTI J.: *Response to Tender CT310/2003 issued by the Superintendence of Cultural Heritage for the Cultural Heritage Inventory Management System: Proposal*. Datatrak IT Services Ltd, 2003

[Gov92] GOVERNMENT OF MALTA: *Development Planning Act* (1992)

[Gov02] GOVERNMENT OF MALTA: *Cultural Heritage Act* (2002)

[Sup02] SUPERINTENDENCE OF CULTURAL HERITAGE: *The Malta Cultural Heritage Inventory and Management System (CHIMS)*. Unpublished, 2002

[Sup03] SUPERINTENDENCE OF CULTURAL HERITAGE: *Cultural Heritage Inventory Management System: Request For Proposal*. Government of Malta, 2003

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
VAST (2006)
M. Ioannides, D. Arnold, F. Niccolucci, K. Mania (Editors)

From the Quarry to the Palette of Natural Earths: Teaching Pigment Analysis with E-learning

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Abstract

This project was conceived within COLORE, a Swiss Virtual Campus project, and aimed to develop set of online instructional objects regarding the basic scientific methodologies normally used in the field of pigment analysis. The first step was the analysis of the instructional context and a research of possible quarries that could serve the purpose. This was followed by the visit at ancient quarries and mines in order to collect samples of natural earths; the district of Verona (Italy) was particularly suitable because of the presence of several types of pigments as yellow and red ochre, green, white and black earths. The visits were digitally reconstructed in order to allow student to see on line how a cave looks like and learn to perceive some geological details. These pigments were then analyzed at the laboratory using basic techniques as well as microchemical tests, microscopic examination of stratigraphies in which these pigment were applied, spectroscopic analysis. The results of further physical and chemical techniques were showed in order to provide a whole description of the diagnostic works. The analysis was videotaped and also made available to students. Finally, the online materials were complemented by a real example of the use of these pigments was showed; the wall painting of Crucifixion scene (A. De Passeri, 1514) at St. Alessandro Church near Como (Italy) was a nice example because of the author used only natural earths, with the exception of sky and roofs (azurite). The paper will present the outline of the project, the design of e-learning materials and how the results can be integrated with traditional teaching. It will also provide insight and lessons learned about how technologies can enhance and support teaching pigment analysis.

1. Introduction

COLORE [COL06] is an e-learning project led by the University of Applied Sciences of Southern Switzerland (Scuola Universitaria Professionale della Svizzera Italiana - SUPSI) in collaboration with the Fachhochschule für Gestalt und Kunst Luzern and the Fachhochschule Bern. It is funded by the Swiss Virtual Campus initiative for e-learning [SVC06] for a two-years period, ending in December 2006, and aims to the development of a set of online resources for teaching the various aspects of colour - colour physics, perception, psychology, production, etc. - to art and design students. In this context, a focus on pigments and analytical techniques for conservation and restoration could not be missing, and its development was the goal of this project, which was labelled module 16 (or COLORE M16).

The production of e-learning materials is not a novelty, both from the point of view of design and that techniques. Nevertheless, the development of a course about the analytical techniques for the recognition of pigments in movable and immovable works of arts for conservators, is a challenging task for at least three reasons: (a) the breadth of the field; (b) the required level of expertise; (c) the scarcity of good pratices in the field.

1. The main problem concerns the subject matter itself, namely, the wide spectrum of existing techniques, the approach chosen (not-invasive, micro-invasive, both), the nature of the works of art, and the large amount of pigments.
2. The level of skill on analytical techniques required for a conservator is another important issue.
   A conservator should master a glossary that allows her/him to interact with scientists, architects, art historians, etc., in order to be able to discuss both with people belonging to the humanities and with people moving among electron beams.

3. Although several teaching resources - or learning object - about basic Chemistry or Physics can be found in the literature or in online repository [Mer06], only very few of them are targeted to professional workers in conservation. In particular, online materials usually focus on learning facts (e.g., elements or formulas) or concepts, and not on supporting hands - on activities - which is the main goal for higher educational professional training.

2. Concept

COLORE M16 is indeed an experimental effort in this field. In order to provide it with a clear focus, we decided to take natural earths as core element, and to develop a learning path, composed by a set of learning activities, around it. E-learning technologies were used to help students to understand the main steps leading from the ancient quarries of natural earths, the excavation techniques through the words of a miner, the manufacturing procedures through the experience of a colour laboratory, the basic techniques used for the characterization and, finally, their use on wall paintings. In one word, to let them see and experience what lies behind the yellow powder box of natural earth they can find in pigments' shops.

More formally, we could express this as a set of learning goals [DCC01]:

1. Be aware of the kinds of location in which natural earths are found.
2. Be aware of the extraction processes required to get natural earth.
3. Identify the main steps in the production of usable pigments form natural earth.
4. Recall the main analytic techniques for the recognition of pigments.
5. Apply the procedures for the main analytic techniques.

The use scenario of COLORE - and consequently of M16 - is blended learning: courses in which class sessions are enhanced by technologies, and integrated with group or self learning activities online.

The idea was then developed as the report of a field experience consisting of (a) identification of locations; (b) visit, extraction of samples of natural earth, shooting and collection of material for multimedia materials development; (c) shooting of lab analysis of samples; and (d) example of a real application. In this part we will follow these steps.

3. Quarries

The pigments (*natural earths* or so called *colouring earths*) were collected from quarries located in the district of Verona (Italy; see Figure 1). This quarries were used from Roman age to the middle of 20th century and gave a good quality of pigments.

Figure 1: *Map of the district of Verona, with indication of the quarries.*

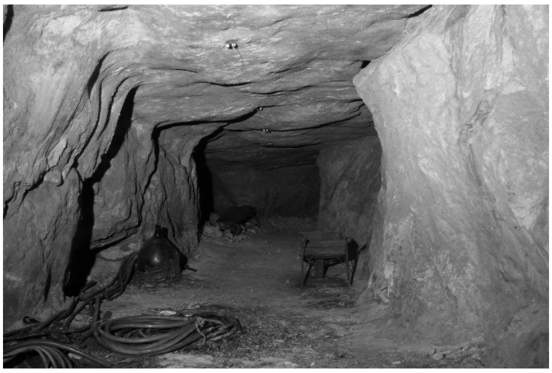

Figure 2: *Via Tirapelle mine (Valdonega, Verona): entrance. Incoherent deposit of yellow ochre.*

The natural earths available are green, yellow, red and black [Zor05].

In this project the choose was oriented to quarries of yellow ochre collected at the Mine in via Tirapelle, loc. Valdonega (Verona see Figure 2 and Figure 3) and near the natural bridge of Veja (Verona, see Figure 4), brown ochre collected at the Mine in via Tirapelle, loc. Valdonega (Verona Figure 3) and red earth collected at Loc. Viali, S. Giovanni Ilarione (Verona), Ca' del Diavolo (see Figure 5) and at Valdonega (Verona).

The mine in Via Tirapelle is a paleokarst cave opening in Eocene Sup. marly limestones filled with limes and insoluble clays coming from carbonatic rocks dissolution.

The caves near the natural bridge of Veja, containing a

Figure 3: *Via Tirapelle mine (Valdonega, Verona): Deposits of colouring earths.*

Figure 4: *Yellow ochre in a cave near the natural bridge of Veja (Verona).*

Figure 5: *San Giovanni Ilarione, (location Viali, Val d'Illasi, Verona). Outcrop of read ochre.*

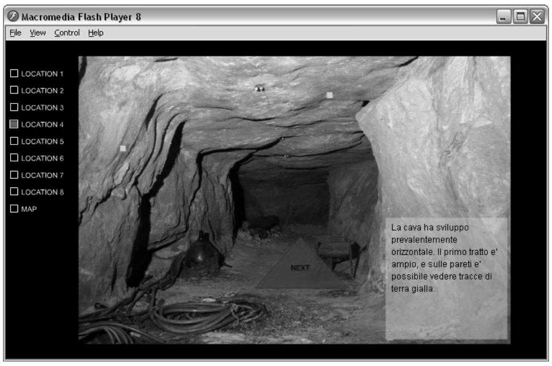

Figure 6: *Screenshot of the virtual tour of the quarry of Via Tirapelle.*

Figure 7: *Screenshot of the virtual tour of the quarry of Via Tirapelle (a detail-zoom).*

very coherent yellow ochre, were exploited from 1944 up to 1957. The main gallery is 300 m in length; the material was carried on the back to the vault of the bridge where a cableway provided to transport it throughout the valley.

An important deposit of red earth is located near the village of San Giovanni Ilarione (loc. Viali, also calle Ca' del Diavolo). The deposit has a thickness ranging from a few decimetres up to two metres.

After the identification, we organized a visit to the location, aimed at (a) collecting samples of natural earths; (b) shooting the location in order to produce materials for a multimedia reconstruction of the quarries; and (c) interviewing people who worked or studies the quarries. The result of the production phase is an animation for each quarry that allows the students to take a virtual tour and focus on specific details (Figures 6 and 7), responding to learning goals 1 and 2.

4. Pigments

The yellow ochre (called *terra bolare* or *yellow ochre of Verona*) exploited in the quarries of Via Tirapelle has the following mineralogical composition [Fed48]: Limonite $2Fe_2O_3 \cdot 3H_2O$ (principal constituent) and quartz.

The red ochre collected at San Giovanni Ilarione is very rich in ematite Fe_2O_3 [Zor05].

After exploitation the earths were dried naturally and then grinded up to obtain the right size. This is a very important parameter because the optical properties depend on the size of the particles; a size ranging from 30 to 40 micron allows to have a *transparent effect* while greater sizes give an overlapping effect [Dol06]. A text with pictures explains these procedures to the students in the online materials, addressing goal 3.

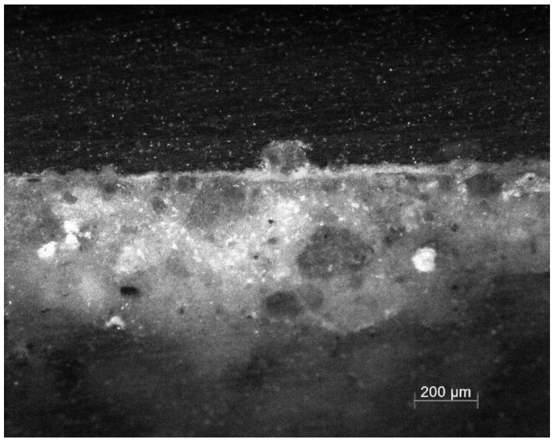

Figure 8: *Cross-section (optical microscopy in reflected light) showing a yellow layer obtained applying yellow ochre on the support.*

5. Analytical techniques

Basic techniques were employed to characterize the pigment collected: microchemical tests and optical microscopy in reflected light of cross-sections in which yellow and red ochre were employed [Ple56], Fourier Transformed Infrared Spectroscopy [Gra01].

The microchemical analysis were arranged in a set of didactically structured experiences: first focusing on the procedures with simple cases, then comparing pigments of different colours (yellow, red, green) but with the same main elements, and then comparing similarly green pigments of different nature. The lab activity was videotaped in a 3-hour's session, with audio comments, and then edited into a set of short clips, then made available to students. These materials addressed goals 4 and 5.

The online materials were integrated with information about the other analytical procedures (optical microscopy as in Figure 8 and FTIR analysis as in Figure 9).

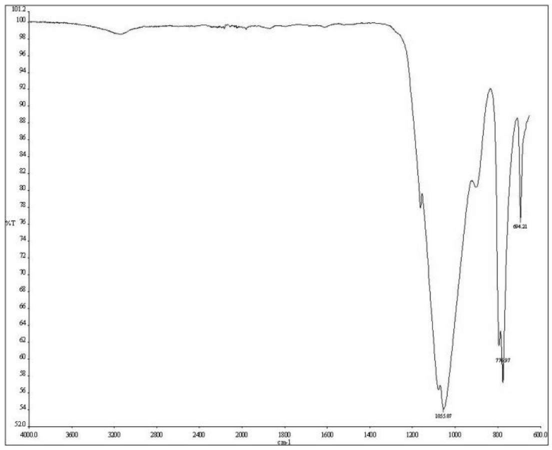

Figure 9: *FTIR of yellow ochre collected at the cave near the natural bridge of Veja.*

6. A real example from Lasnigo

Finally, we wanted the students to have a glimpse of the application possibilities of these analytical techniques in their profession. We took the analysis of the scene of the Crucifixion at St. Alessandro Church in Lasnigo (Como, Italy, see Figure 10). The red, yellow and green pigments employed are natural earths. A few microchemical tests were sufficient understanding the nature of the pigment used because iron was easily detected; yellow is yellow ochre, red is red earth and green is green earth [HGHB03].

7. Conclusion: lessons learnt and open issues

The final application includes a presentation of the topic, the virtual visit to the quarries, the commented videos of lab analisys, and the case study of Lasinigo. It was developed using standard web technologies (HTML and Flash 8.0), with special care for quality of pictures and videos. It is currently hosted on a web server and is freely available under the address www.coloreonline.ch (italian section).

This application will be used and thorougly tested with real student in Winter Semester 2006/2007. It will be used to support a self-learning activity aimed at making the lab session about natural earths more effective.

The development process of this highly innovative project produced several insights about the exploitation of e-learning technologies for the enhancement of teaching in this specific domain.

First, technologies provided a chance to let students become aware, through seeing and interacting, of elements related to the quarries that would be otherwise invisible to

Figure 10: *The wall painting of Crucifixion scene at St. Alessandro Church in Lasnigo (Como, Italy) painted by Andrea De Passeri (1513).*

them. Secondly, the lab videos allow students to become more and more familiar with the techniques they present. Finally, the online materials offer a chance to make teaching more flexible, integrating technology-enhanced sessions and self-learning activities.

Also, the project required a sort of adaptation of technologies to the specific subject matter, e.g., in organizing the footage and the interviews. This was achieved mainly through the tight collaboration of the development team, which fostered the development of a shared view of the project final goals.

Acknowledgments

We are grateful to Mrs. Polly Bertram, COLORE project leader and to A. Bonfanti for the fruitful collaboration. Particular thanks go to dr. R. Zorzin, senior conservator at the Museum of Natural History of Verona (Italy) and to Mr. M. Dolci, manager of the homonymous paint factory at Verona (Italy) for their great willingness. Finally, particular thanks go to Ing. D. Forni for his help in doing Latex version of the paper.

References

[COL06] *COLORE Web site*. Retrieved online on June 23rd, 2006 from www.coloreonline.ch, 2006.

[DCC01] DICK W., CAREY L., CAREY J. O.: *The Systematic Design of Instruction (6th edition)*. Harper Collins College Publishers, 2001.

[Dol06] DOLCI M.: *Private communication*. 2006.

[Fed48] FEDERICI G.: *Materiali utili del suolo e del sottosuolo della provincia di Verona*. La tipografica veronese, 1948.

[Gra01] GRACIA I.: *Applicazioni della spettrofotometria IR allo studio dei beni culturali*. Ed. Il Prato, 2001.

[HGHB03] HRADIL D., GRYGAR T., HRADILOVA J., BEZDICKA P.: Clay and iron oxide pigments in the history of painting. *Applied Clay Science 22* (2003).

[Mer06] *MERLOT online repository*. Retrieved online on September 14rd, 2006 from www.merlot.org, 2006.

[Ple56] PLESTER J.: Cross-sections and chemical analysis of paint samples. *Studies in Conservation 2*, 3 (1956).

[SVC06] *Swiss Virtual Campus Web site*. Retrieved online on June 23rd, 2006 from www.virtualcampus.ch, 2006.

[Zor05] ZORZIN R.: *Le terre coloranti dei monti lessini*. Pitture paleolitiche nelle prealpi venete, 2005.

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
VAST (2006)
M. Ioannides, D. Arnold, F. Niccolucci, K. Mania (Editors)

GENERATION OF LARGE SCALE NUMERIC CARTOGRAPHY: THE CASE OF ILIDZA-SARAJEVO

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Abstract
The present work describes the first results of a Pilot Project financed from Italian Foreign Policies Ministry and Department of Sciences and Techniques for Settlement Processes aiming at the built up of an archaeological-thermal park in the zone of Ilidza-Sarajevo. Thanks to the cooperation of Parma General Company for Aerial Surveys (forward CGR), it has been possible both gathering and analyzing data from digital aero-photogrammetric cameras, finally gaining:

- *image rectifies with GPS/IMU data;*
- *aerial triangulation;*
- *automatic generation of Digital Elevation Models;*
- *generation of medium-large scale orthophotos;*
- *generation of large scale numeric maps.*

On the 30th of April 2005 CGR realized a photogrammetric flight in the Balcan zone regarding Ilidza (archaeological site) and Sarajevo. The goal of this work is to test the digital camera Leica ADS40 in the aim of creating a large scale orthophoto and a numeric cartography (1:1000). Another target is investigating the problems and the data processing tools to obtain these products. In particular, the present work examines data only concerning the archaeological site of Ilidza (Ground Sampling Distance 30 cm) and all the experiments in the test zone was realized with GPro (raw data and orthophoto production), ORIMA (triangulation) and Leica Photogrammetric Suite (automatic DEM, editing DEM and orthophoto production).

1. Introduction

The centre of "*Aquae S...*" in Ilidza (figure 1) by origin was a thermal colony: the archaeological research concluded that life near sulphureous water sources was developed since the end of the I century and the meaningful expansion took place during the II, III and IV centuries d.C..
The Roman evidences of Ilidza indicate the existence of the most important thermal centre in the area of the Balkans. The first diggings in Ilidza have been undertaken in 1892 from the Austro-Ungaric administration, in occasion of the building up of hotels and thermal structures.
In 1989-1990 the archaeological research restart, but the civil war of 1992-1994 stop the works again. In 2004 the searches start again, thanks to a financing campaign of Ministry of Foreign Affairs in collaboration with the Polytechnic of Turin 2ª Faculty of Architecture and the Municipality of Ilidza.
The aim of the Pilot Project is realizing an archaeological-thermal park to be included in the tourist circuits of Ilidza-Sarajevo and Bosnia Herzegovina.
The research organizes in to three phases:
1. topographical survey, cartographic modernization and creation with satellite high resolution images and digital photogrammetric data;
2. georadar surveys, conservation and diagnostic plan;
3. project of the archaeological-thermal park

Within the Pilot Project the present work describes at first the architectural project (at the moment the project team is engaged with the design of a principle plan of an archaeological park); therefore it will be showed some results of the georadar surveys.

Figure 1: *Ilidza-Sarajevo (BiH)*

At last, the main achievement of this work is the realization of numerical and orthophoto large scale maps with a digital photogrammetric camera, by elaborating, in particular, step by step Leica ADS 40 data in order to generate cartography.

2. Phase III

First of all, the plan previews the location of two parking areas for motor vehicles and buses hidden by trees: one is located near the municipal palace and the other one in the place of an existing asphalted large square, close to the entrance of the street to Vrelo Bosne. From these two areas it will be possible to enter the archaeological area following an equipped trail. Such trail is made of a wood pillar structure supporting a wood floor, so that it is possible to walk lifted from earth (figure 2).

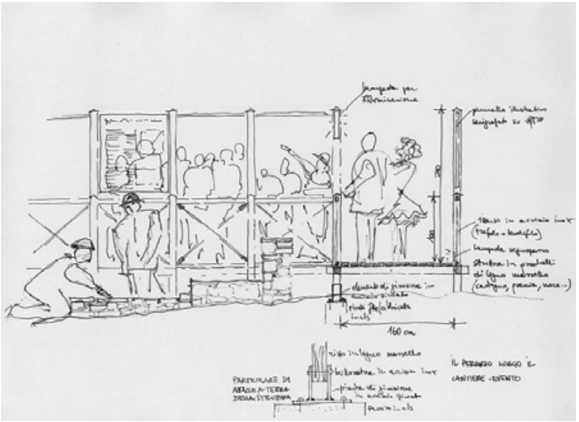

Figure 2: *The equipped trail*

In the main stages of the trail, which is normally characterized by a section of equal width approximately measuring 200 cm, shall be enlarged to form small squares where the visitors will be able to admire both diggings and restoration yards from a closer point of view(figure 3: *The project master-plan*).

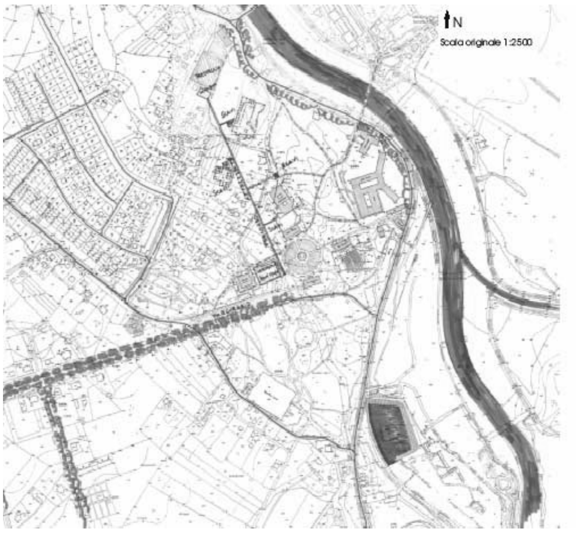

Figure 3: *The project master-plan*

At the ends of the gangway the project provides for two multifunctional pavilions: one of them shall guest coffee-restaurant dehors and a small museum-laboratory, beside of a bookshop, a ticket office and some offices deputed to both guides and park management society; the other, smaller pavilion, just nearby the town hall parking shall include a ticket office and hygienic services.
From a communicative point of view, illustrated panels located in any key places show the history of the Roman site, works, and various other information are provided to visitors along the trail.
The project is expected to be finished by the end of 2006, so some details described in the present work could still change.

3. Phase II

During the second stage of the project the restore team has been cooperating directly with the Bosnian archaeologists in the aim of finding other remains in the immediate surroundings of the existing digging areas (figure 4).

Figure 4: *Area scanned with georadar*

The research group has been investigating the test grounds with a georadar set at the diverse soil levels in order to localize with high accuracy and precision any underground structures still covered (figure 5).
The alignment of the different stripes was did with a GPS instrument.

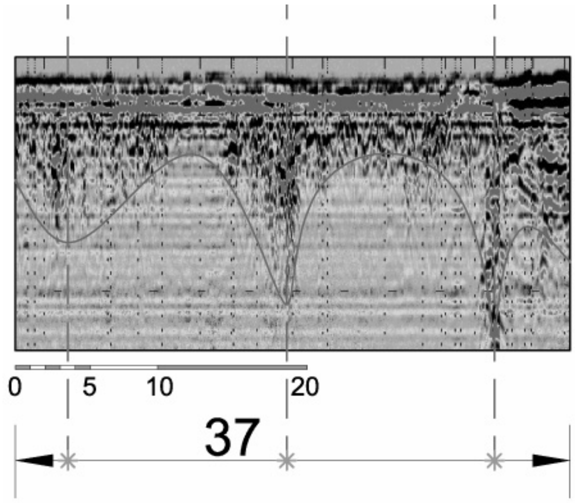

Figure 5: *Georadar stripe (the anomaly of underground has been evidenced with the red colour)*

3. Phase I

The first phase of the present research has been divided into diverse operative stages:

- topographic surveys;
- orthophoto realization from remote sensing data (Quickbird and IKONOS);
- orthophoto and numeric cartography generation with data deriving from digital photogrammetric camera.

The topographical surveys have been operated by two GPS instruments, by measuring about fifty points (twenty points with static observation and thirty with RTK survey) within

three topographic nets intentionally projected for giving a correct geocoding to the territory of Ilidza.
In all static measure operations the GPS permanent station of Sarajevo is involved as a fix point in the computation.
All those points have been used as GCP (Ground Control Point) or CP (Control Point) for the adjustment of both remote sensing and photogrammetric data.
As for Quickbird and Ikonos data it has been tested how the parametric and non parametric models implemented within commercial softwares like PCI Geomatica and ENVI work for the test zone.
The results of both models are very similar since the Ilidza territory does not present many different levels, being in fact prevailingly flat.
In short the third phase of the present work has been focusing on digital photogrammetric data, generated by Leica ADS 40 .

3.1. Photogrammetric flights

As regards the archaeological site it has been planned a low quote flight (figure 6). In order to increase data and observation redundancy the team of Parma CGR carried out three stripes at different stages: the first one at 6.000 m upon the sea level (pixel size 55 cm); the second one at 5.000 m (pixel size 47 cm); the last one at 3.500 m (pixel size 30 cm).
In a small portion of the investigated area (the only part where the project team is working at present) it has been tested both orthophoto and numeric cartography generation.

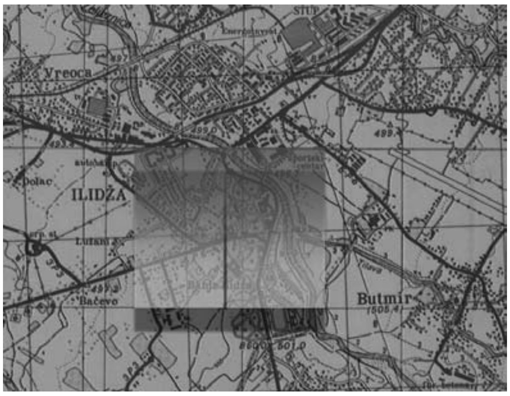

Figure 6: *Low quote flight*

3.2 Data processing

The ADS 40 data processing is very closed and just Leica software can be used for carrying out the first three steps (and it is recommended to continue using the Leica software for the other steps too).
The present research has employed:

- GPro (raw data, Level 0, Level 1, Level 2)
- ORIMA (bundle adjustment)
- Leica Photogrammetric Suite (DEM extraction, orthophoto production, with PRO 600 for the photogrammetric restitution).

ADS 40 is a digital SLR camera with GPS/IMU inside the body; the configuration of the CGR camera is PAN 14 (forward 14°), PAN 28 (backward 28°) and nadir RGB CCD sensors [CCG04].
The first process, after downloading raw data, consists of associating the GPS/IMU data; in the case here examined both for reference station and the topographic measurements it has been used the GPS permanent station of Sarajevo (situated on Sarajevo Polytechnic roof).
At the end of the process just described the Level 0 is generated by GPro. The second step is the Level 1: in this case the software rectifies images for a correction of perspective errors during the acquisition (figure 7).
At the end of this two steps is possible using the images in other softwares and starting photogrammetric processing [CB04].

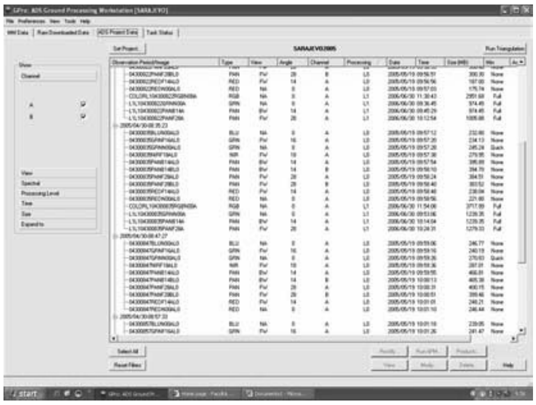

Figure 7: *GPro displayed L0 and L1 images*

From GPro it is also possible to create the APM (automatic point matching) and generate the orthophoto (Level 2) at the end [F01].
The APM is important for the next step (adjustment with ORIMA), and from Leica is recommend to create these points only in GPro and you must have the software for using this point outside (only with ORIMA you can't read the *.ipa file, that contains the APM generated during the GPro process).
Some tests have been doing in this period for estimating if there is any difference between the two approaches (recommended and not recommended).

3.3. Triangulation with ORIMA

As we know ADS 40 have three CCD sensor [SB00], Forward Backward and Nadir, the scan of each line is called a scene, the scene of sensor line is similar to digital image of a frame sensor.
All scenes are scanned synchronously .
The GPS and IMU data give a continuous position and the attitude of the ADS 40.
During the triangulation the software updates this continuous stream of data with the principles of least square bundle adjustment.
The program simulates a frame camera flight using some orientation fixes at regular intervals along the flight path of the push-broom scanner.
Orientation fixes are characterised by:

- the position of the sensor at a certain time;
- the time interval between two fixes depends on IMU quality;
- the six orientation parameters for each fix are updated by the triangulation process;
- each fix is identified by a certain time;
- each image has got multiple orientation fixes.

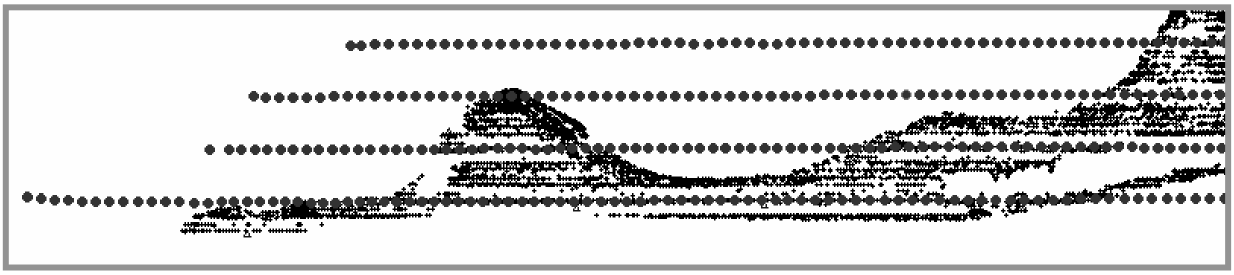

Figure 8: *In blue are showed the orientation fixes and in black the Automatic Point Matching*

The mathematical model [HMTUW04] describes the transformation of a point from a ground control system to the orientation fixes.
This model is very flexible: in some areas lacking of sufficient control or tie points the orientation parameters are computed just with GPS/IMU data; on the other hand if GPS/IMU data cannot be used the orientation can be merely determined by tie point measurements.

$$x_{ij} = F_{ij}(X_i, Y_i, Z_i, X_k, Y_k, Z_k, \omega_k, \varphi_k, \kappa_k, X_{k+1}, Y_{k+1}, Z_{k+1}, \omega_{k+1}, \varphi_{k+1}, \kappa_{k+1})$$

$$y_{ij} = G_{ij}(X_i, Y_i, Z_i, X_k, Y_k, Z_k, \omega_k, \varphi_k, \kappa_k, X_{k+1}, Y_{k+1}, Z_{k+1}, \omega_{k+1}, \varphi_{k+1}, \kappa_{k+1})$$

$$X_j = c_j X_k + (1 - c_j) X_{k+1} + \delta X_j$$

The mathematic model of ADS 40

Typically the GPS/IMU sensor will have a systematic offset to the actual sensor head. This systematic offset between the true orientation and the GPS/IMU observations is compensated and computed by additional parameters within the self-calibration process of triangulation.
After the adjustment, the orientation of GPS/IMU is updated by picewise interpolation from the orientation fixes, which were computed in the bundle adjustment.
In our case for the test area we used 15 GCP combined with the GPS/IMU data and about 1.500 tie points generated in GPro; at the end of the process the results of the adjustment on the control points are:

σ_X 0.075 m; σ_Y 0.069 m; σ_Z 0.105 m

3.4. DEM and Orthophoto generation

The orthorectification process requires the generation of an highly precise DTM for the realization of an accurate map-image.
The use of digital image correlation is common in remote sensing and digital photogrammetry applications in order to find areas of similarity between two or more images overlapping or sharing a common geographic area.
Leica Photogrammetrich Suite – or better OrthoBASE in LPS – makes use of correlation and image matching to automatically extract DTM.
As regards the project this process has been done for generating in the test area an accurate (5 meters) Digital Terrain Model with different strategies (for example it is recommended using one strategy where there are a lot of trees and another strategy in urban areas).
After that, it is necessary to edit the DTM: in this case in LPS there are some algorithms for the automatic editing and some manually tools for a correct interpretation of the terrain. At the end of the editing a correct DTM with some automatic and some manual adjustment has been finally generated.

With the digital terrain model it is possible to build up the orthophoto (figure 9). There are two ways with the Leica softwares for generating this product: using GPro (Level 2) or using LPS.

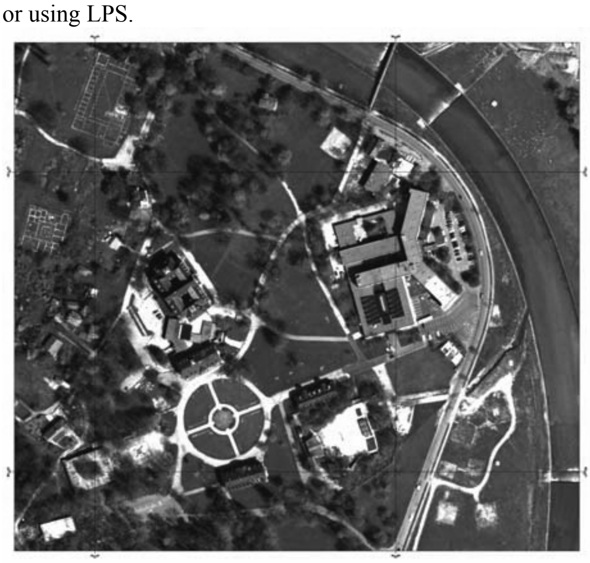

Figure 9: *orthophoto original scale 1:1000*
Ilidza (test zone)

There are no problems to generate orthophoto from LPS or GPro; the real problem is the DTM; the algorithms that are improved in LPS sometimes works not so well, because they are specifically planned for a typical kind of terrain, so if they must work with a not homogeneous area is better to split the terrain and use different algorithms for each area.
In this case, a good solution is to use the algorithms of another software (Socet Set): this algorithms automatically turn to another strategy every time something is changing in the terrain [WM01].
But with other softwares problems certainly arise with the ADS 40 data: so the better way of working is to do a very accurate editing.

3.5. Numeric cartography generation

The last step of the project has been the generation of a numerical cartography of the area where the project team is working for planning the archaeological park.
There are no doubts that the orthophoto is more expressive than a classical vectorial map but, on the other hand, when it is necessary to produce an architectonical project a cassical map is preferred; so one of the achievements of the research project has been the generation of this map.
The numeric map can have different requirements:

- only planimetric: in this type of representation are recorded in the numeric file only points defined by planimetrical coordinates;
- numerical cartography with planimetry and altimetry, where a planimetry (only planimetric coordinates) and an altimetry, constituted from quoted points and contours, are recorded in the file;
- three-dimension numerical cartography: every point is determined by both planimetric and altimetric coordinates.

In the investigated case of Ilidza a three-dimensional map has been generated (figure 10).

Figure 10: *Numeric carthography original scale 1:1000 Ilidza (test zone)*

In Leica photogrammetric Suite there is a module called PRO 600 that combines a CAD software (Microstation) with the 3D viewer of LPS; in this tools it is possible to gain a direct connection between the 3D models generated with the photogrammetric process and the vector file you are creating.The stereoscopic vision from ADS 40 is generated starting from different images: you can combine PAN 14 and PAN 28 for the highest stereoscopic view (this combination is sometimes difficult for the eyes) or better a Nadir (color or panchromatic)image with PAN 14 or PAN 28; this is the better way for working without problems.
For the map of Ilidza the restitution has been operated with PAN 28 and the NADIR_RGB image.
The map is a numerical cartography at a scale of 1:1000 that respects the tolerance requested for a typical cartographical product.
This is the last product for the second year of the Pilot Project; the next step is to generate more large scale maps, first of all a map scale 1 to 500 for a better representation of the architectural project. Then the map needs an accurate verify with some topographical measures and this works will be possible on September, a group of the researcher team is going to Ilidza-Sarajevo for the presentation of the first results, and for doing some new surveys and analysis in that zone.
As for the archaeological remains, another objective is to generate a very high scale representation (1:200) with an integration of archaeological drawings (tested and measured) with the vector map scale 1:1000 or 1:1000.

4. Some conclusions and future works

A general valuation of the digital camera is possible after this part of the work; one of the most important topics is that you can generate very quickly a good orthophoto (with GPS/IMU is possible to have a good precision without topographical measurements). So if the objective is to have a medium scale map: this product can be obtained after the flight in one or three days (naturally depends by the extension of the zone).
On the other hand, much more difficult is the photogrammetric restitution: the stereoscopic view is not so nice (only one RGB image and the other in panchromatic) and the process is very slow.
These cameras are expected to represent the future and it's sure the research should work in this direction to produce orthophoto numeric maps and 3D city models.
The future work perspectives are divided into two field: first of all the improvement of the generated map with new measures and new surveys; then a continuous testing and data processing not just with Leica softwares, but also with other software in order to verify how they work and how they can manage the ADS data.

References

[CB04] Casella V., Banchini G.: Verifica delle qualità metriche della camera Leica ADS40*, Atti della VIII Conferenza ASITA, Roma (2004), pagg. 1983-1988*

[CCG04] Casella V., Cavazzini A., Gentili G.: La camera aerofotogrammetria digitale Leica ADS40: i nuovi orizzonti nelle applicazioni delle riprese aeree digitali per la rappresentazione del territorio, *Atti della VIII Conferenza ASITA, Roma (2004), pagg. 681-686*

[HMTUW04] Hinsken L., Miller S., Tempelmann U., Uebbing R., Walker S.:Triangulation of LH systems' ADS40 imagery using ORIMA GPS/IMU, *Proc. XX ISPRS Symposium (2004), Istambul (Turkey)*

[WM01] Walker S., Miller B.:New developments of SOCET SET,ORIMA and PRO 600, P*hotogrammetric week '01 (2001),Stoccarda (Germany), Fritsh Spiller ed, pagg. 183-187*

[F01] Fricker P, ADS 40-Progress in digital aerial collecting data, *Photogrammetric week '01(2001) , Stoccarda (Germany), Fritsh Spiller ed, pagg. 105-116*

[SB00] Schuster R. , Braunecker B.:Calibration of the LH systems ADS40 airborne digital sensor, *Proc. XIX ISPRS Symposium (2000), Amsterdam (Nederlands)*

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
VAST (2006)
M. Ioannides, D. Arnold, F. Niccolucci, K. Mania (Editors)

Developing a Preservation Program for 3D Computer Graphics Cultural Content

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Abstract

As time goes by, a constantly increasing part of the information produced worldwide today is born digital and comes in a wide variety of formats. Cultural organizations face new preservation challenges, in order to ensure that the digital cultural heritage being constantly produced will remain accessible to the public. Multimedia in various formats is the most frequently met digital objects of the 21st century. Their cultural influence and informational content is immense and rapidly increasing. If multimedia is to be accessed in its original form, policy and technical issues inevitably arise. The proposed work focuses on a specific kind of multimedia, namely 3D digital objects.

This paper aims to present the preservation policy adopted by the 3D Graphics and Animation Sector of the Foundation of Hellenic World, Athens/Greece, as a means of ensuring long-term access to digital cultural information. Specifically, the adopted preservation policy for 3D digital objects includes: a) Aim & Objectives of the Project, b) General preservation planning, c) Technical & practical perspectives, d) Copyrights' Management, e) Workflow and f) Preservation Metadata extraction. The Policy proposed is novel and innovative among Greek cultural organizations.

It is evident that in order to preserve and manage multimedia e-content, cooperation at national and international level is more than necessary. In this context, the proposed work aims at providing a reference point to the development of a common preservation policy framework for 3D-computer graphics content within Europe.

Categories and Subject Descriptors (according to ACM CCS): I.3 [Computer Graphics]: Digital Preservation, Migration, Emulation, Preservation Metadata

1. Introduction

The preservation of the world's cultural heritage is a challenging task, especially within the digital era. UNESCO and other cultural organizations have been examining these issues in order to find viable solutions. All the member states of the European Community have agreed on the need for rapid action to safeguard the digital heritage [UNE03]. Traditional preservation methods have to be reevaluated and accordingly remain or be replaced by others that will better respond to the requirements and characteristics of the new kind of cultural content, the digital one. Additionally, during the last few years, the national governments of the European Community's member states have taken serious measures, in an attempt to provide preservation policies and guidelines for different kinds of digital content [COM05].

In this context, a number of issues need to be discussed. Firstly, there are technical problems in ensuring that the existing digital material will remain accessible in its original form, taking into consideration the fact that software and hardware are constantly evolving and giving their place to more powerful new generations, which ultimately become incompatible with their predecessors, thus leading to the technological obsolescence problem. For example, in just a few years from their digital birth, resources consisting of

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sound and moving graphics or image may become inaccessible due to the lack of backwards compatibility of newer versions of their surrounding software and/or hardware environment.

However, the aforementioned issue is not only a challenge with technical aspects in nature. Organizational and societal issues arise, as it is more a struggle with the responsibility of keeping the access borders open over time.

3D computer graphics content inevitably emerges as a different kind of digital material, needed to be preserved at any cost, since it carries invaluable cultural information. The materialŠs special features necessitate the use of the appropriate preservation methods and techniques, in order to ensure its lifelong sustainability and accessibility. It is worth mentioning that so far, no de facto preservation policy exists for 3D computer graphics content. That can be easily explained, if we consider that it is a new kind of technology, not widely spread and constantly under development. The files that are ultimately produced need to be carefully managed, taking under consideration their specific requirements in size computational power.

The proposed methodological approach relies on observation techniques and data collection for a 3D computer graphics content preservation project held in the foundation of Hellenic World, Athens/Greece. The project aims to develop a preservation program for the aforementioned specialized digital material, produced by the 3D graphics department. The research is still in progress.

2. Definitions

To illustrate how specific terms are used in this project, such terms and concepts are explained below. The list only aims to provide a standard reference point for this project and it is far from being a complete glossary.

With the term *3D Computer Graphics* is meant the creation of images with the use of computer systems. The content of those images includes information about the third dimension (i.e. depth), similarly to the case of simple photos and "living content". The successive demonstration of these images in specific time gives the spectator the feeling of movement.

3D computer graphics content is born digital and traditional preservation methods and techniques are not in the position to reassure its lifelong sustainability and accessibility. *Digital Preservation* "is the generic term for all activities concerning the maintenance and care for curation of digital or electronic objects, in relation to both storage and access" [VER06]. Such activities include "any set of coherent arrangements aiming at preserving digital materials" [COM05]. Consequently, a *Digital Preservation Program* exists, in order to "address all the aspects of preservation responsibility, including policy and strategy, as well as implementation" [UNE03]. A Preservation Program requires the adoption of the necessary *preservation strategies*, which are "methods for keeping material permanently accessible. It refers to all techniques that provide more that would be obtained by merely storing the digital objects and never looking at them again" [VER06].

Regardless which particular preservation program is developed and which strategy is finally adopted, the extraction of the appropriate information from the digital content is needed. The extracted information is called *metadata*, meaning the structured information that describes and/or allows the discovery, management, control, understanding or preserving other information over time [CUN00]. The development of a special metadata section is needed, in the course of preserving digital material. *Preservation metadata* "are to be employed for the management of digital preservation programs, focusing on preservation requirements, describing the means of providing access, along with those elements of resource management metadata required to manage preservation processes" [NLA99].

3. Organizational Profile: The 3D Graphics Department

Foundation of the Hellenic World is a privately funded, non-profit cultural institution, located in Athens, Greece. The foundation's mission is to preserve and disseminate historical memory and traditions, as well as the realization of the universal extent of Hellenism and the projection of its contribution in the evolution of civilization.

In order to accomplish the aforementioned goals, the Foundation established in 1995 the 3D graphics department. The department's main task is to produce digital 3D representations of archeological monuments and sites. Through these, the opportunity is given to the audience to visit spaces that are either difficult to visit in person or no longer exist, and examine objects from diverse and unique points of view. The 3D graphics department develops three types of digital models: a) Photorealistic 3D models, b) VRML 3D models and c) Virtual Reality models.

4. Need for Action

The department numbers a wide range of 3D computer graphics productions. Two main classes of digital objects exist: 1) the final product, an image or images sequence, created after the 3D digital content rendering procedure and 2) the 3D scene/database content, digital information which consists of a digital scene; such as digital cameras, models, textures, lights, animations etc. This kind of data is automatically saved into files of 3D computer graphics software, according to the information's kind and special features (i.e. at Softimage/ XSI 5.0 we have samples like actions, models, pictures, scenes, scripts etc.).

Until 2005 no main preservation program existed. The 3D computer graphics material was stored into different kind of physical carriers, such as: 1) Analog carriers: beta and SVHS videotapes and 2) Digital carriers: a) cartridges, b) CDs, c) DVDs, d) tape libraries and internal or external hard disks.

The lack of a specific preservation policy gradually drove the Department to serious problems related to the information's authenticity and integrity. We need to note that authenticity is extremely important for 3D computer graphics content, as the integrity of the creators' work has to be protected. We should also mention that new information and finds about cultural content make inevitable the storage and retrieval of old data in order to correct and complete it.

The rapid evolution of the used hardware and software technology is the source of the problems. Data stored in old fashioned storage equipment can not be retrieved from new ones; initial physical carriers that were used to conserve digital information are no longer compatible with modern hardware. New versions of the used software can not open 3D databases which were saved in older versions of the same software. In other words, the software needed to interpret the digital information and the necessary hardware became obsolete.

We should mention that the above problems are mainly referred to the retrieval of the 3D scene/database content and not the final product which is usually stored in very common files.

All the aforementioned issues led to the development of the preservation program, as a way of confronting the longevity of digital content. The department's personnel realized that without preservation, access becomes very difficult and in some cases impossible, over time and the produced material decays and disintegrates.

However, it is also evident that the preservation problem has not only technical aspects that need to be taken care of. Administrative, procedural, organizational and policy issues surrounding the management of 3D computer graphics content arises. The material's special nature poses significant implications in respect of the way it is generated, captured, transmitted, stored, maintained, accessed and managed. The project presented below began in mid 2005 as a solution to the problem of preserving 3D computer graphics content. The survey is still in progress and the results appearing in this paper are primitive, but indicative for the case.

5. People Related to the Project

Despite the limited number, the project's team managed to fulfill the proper profile within a range of existing skills area, because of the scientific and professional concerns of its members.

The working group included:

1. A *3D computer graphics artist*, the 3D Graphics Department head, responsible for the project, as he is the one knowing the content's nature and attitude, along with the content's preservation needs and requirements. He had the role of the program manager.

2. A *computer science engineer*, responsible for the technical requirements of the project and the extensive study of preservation methods. He is the one to finally propose the proper preservation method and the adopted one, according to the material's needs and special characteristics.

3. An *information scientist* (archives and library science), responsible for the material's description, the choice of the adequate metadata standard and the preservation metadata extraction.

6. General Preservation Planning

According to international guidelines and preservation policies adopted by libraries and Cultural organizations worldwide, there are specific steps that should be taken under consideration in a first place [UNE03]:

1. *Determine the kind of the material the organization is responsible to preserve*: It is clear that the project aimed to preserve the 3D computer graphics content produced by the 3D graphics department. It was given priority to the material most at risk, followed by the material that was possible to take immediate action, then to the most important material for the Department and finally to the rest of the content. All produced content was to be preserved.

2. *Secure the materials Rights*: we usually need to be aware of different material Rights, like those which have legal implications, including intellectual property Rights, as well as privacy Rights. A preservation policy needs to include active Rights management approaches. However, the Project's team was free from such concerns. That can be easily explained, if we take into account the fact that the foundation of the Hellenic World is the exclusive producer of the 3D graphics content used for all cultural productions. That is why the Foundation holds the copyrights of all the digital content created in the 3D graphics Department, in a way that the rights' management was an easy task during the preservation program development. The difference between the public right to preserve the national memory and the private right to control commercial exploitation, needs to be explicit. At the core of these changes is the tension between two sets of rights: private control and democratic access to the public memory.

6.1. Characteristics of reliable Preservation Programs

Preservation Programs offering long term reliability are expected to have the following characteristics:

7. The Preservation Strategy

There is always a dependent relationship between data and software: all data require some kind of software in order to

PRESERVATION CRITERIA	3D GRAPHICS DEPARTMENT
Responsibility	Full responsibility of the produced content
Organizational viability	Foundation of the Hellenic World is a viable- well established Organization
Financial sustainability	Declared Organizational Statement for Financial Support
Technological and procedural suitability	Technological equipment will be acquired. Procedures under development
System security of a very high order	Security controls exist to ensure that data are exposed to controlled, authorized processes. Standard security measures for vital information assets will be taken
Procedural accountability	Mechanisms & Workflow under discussion

Table 1: *The characteristics of a reliable preservation program*

be presented in a user understandable manner. At the time being, there is no universally acceptable and practical solution to the problem of technological obsolescence not only for 3D graphics content, but also for the digital content in general. Several approaches have been proposed, but it is unlikely that there will be a single solution that offers a cost-effective means o access for all kind of digital materials, for all kind of purposes and for all time.

Under those circumstances it was difficult for the people related to the project to choose a method for preserving the department's content. All preservation strategies in existence today were taken under consideration. However, only two of them seamed to be more efficient for the preservation of our content: a) migration and b) emulation.

Migration "involves transferring digital materials from one hardware or software generation to another... Migration entails transforming the logical form of a digital object, so that the conceptual object can be rendered or presented by new hardware or software" [VER06]. Emulation "involves using software that makes one technology behave as another... this would entail making future technologies behave like the original environment of a preserved digital object, so that the original object could be presented in its original form from the original data stream" [VER06].

Both techniques demand considerable actions in financial and technical terms. Migration is aimed at the digital object itself. It changes or modernizes its format in order to be incorporated into a new environment. Emulation focuses on the environment in which the digital object is rendered in a way that through the environment's recreation the digital object will be rendered in its authentic form. As a general rule, it could be stated that migration is preferred when the number of digital assets is limited, since the migration costs directly depend from the total number of preservation items. On the other hand, emulation is preferred when the number of digital assets is too big, thus excusing the large initial investment that emulation requires.

According to a first estimation, the department will adopt the migration technique. At the time being actions are taking place in order to migrate the information to other formats. We have to state that the reasons for rejecting the emulation method were basically the technique's complexity, the requirements for high degree of effort and specific expertise so it is likely to be very costly. Furthermore, the technique is still in the research stage and as our content is in nature special, the requirements for emulation which may need to include multiple components. In all cases, the working team estimated that the emulation of all aspects of a system and the 3D content database, or application may not be possible.

8. Preservation Metadata

Every stored digital object needs to be described in a structured way using metadata. As mentioned in the previous sections, metadata can contain information on structural, administrative or technical aspects of an object. Preservation metadata usually include a combination of existing metadata sets that provide necessary information for long- term preservation of and permanent access to digital material [OCLC/RLG01].

As being creators of the digital content, the project's team was in the best position to document its technical nature and context. The decision to extract preservation metadata was based on the need: a) to store technical information supporting preservation decisions and actions, b) to document preservation actions, c) to record the effects of preservation strategies and d) to ensure the lifelong authenticity of digital resources. Preservation metadata in our project included technical details on the digital object's format, structure and use of the 3D content; the history of the actions performed on the resource including changes and decisions; authenticity information such as technical features or custody history etc.

We also decided to extract descriptive metadata, in order, in a later phase, to easily find, assess, understand and retrieve the e-content.

The team decided to adopt METS (Metadata Encoding Transmission Schema) which is a scheme designed to be used as a transmission standard. Its main advantage is that it has a highly flexible design which incorporates the use of other "extension" schemes for certain forms of metadata. For the extraction of preservation metadata, the team decided to choose between the element sets introduced by CEDARS project [CED02], the National Library of Australia and NEDLIB project (Networked European Deposit Library), since they are all compatible to OAIS (Open Archival Information System), a standard that seems to dominate the digital preservation landscape. At the end, we decided to take elements from the Cedars metadata specification, such us resource description, custody history, copyright statement etc.

Generally, metadata production is a crucial task, as long as metadata need preservation too. That is why we had to pay attention to issues like: a) the structure: organizing metadata in a standardized document structure, such as an XML schema, would make the preservation easier, b) the linking between metadata records and the digital objects. We decided to keep metadata separately. Separate storage allows metadata to be accessed and updated without interfering with the original digital object. Also, the quality control ensures that the trustworthiness of metadata records is of a high priority and finally, we had to pay attention at the protection, in the way that the integrity of metadata records would be preserved.

Another important issue our team had to deal with was how such metadata would be generated and where it would be kept. Metadata could be stored either in a centralised or distributed fashion and linked to the original resource. Alternatively, metadata could also be embedded in or otherwise directly associated with the original resource. Different solutions might be possible for different types of metadata. In our case, we decided to keep metadata separately, as we are still in the metadata extraction phase. In a later phase, it is very possible that we will link metadata with the original source, meaning the 3D product itself.

Other related issues concerns resource discovery and rights management metadata, which could form part of a searchable database, while metadata specifying the technical formats used, the migration strategies operated and a document's use history could be stored with the document itself. Over a long period of time, this metadata will grow in size and will have to be subject to migration and authentication strategies. However, this matter is not to be discussed in this paper.

9. Conclusion

There is a number of similar projects taken place worldwide, aiming at the development of preservation policies for digital material, but none yet for the preservation of 3D computer graphics material. This paper outlines the main preservation issues or challenges by describing the effort of developing a preservation program for 3D computer graphics cultural content.

As long as the project is still on progress, only general conclusions could be given. Preserving digital content requires responsible decisions and actions that only time can tell whether are right or wrong.

However, it is evident that in order to set a common preservation policy for 3D computer graphics material, cooperation in national and international level is needed. Sustained efforts on the part of governments, creators, publishers, cultural industries and heritage institutions are also of essence. Benefits coming from team efforts include: a) access to tested policies, b) shared development costs, c) shared research and standards/ guidelines development d) shared human resources etc.

There is no doubt that it is necessary to promote and share knowledge and technical expertise, but also, to communicate research results and best practices via cultural organizations infrastructure, as a way to democratize access to digital preservation methods and techniques.

References

[UNE03] UNESCO/ NATIONAL LIBRARY OF AUSTRALIA: Guidelines for the preservation of the digital heritage. *Information Society Division/ United Nations Educational, Scientific and Cultural Organization*, 2003. http://unesdoc.unesco.org/images/0013/001300/130071e.pdf.

[COM05] COMMISSION OF THE EUROPEAN COMMUNITIES: Communication from the commission to the European Parliament, the Council, the European economic and social committee and the committee of the regions: i2010: DIGITAL LIBRARIES. Brussels, 2005. http://europa.eu.int/information_society/activities/digital_libraries/doc/communication/en_comm_digital_libraries.pdf.

[VER06] VERHEUL I.: Networking for Digital Preservation: Current Practice in 15 National Libraries. IFLA Publications 119, Munchen, 2006 http://www.ifla.org/VI/7/pub/IFLAPublication-No119.pdf.

[CUN00] CUNNINGHAM, A.: Dynamic descriptions: recent developments in standards for archival description and metadata. *Canadian Journal of Information and Library Science*, 25, 4 (2000), 3-17.

[NLA99] NATIONAL LIBRARY OF AUSTRALIA: Preservation Metadata for Digital Collections. Exposure Draft, 1999 http://www.nla.gov.au/preserve/pmeta.html.

[OCLC/RLG] OCLC/ RLG: Working group on Preservation Metadata. *Preservation Metadata for Digital Objects: a review of the state of the art* Dublin, Ohio: OCLC Online Computer Library Centre 2001 http://www.oclc.org/research/projects/pmwg/presmeta_wp.pdf/

[CED02] *The CEDARS Project. The CEDARS*

Project to Preservation Metadata. JISC, 2002 http://www.leeds.ac.uk/cedars/guideto/metadata/guidetometadata.pdf.

[METS] Metadata Encoding Transmission Schema http://www.loc.gov/standards/mets/.

[OAIS] Open Archival Information System http://www.rlg.org/en/page.php?Page_ID=3201.

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
VAST (2006)
M. Ioannides, D. Arnold, F. Niccolucci, K. Mania (Editors)

The Use of Laser Scanning and Rapid Manufacturing Techniques for Museum Exhibitions

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Abstract

The 3D digital model of an object provides a means of making the object more accessible, of placing it in a historical context, and of replicating the object without any risk whatsoever to the original piece. The combination of laser scanning and rapid manufacturing techniques, which have both advanced significantly in terms of accuracy and resolution over the past 10 years, allows museums to create authentic replica objects for exhibitions and also to create restored versions of an object without interfering with the original piece in its present day state. The 3D digital model of an object provides a valuable resource that can unlock a whole range of possibilities within a museum exhibition. This paper presents a series of case studies which illustrate the wide range of applications for 3D digital data within an exhibition. The case studies include examples of replicating sculpture,(using a range of rapid manufacturing techniques) to allow visitors to interact both visually and through touch, to improve accessibility to an object and to enhance the learning experience of visitors to an exhibition. The case studies also include an example of 3D visualisation for demonstrating how an important sculpture has been assembled.

Categories and Subject Descriptors (according to ACM CCS): A.0 [General]: Conference Proceedings; J.2 [Physical Sciences and Engineering]: Archaeology; J.5 [Arts and Humanities]: Fine arts; J.6 [Computer-Aided Engineering]: Computer-aided Manufacturing

1. Introduction

The use of laser scanning within the museum and heritage field has grown steadily during the past 10 years. Laser scanning has been employed in many important projects in that time, including the 'Digital Michelangelo project' [LPC*00], the 'Digital reunification of the Parthenon and its sculptures' [STH*03], and 'Digital rock art recording' [TDH05]. It is now widely known that laser scanning provides a means to accurately document sculpture and artefacts in 3 dimensions (3D); valuable information that together with 2D photography, conservation and historical records forms a detailed and important record for an object. Issues of cost, data management and procedure have meant that laser scanning has not yet become a routine part of the documentation process for all objects in a museum's collection; in fact it is currently far more likely to be used on an individual project basis. The 3D digital model of an artefact, however, offers much more than simply a 'record' of the object, it provides a means of making the object more accessible, of placing it in a historical context, of unlocking the hidden story behind the artefact. The 3D digital model of an artefact is an extremely valuable resource. Digital models derived from a single raw 3D data set can be used to enhance the museum visitor's experience in a number of ways: through visualisation of earlier appearances of an artefact using reconstruction of colour and missing or damaged parts; by setting an artefact in its historic context; by allowing a visitor to 'touch' and interact with the surface of a digital artefact through the use of haptic technology [LTCF*04].

The combination of laser scanning and rapid manufacturing techniques, which have both advanced significantly in terms of accuracy and resolution over the past 10 years, allows museums to create authentic replica objects for exhibitions [BCFF*04]. The non-contact nature of this replication process means the risk to the original artefact is minimised. Replicas can be handled by visitors in a way that the original usually cannot, thereby allowing the visitor to investigate the surface form and materials in a way not usually possible. Replicas can travel when a priceless or fragile artefact cannot and replicas can be used to show earlier appearances of an artefact without interfering with the original piece in its present day state.

The 3D digitisation process also enhances accessibility to artefacts. Many museums have far more objects than they are able to display and significant parts of collections are held in store and not easily accessible to either specialists wanting to study them or to the general public. Relatively low resolution 3D computer models can be made available via the worldwide web and high resolution models can be easily sent to all corners of the globe on a variety of storage media. In this way, collections that have become fragmented can be brought together and displayed in 'virtual museums' without any artefacts having to be moved.

This paper presents a series of case studies that have been undertaken over the course of two years at a national museum in the UK, which illustrates the benefits that laser scanning and rapid manufacturing techniques can bring to a museum exhibition. The case studies focus on the areas of visualisation, replication and learning.

2. Method

Laser scanning was undertaken using a 3D Scanners Modelmaker X close-range laser scanning system (working distance approximately 10-20 cm). The system operates using the principle of triangulation and consists of a sensor head mounted onto a 7-axis articulated arm. The arm itself is mounted on a tripod fixed to the floor. The sensor is moved by hand during scanning so that the laser stripe passes over the surface of the artefact (figure 1). Position sensors within the joints of the arm mean that successive scans are automatically registered to the same co-ordinate frame and separate registration is not required. The principle of this scanning system is described in more detail elsewhere [EF03]. This type of handheld system is ideal for recording sculpture and other 3D artefacts as the flexibility offered by the arm allows data to be collected from even the most complex surfaces. The point accuracy for this system is specified as 0.1 mm under ideal conditions.

Figure 1: *Laser scanning using an arm-mounted sensor.*

The raw point cloud data, once collected, was converted into a polygon mesh using InnovMetric Polyworks software. Post-processing of the mesh mainly involved hole filling (for areas where scan data could not be collected: usually deep recesses such as deep folds in drapery) to produce a watertight mesh (required for rapid manufacturing) and decimation of the model to reduce the number of polygons to an appropriate size for the application (without losing detail in the model). These processes were carried out using Polyworks and Rapidform (Inus Technology) software.

For replication, physical models were created from the digital models using a range of rapid manufacturing (RM) techniques including: computer numerical controlled (CNC) machining, stereolithography (SLA), selective laser sintering (SLS) and the z-corp 3D printing process. Once a physical model had been created, hand-finishing was undertaken by conservators to remove signs of the manufacturing process (layer lines in some places for SLA/SLS; tooling lines in some places for CNC machining) and to 'patinate' the surface to create the feeling of 'age'. All RM suppliers had previously signed data agreements controlling use of the 3D digital data.

3. Case studies

3.1 Replication of the Vedica tombstone

In 2005, an exhibition was held at National Museums Liverpool (NML) entitled 'Living with the Romans', which explored the life of ancient Britons living in the Merseyside region of England (on the fringes of the Roman Empire) during Roman times. The tombstone of Vedica (figure 2), carved in sandstone (1.7 m tall), is that of a woman belonging to the Cornovii tribe of Cheshire. The inscription states that she died, aged 30, at the end of the 1^{st}-century AD. The tombstone was found in Ilkley, West Yorkshire in 1884 and is now on display in the town's Manor House Museum. It is believed that Vedica married a Roman soldier and left Cheshire to settle in West Yorkshire.

Figure 2: *Vedica tombstone (Manor House Museum)*

The original tombstone was considered too heavy and difficult to move to a temporary exhibition in Liverpool. Instead, a full-scale replica was created in a high density resin modelboard and coloured to look like aged sandstone. The tombstone was laser scanned on site in 9 hours. A further 45 hours were spent processing the scan data to produce a watertight polygon mesh. The replica tombstone was then created from the digital model using CNC machining. The final stage of replication involved sealing the modelboard with diluted polyvinyl alcohol, spraying with an acrylic base colour, and applying (by hand) patination in the form of acrylic paints.

Figure 3: *Replica Vedica tombstone installed in exhibition.*

The result was a very accurate replica tombstone (figure 3) of an object that could not be loaned out, in an appropriate material for the exhibition. The non-contact nature of the replication process meant that there was no contact with the original tombstone, thereby minimising the risk to a unique artefact.

3.2 Replication of medieval carved graffiti

The Beauchamp Tower of the Tower of London contains many pieces of graffiti carved into the stone walls by prisoners during medieval times. Many pieces are now in a very fragile state and are displayed behind sheets of glass for protection (figure 4). Access to the room containing the graffiti is via a narrow spiral staircase and is difficult for some visitors. In December 2004, a new permanent interactive exhibition describing the life of the prisoners was opened on the more accessible ground floor. Within this new exhibition, three pieces of replica graffiti were installed.

Figure 4: *Carved medieval graffiti in the Tower of London (Historic Royal Palaces).*

The replica pieces of graffiti were produced by laser scanning and CNC machining into a high density resin modelboard. The possibility of moulding the graffiti and casting replica pieces was quickly ruled out due to the fragile nature of the stone surface. Figure 4 shows the ‘Dudley’ graffito, a highly detailed piece carved either by or for John Dudley, one of the brothers of Lord Guildford Dudley (husband of Lady Jane Grey). This piece was scanned on site in 1.5 hours. Post-processing of the raw data took 30 hours, most of this time being taken up cleaning the polygon mesh of features resulting from interaction of the laser stripe with dirt that had built up within the recesses of the surface. This dirt was considered integral to the carving from a historic point of view and could not be removed. A high density polyurethane modelboard was selected as the material for the replica pieces as it is durable and light enough to be mounted on the ‘cage-like’ structure that had been designed for the exhibition.

Once CNC machining had been completed, the replica graffito was ‘hand-finished’ to recreate the soiled and aged appearance of the carving mainly by the application of alkyd paints using brushes, cloths and sponges. A matt varnish was applied to protect the surface.

Figure 5: *Replica ‘Dudley’ graffito installed on open display at the Tower of London.*

Figure 5 shows the replica Dudley graffito installed in the exhibition at the Tower of London. The non-contact processes employed in this instance have enabled the replication of three very important historical pieces of graffiti, without any risk to the original pieces. Installation of the replica pieces on the ground floor of the tower has improved accessibility and has allowed visitors to interact with the carved surfaces in a way not previously possible, through touch.

3.3 Reconstruction of the skull of Leasowe Man

The skeleton of ‘Leasowe Man’, the only known Romano-British skeleton from the Merseyside region of England, was discovered by workmen near Leasowe Castle in Wirral (UK), in 1864. A study of his remains has revealed that he was a well-built man, in his thirties who was used to hard physical work. In 2005 the skeleton was loaned by the Natural History Museum for the exhibition ‘Living with the

Romans'. As part of the exhibition, a full facial reconstruction of Leasowe Man was created from a replica skull.

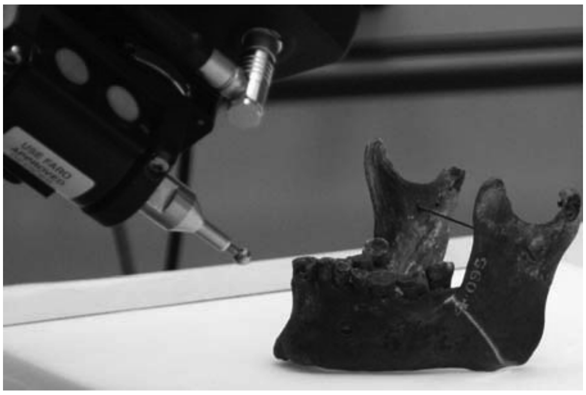

Figure 6: *Laser scanning the mandible of 'Leasowe Man'.*

The Leasowe Man skull is very fragile and in three parts: cranium, mandible and upper jaw. Each part was laser scanned (figure 6) and the data processed to produce an accurate polygon mesh. Scanning took 4 hours, while 30 hours was spent producing a clean watertight mesh suitable for rapid manufacturing. The separate digital models were then combined into a single model of the reconstructed skull that was used to produce an AVI animation for the exhibition website (figure 7). A replica nylon model of the skull was produced from the digital data using selective laser sintering (SLS). The model was built in 0.1 mm layers, with a laser spot diameter of 0.45 mm used to fuse the nylon powder. The mandible was built as a separate part that could be hinged to the rest of the skull.

Figure 7: *Textured 3D computer model of digitally reconstructed 'Leasowe Man' skull.*

The replica skull was then used by a forensic anthropologist at the University of Manchester as the basis for a full facial reconstruction of Leasowe Man, which was exhibited in the exhibition alongside his skeleton, giving visitors an idea of how this ancient Briton may once have looked. In this instance laser scanning and rapid manufacturing techniques have been combined to produce a highly accurate replica skull of an extremely fragile unique object. The result of this work (both the digital model of the reconstructed skull and the replica skull) has been used to aid visualisation for visitors both to the exhibition and to the website.

3.4 Replication of an 18th-century marble bust of Captain Cook

Figure 8 shows an 18th-century marble bust of Captain Cook by the sculptor Lucien Le Vieux, belonging to the National Portrait Gallery (London). This bust was selected to go into an exhibition at Beningbrough Hall near York (National Trust) entitled 'Making Faces: 18th-Century Style'. The exhibition brings 18th-century portraiture to life by engaging visitors through a series of interactive exhibits that explore the hidden stories behind a portrait, the commissioning process and the materials and techniques used to create a portrait.

Figure 8: *18th-century marble bust of Captain Cook by Le Vieux (National Portrait Gallery).*

Laser scanning and CNC machining was used to create an actual size replica of the bust of Captain Cook in marble. The replica bust was installed in the exhibition close to the original bust and can be explored by visitors through touch; revealing hidden details in the sculpture and enhancing appreciation of the fine materials used in its creation. The original bust was laser scanned in 8 hours. Post-processing of the data took 18 hours. The watertight polygon mesh was then used in the machining of a fine block of white statuary grade Carrara marble. A 5-axis CNC machine was used to cut the replica bust, which was then hand-finished using a selection of traditional carving tools and fine grades of sand paper to remove machining lines and sharpen and deepen some carved detail, particularly in the curls of the hair, around the eyes and the lettering of the inscription on the base. A coating of a microcrystalline wax was applied and the bust buffed before being installed, the wax coating providing a sacrificial buffer layer between the marble surface and dirt that would build up over time from handling in the exhibition. Figure 9 shows the replica bust on display close to the original.

Figure 9: *Replica bust (foreground) and original bust (background) on display at Beningbrough Hall.*

In addition to the marble replica, an interactive 'face-mask' exhibit was also derived from the polygon mesh. This exhibit was designed so that visitors could attempt to reconstruct an imaginary broken part of the bust. Haptic technology in the form of the Phantom arm and Freeform software developed by Sensable Technologies was employed to remove a section of Cook's nose and create a textured break surface on the polygon mesh, as if the nose on the original bust had been accidentally broken. The computer model was cut so that the back of the head was removed, leaving a 45 degree angle to the face for display purposes. Once changes to the computer model had been completed, a prototype of the face mask was produced by the z-corp 3D printing process. A mould was created from this prototype and two models cast in a durable resin, the colour of which was close to that of the marble bust (figure 10). The face masks have been installed close to the marble busts of Captain Cook and visitors are able to practise modelling a new nose in plasticine.

Figure 10: *Resin face masks produced for interactive nose-modelling activity.*

Here, the combination of laser scanning, haptic technology, CNC machining and 3D printing processes has enabled the accurate replication of an 18th-century marble portrait in marble and the creation of new realistic exhibits that allow the visitor to interact through touch as well as sight and to learn something about modelling through 'having a go'.

3.5 Digitisation of a life-sized statue of Artemis

Figure 11 shows a screenshot of a 3D digital model of a marble statue of Artemis (approximately life-sized), the Greek goddess of the wilderness, the hunt and wild animals. The sculpture is part of the Ince-Blundell collection of Classical sculpture (comprising some 500 pieces, one of the largest and most important such collections in the UK) put together by Henry Blundell in the late 18th and early 19th-centuries. This sculpture was actually made in the 18th-century from Classical pieces of the original sculpture, from pieces of other Classical sculptures that were reworked to fit and from pieces that were 'newly' carved. Artemis is actually a highly complex 3D puzzle comprising 123 pieces. The sculpture was in fact used as a 'showcase' for the restoration studio that created her, to demonstrate that they could indeed 'make anything'.

Figure 11: *Screenshot of 3D digital model of Artemis statue (National Museums Liverpool)*

The Artemis statue has recently been conserved and was included in a museum exhibition entitled 'Reveal' about conservation and scientific investigation of museum artefacts. It was decided to create a reduced-scale physical model (49 cm tall) of Artemis comprised of eight separate parts as a simplified 3D puzzle of the real Artemis. Such a model is a fun way for visitors to learn about the construction of statues such as Artemis.

The statue of Artemis was laser scanned in 17 hours and a complete high quality polygon mesh created after a further 78 hours (figure 11). The digital model was then cut into eight parts and the internal faces of each part created using haptic technology and Freeform software. The cut lines and internal faces were designed so as to ensure that the 8 pieces of the final Artemis model would fit together and to ensure sufficient stability in the model when assembled. Stereolithography was then used to create a prototype part for each of the sections. Silicone rubber moulds were made and the final sections vacuum cast in a highly durable resin able to withstand regular use by visitors to the exhibition (figures 12, 13).

Figure 12: *Artemis 3D puzzle in pieces*.

Figure 13: *Artemis 3D puzzle assembled.*

In addition to the 3D puzzle, a 3D animation has been created in 3D Studio Max software using the digital model of Artemis to highlight some of the parts of the statue and identify them as either 'original Artemis', 'reworked Classical' or '18th-century new'. The basic animation shows a slowly rotating textured Artemis model, using different colours fading in and out to highlight the relevant pieces.

The 3D digitisation of Artemis has provided visitors with access to hands-on interactive exhibits that effectively enhance their learning experience gained from the audio-visual displays that sit alongside the original statue.

4. Conclusions

The case studies presented here clearly demonstrate the benefits that laser scanning and rapid manufacturing techniques can bring to an exhibition through aiding visualisation, enhancing accessibility, digital reconstruction and replication in both synthetic and natural materials. Both technologies have reached a point now where realistic replicas can be created and used in imaginative ways to enhance the learning experience of visitors. Replicas can be handled in a way that the original artefact often cannot and replicas can be transported without the high risk attached to an original unique artefact. Museums often have many artefacts in store, out of site and difficult to access. The advances in laser scanning over the last 5-10 years, the significant increase in the amount of memory available in standard personal computers and the availability of downloadable 3D viewers have meant that high quality 3D computer models can now be widely accessed. Although there are still issues for access to large data sets via the worldwide web, good quality 3D models of artefacts can now be accessed through the internet.

In addition to the benefits that these case studies have demonstrated, laser scanning has created a highly accurate 3D surface model of each artefact that will form an important part of its archive. Presently, many projects involving 3D digitisation in museums are undertaken for one reason only; it may be to create a replica or to produce a 3D animation for example. However, in many cases the full potential of the 3D dataset is seldom realised. The 3D digital model of an artefact is a valuable resource and with good planning, imagination and joined-up thinking between different museum departments can be used not just in a single exhibition, but in a range of other areas including: research, condition monitoring and income generation.

4. Acknowledgements

The authors are grateful to Christopher Dean, Sam Sportun and the Sculpture Conservation department of National Museums Liverpool for their expertise in hand-finishing of the replicas shown in this paper. The authors are also grateful to the Office of Science and Technology (of the UK Government) PSRE fund for financial assistance during the course of this work. The authors would also like to acknowledge the Manor House Museum (Ilkley, UK), Natural History Museum (London, UK), University of Manchester (Dr. Caroline Wilkinson), Historic Royal Palaces (UK), National Portrait Gallery (London, UK) and National Trust (UK) for their valued involvement in the case studies presented here.

5. References

[BCFF*04] BALZANI M., CALLIERI M., FABBRI M., FASANO A.: Digital representation and multimodal presentation of archaeological graffiti at Pompeii. In *VAST 2004, Proc. of 5th International Symposium on Virtual Reality, Archaeology and Cultural Heritage* (2004), pp.93-104.

[EF03] EKLUND J., FOWLES P. S.: Three-dimensional recording by laser scanning of the petroglyphs at Rombald's Moor, West Yorkshire. *Conservation and Management of Archaeological Sites 6*, (2003), 11-22.

[LPC*00] LEVOY M., PULLI K., CURLESS B., RUSINKIEWICZ S.: The digital Michelangelo project:3D scanning of large statues. In *Proc. SIGGRAPH 2000* (2000), pp.15-22.

[LTCF*04] LOSCOS C., TECCHIA F., CARROZINO M., FRISOLI A.: The museum of pure form: touching real statues in a virtual museum. In *VAST 2004, Proc. of 5th International Symposium on Virtual Reality, Archaeology and Cultural Heritage* (2004), pp.271-279.

[STH*03] STUMPFEL J., TCHOU C., HAWKINS T., MARTINEZ P.: Digital reunification of the Parthenon and its sculptures. In *Proc. of 4thInternational Symposium on Virtual Reality, Archaeology and Intelligent Cultural Heritage VAST* (2003).

[TDH05] TRINKS I., DIAZ-ANDREU M., HOBBS R., SHARPE K. E.: Digital rock art recording: visualising petroglyphs using 3D laser scanning data. *Rock Art Research 22*, 2 (2005), 131-139.

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
VAST (2006)
M. Ioannides, D. Arnold, F. Niccolucci, K. Mania (Editors)

3D Laser Scanning as a Tool for Conservation: The Experiences of the Herculaneum Conservation Project

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Abstract
The Herculaneum Conservation Project (HCP) is a project of the Packard Humanities Institute in collaboration with the Soprintendenza Archeologica di Pompei and the British School at Rome. The ancient Roman city of Herculaneum (Italy), which was destroyed and buried along with Pompeii by the volcanic eruption of Vesuvius in AD 79, has a history of excavation dating back to the early eighteenth century. The project arose from a recognition of the risks to the survival of the unique and irreplaceable heritage to be found in Herculaneum. Its aim is both to support the Italian heritage agency in the protection and preservation of the site, and to extend scientific understanding and public interest and awareness. The most immediate task is to halt the widespread decay afflicting the entire site. The longer-term aim is to develop a conservation strategy which will ensure its survival, understanding and enhancement. The project aspires to learn lessons that will not only feed into the management of the site of Herculaneum, but that can enrich conservation working practices in Pompeii and elsewhere.
In 2006 trials were launched to see how three-dimensional laser scanning could help the project, not only in terms of documentation, but also as a tool for monitoring decay and informing conservation decisions, and as a source of rich but accurate visual material to illustrate areas of the site currently closed for conservation works and thereby enhance the visitor experience. In collaboration with the University of North Carolina, the Suburban Baths were chosen for trial survey work with a 3rdTech Inc. DeltaSphere-3000 laser scanner. This Roman bathing complex is remarkably well-preserved with intact wood, metal and decorative features, but the delicate nature of these architectural features together with a variety of grave conservation problems throughout the structure mean the area is currently closed to visitors. The 3D survey work was carried out as an analytical basis for the technical/scientific studies that are underway in this building in order to conserve it and reopen it to the public.
This paper describes the experience of the HCP team using the 3D laser scanner, and discusses the success and challenges of the work and the potential applications the results have both for the mix of heritage professionals working within the HCP team and for the wider public.

Categories and Subject Descriptors (according to ACM CCS): I.4.1 [Image Processing and Computer Vision]: Digitization and Image Capture; I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism

1. Introduction to Herculaneum and the Herculaneum Conservation Project

The archaeological site of Herculaneum is located just south of Naples in Italy, and contains a large part of the Roman city that was buried by volcanic material during the eruption of Mount Vesuvius in AD 79. The nature of the city's destruction has led to a remarkable state of preservation, and the site is of particular note for the survival of buildings up to a height of several storeys, often with decorative features, fixtures and fittings intact, including a wealth of organic remains (wood, food stuffs, cloth, rope, etc).

When the most ambitious campaign of open-air excavations were carried out at Herculaneum in the early twentieth century, a programme of conservation and maintenance was launched and, for an initial period this ensured that although the archaeological remains were exposed to the elements they were offered some level of protection. However, within the later half of the twentieth century these programmes began to suffer a reduction in resources and eventually failed, leaving the site in an ever more serious state of decay with every year that passed.

In 2000 Dr David W. Packard of the *Packard Humanities Institute* visited Herculaneum and was so concerned about the conditions on site that he decided to launch a project to tackle the conservation issues. In 2001 an agreement was reached between the *Packard Humanities Institute* and the local heritage agency, the *Soprintendenza Archeologica di Pompei*, which resulted in the *Herculaneum Conservation Project* (www.herculaneum.org) [GCR05; CMRW06]. The project was further strengthened by the entry of the *British School at Rome* in 2004. These three partners continue to work together to identify and tackle the causes of decay on site and to develop a long-term conservation strategy that will ensure Herculaneum's survival, understanding and enhancement. The project aspires to learn lessons that will not only feed into the management of the site of Herculaneum, but that can enrich conservation working practices in Pompeii and elsewhere (for another example of a multidisciplinary conservation project tackling issues of data management see [Won05]).

The *Herculaneum Conservation Project* is made up of various specialists representing many different heritage professions, and this allows the site's conservation issues to be tackled by a multidisciplinary team. One of the areas that is being explored by a team from the archaeological company *Akhet* is survey, documentation and information management; and it was within this area that a collaboration was formed with the *University of North Carolina at Chapel Hill* for test surveys with a three-dimensional laser scanner. The first trials with this equipment were carried out in Herculaneum's Suburban Baths, a building chosen because of its archaeological importance, its closed spaces and the serious nature of its decay.

2. The Suburban Baths

The Suburban Baths were built in the Flavian period, next to the block of houses known as the *Insula Orientalis I*, on the side that faces onto the ancient shoreline (fig. 1). This building is the second large public bath complex known in Herculaneum, where so far only a single house has been found to have private bathing facilities.

Fig. 1: *View of the Suburban Baths in context at Herculaneum.*

Herculaneum's Suburban Baths are the best conserved bath complex that survives from antiquity (fig. 2); they are entered from an open area (probably used as a *palaestra*), through a door and down a flight of stairs (H1) to a vestibule (H/A), which is laid out around four central columns that support a double series of arches. From the vestibule the usual succession of differently heated rooms can be reached: the *frigidarium* (F) with a first pool of cold water, then a room with stucco decorations (E) from where, on one side, lies the *tepidarium* (T) with its large pool heated by a "samovar" system, and, on the other side, the *caldarium* (C) that still contains the large marble basin which was swept over by the volcanic mud flow and into which fell fragments of the smashed window glass. The baths were also equipped with a *laconicum* (L), or sauna room, accessible from the *tepidarium*, and a room with large panoramic windows overlooking the sea (D), which was also connected to the vestibule.

The topographical location of the baths with respect to the main urban area of the ancient city, and the dynamics that led to its burial in the AD 79 eruption, helped to ensure the

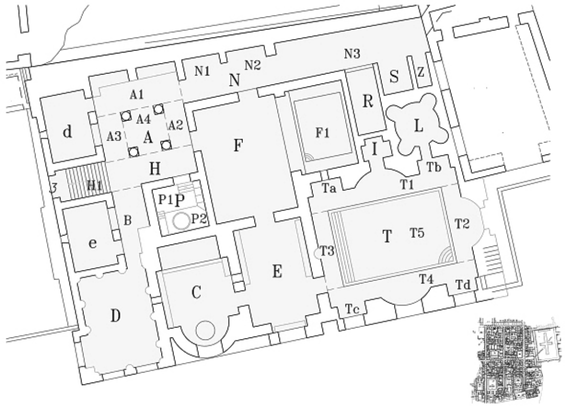

Fig. 2: *Plan of the Suburban Baths and their location within the archaeological site.*

complete preservation of the building's structure and a large part of its wall and floor decorations, as well as its furnishings and the bath's hydraulic infrastructure and some of the wooden fittings. In fact the mass of the volcanic material did not destroy the roof vaults, but entered inside the building and filled the rooms through doors and windows with such pressure that enabled it to fill the cavities between the walls and the typical linings found in Roman bath heating systems.

This extraordinary building is without equal in surviving ancient architecture, but its very uniqueness does however present extremely complex conservation problems, due to the range of materials it contains and the multiple causes of decay. Among the decay agents, it has been recognised that the main problem that the baths face is humidity, which is a consequence of the morphological and geological characteristics of the area (for an introduction to the research

Fig. 3: *The laser scanning equipment and some of the survey team at work.*

being carried out on water in Herculaneum, both its ancient supply and drainage systems, and the problems it currently causes, see [CMTW06]). The baths are in fact saturated both by surface water that drains off the *domus* above, and by ground water as it flows down to the sea. This problem, which surely existed in ancient times as well, has led to the deterioration of some of the vault linings of the *tepidarium* and has caused the Superintendency to close the building to the public.

Over the last year or so the *Herculaneum Conservation Project*, and its specialised team led by water engineer Ippolito Massari, has been monitoring the humidity levels in the building and proposals are being developed to solve the various problems brought about by the water infiltration and rising damp that are putting the building's conservation at risk.

3. Equipment

Three dimensional modelling of cultural heritage sites and objects using a laser scanner is a fairly recent technique. There is, of course, a long history of survey using theodolites and photogrammetry. A great deal of the earlier laser scanning work concentrated on statues and other objects [e.g. LPC*00]. More recently there have been projects to create dense 3D models of exteriors and interiors of cultural-heritage buildings and sites [AST*03; EBP*04; GLSA05].

The equipment used for the survey of the Suburban Baths was a *3rdTech Inc*. DeltaSphere-3000 laser scanner, which was kindly made available by Prof. Anselmo Lastra of the Department of Computer Science at the *University of North Carolina at Chapel Hill*; and the survey data were then managed with the associated software SceneVision-3D.

The DeltaSphere was designed for surveying small to medium spaces, and is primarily used by scientific police departments for crime scene surveys. It contains an infrared laser range-finder that uses a time-of-flight technique to compute the distance to the nearest points. A spinning mirror is used to capture the range to points in a vertical slice, and a motor rotates the complete unit to capture a total of 360° horizontally by 270° vertically. The measurements are accurate to ±0.3cm over a range of 0.3-15m.

Since the number of samples captured per degree can be set over a range from 5-20, the amount of data generated is quite large. The DeltaSphere is connected to a PC, usually a laptop for convenience in the field, in order to store the data on disk. This also enables monitoring as the scan is being collected. A colour option includes a digital camera that can be mounted on the unit. Technical details of the prototype from which the commercial produce was developed are available in [NLM*01].

With this scanner it is possible to register various scans without using georeferenced points, but instead by using those areas of scanned points that they have in common. This is done by using the iterative closest point (ICP) algorithm [BM92]. The operator chooses a small number of points to obtain an initial registration, and the algorithm refines the solution by minimizing the distance between the sets of points. The scans to be registered must contain enough overlap to ensure that ICP can reach a unique solution.

Another property of the instrument and its associated software is the possibility of mapping the surveyed surfaces both with photographs taken contextually with the scan, as well as with images taken from different positions. Currently points of correspondence between the colour and range images are chosen manually, but we expect that in the future it will be possible to map colour automatically [WLH*04; HL04].

Both the automated registration and the ability to map arbitrary colour images to range samples make work in the field much quicker. The SceneVision package includes a polygonal simplification [LRC*02] module that reduces the size of the captures geometric model in order to enable interactive display on a PC:

4. Fieldwork

After training for the survey team and a brief trial period, work was divided into two phases with the creation of a 3D model as the end result. Time issues related to the restricted availability of the equipment and limited access to the bath building led to a first fieldwork phase where all the numeric and photographic data were acquired; only later in a second phase was the data processing carried out and the model created.

The fieldwork phase lasted about four weeks, during which the measurements and photographs necessary for generating the model were acquired (fig. 3). In this phase various problems arose. For example, it was necessary to set up a number of survey stations, due to the quantity and characteristics of the spaces which make up the bath complex. There are a series of quite small rooms, with high vaults, that in some cases are two floors high (fig. 4).

Fig. 4: *An example of the complexity of the building's spaces.*

Another problem that is common to any type of survey carried out with a laser scanner, is the scanner's (and the camera's) viewpoint. The increased number of survey stations necessary to cover the rooms' surfaces was caused by the presence of protruding parts of the walls (stucco or plasterwork features), rather than corners or objects within the rooms (for example, scaffolding used for conservation work in progress). It also often proved to be difficult to move the equipment in the restricted spaces (fig. 5).

Alongside the scanning in the field, photographs were taken to create the 3D model. In this case the biggest difficulties were those related to the different light levels. The bath complex is partly on an underground level made up of closed spaces with marked variations in the amount of light, due to the various light sources (small windows in the walls or ceilings). This made it particularly difficult to obtain uniform images in terms of luminosity and contrast within each of the different rooms.

The high humidity levels in the rooms (see above) and the subsequent presence of dark-coloured mould and lichens also created problems for the scanner: the reflection of the laser ray, by which the triple coordinates of every single surveyed point are registered, either did not register or was extremely weak.

Where there were black surfaces, holes appeared in the mesh of points (although it should be noted that often surfaces that seemed black, were not so for the infrared frequencies and resulted in optimal surveys). A similar problem was found in those areas of the building where there was a significant amount of water on the walls, which equally limited the rays' ability to reflect.

5. Data processing and model creation

The model of the Suburban Baths is currently being finalized using the software SceneVision-3D, which is also by *3rdTech Inc*.

The aligning of single scans, so that the entire volume of the rooms is covered, is done by using common surveyed points, as mentioned above.

The next step is to also align the individual digital images that were recorded contextually with the scan in the field. At this stage it is necessary to ensure that the model's surface points are identified and made to correspond with the same ones on the images. In this way a point cloud is created, where every pixel of the image is associated with a numeric value and colour (fig. 6).

The final 3D model is produced by creating a triangulated irregular network (or TIN) by interpolating the measurements, which are then draped with digital images. It is saved as a VRML file, which is a 3D file format that can be exported, and that is readable with various visualizers freely available on the internet (the software used can also create a high resolution 3D model in the same way, but one with a regular mesh that respects the totality of the surveyed points, instead of an irregular TIN). The VRML standard makes it possible to import the 3D model into more common 3D graphic software programs (fig. 7).

In order to guarantee realistic perception of the model, particular care was taken to reprocess all the digital images, correcting their luminosity, contrast and colour uniformity.

In general terms the data processing phase, from the alignment of the scans to the texturization, proved to be long and complex; it was necessary to change format and use various 3D modelling software packages and adequate hardware. In fact it has been calculated that for every day of data gathering in the field a week of processing is needed in the office.

Fig. 5: *Some examples of the difficulties met during the survey work.*

Fig. 6: *Above: a complete 360° scan; below: the alignment of a digital image and the application of colour onto the scan.*

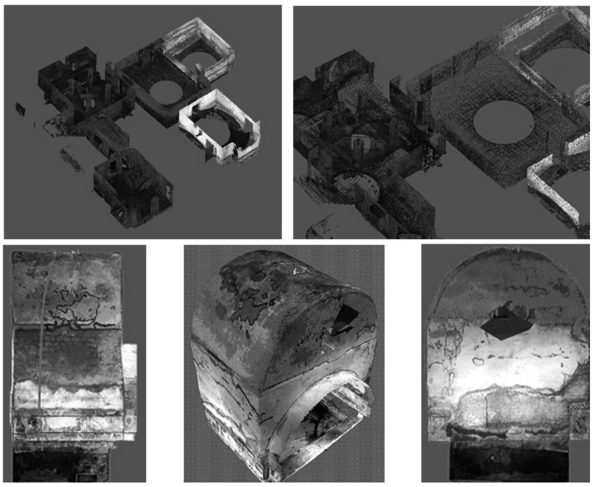

Fig. 7: *Above: views of the 3D model under construction; below centre: prospective view of a room, below left and right: two orthographic views.*

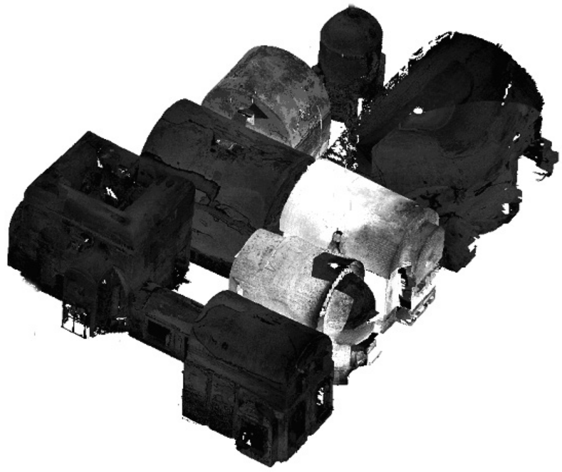

Fig. 8: *Prospective view of the model with various of rooms joined together.*

6. Results

The immediate result of creating a texturized digital model is an extremely realistic 3D virtual environment that can then be utilized as the basis for other uses (fig. 8).

The processing software contains tools that can take measurements (linear distances and angles) directly within the 3D model as soon as it is generated (fig. 9). The data are recorded as text notes that can be recalled and modified according to need. Other graphic editing tools allow linear and polygonal elements to be drawn on the model, and these can be labelled either with alphanumeric and hyperlink labels that connect to external data (files or database records). These created elements themselves can be exported in VRML format and managed separately within the graphic processing software.

Considering the normal requirements of an architectural survey, the numeric model has the capacity to totally describe a surveyed object and offer a result that is very similar to reality. Unlike traditional surveys, where only a small number of an object's points are measured (meaning that the missing and interpreted areas are greater than the data objectively surveyed), with the 3D scanner the object's surfaces enormous numbers of points are measured and represented by a mesh obtained from their interpolation. This theoretically allows an infinite number of two-dimensional projective models (plans, sections and elevations) and three-dimensional models to be created, which are not dependent on the viewpoints established *a priori*. The possibility of having available the total coverage of a building, in terms of data acquisition, changes the very idea of a survey and its scale of reference. Unlike a traditional plan where the choice of section cannot be changed, 3D laser scanner technology allows sections to be created through the digital model at any point according to what is required. This is as true for the horizontal planes (plans) as for the vertical ones (sections and elevations; fig. 10).

However, faced with these undeniable advantages the real needs of the survey archaeologist should not be forgotten, whereby the main aim of any survey is to gain critical information, whatever the nominal scale that it is done at. It is only by direct observation that an object can be defined, divided into its component parts, characterised and interpreted.

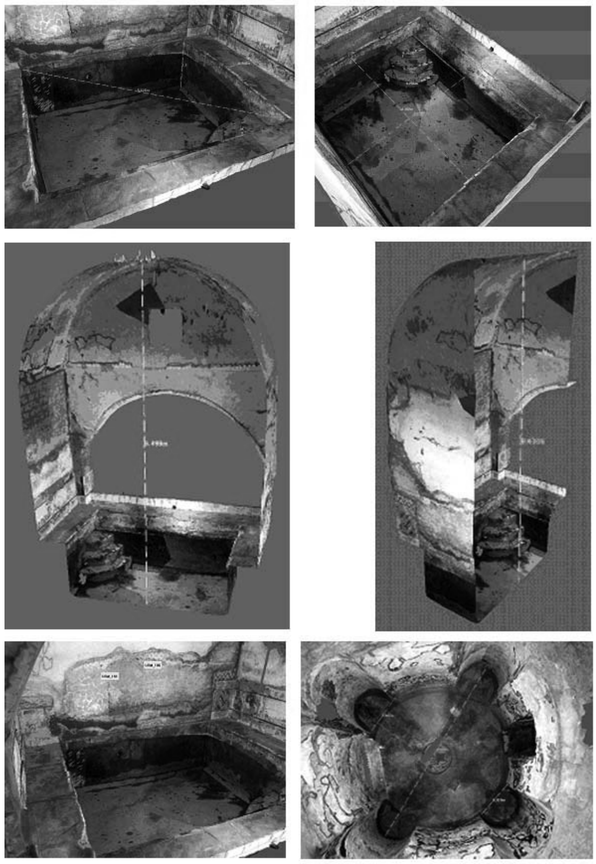

Fig. 9: *Examples of measurements and analysis of parts of the model within the management software.*

Therefore, only if the two methodologies – old and new – are thoughtfully integrated can the best results be obtained in terms of representation, comprehension and transmission of data – all by definition fundamental elements of a good archaeological survey.

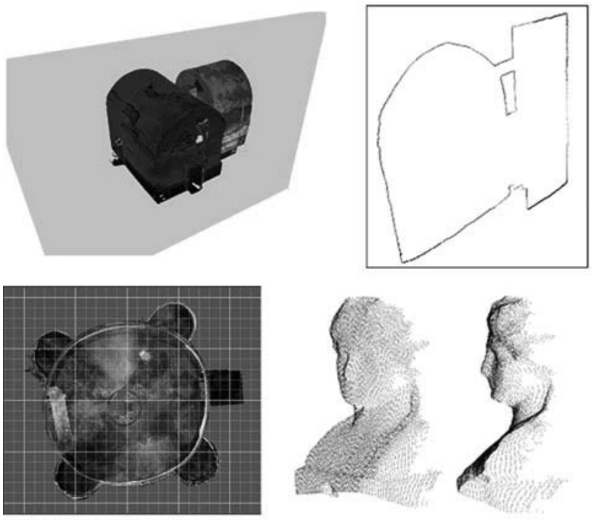

Fig. 10: *Examples of sections or plans drawn from the model.*

Another application of the model relates to data management in a 3D GIS environment for an interdisciplinary analysis of a structure. Within the *Herculaneum Conservation Project*, a geodatabase was created for Herculaneum's *Insula Orientalis I* [BDS*05]. It was structured so as to archive the graphic documentation and recording forms used in archaeological analyses and conservation interventions. In this case the 3D model was created from plans and elevations obtained with traditional methods (direct instrument survey and rectified digital photographs). The aim was to create a 3D model to which the spatial and alphanumeric information could be linked, and then managed with GIS software.

In the case of the Suburban Baths, should a similar research project be launched there, it would be possible to use the model obtained with the laser scanner for the 3D spatial basis, greatly facilitating the documentation of every single element of the building.

The use of the laser scanner offers another possible application, as by using processing software it is possible to drape the 3D model with images that were not taken at the same time as the scan.

The model can be used as a very detailed base onto which archive images can be aligned, for a comparison between the state of the structure at the time of its discovery and the current situation (fig. 11). Obviously this method can also be applied to images that were taken from various photographic campaigns, without the need of taking new scans. It is clear that this would allow an almost continual monitoring of the decorative features' and the structure's state of decay (for another example of the application of 3D laser scanning to the recording and monitoring of archaeological sites see [BCD*05]). In this context, the possibility of carrying out scans only of those areas that are subject to specific forms of decay or that need particular attention could be considered, and these scans could then go to integrate or update an already existing scan.

In fact, a modest campaign of emergency laser scanning was recently carried out by *Akhet* on spaces across Herculaneum that are both spatially and decoratively elaborate, and that are particularly vulnerable to immediate loss of archaeological features (due to the speed of deterioration and the difficulties of intervening promptly). This allowed the project to exploit the potential for rapid data collection with data processing at a later stage.

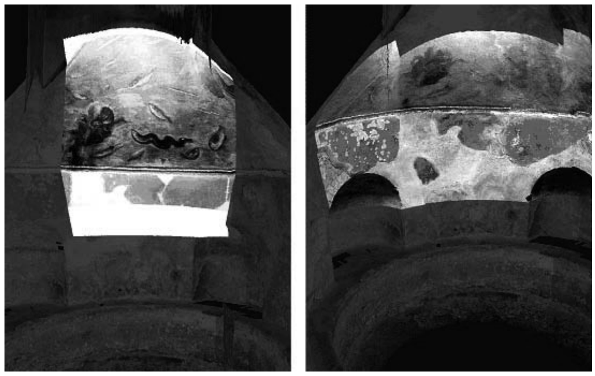

Fig. 11: *Example of the model using a photograph taken during the scan (right), compared to an archive photo (left).*

In the case of the Suburban Baths, the building's state of decay caused the closure of the complex to the public. However, the use of this technology has allowed us to create complete graphic documentation (3D and photographic surveys). It will be possible to create a virtual tour within the model, which would immediately allow the architectural spaces to be experienced and also shows the decorative complexity of the building. This is undoubtedly a huge advantage offered by this survey technique. The texturized digital model is, in fact, an extremely realistic environment that can constitute the base for any type of multimedia processing of the product (video, virtual reality, etc) in such a way as to allow a building to be enjoyed both in cases when it becomes inaccessible, as well as in the case where the archaeological site is at a distance (virtual tours via the internet, for example). The *Herculaneum Conservation Project* will be exploring the best ways to offer this potential tool to visitors to the site, and to a distant but interested public online, as part of a research and outreach programme (for example, the use of IT applications for distance learning of heritage subjects has been explored more thoroughly in the case of the ancient history syllabus in New South Wales, Australia where Herculaneum is studied by around 10,000 students a year, the majority of whom cannot visit the site in person, see [Cou06]).

7. Conclusions

The opportunity offered by the collaboration with the *University of North Carolina at Chapel Hill* to experiment with laser scan surveying was not only advantageous to the *Herculaneum Conservation Project* in terms of data acquisition and technological advances, but also because it offered a chance to employ a reflexive methodology.

The latest technology does not necessarily present the best choice in conservation, as it can be time-consuming without offering concrete benefits beyond the aesthetic. Technology can also create a certain distance between the archaeological remains and the surveyor, which does not contribute to thoughtful analysis and consideration of a structure's complex history and conservation needs. However, where technology is thoughtfully employed the benefits can be great. In this case, the *Herculaneum Conservation Project* benefited from the fact that the *3rdTech Inc*. DeltaSphere-3000 laser scanner, and related software, is a tried and tested instrument used widely by law enforcement agencies in the USA, as this offered us advanced technology that had already undergone extensive "road testing" and ensured optimum application. 3D laser scanning is being tested for its use in long-term monitoring of decay situations (even from periods prior to the project that are only documented in archive photographs), and for its ability to offer almost infinite views of the building, which will prove incredibly helpful in future conservation efforts.

From this strictly technical point of view the 3D laser scanner technology is an increasingly important tool for archaeological survey and restoration work. However, this work should also be seen in the light of the Herculaneum Conservation Project's efforts not only to be multidisciplinary in its planning stages but also in the more delicate site-works phase. Work on site notoriously requires flexibility, speed and the immediate use of analytical data in order to develop linear operations, and in these cases a 3D laser scan of an entire building complex (such as the Suburban Baths) can provide rapid data acquisition and complete data coverage. These two basic elements then become "common ground" for discussion among all the consultants, present and future.

From our point of view a 3D model offers: an extremely flexible tool that can instantly create plans or sections for the planning phase of works (for architects); an objective basis from which to monitor and evaluate static and environmental risks (for architects, structural engineers, conservator-restorers); a method for comparing past graphic and photographic documentation (for conservator-restorers, archaeologists); a three-dimensional basis for managing GIS data (for archaeologists, conservator-restorers, technical experts); a starting point for creating hypothetical virtual reconstructions (for archaeologists); an opportunity for academics and members of the wider public to "visit" a building that is inaccessible during conservation works or at a long distance (for the public).

The spirit of this initiative was to provide a practical tool while experimenting and comparing different approaches to surveying in an archaeological and conservation context. If this perhaps appears to be simply the latest 3D laser scanning project, it should also be noted that a specific effort was made to ensure that a thorough and high-quality project was carried out in order to define the limits and advantages of this tool within a multidisciplinary and symbiotic project – perhaps establishing a further point of departure for the evaluation of new technologies in this particular applied field.

8. Acknowledgements

The work described in this paper was carried out as part of the *Herculaneum Conservation Project*, and we would like to acknowledge and thank the project partners: the *Packard Humanities Institute,* the *Soprintendenza Archeologica di Pompei* and the *British School at Rome*. In addition thanks are due to all the *Herculaneum Conservation Project* team who continually offer positive input to each aspect of activity on site, and in particular to Jane Thompson and Domenico Camardo, who offered feedback on drafts on this paper.

Finally, we would like to recognise the generosity of the Department of Computer Science at the *University of North Carolina at Chapel Hill* who loaned us the 3D laser scanner equipment, and we are particularly grateful for the energy and expertise of Prof. Anselmo Lastra.

9. References

[AST*03] ALLEN, P., STAMOS, I., TROCCOLI, A., SMITH, B., LEORDEANU, M. & MURRAY, S. New Methods for Digital Modeling of Historic Sites. In *IEEE Computer Graphics and Applications* (2003), 32-41.

[BCD*05] BARNETT, T., CHALMERS, A., DÌAZ-ANDREU, M., LONGHURST, P., ELLIS, G., SHARPE, K. & TRINKS, I. 3D laser scanning for recording and monitoring rock art erosion. In *International Newsletter on Rock Art 41* (2005), 25-29.

[BDS*05] BRIZZI, M., D'ANDREA, A., SEPIO, D., DE SILVA, M. & COURT, S.: Planning a conservation project: the information system of the Insula Orientalis I. In *International Cooperation to Save the World's Heritage: CIPA 2005 XX Symposium, 26 September-1 October 2005, Torino, Italy* (2005), 691.

[BM92] BESL, P.J. & MCKAY, N.D.: A method for registration of 3D shapes. In *IEEE Pattern Analysis and Machine Intelligence 14* (1992), 239-256.

[CMRW06] CAMARDO, D., MARTELLI CASTALDI, M., RIZZI, G. & WALLACE-HADRILL, A.: The Herculaneum Conservation Project. *Oebalus 1* (2006).

[CMTW06] CAMARDO, D., MARTELLI CASTALDI, M., THOMPSON, J., & WALLACE-HADRILL, A.: Water supply and drainage at Herculaneum. In *Die Symposiumsakten "Cura Aquarum in Ephesus"* (2006).

[Cou06] COURT, S.: The Herculaneum Conservation Project and learning initiatives. *Teaching History 39*, 4 (2006), 38-44.

[GLSA05] GIUFFRIDA, A., LIUZZO, M., SANTAGATI, C., ANDREOZZI, L. The laser scanner for archaeological survey: "Le Terme Dell'indirizzo" In *Proceedings of CIPA* (2005).

[EBP*04] EL-HAKIM, S., BERALDIN, A., PICARD, M. & GODIN, G. Detailed 3D reconstruction of large-scale heritage sites with integrated techniques. In *IEEE Computer Graphics and Applications 24.3* (2004), 21-29.

[GCR05] GUIDOBALDI, M.P., CAMARDO, D. & RIZZI, G. (2005) The Herculaneum Conservation Project. In *Nuove ricerche archeologiche a Pompei ed Ercolano* (2005), 9-18.

[HL06] HANTAK, C. & LASTRA, A. Metrics and optimization techniques for registration of color to laser range scans. In *Third International Symposium on 3D Data Processing, Visualization and Transmission* (2006).

[LPC*00] LEVOY, M., PULLI, K., CURLESS, B. ET AL. The digital Michelangelo project: 3D scanning of large statues. In *Proceedings of SIGGRAPH* (2000), 131-144.

[LRC*02] LUEBKE, D., REDDY, M., COHEN, J., VARSHNEY, A., WATSON, B. & HUEBNER, R. *Level of Detail for 3D Graphics.* Morgan-Kaufmann, 2002.

[NLM*01] NYLAND, L., LASTRA, A., MCALLISTER, D., POPESCU, V. & MCCUE, C. Capturing, processing and rendering real-world scenes. In *Videometrics and Optical Methods for 3D Shape Measurement (SPIE 4309)* (2001), 107-116.

[WLH*04] WILLIAMS, N., LOW, K., HANTAK, C., POLLEFEYS, M. & LASTRA, A. Automatic image alignment for 3D environment modeling. In *Proceedings of the 17th Brazilian Symposium on Computer Graphics and Image Processing* (2004), 388-395.

[Won05] WONG, L. From Silk Road to digital domain: managing information for a wall paintings conservation project. In *Conservation: the Getty Conservation Institute Newsletter 20.3* (2005), 21-24.

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
VAST (2006)
M. Ioannides, D. Arnold, F. Niccolucci, K. Mania (Editors)

3D Modelling for the Urban Area "Porta Napoli "

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ABSTRACT

Within the Prize New EPOCs (reNEWing Economic prosperity for POrt Cities) the urban modelling of the area between Porta Napoli and the Molo Polisettoriale is realized with the purpose to preserve both patrimony and cultural identity of the port area in Taranto. Today this area includes some architectural complexes of extraordinary importance, ancient shops useful in the past for the storage of big amounts of agricultural products and the church of S. Maria in Costantinopoli completely rebuilt after its moving in 1928.

A 3D model of the urban area actual state is realized using integrated survey methodologies (traditional topographical survey, GPS, photogrammetric survey, laser scanners and remote sensing). On the base of historical - opportunely georefered - cartographies the urban evolution of the area is chronologically reconstructed by 3D modelling in environment GIS, and a recovery plan is suggested in order to improve the port area.

1. The ionic inlet of Taranto gulf

Taranto city (figure 1) rises on a strip of land between two seas; outside Mar Grande connected to that inside Mar Piccolo through two channels, the natural one on the west of the island where the historical city rises and the artificial one on to east. The first one is crossed by Porta Napoli Bridge (St. Egidio), the second one by the Revolving Bridge.

The historical nucleus rises on a portion of land currently set a part from the firm land, the modern city on the two portions of firm land. The first one developed in disproportionate manner and with the principal city institutions, the second one, instead, for a long time neglected by the town planning becoming place of the principal industrial and productive activities.

Figure 1: *Map of Taranto city.*

1.1 Area of study

The area of study is the urban portion expanded over the Porta Napoli Bridge (figure 2); it has a triangular form and is limited on the north by the railway line, on the east by Mar Grande and on the south by Mar Piccolo. Today it is strongly congested and degraded and shows evident contradictions because of stores connected with the port activity and the principal systems of communication and access to the city.

Notwithstanding the original centrality, this area becomes marginal and peripheral for the presence of the terminal buses, of the port and the railway station [CDPR78].

Figure 2: *Aerial view of Porta Napoli area.*

1.2 Object of the research

The centrality of the area and the function of entrance pole to the city makes necessary an urban intervention that gives back new dignity to the area and is occasion for adding a series of new functions to the already existing ones [PS89].

This intervention, of course, cannot leave out of considerations the analysis of the events that make peculiar the conformation and the definition of the area; our analysis of the urban transformations goes from the beginning of 800 to our days with attention above all to meaningful moments of development.

1.3 Historical reconstruction

The reconstruction starts from the actual configuration of this urban portion, on the base of the aereophotogrammetric surveying and a new acquired data, and comes back to the beginning of XIXth century. The research, in fact, underlines a progressive decrease of the documentation in time, therefore we choose to limit the investigation to this date.

We also choose a methodology of metric approach that allows a clear reading of the elements we have. Therefore we bring all the cartographic sources in the same planimetric projection system (georeferentation) and use survey methodologies able to reconstruct elements of architectural meaning and historical value [CB87].

2. Metric restitution

The increase of raster informative sources (figure 3) - as for instance ortophotos - high resolution images and historical cartographies allow today to prepare a lot of useful files within urban improvement planning and in general in territorial planning.
Just to avoid data become unusable, it is of the main importance that their analysis happens in short times with the cognitive support of cartography and places.

Figure 3: *Iconographic documentation.*

In the metric analysis the historical cartographies present a strong dishomogeneity due to the different modality of cartographic representation and due to the geomorphology and urban changes in the area.
It is necessary in fact, also for the georeferentation of the maps, to follow an approach inverse to chronological evolution.
The metric restitution is realized performing a first survey planning and a planning of the operational formalities, pointing out common and easily recognizable points between the aerophotogrammetric survey (1999) at our disposal and the ground.
Subsequently, we have georeferentated the historical documents on the base of the Ground Control Points (GCPs) that are surveyed (image to map method) and present on the maps and on the base of new points recognizable on the different maps (image to image method).

2.1 Georeferentation of the images

For georeferentation of the images in a established system of reference, it is required to point out of land control points (GCP) to remove the accidental distortions and the residual unknown systematic distortions, inherent to the raw data.
To point out the parameters of the transformation (translations, rotation and scale factor) is necessary have a certain number of points of known coordinates, easily recognizable on the image.
To avoid intrinsic distortions in some images, it is necessary to perform transformations based on precision algorithms among which: projective, that associates a notparallel grate to a parallel grate (transformation to eight parameters); similar, based on a linear model that corrects rotation, translation, affinity and staircases in X and Y (bidimensional transformation to six parameters); Helmert, built on a linear model that corrects rotation, translation and a constant scale factor in X and Y (conformed transformation and bidimensional to four parameters); Polynomial Equations, constituted by complex mathematical models, the degree of the complexity of the polynomial is expressed as the order of the polynomial; Finite Element, model used for correcting images that have not conformed distortions, as those produced by an airborne analyser [CCT03].

2.2 Methodology of survey

Two sessions of measures GPS are performed of 32 GCPs, employing contemporarily more receivers in the three days of surveying.
In the observations four double frequency receivers operate contemporarily, three of them work in fast-static formality, and the fourth one is the permanent station installed on the DIASS - Politecnico di Bari.
The average duration of the sessions, related to the acquisition of the mobile points, is of 15 minutes and 45 baselines are measured altogether with distances that don’t overcome 9 kms.
The calculation of the baselines is performed by dividing the session of measure in 3 subsessions, each of them with reference to one day of observation.

2.3 The process of georeferentation

Below some results of the georeferentation adopted for an IKONOS image are shown and different historical cartographies in fully grown raster [CCC*01].
The goodness of the operations is appraised: both differences between coordinates that are read on the georeferentated images and the cartographic coordinates and both the difference between coordinates of the image and by surveying obtained coordinates GPS, as comparing the distances between points measured on the image or on the georeferentation cartography and the same distances measured with land surveying or on the cartography. Finally, we proceed to georeferentation of each image and almost-automatic vectorialization of the same ones (figures 4-5-6-7).

Figure 4: *Georeferentation and vectorialization map by Saint Bon 1865-66.*

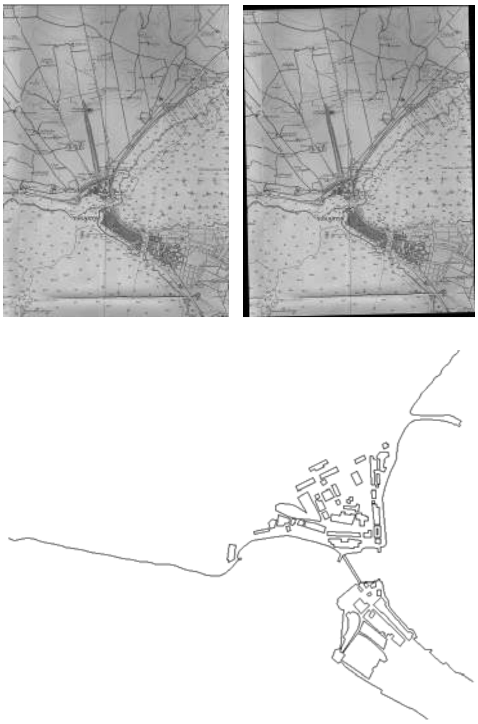

Figure 5: *Georeferentation and vectorialization map of Mar Grande e Mar Piccolo (1890).*

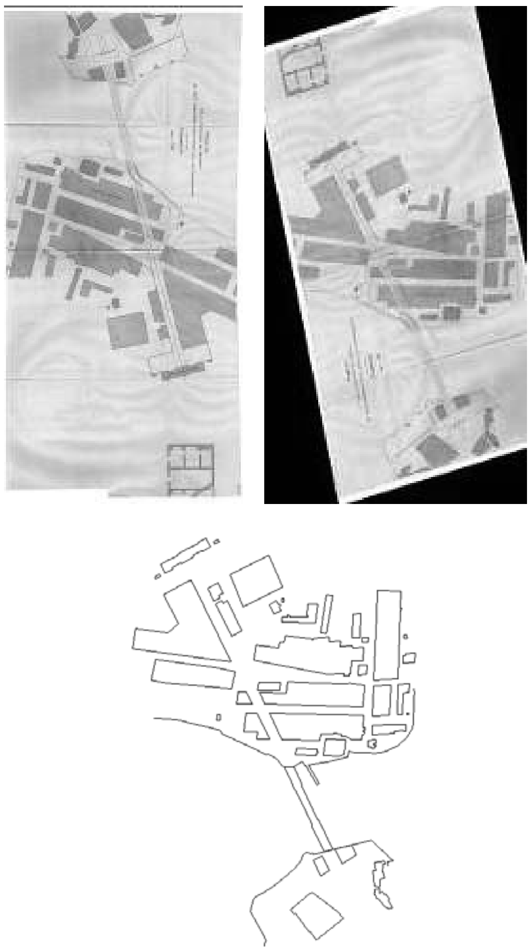

Figure 6: *Georeferentation and vectorialization map (1926).*

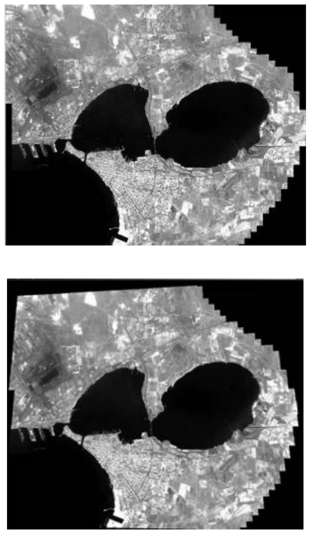

Figure 7: *Georeferentation and vectorialization IKONOS.*

3. 3D modelling

A 3D model contains a quantity of informations that can be analyzed and increased and that can be used for the understanding of a site.
That is important for all sites of artistic and historical interest whose documentation becomes fundamental in case of loss or damages (figure 8-9-10-11-12-13-14-15).
A 3D model of the present state allows a possible intervention of restauration or improvements faithful to the original form. It is desirable that such models result practical and efficient to be managed with commercial and easily modifiable tools, also preserving elevated geometric resolution and accuracy.
Today the above said results can be reached thanks to the new surveying technologies in particular through laser scanning, which allows, in rapid times and with suitable precision, to get realistic and each other integrating with already consolidated techniques models 3D of the investigated object.
The obtain results allow the constitution of a 3D metric file in continuous updating and that is also necessary to appraise possible phenomena of degrade and damage.

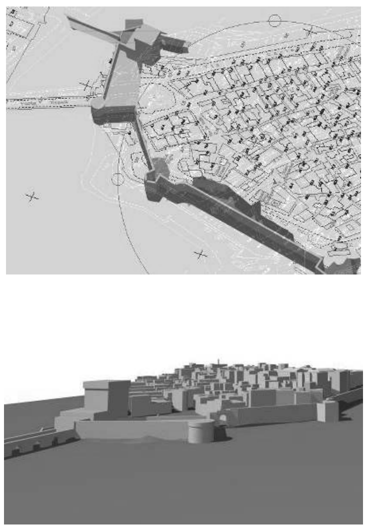

Figure 8: *Construction of urban transformation 1800.*

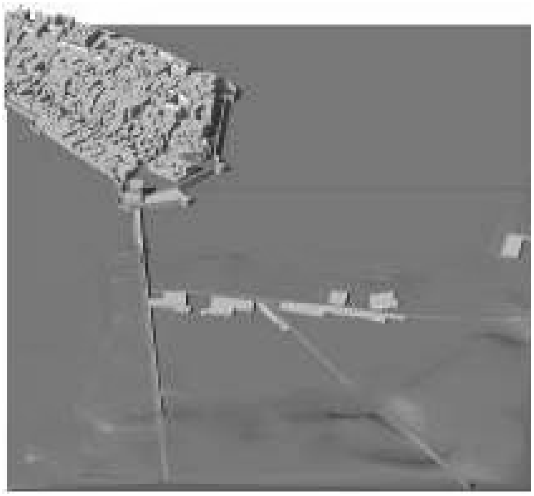

Figure 9: *Urban transformation 1800.*

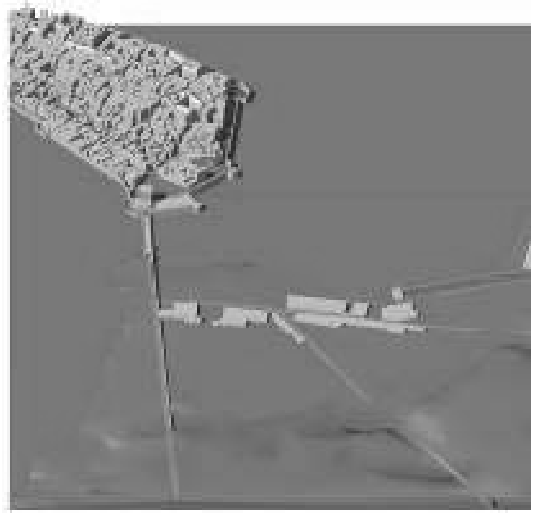

Figure10:– *Urban transformation 1860.*

Figure 11: *Urban transformation 1885.*

Figure 12: *Urban transformation 1900.*

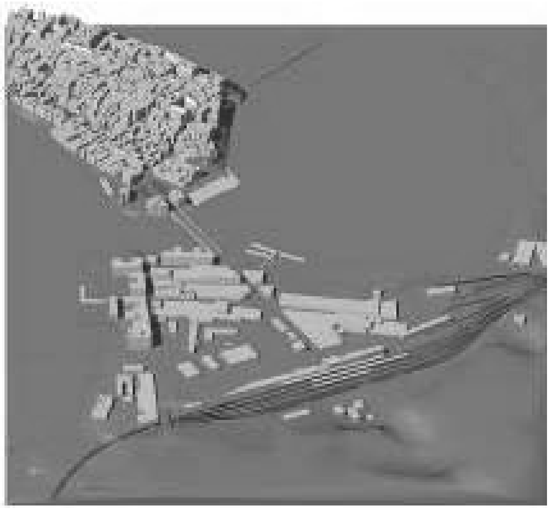

Figure 13: *Urban transformation 1930/40.*

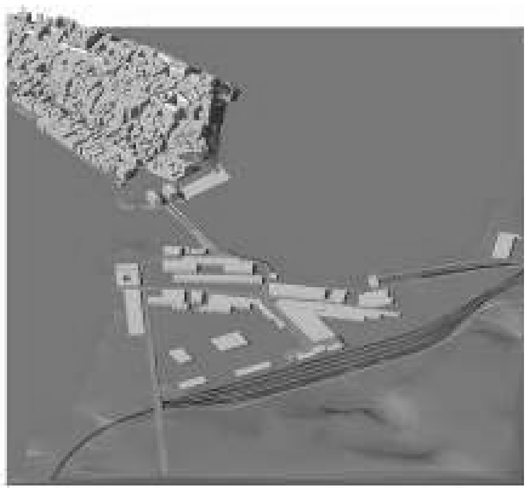

Figure 14: *Urban transformation 1960.*

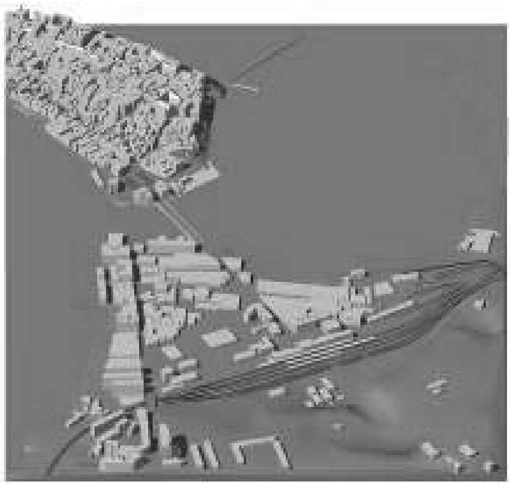

Figure 15: *Today.*

4. Laser Scanner survey

The object that is selected to apply the methodology of laser scanner surveying is the Porta Napoli Bridge, because of its architectural and historical value. In fact it is a strategic link between the historical area and the expansion on the firm land. The actual configuration is only the last one of series of structures (figure 16-17) followed each other from the beginning of '800 to today (figure 18).

Figure 16: *Porta Napoli bridge (1890).*

Figure 17: *Porta Napoli bridge (1930).*

Figure 18: *Porta Napoli bridge today.*

The laser survey activity is planned on the base of a project thought (figure 19) following a series of examinations where different strategies of intervention are singled out, necessary either for the creation of a topographical support net or for the individualization of the points of the taking laser scanners [CCR*05].
The surveying project is checked and simulated on the field, by singling out the net and the single stations; the net and the relative detail points are simulated in the laboratory through specific software with the purpose to quantify the obtainable precisions previously with the instruments used for the phases of surveying.

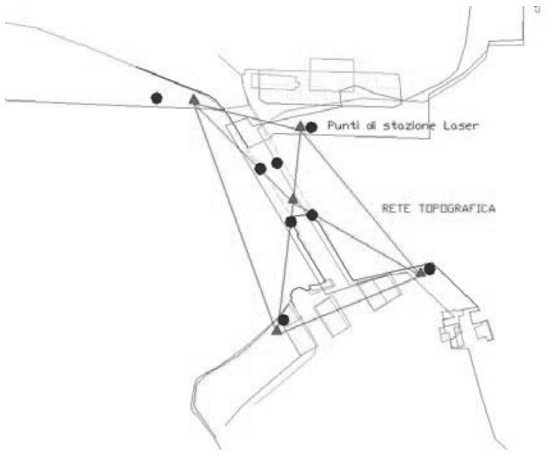

Figure 19: *Survey project.*

The laser acquisitions are realized using a Laser HDS 3000 Leica. To integrate the data acquired with laser scanner and topographical surveying, special monographs of the natural points and a detailed diary of all points are compiled.
The clouds points, as result of single acquisitions, are, in a first moment, assembled to obtained front west, front east and above unities (figure 20).
Subsequently the clouds points are assembled on the base of topographical survey using the targets and the natural points recognizable in the scannings in order to constitute a single cloud coherent with an only system of reference (figure 21).

Figure 20: *Assemblage of point clouds.*

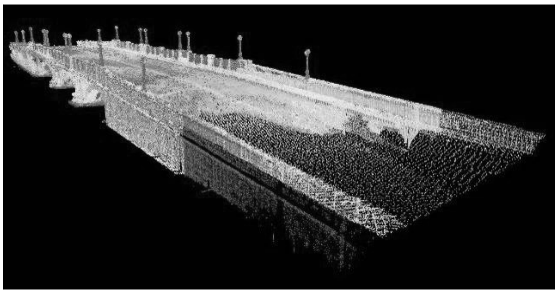

Figure 21: *Representation 3D of point clouds.*

Meaningful elements of the constructive and decorative apparatus are chosen for later elaborations (figure 22-23-24).

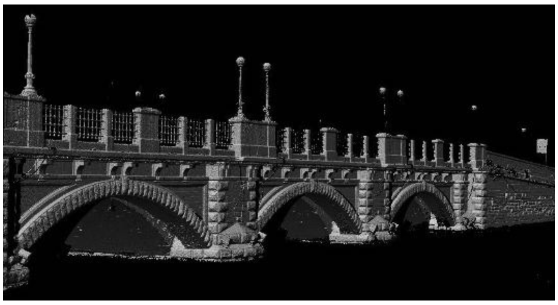

Figure 22: *Representation 3D for complex mesh.*

Figure 23: *A particolar of model.*

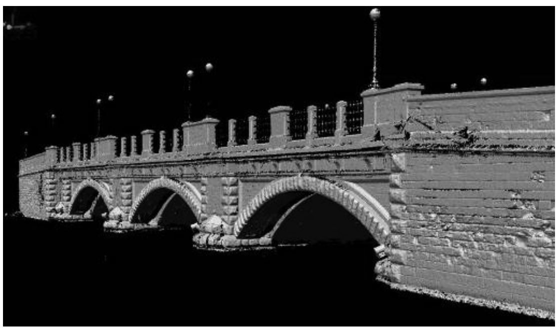

Figure 24: *A particular of model.*

5. Guidelines for a "Parco Urbano Portuale"

The here advanced proposal foresees the realization of a "Parco Urbano Portuale" for Taranto and individualizes some guidelines for a future planning.

The activity intends to move the centre of the city toward the western suburb by creating a new equipped area with positive relapses on the process of improving the bordering historical centre [R03].

The recovery of the historical area can become occasion to endow the city of a series of equipments and services of public utility.

The investigation on the urban transformations underlines pregnant priority of historical value that can be guidelines for the intervention planning.

Besides the proposal includes strategies to evoke the cultural character of the area and underlines the relationship between city and sea by increasing pedestrian areas, with additional services for tourism and for the activities of leisure time, by improving the open public spaces and by helping the question of new occupational figures.

It is foreseen also preservation politics regarding historical buildings, founds of industrial archaeology, with the objective to find in them new spaces for the museum of fishing, of the tradition of *mitilicoltura*, of the handicraft, etc..

This proposal is a light transformation respectful of the historical values of the area that foresees superficial interventions of lifting and radical interventions of demolition and reconstruction according to the guidelines for the creation of a "Parco Urbano Portuale" (figure 25-26-27-28-29-30).

Figure 25: *Parco Urbano Portuale.*

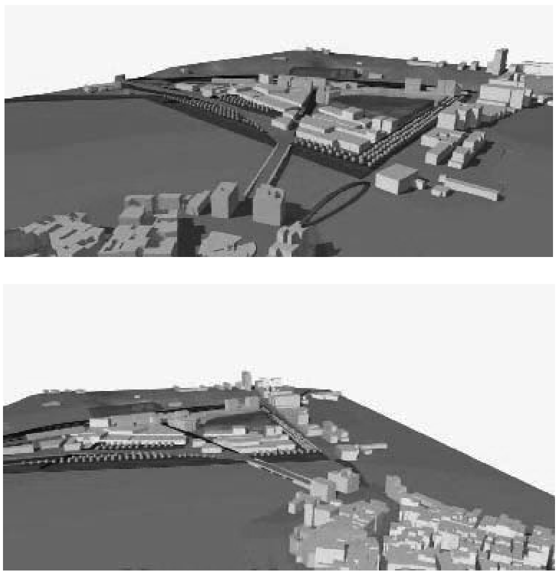

Figure 26: *Parco Urbano Portuale - 3D Simulation.*


Figure 27: *Parco Urbano Portuale – Simulation.*


Figure 28: *Parco Urbano Portuale – Simulation.*


Figure 29: *Parco Urbano Portuale – Simulation.*


Figure 30: *Parco Urbano Portuale – Simulation.*

6. References

[CDPR78] V. Cazzato, R. Davanzo, M. di Puolo, E. Rosio, AA.VV.: *Il porto di Taranto*, (1978), Roma.

[CCC*01] Capra, M. Caprioli, D. Costantino, A. D'Addabbo, S. Gagliardi: *Immagini telerilevate ad alta risoluzione per l'aggiornamento cartografica*, (2001) Atti della 5ª Conferenza ASITA – Ed. Artestampa s.a.s., Daverio (VA) Rimini, pp. 363-368.

[CCT03] Capra, D. Costantino, S. Todaro: *La georeferenziazione delle immagini cartografiche e telerilevate*, (2003) Atti della 7ª Conferenza ASITA – Ed. Artestampa s.a.s., Galliate Lombardo (VA), Verona, pp. 597-602.

[CCR*05] A. Capra, D. Costantino, G. Rossi, M. G. Angelini, M. Leserri: *Survey and 3D modelling of Castel del Monte*, (2005) - CIPA XX International Symposium – International Cooperation to save the World's Cultural Heritage – Torino, pp. 183-188.

[CB87] Carlone, G., Blasi, O.: *La Provincia di Taranto. Atlante storico della Puglia*, vol. 3 (1987), Cavallino (LE).

[PS89] F. Porsia, M. Scionti: *Taranto. Le cento città d'Italia* (1989), Ed. Laterza, Bari.

[R03] G. Rossi: *Piazza dei Mercadanti a Lecce. Indagini grafico/visuali sulle trasformazioni urbanistiche di Piazza Sant'Oronzo*, (2003) Collana Imagines, Studi su architetture, ambienti e città del Mezzogiorno d'Italia, Ed. del Grifo, Lecce.

Acknowledgement

SCUE Studio di Consulenza per l'Unione Europea; Archivio di Stato di Taranto; Archivio Storico Comunale; Leica Geosystems S.p.A.; Comune di Taranto.

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
VAST (2006)
M. Ioannides, D. Arnold, F. Niccolucci, K. Mania (Editors)

VENUS, Virtual ExploratioN of Underwater Sites

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Abstract

The VENUS project aims at providing scientific methodologies and technological tools for the virtual exploration of deep underwater archaeology sites. Underwater archaeological sites, for example shipwrecks, offer extraordinary opportunities for archaeologists due to factors such as darkness, low temperatures and a low oxygen rate which are favourable to preservation. On the other hand, these sites cannot be experienced first hand and today are continuously jeopardised by activities such as deep trawling that destroy their surface layer. The VENUS project will improve the accessibility of underwater sites by generating thorough and exhaustive 3D records for virtual exploration. The project team plans to survey shipwrecks at various depths and to explore advanced methods and techniques of data acquisition through autonomous or remotely operated unmanned vehicles with innovative sonar and photogrammetry equipment. Research will also cover aspects such as data processing and storage, plotting of archaeological artefacts and information system management. This work will result in a series of best practices and procedures for collecting and storing data. Further, VENUS will develop virtual reality and augmented reality tools for the visualisation of and immersive interaction with a digital model of an underwater site. The model will be made accessible online, both as an example of digital preservation and for demonstrating new facilities of exploration in a safe, cost-effective and pedagogical environment. The virtual underwater site will provide archaeologists with an improved insight into the data and the general public with simulated dives to the site. The VENUS consortium, composed of eleven partners, is pooling expertise in various disciplines: archaeology and underwater exploration, marine robotics and instrumentation, knowledge representation and photogrammetry, virtual reality and digital data preservation.

Categories and Subject Descriptors (according to ACM CCS): I.3.7 [Computer Graphics]: Virtual Reality

1. Project Summary

The VENUS project aims to provide a virtual exploration of deep underwater archaeological sites. Virtual exploration of our underwater environment will permit both experts and the general public to study interesting archaeological sites in a safe, cost-effective and pedagogical environment.
Precious underwater archaeological sites, for example shipwrecks, are continuously jeopardized by activities such as trawling that destroys the crucial surface layer of the site. The generation of a thorough and exhaustive 3D record of these wrecks consequently gains importance daily. These sites can never be experienced first hand by the majority of archaeologists or the general public: our project will provide a faithful accurate 3D immersive reconstruction of the

site providing virtual access to all. Our project is composed of five objectives: Initially we will define a series of best practices and procedures for collecting and storing data in an efficient, economic and safe way from the underwater archaeological site.

Our second objective will be to survey wrecks, (at various depths), using AUVs / ROVs (Autonomous Underwater / Remotely Operated Vehicles) and various techniques of data acquisition (sonar + photogrammetry). We will then provide archaeologists with software tools for signal, data and information processing and management. The generation of these tools is our third objective and will allow the extraction of digital models and management of confidence levels of the data collected from objective two.

Our fourth objective is to generate virtual reality and augmented reality tools for the immersive interaction and visualization of the models created in objective three. These tools will provide archaeologists with an improved insight into the data and the general public with simulated dives to the site.

Finally we will disseminate our results via a dedicated website and publications within the field of archaeology, sea exploration, photogrammetry and virtual reality.

2. Project Objective

The VENUS project aims at providing scientific methodologies and technological tools for the virtual exploration of deep underwater archaeology sites. This exploration relies on the accurate construction of a virtual submarine environment representing the site. The VENUS project is a pipeline of five steps:

- Data acquisition on the site;
- Data processing and storage;
- Construction of a virtual model of the site;
- Plotting archaeological artefacts and information system management;
- Dissemination of the procedures adopted for data acquisition and processing, as well as software tools and end-results of the project via traditional and internet publication.

This pipeline process will provide a fully functional virtual environment for archaeologists and the general public. Each step raises interesting research problems and technical challenges.

2.1. Motivations

The studies on ground archaeological sites, as well as shipwrecks sites, have always aimed at obtaining very accurate graphical representations of reality. As soon as appropriate tools became available, there was also a trend towards obtaining 3D representations on graphic displays. Over recent years, the field of archaeology has witnessed increasing interest in Virtual and Augmented Realities, or more generally Mixed Reality. The technologies available have paved the way for the presentation (in a realistic manner) of reconstruction assumptions of archaeological sites, either for freely exploring these assumptions in a Virtual Reality framework, or by exploring the site itself mixed with a reconstruction assumption within an Augmented Reality framework. [CWSB01] Underwater archaeology is a challenging issue for Mixed Reality since the environment may not be accessible to man and is often considered hostile. As a matter of fact, deep wrecks are out of reach for divers, (beyond 60m, traditional air diving is prohibited and diving beyond that limit requires gas mixtures and significant surface facilities). [Bas70].

Wreck preservation in the open sea is facilitated due to several factors such as darkness, low temperature and low oxygen rate. However, deep wrecks are now jeopardized by emerging deep trawling that destroys the surface layer of the sites and thus scrambles legibility. Indeed, the twenty year old assumption that deep wrecks would be protected from trawling is not true anymore as trawls can nowadays be deployed down to depths of 1000m. Therefore, many of theses wrecks are likely to be destroyed even before they can be studied. More generally, this project is oriented toward

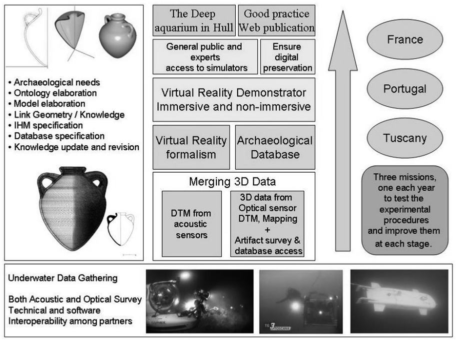

Figure 1: *VENUS project architecture diagram.*

both kind of sites, those reachable by divers and those reachable only with submersible vehicles; in both cases the project will develop methodologies and techniques for data acquisition by means of unmanned vehicles, i.e., Autonomous Underwater Vehicles (AUVs) and Remotely Operated Vehicles (ROVs). The use of AUVs and ROVs will be a great improvement in terms of efficiency, economy and safety and will permit high quality automatic data capture. Regardless of diver accessibility, an underwater site is out of physical and practical reach for the majority of archaeologists and for the general public: our project aims at drastically changing this situation, by making the site virtually accessible to everybody. Due to the complexity of this ambitious project we will have always two points of view: the first one is to offer to archaeologists best practice, efficient, safe and cost effective tools to collect and manage archaeological data from shipwrecks; the second point, is to show what can be achieved without the constraint of a tight budget (which is generally

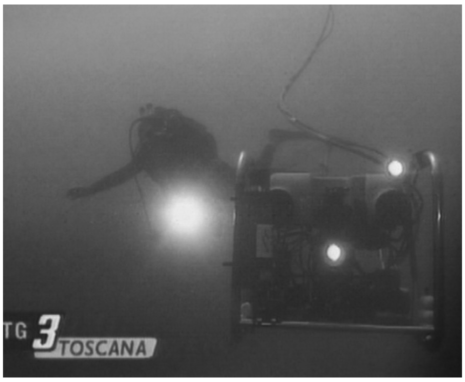

Figure 2: *ROV and Diver, ISME.*

the case in archaeology). The budget has a particularly high influence on the technological aspect of this project: especially for underwater data acquisition and virtual reality immersion. In this project it is also planned to survey a deep shipwreck in order to apply the entire VENUS platform to a shipwreck in an excellent state of conservation and to show some possible immersive VR applications. We now present the five general objectives of this project and in addition, Objective Six, "Missions in open sea" which represents the three missions necessary to collect data and test and improve the methodologies adopted.

2.2. Objective one: Underwater exploration best practices and procedures

The first aim is to define a series of procedures and best practices for collecting data in an efficient, economic and safe way on underwater archaeological sites:

- Efficiency is related to the automatic collection of enough data, of sufficient good quality to allow for a satisfactory virtual reconstruction;
- Economy relates to the possibility of using, with suitable adaptations, "off-the-shelf" equipment, that archaeologists can easily get and employ;
- Safety has to do with the reduction of risks and inconvenience for human beings when operating at great depths and/or in a hostile environment.

The key technology we propose to exploit in pursuing this objective is based on the extensive use of Uninhabited Underwater Vehicles (UUVs), both remotely and autonomous vehicles (ROVs/AUVs). UUVs, equipped with acoustic, magnetic and optical sensors of various kinds, are becoming the tools "par excellence" in underwater archaeology as the technology offers ever increasing user-friendly and economical solutions, in particular because they allow the exploration and preservation of sites located at prohibitive depth for divers (see Proceedings of The International Congress on The Application of Recent Advances in Underwater Detection and Survey Techniques to Underwater Archaeology, Bodrum, Turkey, 2004; Proceedings of Workshop on Innovative Technologies for Underwater Archaeology, Prato, Italy, 2004 and the references therein). [ABB04] [SP04] However, the potential of an approach that combines underwater robotics technology and virtual and augmented reality in gathering data and then simulating underwater archaeological sites have not yet been completely explored nor exploited. In particular, data gathering procedures have not been optimized with respect to post processing. Also, best practices about the combined use of different kinds of UUVs and sensory systems and devices have not yet been defined. *Measure of success:* A thorough and clear definition of the platforms, sensors, and methodologies that will be used to acquire, process, and display underwater archaeological data. Namely: i) definition of the platform (AUV, ROV) configurations and equipment that will be used to gather vision and acoustic data and of the interfaces required to ensure inter-partner systems compatibility, ii) full assessment of the compatibility of the DTM (digital terrain map) + photogrammetric data with 3D Virtual/Augmented reality systems, and iii) development of software for image processing to compensate for refraction errors that arise in the process of acquiring vision data underwater. [PSO05], [SDV*04].

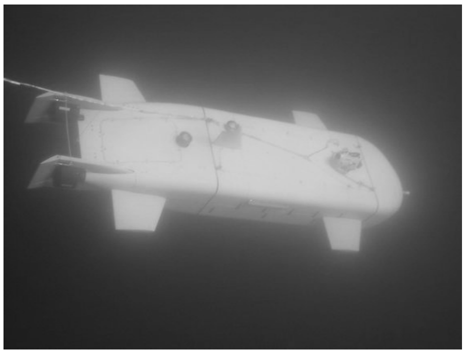

Figure 3: *Autonomous Underwater Vehicle (AUV) of IST.*

2.3. Objective Two: Underwater 3D survey merging optic and acoustic sensors

The second objective aims at defining practical procedures for merging optical and acoustic data, acquired during the surveying of underwater sites, into a coherent representation. [CWSB02].

The project will witness the application of advanced techniques for underwater data acquisition and processing to the mapping of selected archaeological sites. An Autonomous Underwater Vehicle (AUV) and a Remotely Operated Vehicle (ROV), equipped with acoustic and vision sensors (for sonar mapping + photogrammetry), will be used to acquire relevant data in an efficient, systematic, and safe manner at the sites, including one that is out of reach for divers. [DL05].

The need of geo-referencing the gathered data will be considered. Steps will be taken to endow the vehicles with navigation systems capable of providing information on their position with the accuracy that is required for the applications envisioned. [BT00], [GZ03].

Simplified underwater photogrammetric techniques will be developed to allow the use, after appropriate image processing, of software originally conceived for terrestrial photogrammetry. A semi-automatic surface densification technique will be developed in order to automatically generate a large amount of 3D point data based on multiple image correlation and to facilitate the time consuming photogrammetric process during the plotting phase (in the laboratory). A convenient tool for digitalization will be developed, offering to the archaeology community a convenient way to make accurate 3D measurements based on the product of the merging operation: a 3D mesh and a set of oriented photographies in the same reference system. [DDPL05], [DSL03].

We plan to make at least three experimental surveys, two in shallow water (on wrecks already studied) with archaeologists and divers and the final one in deep water to enhance the innovative aspect of this project. These surveys will be performed by conforming to the data collection guidelines specified in objective one.

Measure of success: Data gathering by means of robotic tools and the integration of acoustic and photogrammetric data at a sufficiently small scale will make virtual access, exploration and study of underwater archaeological sites possible. Access to these sites are currently beyond reach for the large majority of archaeologists and, in many cases, for the general public. The demonstration that i) archaeological surveys can be automated by using underwater robots that are easy to program seamlessly, and ii) sufficient navigational accuracy can be achieved so as to meet the precision requirements compatible with the scale dimensions envisioned, will provide quantitative indicators of the results obtained and a measure of success.

2.4. Objective Three: managing and revising archaeological knowledge

Objective three aims to provide underwater archaeologists with software tools for signal, data and information processing and management. These tools will allow for the extraction of digital models and management of confidence levels of the data collected from objective two. [Ace03] In the last decade, the tools developed for managing archaeological data have only focused on the geometric aspects; however, in order to integrate the archaeologist's knowledge and designing tools managing both data and knowledge, an appropriate representation of the archaeological knowledge is required. [BHLW03].

Another important factor is the management of this knowledge. We deal with pieces of information of different nature that also originate from different sources characterized by various degrees of confidence. The methods of acquisition differ and provide data of unequal quality. Moreover, most of the time, the pieces of information are incomplete, uncertain, or inaccurate and have the potential to conflict with each other and hence may need the definition of fusion operations. Different cases arise according to the nature of the data used for fusion.

[JP00] The proposed work for this particular objective starts with a case study of archaeologist knowledge and procedures in order to define data management systems and a virtual universe.

We plan to investigate how artificial intelligence methods and tools could be used to represent the archaeological information and to perform revision and fusion according to the following points:

- to design and build specific ontology: by analyzing the relevance of the objects which can be handled in a particular archaeological application, independently of the expected data; to carefully examine their definition and the kind of implicit knowledge it carries; to compare how the data, with their quality depending on the observation process, and the recording process, can fit with the object definition; [SDP03]
- To design which knowledge representation formalisms are suitable to represent semi-structured information, paying attention to the specificity of the archaeological data: 3D spatial reference, topological relationships and spatial correlations, specific expert knowledge and specific ontology;
- To select which fusion strategy is best suited to the representation formalism chosen according to the nature of the situation, and the availability of relevant data, and their degree of quality and reliability. For instance, revision is relevant if one data set is strongly reliable;
- To assess the tractability of the fusion: How can the nature of the data help in defining tractable classes of problems for merging? How should existing general algorithms be adapted for merging? How can heuristics be defined that stem from the specificity of the nature of data to speed up algorithms?
- To define reversible fusion operations. This stems from the fact that, in general, the existing fusion operations developed in the field of artificial intelligence are not reversible; this is in contrast with the fact that reversibility is mandatory when facing real scale applications. [NS97], [BBJ*05].

Measure of success: The first draft of the "archaeological ontology" description, in Task 3.2, must be able to encompass most of the various features, properties, processes or behaviours collected during the first months of discussion between the computer scientists and the archaeologists of the consortium. A "typical" archaeological campaign will be summarized and described at the beginning of the project, as a baseline test bed for the further representation formalisms.

A confrontation of this baseline to external expert will permit to measure its relevance, and therefore, to measure the relevance of the representation formalisms against it.

2.5. Objective four: Mixed reality modelling

Archaeologists need to explore and make an inventory of deep wreck sites unreachable by divers as these sites may be jeopardized by deep trawling in the next few years. The digital preservation aspect should also be addressed by this objective. [CVM04].

The main goal of objective four is therefore to immerse archaeologists inside a virtual universe depicting a reconstructed archaeological site, for example a shipwreck, and allow them to work on this site as naturally as possible. The digital model generated in the previous section will then be used, with the help of virtual reality and mixed reality, for constructing immersive, virtual environments that enable archaeologists and general public to experience an accurate and fully immersive visualization of the site.

Archaeology is a challenging issue for Virtual and Augmented Reality (and more generally Mixed Reality) as these techniques can offer a realistic rendering of reconstruction assumptions either within the framework of Virtual Reality for exploring theses assumptions or within the site itself by using Augmented Reality. [AVLJ01], [ATP*04].

Up to now, virtual reality has been used in archaeology only in the context of assumptions visualization which is already suitable for general public, the goal here is therefore to produce an immersive interface which could enable archaeologists to study a site reconstruction using the surveys, but also to generate reconstruction assumptions directly in virtual immersion. This project tackles the concept of augmented reality. More specifically, within the framework of underwater archaeology, the main difficulty of this type of exploration lies in the expensive deployment of heavy equipment to enable a team of archaeologists to explore, make an inventory and chart an underwater site before expressing the slightest assumption about the nature of a wreck or its cargo. Virtual Reality would also provide an overall view of a site and allow data exploration in a contextual way. Novel interaction and visualization techniques will be developed in order to meet the requirements of this objective. [LSB*04] Completing this objective should offer the opportunity for archaeologists to explore a digital mock-up of a wreck site built upon the digital models mentioned in the previous objective. This exploration should be immersive in order to maintain the same framework as real dives (without any risk or constraints), but should also offer new opportunities to archaeologists. Ultimately this virtual environment should offer the same tools as during real dives (such as navigation, measures, annotations, etc.). This environment should also provide new tools for creating reconstructions assumptions of various artefacts discovered on the wreck site in order to enrich the database created from the site.

Such a virtual exploration should also be performed by several researchers at the same time, by offering Collaborative Work facilities. [PCVH04]. In addition, Collaborative work raises the problem related to hardware requirement for each of the researchers. Some of them might have access to high level hardware such as immersive platforms, whereas others may only have access to a simple desktop computer. The key idea would therefore be to build several demonstrators using the same engine:

- An immersive demonstrator using purely immersive devices such a VR helmet and data gloves for interacting with the site;
- A semi-immersive demonstrator using stereo large scale screen and 3D joystick (or data gloves) to interact with the site;
- And finally a low end platform using only the standard devices of a desktop computer. Each of these various platforms may require specific interaction models, but the goal is to keep the same functionalities on the different platforms.

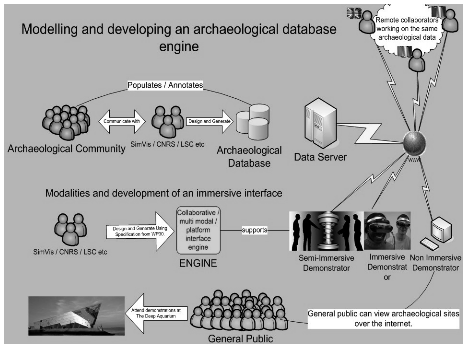

Figure 4: *Synoptic schema of integrated Virtual Reality in VENUS.*

Measure of success: All the functionalities developed in these various demonstrators are based on a case study of archaeologists working modalities in order to define interaction modalities and available tasks within the virtual universe connected to the underlying archaeological database. This is why the last task of this objective is devoted to the demonstrator evaluation on the basis of the previous case study by archaeologists.

2.6. Objective five: dissemination

The ultimate objective of the project is scientific dissemination in the fields of archaeology, marine exploration, photogrammetry and virtual reality through the publication of best practice recommendations, a set of open source software tools, and online preservation of an exemplar archive. Dissemination will be organized in four stages:

1. to refine digital preservation techniques so that they can be readily applied to the unusual range of data formats captured during underwater archaeological investigation;

2. to ensure that partners within the consortium learn about digital preservation;
3. to promote best practice in digital preservation through publication of a short practical guide based on this shared experience;
4. to adopt and trial these best practice techniques within the project.

- The first objective will be achieved through completion of a desk-based study, supported by a number of data audits carried out at the start of the project. The principal investigator for this work package will be a digital preservation specialist who will spend time with active fieldworkers, surveying the techniques that they use and establishing the most appropriate methods for digital preservation associated with these file formats. This preservation path, based on an implementation of the OAIS reference model for digital preservation and the PREMIS metadata model, will provide a preservation manual for long term curation of digital data;
- The second objective will be met in part through the data audit process described above whereby the principal investigator will discuss issues of digital preservation informally with project partners, and report back to them the results of that research. The objective will be mainly met through the organization of a two-day project workshop on digital preservation to which senior members of each partner organization will be invited. This workshop will be managed by the Archaeology Data Service and will draw from existing curricula that the UoY-ADS offer on digital preservation;
- Participants at this workshop will be invited to form an editorial committee and nominate a peer review group who will assist the principal investigator in the writing of a short guide to good practice for underwater archaeology. This guide will join the existing guides in the much praised "Guide to Good Practice" Series (http://ads.ahds.ac.uk/project/goodguides/g2gp.html). It will be distributed in print to all partners and key stakeholders, as well as being made available for free online for all readers;
- By the end of the project, partners will not only have adapted their tools to ensure digital preservation, but they will be in a position to apply that best practice in real life situations. An exemplar archive will be lodged with the UoY-ADS and preserved into perpetuity. This scholarly archive will also be disseminated online alongside other research archives maintained by the UoY-ADS. It will therefore be available for re-use and interrogation by all visitors to the UoY-ADS site and will stand as a worked example of good practice to demonstrate the project outcomes to the wider profession.

To avoid duplication of efforts in a rapidly changing field a "technology watch" will be maintained, in close collaboration with the EPOCH 6th Framework Network of Excellence. The project team will present reports on its activities at appropriate technology and humanities conferences. Finally, the 3D and virtual reality aspects of the project make it appropriate for wider public dissemination, which will be most effectively achieved via the Internet.

Measure of success. The success of the workshop and subsequent Guide to Good Practice will be measurable by the extent to which the standards are endorsed and taken up by the sub-discipline of underwater archaeology. The number of Guides sold, and the number of visits to the on-line publication provides one measure of the visibility of the Guide. Previous Guides in the series, such as that for GIS, have sold out and have had to be re-printed. They have been widely and positively reviewed, and have been adopted by national and international standards bodies, and cited in undergraduate and postgraduate reading lists. The successful dissemination of the exemplar archive is also measurable, to same extent, by the number of visits to the site. This will be monitored by UoY-ADS standardized benchmarks for site visits, and can be compared against other online resources. The web site can be promoted through the UoY-ADS outreach programme and related publications, and qualitative feedback can also be collected.

2.7. The case study: The Mediterranean archaeological context

If the "first civilizations" were born in the Eastern Mediterranean from the Near East, this sea has been empty for millennia before becoming the main stage of shocks, conflicts and discovery of civilizations. From Marathon to Lépante, from Punic Wars to crusades, the Mediterranean space/area is full of historical reappearances and lights coming from the dead world. Beyond its current political divisions, it is divided into three cultural communities: Christian, Islamic and the Greek orthodox universe, that is an affiliation more or less linked to Rome, Carthage and Constantinople. One particular period interests us here. In ancient times, by imposing its will and political unification on the Mediterranean world, Rome did not erase the cultural differences but built its internal sea as a gigantic trading crossroad where oils and brines from Spain would cross with corn from Egypt, wines from Algeria and Rhodes, slaves from Nubia, ceramics from Gallia, marbles from Greece and bronzes from Italy. [ANS04], During the Roman Empire, among all these various products coming from the Mediterranean, a great quantity of Portuguese amphorae were sailing from Hercules Pillars to the Rhine frontiers and carried the famous Lusitanian fish sauce. Today underwater archaeology opens, from the deep past of the sea, a direct route to these shipwrecks, complex works that testify the wealth and the diversity of exchanges and of men. In this project, the methods of excavation, the systems of data capture and of the data's visualization and the coop-

eration of archaeologists and multinational specialists, will enable historical restoration of these trades and to continue these faraway sailing journeys, brutally interrupted.
We plan to make three experimentations in different archaeological contexts and under different sea conditions. The first one, leaded by MIBAC-SBAT in Tuscany will focuss on a very interesting archaeological site near the Pianosa island, and will be considered as a shallow water (-36m) mission. The wreck site consists of a large area of mixed amphorae probably due to more than one wreck superposition. The second experimentation, in Portugal, concerns two sites: a probable Roman period wreck on the southern coast of Portugal (Algarve) where amphorae (Beltan IIb) were recovered by fishermen at a depth of 50m in the ocean; the other one lies on the Portuguese east coast, near Troia (a roman industrial complex for processing fish, and wine from the surrounding area, which used locally produced amphorae). This shipwreck probably contains amphorae and may be the result of a geomorphologic process that has buried structures and amphorae.

Figure 5: *A view of the site close to Pianosa, Photo Alessandro Parotti, 2000*

The third one is an extremely well preserved shipwreck near Marseille. Discovered in 1999 by COMEX the "Calanque de Port Miou" is probably the most beautiful wreck in the Marseilles area nowadays. The site was explored by MCC in the year of its discovery, in 1999, with heavy logistics provided by COMEX.

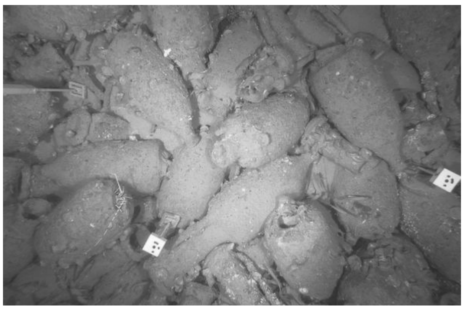

Figure 6: *The "Calanque de Port Miou" photograph from ROV of COMEX.*

The wreck site (which seems to be still intact) presents a very large tumulus of Roman wine amphorae, Dressel 1A. Visible on 22 m length and ten meters broad, it is located at a depth of 120m.

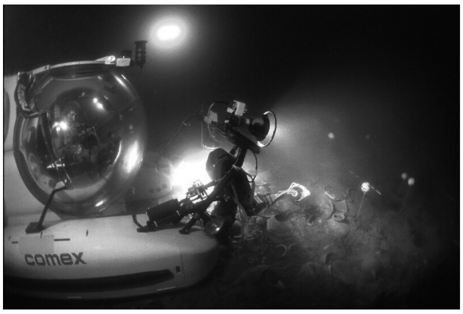

Figure 7: *The submarine REMORA 2000 of COMEX during rhe Grand Ribaud F excavation, 2000. Photo Frederic Bassemayousse.*

3. Conclusion and future work

This paper has described a new project that focuses on the virtual exploration of underwater sites. Our international research group has expertise in a wide range of areas including archaeology and underwater exploration, marine robotics and instrumentation, knowledge representation and photogrammetry, virtual reality and digital data preservation. Research conducted throughout this project will contribute to all these disciplines. This European Community funded project began on the 1st July 2006 and will last for 36 months. A dedicated project website is available here: http://www.VENUS-project.eu/

4. Acknowledgements

Work partially supported by the European Community under project VENUS (Contract IST-034924) of the "Information Society Technologies (IST) programme of the 6th FP for RTD".
The authors are solely responsible for the content of this paper. It does not represent the opinion of the European Community, and the European Community is not responsible for any use that might be made of data appearing therein.

References

[ABB04] AKAL T., BALLARD R. D., BASS G. F.: The application of recent advances in underwater detection and survey techniques to underwater archaeology. In *Proc. International Conference* (Bodrum, Turkey, May 2004).

[Ace03] ACERES C.: Inference services for description logics. *Description Logic Day* (2003).

[ANS04] ANSER: Project anser, anciennes routes maritimes méditerranéennes european commission. *Programme Interreg IIIB Medocc http://www.projet-anser.net/* (2004).

[ATP*04] ALVIK R., TIKKANEN S., PALMA P., GREGORY D., LEINO M., JÃŰNS H., WESSMAN S., CEDERLUND C. O., OOSTING R., KRESSE W., MANDERS M., LÃIJTH F.: Moss project final report.

[AVLJ01] ACEVEDO D., VOTE E., LAIDLAW D. H., JOUKOWSKY M. S.: Archaeological data visualization in vr: Analysis of lamp finds at the great temple of petra, a case study. In *In proceedings of IEEE Visualization* (San Diego, California, 2001).

[Bas70] BASS G. F.: *Archaeology under Water*, vol. 183. Harmondsworth, 1970.

[BBJ*05] BENFERHAT S., BENAIM J., JEANSOULIN R., KELFALLAH M., LAGRUE S., O. PAPINI N. W., WÃIJRBEL E.: Revising geoinformation : the results of rev!gis" proceedings of the eighth european conference on symbolic and quantitative approaches to reasoning with uncertainty. In *Lecture Note in Artificial Intelligence* (Barcelone, July 2005), nÂř 3771 S. V., (Ed.), ECSQARU'05, pp. 452–464.

[BHLW03] BAADER F., HLADIK J., LUTZ C., WOLTER F.: From tableaux to automata for description logics. *Fundamenta Informaticae 57* (2003), 1âĂŞ33.

[BT00] BECHAZ C., THOMAS H.: Gib system: the underwater gps solution. In *Proc. 5th Europ. Conf. Underwater Acoustics* (Lyon, France, 2000).

[CVM04] CHAPMAN P., VIANT W., MUNOKO M.: Constructing immersive virtual environments for the visualization of underwater archaeological sites. In *XXXII Computer Applications and Quantitative Methods to Archaeology Conference* (Prato, Italy, April 2004).

[CWSB01] CHAPMAN P., WILLS. D., STEVENS P., BROOKES G.: Visualization viewpoints: Real-time visualization in the offshore industry. *IEEE Computer Graphics and Applications 21*, 4 (2001), 6–10.

[CWSB02] CHAPMAN P., WILLS. D., STEVENS P., BROOKES G.: Visualizing underwater environments using multi-frequency sonar. *IEEE Computer Graphics and Applications ISSN: 0772-1716 19*, 5 (2002), 61–65.

[DDPL05] DRAP P., DURAND A., PROVIN R., LONG L.: Integration of multi-source spatial information and xml information system in underwater archaeology. In *XX Symposium of CIPA* (Torino, Italy, September 26th to October 1st 2005), the ICOMOS, on Documentation of Cultural Heritage I. C., (Eds.).

[DL05] DRAP P., LONG L.: Photogrammétrie et archéologie sous-marine profonde. le cas de lâĂŹépave étrusque grand ribaud f. *Revue XYZ 104-104* (2005).

[DSL03] DRAP P., SEINTURIER J., LONG L.: Archaeological 3d modelling using digital photogrammetry and expert system. the case study of etruscan amphorae. In *The Sixth International Conference on Computer Graphics and Artificial Intelligence* (Limoges, France, 2003).

[GZ03] G.CONTE, ZANOLI S.: Rov depth control. *Control Eng. Pract. 11* (2003).

[JP00] JEANSOULIN R., PAPINI O.: *RÃľvision et information spatiale Âż, dans Le temps, lâĂŹespace et lâĂŹÃľvolutif en sciences du traitement de lâĂŹinformation*, c. garbay (eds.) ed. CÃľpadues-Ãľditions, 2000, pp. 293–304.

[LSB*04] LIAROKAPIS F., SYLAIOU S., BASU A., MOURKOUSSIS N., WHITE M., LISTER P.: An interactive visualization interface for virtual museums. In *VAST âĂŹ04. Proceedings of the 2004 conference on Virtual Reality and Cultural Hertiage* (Belgium, 2004), pp. 47–56.

[NS97] NIEMELA I., SIMONS P.: Smodels: An implementation of the stable model and well-founded semantics for normal logic programs. In *In Proceedings of the 4th International Conference on Logic Programming and Nonmonotonic Reasoning (LPNMR-97)* (1997), p. 420 429.

[PCVH04] PANSIOT J., CHAPMAN P., VIANT W., HALKON P.: New perspectives on ancient landscapes: A case study of the foulness valley. In *The 5th International Symposium on Virtual Reality, Archaeology and Cultural Heritage* (Belgium, 2004), pp. 251–260.

[PSO05] PASCOAL A., SILVESTRE C., OLIVEIRA P.: Vehicle and mission control of single and multiple autonomous marine robots. *Advances in Unmanned Marine Vehicles Editor: G. Roberts and R. Sutton* (2005).

[SDP03] SEINTURIER J., DRAP P., PAPINI O.: Fusion rÃľversible : application Ãă l'information archÃľologique. In *Actes des JournÃľes sur le Raisonnement Non-Monotone (JNMR'03)* (Paris, November 2003).

[SDV*04] SEINTURIER J., DRAP P., VINCENT N., CIBECCHINI F., PAPINI O., GRUSSENMEYER P.: Orthophoto imaging and gis for seabed visualization and underwater archaeology. In *Proceedings of CAA2004* (Prato, Italy, April 2004), Computer Applications and quantitative Methods in Archaeology.

[SP04] SILVESTRE C., PASCOAL A.: Control of the infante auv using gain-scheduled static output feedback. *IFAC Journal of Control Engineering Practice 12* (2004), 1501–1509.

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
VAST (2006)
M. Ioannides, D. Arnold, F. Niccolucci, K. Mania (Editors)

How Does Hi-tech Touch the Past? Does It Meet Conservation Needs?

Results from a Literature Review of Documentation for Cultural Heritage

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Abstract

- *Only 1/6th of the reviewed literature is strongly relevant to conservation*
- *Simple and easy-to-use tools are not published or widely disseminated*
- *Often, hi-technology tools do not meet the current needs of conservation*
- *Documentation literature is not extensively published outside of Europe*
- *Literature frequently targets already informed and highly specialized professionals, thus limiting the audience and reducing the influence of significant ideas, techniques and methods.*

These are some of the conclusions drawn from a recent literature review on recording built heritage. As part of a larger project to identify examples of good documentation practice, the Getty Conservation Institute conducted this review, reading over 700 articles, books, conference proceedings and white papers. Although our research was not a scientific random sampling, our selection set is nevertheless a good indication of trends in the field. The material was drawn from library catalogues, databases, and interviews with international professionals, and then debated by a team of four people over the course of a year. A rating system was created to quantify the results and centers around the following questions: What is the conservation issue? Is there a correlation between the documentation phase and the conservation process? Are the tools appropriate and effective enough to address the issue?

*In other words**: Does documentation serve conservation? Does it truly inform the conservation process?***
Through a detailed analysis of this review, we identify significant risks and propose solutions. Documentation practitioners need to be aware of and overcome prevailing challenges to ensure that documentation truly serves the preservation of our cultural heritage.

A.1 [GENERAL]: Introductory and survey. A.2: Reference.

1. Introduction

Conservation is the protection and preservation of the integrity of our cultural heritage through examination, preventive care, carefully planned interventions, and vigilant monitoring. It is a process that relies on informed decisions drawn heavily from research, survey and on-site investigations. The findings recorded from these methods of examination are loosely known as documentation, which is a cornerstone to conservation and a priority when dealing with cultural heritage – something that should not be overlooked.

Technology has significantly touched the past as it assists in this documentation with measured surveys, digitally recorded condition and images; and by improving communication and quickly retrieving research. Recently, cutting-edge technologies such as virtual reality, augmented reality, laser scanning, 3D GIS, or rapid prototyping, among others, have been used in the documentation of cultural heritage. These cutting-edge technologies represent the far-end of the hi-tech spectrum and have been, only recently, introduced into the field of conservation. Because practitioners come from a wide variety of disciplines such as architecture, archaeology, painting and object conservation, exposure to technology varies. Exposure is also affected by geography and access to resources, thus knowledge varies throughout the world. Therefore, in this paper, hi-tech will refer to cutting-edge tools.

Do hi-tech tools effectively assist documentation? Or have they become an end unto themselves? Are the tools appropriate and effective enough to address the issue?

In other words: does documentation serve conservation? Does it truly serve to inform the conservation process?

The answers are surprising.

In the past decade, hi-tech tools have continued to evolve and improve exponentially while their *application* in the conservation of our cultural heritage has not proceeded at the same pace. The most significant way for us to "touch" the past is through conservation; therefore, this trend is alarming. While it is completely understandable that research and development in hi-tech tools is carried out, it is perplexing that within the context of cultural heritage, conservation is not a primary concern.

Recently, as part of a larger project to identify good conservation documentation practice, an extensive literature review was completed. Over 600 articles, conference proceedings, and books were read, rated and debated by a team of four conservation professionals of different backgrounds over the period of one year. This material is largely drawn from the last 20 years and, although not a scientific random sampling,[1] it still provides insight into documentation for cultural heritage conservation. It also offers some answers to the previously asked questions.

The results obtained through this literature are analyzed in the following paper. Significant risks are identified and solutions are presented as challenges.

2. Method

The goal throughout this process was to identify good examples of documentation practice that assisted and informed conservation. Material was collected from a wide variety of online databases, catalogues, and indices such as AATA Online, OCLC, Online Union Catalogue, ICCROM Library catalogue, Scopus, the Documentation Center of UNESCO-ICOMOS Online Database, the ISPRS online archives, etc. Sources were also found from browsing and cross-referencing citations in books, journals and conference proceedings. Discussions with conservation and survey professionals and attendance at various conferences brought additional examples. Based on this research, an extensive bibliography of useful reference material was compiled.[2]

The material collected covers three thematic areas:

- Publications with a conservation focus that featured survey or documentation;
- Survey and documentation publications and conference proceedings with a cultural heritage component (CIPA proceedings, survey periodicals, etc.); and,
- Periodicals relating to cultural resources.

A balance was sought between these thematic areas as well as disciplines, documentation techniques and geographical distribution of the selected readings. Identification of important conservation issues as they recurred throughout the readings was also crucial. Although most publications are in English, articles in other languages, including French, German, Italian, Spanish, Korean, Chinese and Japanese were also included.

2.1. Evaluation

A rigorous evaluation system was established to guide the reading process. All sources were thoroughly reviewed, organized into a matrix, and rated on a scale of 1 to 3 against the following questions:

- Is a conservation issue clearly stated?
- If so, is the scope of the issue addressed by documentation?
- Is there a correlation between the documentation objectives and the conservation process?
- Are the documentation tools appropriate to address the conservation issue in terms of costs, details, precision, time, and availability?
- Are the tools effective in informing the conservation process?
- Is the writing style clear?
- Does the author have good expertise on the topic?
- Are references provided?

Other important details were the affiliations and provenance of the authors, the location and sponsors of the project and the country of publication.

As this material was researched, it was divided into six disciplines (architectural conservation, decorative finishes, structural conservation, conservation planning, archaeological conservation and landscape preservation), which helped in distributing the readings among the team members with different specialties. All team members read the articles and debated their various merits and issues based on the scores obtained.

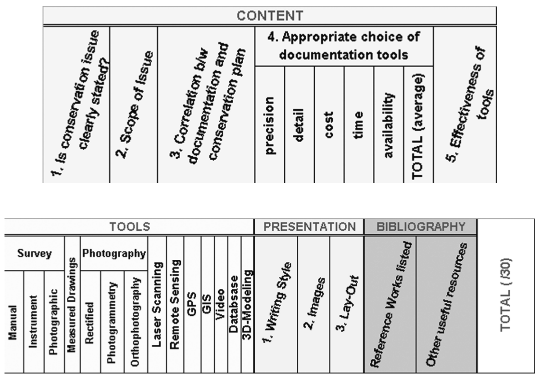

Figure 1: *Example of the rating matrix.*

3. Results and Risks

The results of this review guided the selection of case studies illustrating good applications of documentation for conservation. Yet this survey yielded a wealth of qualitative and quantitative information to formulate trends in documentation within the field of cultural heritage.

Most articles were informative reports of academic research on technology development and innovative tool applications where the subject was cultural heritage, while others presented a conservation project with a documentation component. The results of this literature review can be summarized into five major results.

3.1. Only 1/6th of the reviewed literature is strongly relevant to conservation

Within the context of cultural heritage, the fact that so many articles and proceedings do not address a conservation issue is troubling. There are various reasons for documentation including education, academic research, advocacy, and as a record for posterity; however, *direct* conservation of the physical fabric and design integrity is the most significant way to preserve our cultural heritage.

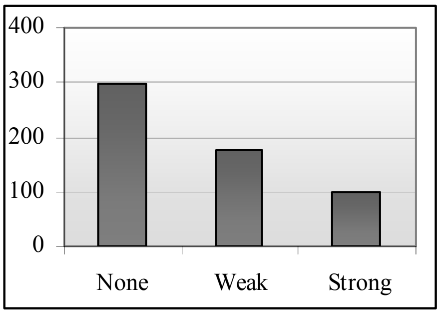

Figure 2: *Conservation relevance.*

This result was surprising and led to the formulation the following risk:

Risk: Conservation professionals may dismiss important documentation projects and useful new tools if the applications toward conservation are not readily apparent. Information that could assist them in their collection of data in order to make informed decisions may go overlooked.

A very good article was reviewed during this process and featured the mapping of an archaeological site in the Middle East. The article mentions the appropriate use of tools such as historic research, satellite imagery, and GPS. The site is thoroughly mapped topographically and archaeological details recorded, producing an excellent record of the site. However, primary conservation issues such as drainage and soil erosion, undercut foundations, looters trenches and mortar loss are barely, if at all, mentioned. There is a statement made about protection toward the end of the article but important conservation issues are not addressed. If this article had mentioned some of these site issues, it could have been a valuable resource for conservation.

3.2. Simple and easy-to-use tools are not published or widely disseminated.

Although too difficult to quantify, the results reflected an increasing bias toward hi-tech tools and complicated procedures. This result is understandable as researchers continue to develop new tools and technology progresses; however, it is not acceptable given that the majority of professionals tasked with conservation are practitioners who need assistance and training in the principles and methods of documentation. While the use of these simple documentation tools may not be considered worthy of publication within the research field, they are nonetheless valuable and necessary for conservation. This led to the following risk:

Risk: Low-tech but very useful and effective tools that can assist in the conservation of cultural heritage will go unnoticed if not published.

For example, one very useful tool for conservators is the Leica Disto - a simple (EDM) device that measures distances. A good article describing the proper use of this tool and how simple drawings can be made was nearly impossible to find. This tool was recently shown to a group of conservators and they asked "this is a very useful device – when was it invented?" There were other difficult to find articles on rectified photography and the use of a plumb bob.

3.3. Often, hi-technology tools do not meet the current needs of conservation

The efficiency of documentation in the field of conservation was measured against three different criteria:

- How well the documentation objectives correlate to the conservation issue and the scope of the conservation project;
- How suitable the tools are, based on the requirements for accuracy and level of detail needed for the entire project, as well as in terms of cost, time (for data gathering and data processing) and local availability[3]; and,
- How effective the tools are in providing an answer to the conservation issue.

The following graphs show the ratings for each of the criteria the entire review.

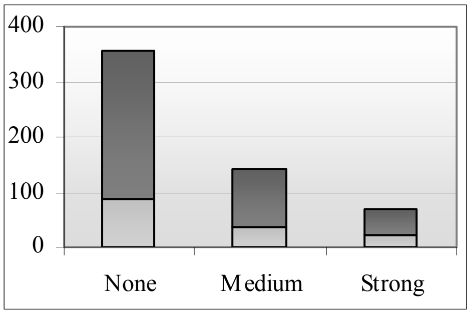

Figure 3: *Correlation between conservation and documentation. The lighter area represents the articles featuring hi-tech tools.*

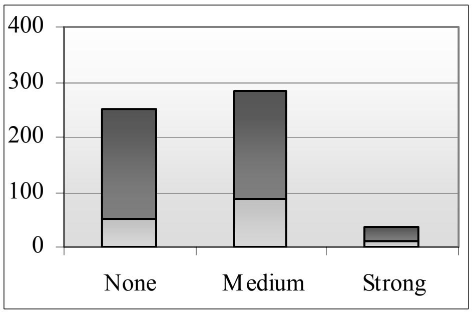

Figure 4: *Appropriate tool selection. The lighter area represents the articles featuring hi-tech tools.*

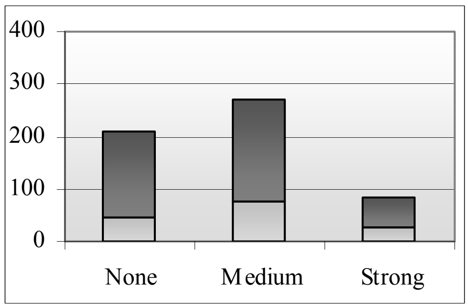

Figure 5: *Effectiveness of documentation results in planning intervention implementation. The lighter area represents the articles featuring hi-tech tools.*

The tool applications rarely serve the purpose or the needs of the project. There is a clear gap in correlating the objectives of the project with the type of information needed to address the conservation issues. In most cases, the failure to identify what kinds of records should be made and how they should meet the constraints and requirements of the project influence how effectively the results are used in planning and implementing conservation.

The processed data and the results do not help solve the conservation issue because the tools were not appropriate in providing the specific information required for conservation planning. Hi-tech tools in general seem to provide a superfluous amount of information that falls short of the important target of diagnosing, examining, or monitoring for conservation purposes. The following risk sums up this finding:

Risk: The majority of professionals concerned with cultural heritage conservation may dismiss these hi-tech tools as irrelevant, and this may stymie research in the field.

3.4. Documentation literature is not published extensively outside of Europe

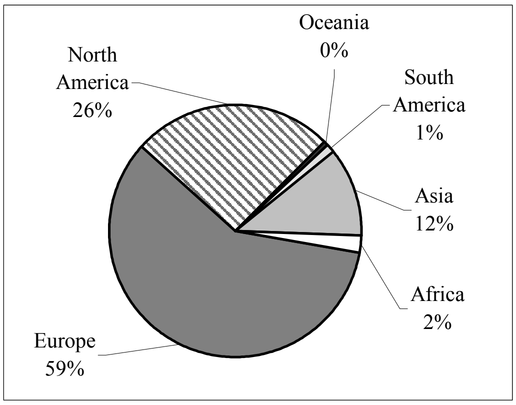

Figure 6: *Geographic distribution of country of publication.*

Of all the material reviewed over half was published in Europe. This is not surprising given that most universities, conferences, and publishers concerned with cultural heritage are concentrated in Europe (including World Heritage Sites[4]).

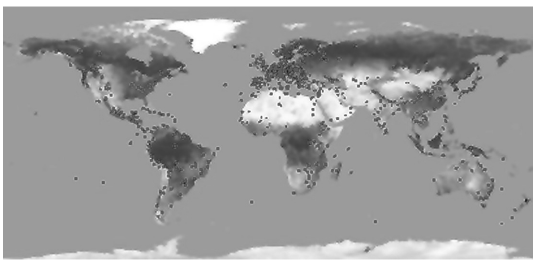

Figure 7: *A map of sites on the World Heritage List correlates with this result.[5]*

It is nonetheless an interesting finding, which led to an additional question:

How many projects are published in the same location as the cultural heritage? The answer is that nearly half are NOT published in the same country[6]. In other words, documentation is carried out in one place and the results and data are published in another. This led to the formulation of the following risk:

Risk: Conservation professionals (outside Europe and North America) may not have access to all the information available about a site within their own country. This information would also be helpful for conservation. They may also not be exposed to useful new documentation tools and techniques.

Recently, a large endangered site in South America was documented using the latest satellite remote sensing and aerial photography. The data was collected and returned to a European university where the results were then published. At the time of publication the data had not yet been copied for return to the country of origin.

3.5. Literature frequently targets already informed and highly specialized professionals, thus limiting the audience and reducing the influence of significant ideas, techniques and methods.

Several factors limit the dissemination of the tool applications and of its potentials to positively contribute to conservation. In conducting the survey, the reviewers paid particular attention to the occupation of the author(s), their writing style and the source of publication.

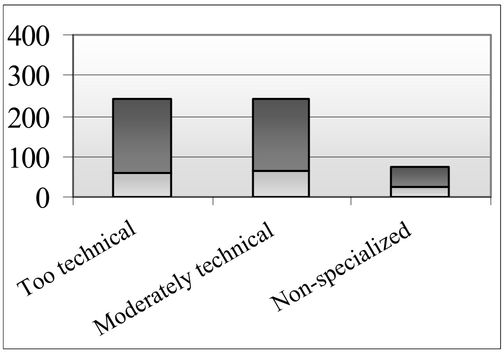

Figure 8: *Writing style (The hatched area represents articles featuring hi-tech tools).*

Two-thirds of the articles were published in journals, conference proceedings or other specialized types of publications dedicated to photogrammetry, virtual reality, 3D modeling or remote sensing. Nearly four-fifths of the surveyed case studies used specialized terminology that required detailed technical knowledge to understand the content. For documentation to be helpful to the conservation specialist in making an informed decisions these tools must be easily understandable and disseminated in non-technical channels.

Risk: Cultural heritage professionals may not be aware of all the possibilities available. They are not well informed of the ways in which useful technology can be put to the service of saving cultural heritage.

A good example of a useful tool is the "3X3 Rules for Simple Photogrammetric Documentation of Architecture" [WO94]. All conservation practitioners can utilize the methodology of this practical information. However, because articles on this method have only been published in venues specialized in photogrammetry such as the CIPA conference and ISPRS symposium, this valuable information has not reached conservation practitioners.

4. Conclusions and Challenges

In this literature review there were many very good articles and project descriptions that contained information and methods that could be useful to the conservation profession. However, the risks outlined above clearly show that, until now, conservation is seldom a primary preoccupation in the documentation of cultural heritage. There are several challenges that documentation providers should overcome to actively contribute to conserving cultural heritage.

4.1. Cultural heritage related articles, regardless of tool, technique or technology should, in some way, address conservation.

Even if the main focus is on a new device or method, a conservation statement should be included. This statement could comprise several different elements such as threats to the site, condition and how conservators could use the results for intervention. "[Conservation-based Research Analysis] should be properly managed to ensure that any work is of benefit to the conservation process" [Cla01].[7] Authors should always keep in mind that one of the most important aspects of cultural heritage is conservation.

4.2. Articles featuring simple low-tech tools and methods must be published.

Principles for good documentation are the same regardless of the level of technology and, although not groundbreaking, these topics will be very helpful to conservation specialists. Conservators are often slow adopters of technology and, if introduced to these principles and low-tech tools, they will gain an appreciation for the advantages of hi-tech research.

4.3. Objectives of documentation should match the needs of the project.

This requires more communication between the conservators and the documentation specialist. It is important to align the objectives of the documentation phase with those of the project as a whole by analyzing what is needed. "Conservators perform documentation based on the belief that by recording the tangible aspects of material culture, one can preserve its inherent information and aesthetic value or at least its potential value that may be lost [...] or altered" [Mat03]. Therefore, before beginning documentation, central questions relating to scale, accuracy, output and storage should be posed as well as defining what is being documented and who will be using this information [Cat00]. This will also direct the selection of suitable tools that will provide answers and inform conservation decisions.

4.4. Results of work where cultural heritage has been documented ought to be published locally.

Ideally, the results should be published in the local language and data shared with the partner or community institution. This will disseminate the results where they will have the most impact and permit the data to be used for conservation in the future by regional conservators. Those collecting and managing the documentation data should commit themselves to "facilitating access to and the diffusion of information in the public domain, particularly... in heritage, cultural, architectural [...] services under the responsibility of local communities" [Exe03].

4.5. Outlets for documentation research and work need to be broadened.

Because conservation is multidisciplinary, it is important to publish outside the current documentation venues. "The users have to have enough information to be able to choose the method that best matches their needs and to be able to communicate with information technology specialists in a more productive way" [Sch05]. There are a large number of conservation journals, conferences, as well as periodicals focusing on architectural conservation, archaeology, structural engineering, historic landscapes and urban planning. These should be considered to disseminate to a wider audience of preservation experts. Additionally, it is important to keep in mind who the audience is, so that when rewriting papers with conservation themes in mind, one should use a less technical terminology.

In summary: Does hi-tech documentation assist conservation documentation and meet the needs of planned interventions? Does it truly serve to inform conservation?

The answer is no: hi-tech tools frequently do not meet the needs of conservation, and have become increasingly a means unto themselves. From this literature review, it is clear that many recent documentation tools do not serve to inform conservation decisions and cultural heritage is not effectively being preserved.

We were able to recognize important risks to the field of documentation of cultural heritage that should be remedied by correlating the needs of conservation with what documentation has to offer, by publishing results on low-tech tools, seeking active partnership in publishing, and by disseminating to a diverse and wider audience - both geographically and in discipline.

By addressing these challenges, documentation will effectively "touch the past" by engaging in the conservation process and securing its long-lasting preservation.

Endnotes

1) Cluster sampling was used rather than random sampling.
2) A partial bibliography is available on the World Wide Web at http://gcibibs.getty.edu/asp.
3) Each attribute for this criterion was rated individually and then averaged to give the score for this criterion.
4) Of the 658 cultural and mixed sites (820 total, 162 natural), 363 (that is, about 55%) are in Europe and 295 outside Europe.
5) Map taken from World Heritage Center: World Heritage list. Available at http://whc.unesco.org/en/map/
6) 47% of all work reviewed was published outside the country where the cultural heritage is located.
7) Conservation-based Research Analysis is "defined as the research, analysis, survey and investigation

necessary to understand the significance of a building and its landscape and thus inform decision about repair, alteration, use and management" [Cla01]. This refers to documentation and recording used to inform conservation.

References

[Iga96] 11th ICOMOS General Assembly. 1996. *Principles for the recording of monuments, groups of buildings and sites*. Paris: ICOMOS.

[Cat00] Cather, Sharon. 2000. "Costing Graphic Documentation: How Much Money and Whose Time?" In *GraDoc: graphic documentation systems in mural painting conservation: research seminar, Rome 16-20 November 1999,* ed. Werner Schmid, 16-20. Rome: ICCROM.

[Cla01] Clark, Catherine. 2001. *Informed Conservation: Understanding Historic Buildings and Their Landscapes for Conservation*. London: English Heritage.

[Deq05] Dequal, Sergio, Ed. 2005. *Proceedings of the XXth International Symposium, CIPA 2005: International Cooperation to Save the World's Heritage: Torino (Italy), 26 September-01 October, 2005.* Turin: CIPA Organizing committee.

[EC05] Eppich, Rand and Amel Chabbi. 2005. "Recording and documenting cultural heritage - 3D modeling for conservation in developing regions." Paper presented at the International workshop on recording, modeling and visualization of cultural heritage, 22-27 May, 2005, Ascona, Switzerland.

[Exe03] Executive Secretariat of the Lyon Summit. 2003. "Declaration of the World Summit of Cities and Local Authorities on the Information Society," Art. 32. http://www.unchs.org/downloads/docs/246_56156_Declaration%20of%20the%20World%20Summit%20of%20Cities%20and%20Local%20Authorities%20on%20the%20Information%20Society.pdf (accessed July 21, 2006).

[LE05] LeBlanc, François and Rand Eppich. 2005. "Documenting our past for our future*." Conservation: the GCI Newsletter,* 20 (3): 5-9.

[Mat03] Matero, Frank G. 2003. "Managing change: the role of documentation and condition survey at Mesa Verde National Park." *Journal of the American Institute for Conservation* 42 (1): 39-58.

[Sch05] Schmid, Werner. 2005. "People and technology. A discussion about heritage documentation." By Jeffrey Levin and Rand Eppich. *Conservation: the GCI Newsletter,* 20 (3): 10-16.

[WO94] Waldhäeusl, P. and C. Ogleby. 1994. "3x3-rules for simple photogrammetric documentation of architecture." In *Close Range Techniques and Machine Vision. Proceedings of the Symposium of Commission V of ISPRS in Melbourne, Australia, 1-4 March 1994.* ISPRS XXX/5, 426-429. England: ISPRS.

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
VAST (2006)
M. Ioannides, D. Arnold, F. Niccolucci, K. Mania (Editors)

New Tools to Assist Excavation 4D Analysis: DATARCH© Archaeological Data Management System and "Variable Transparency Image Stacker". Beyond the Harris Matrix?

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Abstract
Data management systems have been intensely studied and greatly developed in Computer Applications to Archaeology, since they encouraged the diffused ambition to manage huge and heterogeneous archaeological data sets. One of the most promising perspectives of these systems was a strong integration of alphanumeric and photo/graphic data, but as a matter of fact past solutions rarely achieved satisfying results. New approaches to these goals will be discussed in this paper, focusing on a new Archaeological Data Management System (DATARCH©) and related tools intended to improve visualization and analysis of physical and stratigraphic relations by means of syncro-diachronic photography. DATARCH is a modular system which manages alphanumeric, graphic and photographic data. Its hierarchical structure fits very well the archaeological research workflow: it is organized in three main areas allowing users to access, edit and manage operations of three main phases: a) data acquiring (ACQUIRE), b) data analysing (ANALYSE), c) data sharing and publishing (SHARE). One of the most innovative DATARCH analysis tools is the "Variable Transparency Image Stacker": for the various phases of an excavation it allows to build up stacks of overlapping referenced orthophotographs managed as layers at variable transparency values. The "Variable Transparency Image Stacker" emphasizes and makes easily visible space relations among objects throughout the layers/time, assisting effectively data interpretation and comprehension. In the next steps of the research the implementation of the overlapping and control features, at present limited to orthophotographs, will be extended to stereophotogrammetric models, aiming to build up a real 4D data management system. Further studies should improve the integration of different kind of data, making the 4D model an interface to access alphanumeric archives relative to the excavations.

Categories and Subject Descriptors (according to ACM CCS):): H.2.8 [Database Applications]; I.3.3 [Picture/Image Generation].

1. Introduction

Salvatore Settis recently points out various decisive methodological issues about Cultural Data Management, one of the most relevant fields of application of ICT in archaeology: "Dealing with data, or data bases, we run the risk to believe that data are neutral, but they are not, and the way they create (or do not create) knowledge depends on their structure and their presentation… Experts' cultural choices strongly determine contents and structures, so they should be declared and highlighted …. Publication of museum and culture information requires that the leading force is knowledge, not technology, technology should serve content, and this way it will deal with new challenges and new progresses" [Set02].

Starting from this methodological background this study proposes archaeological data management protocols, based on the development of efficient, modular, interoperable, user friendly, support tools.

The essential keywords of the research are: - Different data sets integration; - Exploiting of photo/graphic information; - Interaction and networking; - Modularity; - Flexibility; - Vocabularies, graphical libraries, utilities.

The archaeological excavations of the Foce Sele (Paestum) Hera Sanctuary directed by Dipartimento di Discipline Storiche E. Lepore of Università degli Studi di Napoli Federico II have been selected as a suitable case-study for their peculiar problems of data acquisition, management, storage, analysis. Indeed since the very first exploration in Thirties, held by Paola Zancani Montuoso and Umberto Zanotti Bianco, Sanctuary investigations have been carried on in different periods and applying different methodologies, producing a large amount of data, very complex to manage [ZZ54].

In the last years a research group directed by prof. Giovanna Greco has been planning and organizing a systematic edition of the Sanctuary archaeological data [GF03].

The project seemed to be a good chance to apply new technologies and to face the definition of new protocols of data managing, archiving, sharing.

The first result of the study is the development of a new archaeological data management system/workflow protocol (DATARCH), whose main feature is a strong integration between photo-graphic and alphanumeric documentation.

2.Data management systems and methodologies in archaeology

It is well known that archaeological data management is one of the first and central fields of application of ICT technologies in archaeology.

G. Lock [Loc03] points out that the introduction of Information technology in archaeological data management was somehow facilitated by the methodological evolution of excavation documentation in Seventies. In that period in Great Britain two different documentation and recording systems were created and diffused: the Frere Report and the Harris Matrix. Both systems were based on a formalization of archaeological data that fits very well computerization, hence they encouraged computer introduction in archaeological data management.

Since then many systems have been developed, mainly based on a relational database model, but with different data structures, to support different research needs.

ArcheoDATA [Arr94], GUARD [Mad01], SYSAND [PPAM*96], Petradata [CNTV00] are only few of a very rich variety of realizations, with many similarities and many differences.

Other remarkable products are ArchED, Stratify [Her04]and GNET/JNET [Rya01] with a strong innovation in Harris-Matrix automatic generation.

In Mediterranean Countries and in Italy there is a different methodological background: archaeological informatics are relatively recent and not generally spread. In these studies recent National authorities initiatives in standardization and digitization are slowly changing the historical trend to specific and local solutions.

Among Italian projects noteworthy systems are ARGO (Pisa University) [AGR86], ODOS (Lecce University) [Sem97], ALADINO (Bologna University and Regione Emilia Istituto Beni Culturali) [Gue90]; OPEN ARCHEO (Siena University) [Val00].

It is worthwhile to remember that in South Italy there is a considerable diffusion of a French system, SYSLAT, affected in the last years by technological obsolescence problems [Py97].

G. Semeraro reviews Italian applications and underlines that they aim mainly to fulfil two research needs, stratigraphy analysis and urban studies, but she points out that these complex system are still upset by interoperability and standardization problems, far away from a definitive solution [Sem97].

3.DATARCH: project, methodology, development strategies

So far it has been not achieved a standardized and complete solution to store, study and integrate excavation data and photo/graphical information. This study intends to address these needs and to develop efficient workflow protocols.

The proposed application has been developed making the most of MS Visual Studio.Net environment.

Visual Studio is a complete set of tools to develop Web ASP applications, Web XML services, desktop and portable solutions. Visual Basic .NET, Visual C++ .NET, Visual C# .NET and Visual J# are fitted in a single Integrated Development Environment (IDE) which allows to share tools and resources to create solutions with mixed languages.

These features support the step-by-step development procedures proposed, both in the present release and in the next steps required. The multiple network language compatibility fits the future expansions of the software.

In this phase we focused on DATARCH, the archaeological part of a modular structure, the DASSACH, Data Acquiring and Sharing System for Archaeology and Cultural Heritage.

The system can manage all excavation steps data: alphanumeric, photo/graphic information, and additional documents.

DATARCH is released as a stand-alone application: users can install the software on the target machine with the provided installer.

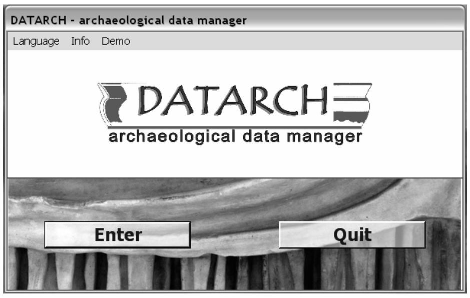

Figure 1: *DATARCH Starting Panel*

After an essential and functional Starting Panel, enabling basic operations such as logging in or logging out and viewing a short help file, user can enter the Main Form.This interface collects access to the highest level operations, organized in a semantic and hierarchical structure. Interface design aims to assemble functions as much as possible, to get a task with the minimum number of actions.Graphics, icons, colours, directions collaborate to convey meaningful signs in a semantic environment.

DATARCH key-concept is to reproduce the archaeological research workflow, from data acquisition (ACQUIRE), to data management and analysis (ANALYSE), to data publication and reporting (SHARE).

Data input (ACQUIRE) is distributed in several acquisition forms, which use tabs to aggregate information meaningfully in order to help easy and quick recording.

Analysis area (ANALYSE) gives users different tools to interrogate data: among them, the Dynamic Query Tool allows users to create queries by combining all the features and the records of the data set; tables are listed in a menu, in which user can select the data set to study.

This strategy's aim is to provide flexible solutions to manage and examine data. This way DATARCH provides an analyse procedure, more useful than a set of pre-defined, but numerically and methodologically limited solutions.

New solutions have been investigated to manage photo/graphic information, examining methodological issues raised during 2004 excavations in Foce Sele Hera Sanctuary. In that period tests and experiments were performed to study the possibility of a better exploitation of information collected by means of photographic techniques, by increasing the quality and the scientific value of acquisition and management processes.

First, guidelines were drawn to integrate orthophotographic and stereophotogrammetric information in Foce Sele Hera Sanctuary documentation.

Orthophotos of archaeological strata were realized and overlapped in semitransparent layers to excavation drawings: this allowed a quick, economical, in-situ quality check for the graphic documentation drawn with traditional techniques.

Figure 2: *The Variable Transparency Image Stacker*

This feature has been integrated in the DATARCH, by developing a tool called "Variable Transparency Image Stacker". When DATARCH is installed, it creates an IMAGES folder in the user hard disk. In the ACQUIRE panel, a wizard allows user to drag and drop images into the IMAGES folder, to easily store them. Thus images are ready to be processed by the "Variable Transparency Image Stacker". The Stacker makes it possible to select the various orthophotos of the different strata, stored in the IMAGES folder, and to overlap them: a panel allows to choose images and to control the transparency value of the different layers chosen.

Hence the "Variable Transparency Image Stacker" has been included into the DATARCH system, to introduce the concept of "syncro-diacronic photography" and to exploit its application advantages in archaeological interpretation: this way it is possible to dynamically reconstruct a stereo-vision of the excavation in order to analyse spatial relationships among archaeological strata. Further studies will investigate the possibility to link alphanumeric data to their photo/graphic representation.

It is useful to point out that this tool proposes a methodology to examine excavations based on their photographic representations. The syncro-diacronic photography is integrated in the archaeological data management system and it supports the whole process of construction of knowledge.

Thus this phase has been the first step in the process of developing a virtual reconstruction of archaeological excavations based on overlapping of strata 3D images.

The stereo-vision of the excavation may lead to a complete and direct analysis of the archaeological information, based on images and on their interconnection, blunting the present necessity of symbolic graphical reconstructions.

Finally, DATARCH is completed with a reporting area (SHARE), which allows users to produce Standard

Italian Ministry forms, and catalogues related to Hera Sanctuary archaeological data edition. DATARCH can be further extended with extra customized reports.

4. Main benefits, further developments and perspectives

Beyond this phase achievements, this research can be considered the methodological background of additional studied dedicated to enhancements of archaeological data management systems.

More studies will be dedicated to project broadening from a chronological, geographic, disciplinary point of view.

After a preliminary step dedicated to an analysis of the methodological context, the operative phase of this study led to define, propose and test a new protocol to manage and check workflow quality in archaeology.

In the preliminary review we observed the features of existing management systems: they fit very well specific research unit needs, but on the other side they produce not standard data and not interoperable information. Often these systems do not integrate alphanumeric and photo/graphic documentation.

Hence the first focus of this experimentation was the normalization of archaeological vocabularies used.

In this field further studies will cover archaeological onthologies and semantic web, but so far this field of investigation has been only drafted.

These normalization needs have been mainly addressed with the development of a new archaeological management system prototype, called DATARCH (Archaeological Data Manager).

DATARCH main benefits are:

- It is developed using MS Visual Studio.Net: This feature makes it possible to make the most of a powerful and flexible environment, also for the next steps of the project, primarily dedicated to improve networking.

- Data structure and interface fit archaeological workflow; ACQUIRE, ANALYSE and SHARE panels guide users to the related operations: Beta testers learned very quickly to use the program.

- Dynamic Queries: data analysis is very flexible and queries are possible on the whole data base features, without predetermined interrogations.

- “Variable Transparency Image Stacker” and syncro-diachronic photography. This tool allows to visualize and analize excavation data in a new, completely visual way.

- Analysis of archaeological stratigraphies is supported by a stacker of images, which allows to overlap orthophotos of different strata, and to control tranparency level of each layer. This feature is a first step of the realization of a tridimensional virtual excavation reconstruction.

- Reports. The prototype includes reports corresponding to Italian ministry formats, but the modular development strategy allows the integration of additional reports following this, to fulfil other needs, such as publications, papers, multimedia, etc.

- On field tests: the prototype has been tested by actual users. This step allowed fixing bugs and re-orienting in itinere the development process on the basis of the feedback. The prototype application to the Hera Sanctuary data already achieved remarkable results in normalizing, standardizing, checking, speeding up, empowering archaeological data analysis.

5.Conclusions

Beyond the present results, this research points up several methodological issues.

Considerations on vocabulary normalization, on metadata, on onthologies in archaeological data structures will be further investigated as they are relevant to a better information exploiting.

In the next steps networking and Internet features of the software will be improved. Peer to peer and hub-based structures will be particularly investigated as they can enrich archaeological data exchange [Can05].

Translation and multilingual features will be investigated as well. Anyhow it is to underline that while interface translation and software localization have not important methodological aspects, it may be difficult or complex to manage archives contents language.

“Variable Transparency Image Stacker” and syncro-diachronic photography will be empowered to make the most of this anaysis tool by overlapping tridimensional models instead of bidimensional pictures.

The better and dynamic integration of alphanumeric data and the “Variable Transparency Image Stacker” seem to be very promising for the hypothesis of a virtual 3D excavation reconstruction.

Further efforts will be dedicated to the integration and standardization of bibliographic information and to the Harris Matrix generation.

Moreover the need of accurate and complete chromatic data acquisition led to the study of new hardware tools, such as Pantone Color Cue. These data will be integrated in archaeological material forms; different colour codes (Munsell, Pantone, etc.) will be managed by comparison tables.

DATARCH is meant to be a module of a wider data structure, DASSACH, on Cultural Heritage Data: Interdisciplinary networks will support such developments.

Bearing in mind S. Settis words about technology neutrality and on cultural data archives, it is clear that each time analysis deals with data structures it conveys methodological issues.

As a result, protocols proposed support not only operation but mostly data interpretation.

It is necessary to be aware of methodological aspects of data management processes, to avoid technological determinism that in the past often affected a technological development technology-driven instead of culture-driven.

References

[AV92] AAVV: *Data and Image Processing in Classical Archeology*. April 1992, Ravello

[AA00] AAVV: *Creating Digital Resources for the Visual Arts: Standards and Good Practice*. Oxford,Visual Arts Data Service/Oxbow Books, 2000.

[AA03] AAVV: *Conferenza Europea di Minerva. Qualità del Web per la cultura. Il patrimonio culturale in rete per la ricerca, per la didattica, per il turismo culturale*, Parma, 2003.

[All04] AAVV: *DigiCULT Thematic Issue 3: Towards a Semantic Web for Heritage Resources*, 2003.

[All04] ALLARD,M.: The RGZM web databases. Java implementations on cultural heritage websites. In AAVV. *Proceeding of the 27th CAA, April 1999. Making the connection to the Past CAA99. Computer Applications and Quantitative Methods in Archaeology*, Leiden, The Netherlands, Dublin, Ireland, CAA, 2004.

[AGR86] ALOIA,N. - GUALANDI,M.L. - RICCI,A.: Argo. Uno strumento per la gestione dei dati nella ricerca archeologica sul campo. *Quaderni di Informatica e Beni Culturali* 19, Siena, 1986.

[AGMT99] ANCONA,M.- GIANUZZI,V.- MIGLIAZZI,M.- TINE,V.: Computer Supported Cooperative Work in field archaeology: the Ade system. In AAVV, *Proceeding of the 26th CAA, March 1998. Techniques for Old Times CAA98. Computer Applications and Quantitative Methods in Archaeology*, Oxford, UK, Barcelona, Spain, Archaeopress, 1999.

[ADMT99] ANCONA,M.- DODERO,G.- MONGIARDINO,M.- TRAVERSO, A.: *Taking digital Notes in the Field: the Archeo tool-set . Proceeding of the 26th CAA, March 1998. Techniques for Old Times CAA98. Computer Applications and Quantitative Methods in Archaeology*, Oxford, UK, Barcelona, Spain, Archaeopress, 1999.

[AM04] ANDRESEN,J.- MADSEN,T.: IDEA-the Integrated Database for Excavation Analysis. In AAVV, *Proceedings of the 23th CAA conference, Leiden, 1995. Interfacing the past: Computer Applications and Quantitative Methods in Archaeology* 1995, Leiden University, Leiden, 1996.

[ADFH04] ARNOLD,D.B. - DAY,A.M. - FELLNER,D.W.- HAVEMANN,S.: The CHARISMATIC approach to modelling and rendering of historic urban environments. In AAVV, *Proceedings of the 30th CAA conference, April 2003. Enter the Past. The E-way into the four Dimensions of Cultural Heritage. CAA 2003, Computer Applications and Quantitative Methods in Archaeology*, BAR, 2004..

[AL093] ARROYO BISHOP,D.- LANTADA ZARZOSA,T.: Planning for inter- and intra-site data management and interpretation. In AAVV, *Proceedings of the 20th CAA conference, 27-29 March 1992. Computing the Past: Computer Applications and Quantitative Methods in Archaeology*. 1992, Aarhus, Denmark, Aarhus University, Aarhus, Denmark, Aarhus University Press, 1993.

[Arr94] ARROYO BISHOP,D.: Advancing in archaeological recording and interpretation: The ArchéoDATA groups and entities. *Archeologia e Calcolatori* 5, 1994.

[Arr96] ARROYO BISHOP,D.: Relating time within the general methodological structure of archaelogical interpretation. Topographic and Urbanistic Studies. III Convegno Internazionale di Archeologia e Informatica 1995, Roma, *Archeologia e Calcolatori*, 1996.

[AM04] ASMUS,B.- MEISTER,C.: The Cederberg Rock Art Survey Project: A Co-Ordinated Field Record And Database Structure. In AAVV, *Proceedings of* *the 30th CAA conference, April 2003. Enter the Past. The E-way into the four Dimensions of Cultural Heritage. CAA 2003, Computer Applications and Quantitative Methods in Archaeology*, BAR, 2004.

[Ave01] AVERN,G.J.: A new Technique for Recording Archaeological Excavations: Research Progress Report. In AAVV, *Proceedings of the 28th CAA conference, 25-29 April 2001. Computing Archaeology for Understanding the Past CAA2000. Computer Applications and Quantitative Methods in Archaeology,* Oxford, UK, Ljubljana, Slovenia, Archaeopress, 2001.

[Azz00] AZZENA,G.: Rischio archeologico: se lo conosci lo eviti. Convegno di studi su cartografia archeologica e tutela del territorio (Ferrara, 24-25 marzo 2000). *Archeologia e Calcolatori* 11, 2000.

[BABB*99] BAENA PREYSLER,J.- ALVAREZ SANCHIS,J.- BERMTIDEZ,J.- BLASCO,C.- SANCHEZ MORENO,E.: Digital Cartographical Databases and their Application to Archaeology. In AAVV, *Proceeding of the 26th CAA, March 1998. Techniques for Old Times CAA98. Computer Applications and Quantitative Methods in Archaeology*, Oxford, UK, Barcelona, Spain, Archaeopress, 1999.

[BHD01] BAGGE NIELSEN,L. - HANSEN,H.J. - DAM,C.: SMR in New Clothes: The Danish National Record of Sites and Monuments on the Verge of a New Era. In AAVV, *Proceedings of the 28th CAA conference, 25-29 April 2001. Computing Archaeology for Understanding the Past CAA2000. Computer Applications and Quantitative Methods in Archaeology*, Oxford, UK, Ljubljana, Slovenia, Archaeopress, 2001.

[Bar92] BARCÉLO,J.A.: Programming an intelligent database in hypertext. In AAVV, *Proceedings of the 19th CAA conference, 25th to 27th March, 1991. Computer Applications and Quantitative Methods in Archaeology* 1991, Oxford, UK, University of Oxford, UK, Tempvs Reparatvm, 1992.

[BGK99] BEKIARI,C. - GRITZAPI,C. - KALOMOIRAKIS,D.: POLEMON: A Federated Database Management System for the Documentation, Management and Promotion of Cultural Heritage. In AAVV, *Proceeding of the 26th CAA, March 1998. Techniques for Old Times CAA98. Computer Applications and Quantitative Methods in Archaeology*, Oxford, UK, Barcelona, Spain, Archaeopress, 1999.

[BB02] BUCKLAND,P. - BUCKLAND,P.: How can a database full of Bugs help reconstruct the climate? In AAVV, *Proceedings of the 28th CAA conference, 25-29 April 2001. Archaeological Informatics: Pushing The Envelope CAA2001. Computer Applications and Quantitative Methods in Archaeology*, Oxford, UK, Visby, Gotland, Sweden, Archaeopress, 2002.

[Can05] CANTONE,F.: Shared technologies in archeologia: nuove prospettive di gestione e condivisione di dati in rete. *Archeologia e Calcolatori* 16, 2005.

[CM94] CHARTRAND,J.- MILLER,P.: Concordance in rural and urban database structure: The York experience. *Archeologia e Calcolatori* 5, 1994.

[CH92] CHEETHAM,P.- HAIGH,J.G.B.: The archaeological database - new relations? In AAVV, *Proceedings of the 19th CAA conference, 25th to 27th March, 1991. Computer Applications and Quantitative Methods in Archaeology* 1991, Oxford, UK, University of Oxford, UK, Tempvs Reparatvm, 1992.

[CFR03] CLARKE,A.- FULFORD,M.- RAINS,M.: Nothing to Hide - Online Database Publication and the Silchester Town Life Project. In AAVV, *Proceedings of the 29th CAA conference, April 2002. The Digital Heritage of Archaeology. Computer Applications and Quantitative Methods in Archaeology*, Heraklion, Crete, Greece, Hellenic Ministry of Culture, 2003.

[Coh96] COHEN,R.: Integration of distributed database. Sites and Monuments Records. *III Convegno Internazionale di Archeologia e Informatica* 1995, Roma, 1996.

[Cor02] CORBOUD,P.: Creating of a database for prehistoric sites: which are the goals, the strategy and what means to put in place? In AAVV, *Proceedings of the 28th CAA conference, 25-29 April 2001. Archaeological Informatics: Pushing The Envelope CAA2001. Computer Applications and Quantitative Methods in Archaeology*, Oxford, UK, Visby, Gotland, Sweden, Archaeopress, 2002.

[CNTV00] CRESCIOLI,M.- NICCOLUCCI,F.- TONGHINI,C.- VANNINI,G.: PETRA: un sistema integrato per la gestione dei dati archeologici. *I Workshop Nazionale di Archeologia Computazionale* 1999, Napoli-Firenze, 2000.

[FBBJ99] FARCIC,V.- BENUSI,I.- BONDZIC,N.- JOVANOVIC,M.: The Archaeological Database of Serbia. In AAVV, *Proceeding of the 26th CAA, March 1998. Techniques for Old Times CAA98. Computer Applications and Quantitative Methods in Archaeology*, Oxford, UK, Barcelona, Spain, Archaeopress, 1999.

[GF03] GRECO, G. – FERRARA, B.: *L'Heraion alla Foce del Sele,* Salerno 2003

[Gue90] GUERMANDI,M.P.: ALADINO: verso un sistema computerizzato per lo studio e l'analisi dei dati archeologici. *Archeologia e Calcolatori* 1, 1990.

[Han93] HANSEN,H.J.: European archaeological databases: problems and prospects. In AAVV, *Proceedings of the 20th CAA conference, 27-29 March 1992. Computing the Past: Computer Applications and Quantitative Methods in Archaeology*. 1992, Aarhus, Denmark, Aarhus University, Aarhus, Denmark, Aarhus University Press, 1993.

[Hin94] HINGE,P.: New fusions: Archaeological information in the relational database. *Archeologia e Calcolatori* 5, 1994.

[Her04] HERZOG,I.: Group and conquer - a method for displaying large stratigraphic data sets. In AAVV, *Proceedings of the 30th CAA conference, April 2003. Enter the Past. The E-way into the four Dimensions of Cultural Heritage. CAA 2003, Computer Applications and Quantitative Methods in Archaeology*, BAR, 2004.

[Kad99] KADAR,M.: Distribution of Copper Ores in the Carpathians. Data Management With Relational Databases. In AAVV, *Proceeding of the 26th CAA, March 1998. Techniques for Old Times CAA98. Computer Applications and Quantitative Methods in Archaeology*, Oxford, UK, Barcelona, Spain, Archaeopress, 1999.

[KBC03] KADAR,M.- BUCUR,V.- CEUCA,E.: Relational Database Management System for the Early Metallurgy of Copper and Bronze in Transylvania, Romania. In AAVV, *Proceedings of the 29th CAA conference, April 2002. The Digital Heritage of Archaeology. Computer Applications and Quantitative Methods in Archaeology*, Heraklion, Crete, Greece, Hellenic Ministry of Culture, 2003.

[Kar03] KARIMALI,E.: Designing a Three-layered Database for Modeling Lithic Distribution: the Example of the Aegean. In AAVV, *Proceedings of the 29th CAA conference, April 2002. The Digital Heritage of Archaeology. Computer Applications and Quantitative Methods in Archaeology*, Heraklion, Crete, Greece, Hellenic Ministry of Culture, 2003.

[LDLI*03] LEGGAT,M.- DOWLING,B.- LEGGATT,G.- ISON,S.- CHIPPINDALE,C.: Online Database of Chilean Rock-Art. In AAVV, *Proceedings of the 29th CAA conference, April 2002. The Digital Heritage of Archaeology. Computer Applications and Quantitative Methods in Archaeology*, Heraklion, Crete, Greece, Hellenic Ministry of Culture, 2003 .

[Mad01] MADSEN,T.: Transforming Diversity into Uniformity - Experiments with Meta-structures for Database Recording. In AAVV, *Proceedings of the 28th CAA conference, 25-29 April 2001. Computing Archaeology for Understanding the Past CAA2000. Computer Applications and Quantitative Methods in Archaeology*, Oxford, UK, Ljubljana, Slovenia, Archaeopress, 2001.

[NNSC*04] NAUTIYAL,V.- NAUTIYAL,S.- NAITHANI,M.- SANJIV,J.- CLARK,J.T.- LANDRUM,J.E.I.- BERGSTROM,A.- FROVARP,R.- HAWLEY,J.- EICHELE,D.: 3D modelling and database of Indian archaeological pottery Assemblageshnbgu-NDSU collaborative initiative. In AAVV, *Proceedings of the 30th CAA conference, April 2003. Enter the Past. The E-way into the four Dimensions of Cultural Heritage. CAA 2003, Computer Applications and Quantitative Methods in Archaeology*, BAR, 2004.

[NMSM*99] NEGRONI CATACCHIO,N.- MIARI,M.- SETTI,B.- MELONI,G.- FERRARI,R.- GROPPO,E.: *EARP* -- European Archaeological Research Projects. Fieldwork Opportunities Database on the Internet. In AAVV, *Proceeding of the 25th Anniversary CAA, April 1997. Archaeology in the Age of the Internet CAA97. Computer Applications and Quantitative*

Methods in Archaeology, Oxford, UK, University of Birmingham, 1999.

[NDC01] NICCOLUCCI,F.- D'ANDREA,A.- CRESCIOLI,M.: Archaeological Applications of Fuzzy Databases. In AAVV, *Proceedings of the 28th CAA conference, 25-29 April 2001. Computing Archaeology for Understanding the Past CAA2000. Computer Applications and Quantitative Methods in Archaeology*, Oxford, UK, Ljubljana, Slovenia, Archaeopress, 2001.

[Osi02] OSINTSOV,Y.- CHRISTOV,Y.- GERASIMOV,D. The Computer Catalogue of the Kunstkammer Museum Collections and perspectives of an Internet-shared Anthropological Database. In AAVV, *Proceedings of the 28th CAA conference, 25-29 April 2001. Archaeological Informatics: Pushing The Envelope CAA2001. Computer Applications and Quantitative Methods in Archaeology*, Oxford, UK, Visby, Gotland, Sweden, Archaeopress, 2002.

[Pap03] PAPAIOANNOU,G.: Designing an Exploitable and Expandable Archaeological Database: the case of the Late Prehistory of NW Greece. In AAVV, *Proceedings of the 29th CAA conference, April 2002. The Digital Heritage of Archaeology. Computer Applications and Quantitative Methods in Archaeology*, Heraklion, Crete, Greece, Hellenic Ministry of Culture, 2003.

[PPAM*96] PIEROBON,M.- PIEROBON BENOIT,R.- AGRESTI,E.- MAGGIOLO SCHETTINI,A.- SACCOCCIO,R.: Handling Excavation Maps in SYSAND. In AAVV, *Proceedings of the 23th CAA conference, Leiden, 1995. Interfacing the past: Computer Applications and Quantitative Methods in Archaeology* 1995, Leiden University, Leiden, 1996.

[Py97] PY,M.: *Syslat 3.1. Systéme d'Information Archéologique. Manuel de référence (Lattara 10)*. Lattes, 1997.

[Rya92] RYAN,N.S.: Beyond the relational database: managing the variety and complexity of archaeological data. In AAVV, *Proceedings of the 19th CAA conference, 25th to 27th March, 1991. Computer Applications and Quantitative Methods in Archaeology* 1991, Oxford, UK, University of Oxford, UK, Tempvs Reparatvm, 1992.

[Rya01] RYAN,N.S.: Jnet, a successor to Gnet. *Archaologie und Computer, Workshop 6*, Vienna, Forschungsgesellschaft Wiener Stadtarchaologie, 2001.

[Sch02] SCHLADER,R.: Archaeological databases: what are they and what do they mean? In AAVV, *Proceedings of the 28th CAA conference, 25-29 April 2001. Archaeological Informatics: Pushing The Envelope CAA2001. Computer Applications and Quantitative Methods in Archaeology*, Oxford, UK, Visby, Gotland, Sweden, Archaeopress, 2002.

[Sch99] SCHLOEN,D.: Database Design and the Electronic Publication of Archaeological Information. In AAVV, *Proceeding of the 26th CAA, March 1998. Techniques for Old Times CAA98. Computer Applications and Quantitative Methods in Archaeology*, Oxford, UK, Barcelona, Spain, Archaeopress, 1999.

[Sem97] SEMERARO,G.: Il sistema per la gestione dei dati di scavo. Aspetti metodologici. *Metodologie di Catalogazione dei beni archeologici*, 1997.

[Set02] SETTIS,S.: *Italia S.p.A. L'assalto al patrimonio culturale*. Torino,Einaudi, 2002.

[Val00] VALENTI,M.: La piattaforma GIS dello scavo. Filosofia di lavoro e provocazioni, modello dei dati e "soluzione GIS". *I Workshop Nazionale di Archeologia Computazionale,1999*, Napoli-Firenze, 2000.

[ZZ54]: ZANCANI MONTUORO, P. - ZANOTTI BIANCO, U. *Heraion di Foce Sele I-I*, Roma 1951-54

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
VAST (2006)
M. Ioannides, D. Arnold, F. Niccolucci, K. Mania (Editors)

Colour Reproduction of Digital Still Cameras Simple Test and Affordable Solution

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Abstract

One of the most relevant problems in the imaging of cultural heritage is the faithful rendition of colours (if any). Control on the spectral sensitivity of the chemical sensor (i.e. the film) is not possible; firmware governing first phase processing of images acquired by digital still cameras allows, instead, to control to some extent colours and hues due to non-standard (i.e. not consistent with CIE criteria) lighting.

The problem of chromatic deviation is particularly serious during on site, open-air shooting sessions, as in archaeological excavations, where the use of appropriate standard lighting is excluded and the natural light (the only available) is often more or less affected by various chromatic intonations.

A relative aid to manage the question is offered by digital still cameras with the so called white balance (WB), a feature pretending to adjust colour temperature in order to match the chromatic sensitivity of the sensor to the actual light source spectrum.

The paper reports a simple, affordable and reliable way to test how much you can trust the white balancing of your still camera.

Furthermore, a comparison with a "reference" shot of an appropriate subject (containing a grey scale and the basic colours) indicates that a well known SW (a standard de facto) can be the simple but effective solution to the correct (i.e. rather faithful) rendition of colours and hues in various chromatic intonations of light during a shooting session.

Categories and subject descriptors (according to ACM CCS): I.3.4 [Graphics Utilities]; I.4.1 [Digitization and Image Capture]

1. Introduction

It is well known that the correct reproduction of the colours is one of the most difficult problems in scientific photography, despite the type of camera and the light sensor used (chemical or digital).

Even if the shooting is performed in controlled light, corresponding precisely to the indications of CIE protocols, the final result is affected/impaired by a certain numbers of factors that can be only partially controlled:

1. in the case of traditional (chemical) film, the spectral sensitivity and the chemical processing itself
2. in the case of digital still camera, the type of sensor, its spectral sensitivity and (last but not least) the way the information on the light on single pixel is post-processed in the camera itself (i.e. type of file produced, rate of compression, quality and "oddities" of the firmware implemented in each camera)
3. final printing quality
4. chromatic "quality" of the light used to examine the image produced!

An absolutely faithful correspondence to the colours of the "original" is, therefore, not only a quite impossible task in the every day life of a scholar, but the whole affair could appear as non sense if the main purpose is the production of an image having a reasonably good chromatic fidelity to the original object of the cultural heritage, avoiding only appreciable chromatic “distortions”.

Chemical sensor (film)

In this case, the way to get a good chromatic correction consists of:

a. measurement of the light colour by means of a colorimeter, indicating the amount of deviation from the standard the film was calibrated for
b. accurate application of the appropriate filter, chosen from a quite large and expensive set (e.g. Kodak’s filters for technical and scientific applications)

The purpose is to make the spectrum of existing light to conform to the spectral sensitivities of the films, at present available in only two basic types: for daylight and tungsten (incandescent) artificial light (“special” films are not considered, e.g. UV or IR).

Digital solid-state sensor

Digital still cameras, that have almost completely superseded the traditional ones, among other useful features, (pretend to) offer the adjustment for colour temperature, called white balance (WB): it is intended to match the sensor to a particular light source. Some cameras have the WB options in their menu systems, others on a dial. For most situations it is preferable to leave the WB on AUTO and let the camera determine the proper setting. In certain situations (when lighting is of a well known and fixed type) better results (in terms of colour fidelity and response stability) can be obtained by manually selecting the WB to suit specific light source: e.g. tungsten, daylight, fluorescent or one of the other light settings available on that camera.

2. Simple and affordable tests

In the philosophy of digital cameras (ready use and quick response and process of images) a test, very easy to be performed, is proposed for testing the real ability of the camera in terms of white balance (WB).

Ideally, the WB option should enable the camera to offer a correct chromatic reproduction of a subject despite the various light conditions and spectral sensitivity of the specific photographic sensor used. The reality is rather different and the WB option (as all the automatic features) only works if the deviation from “standard” light conditions

- remains limited
- is of a “certain” type.

The first step is verifying the reliability of our camera in terms of correct colour reproduction in light conditions affected by a controlled chromatic deviation.

3. Practical procedure

In order to obtain a precise picture of the WB option performance, the following procedure was realized:

1. in condition of lighting possibly similar to day light (better in real day light), a first shot is performed of a suitable “standard” subject (i.e. a standard 18% reflective grey card plus basic colours – both additive and subtractive- and grey scales)
2. a series of pictures of the same subject is then taken (with the same lighting) with filters of the colours Cyan, Magenta and Yellow, at increasing density (5 – 10 – 20 – 30 – 40 – 50)
3. application of a bluish 80B filter simulates the rather cold intonation of the light early in the morning
4. a Yellow-Green filter (YG) simulates the intonation affecting the light under the foliage in a forestry
5. the images obtained are easily compared with the initial unfiltered one, assumed as a reference.

To allow a certain comparison, this procedure was applied to two different digital cameras:

a. Nikon reflex digital camera D200
b. Nikon reflex digital camera D70

producing two different series of images of the same subject in identical lighting conditions.

In each series, a comparison was carried on in order to get a visual evaluation of efficiency of white balancing of each camera (but the procedure is valid for all cameras).

It is worthwhile remembering that the human eye has rather poor ability to appreciate absolute “quality” of colours but is highly reliable when it compares two images of the same subject placed side by side and identically lightened.

If the result is an appreciable (to the human eye) correspondence of colours of the picture in conditions of non standard lighting, a visual evaluation can be completely adequate, avoiding, therefore, the quite cumbersome procedure of recurring to a precise quantification of chromatic deviations in the colour space.

4.Results

Both the cameras performed rather similarly: in presence of the definite light intonation due to filtering, WB seems to have an overall rather poor effect. Images produced by D200 are clearly "coloured" even at the lowest filter density; a little better is the performance of D70 for the yellow filtering only: its WB is able to compensate rather nicely up to a density of yellow 40. On the other hand, the images produced by D70 are nicely processed and corrected except those ones filtered in yellow and magenta at density 50: after the usual SW processing the chromatic deviation is only reduced but still evident.

Blue colouring of B80 filter was very well corrected for both the cameras, with a perfect correspondence to the reference shot.

Yellow-green light colour appears to be quite difficult for the SW to correct: an evident, rather intense, intonation remains on the image, for both the cameras.

5. Conclusions

White balancing of the cameras tested was not able to correct the precise hue introduced by the various filters: even in the case of the lowest density (value=5), the image appears affected by a light but appreciable chromatic intonation, with the exception of yellow (up to density 40) for the Nikon D70

The automatic colour control of PhotoShop CS2 allowed to obtain an image very well corrected, really near to the reference (as human eye can judge).

If a not too severe colour control but a good overall chromatic correspondence is required (i.e. correction of most evident/disturbing colour deviations), the proposed procedure and the subsequent comparisons indicate that the automatic colour control in PhotoShop CS2 is certainly a practical, quick and effective tool, not depending on the behaviour of the particular camera used.

6. Cautions

The proposed practical procedure is intended as a way to obtain images with a satisfying chromatic rendition, avoiding cumbersome and expensive measuring and filtering.

Limits exist in the rather different behaviours of the various digital still cameras, due to both the specific spectral sensitivity of each sensor and to the performance of the firmware implemented in each camera.

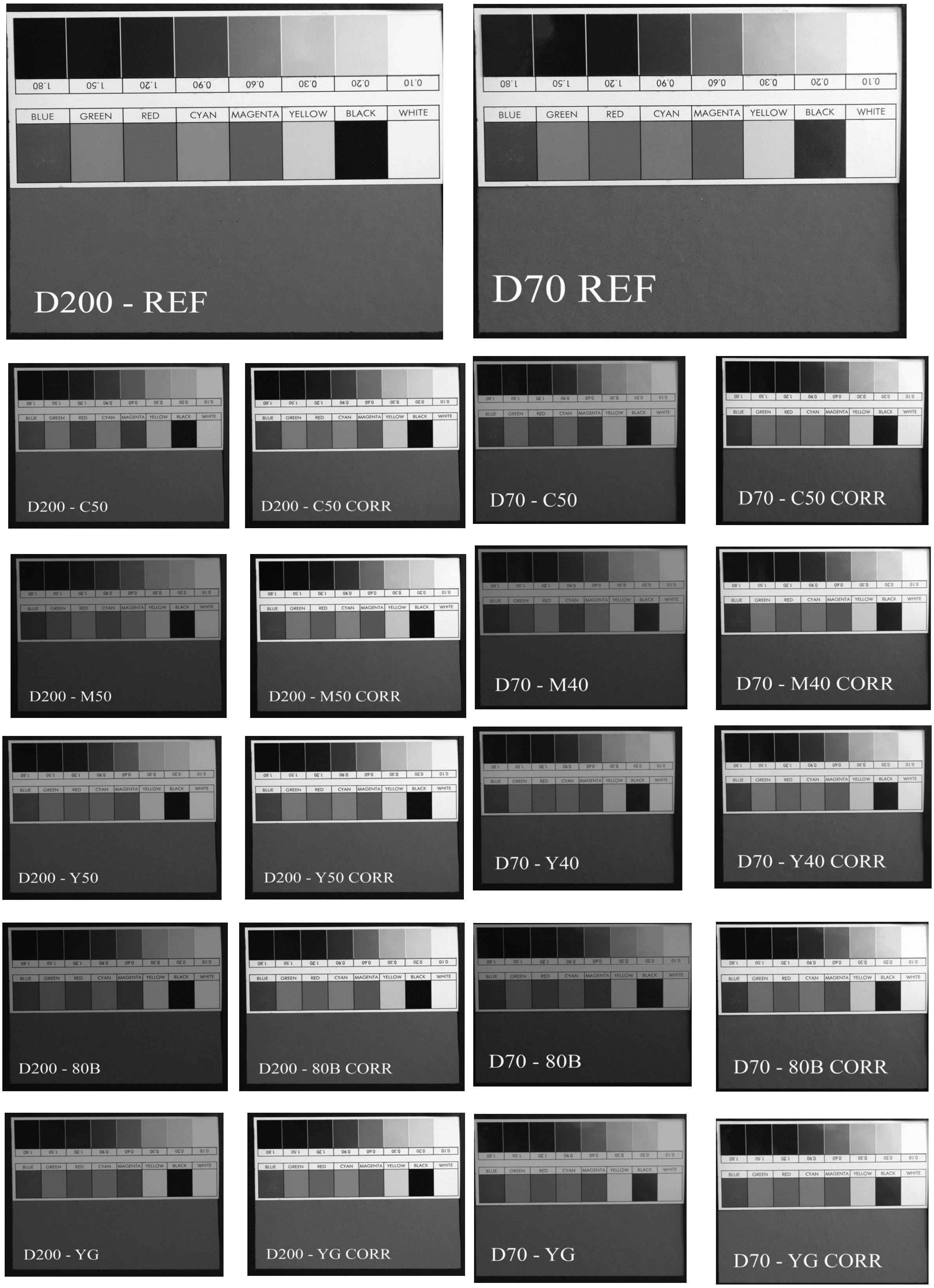
Including (always) a chromatic and grey scale in your real images offers a simple and easy comparison with a reference shot to confirm immediately the reliability of the final image, obtained e.g. after a processing (both optical and via software).

7. Labels on images

Labels on the images should be read as follows:

- **D200 REF**: reference shot for Nikon D200
- **D70 REF** : reference image for Nikon D70
- **CXX**: Cyan filtering density XX
- **MXX:** Magenta filtering density XX
- **YXX:** Yellow filtering density XX
- **80B:** blue filtering 80B
- **YG:** yellow-green filtering
- **CORR:** denotes the image "corrected" by SW

.


BLUE
GREEN
RED
CYAN
MAGENTA
YELLOW
BLACK
WHITE
D200 - REF
D70 REF
D200 - C50
D200 - C50 CORR
D70 - C50
D70 - C50 CORR
D200 - M50
D200 - M50 CORR
D70 - M40
D70 - M40 CORR
D200 - Y50
D200 - Y50 CORR
D70 - Y40
D70 - Y40 CORR
D200 - 80B
D200 - 80B CORR
D70 - 80B
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D200 - YG
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Computer Assisted Archaeo-Anthropology on Damaged Mummified Remains

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Abstract

In this work we present the results of innovative methods in the anthropological analysis of a preincaic mummy. This mummy is seriously damaged and dismembered in six fragments. Moreover, due to the mummified soft tissues which cover the bones of the real mummy, researchers are prevented from performing traditional morphometric analysis. Therefore CT acquisition and 3D surface reconstruction of the rare bones provide a unique and extensive data-set to enhance the results of scientific studies. Landmarks identification and detailed measurements have been carried out on the virtual skeleton of the whole mummy, whose original position had been previously identified. In order to perform repeatability and comparison of measures, especially on the limbs, a detailed orientation procedure has been applied. Moreover the integration of Virtual Reality and CAD (Computer Aided Design) tools lead to the computation of additional geometric features on selected single bones. Several considerations are provided by the computation of detailed indexes on the sections, distances and curvatures of the limbs. Furthermore the virtual skull has been analysed following a computer based approach for the evaluation of artificial cranial deformation. Silhouettes extraction, multivariate analysis and 3D visualization allow estimating the place of origin in accordance with previous scientific and recognised works on the classification of induced deformations. These are the results of a complex work that aims at a project based approach exploiting new computer based technologies in the analysis of ancient human remains. A modular and integrative approach shows how a multidisciplinary team, made of engineers and anthropologists, can really enhance the knowledge on the mummy and present it in a sustainable way.

Categories and Subject Descriptors (according to ACM CCS): I.3.8 [Computer Graphics]: Applications, J.2 [Physical Sciences and Engineering]: Archaeology

1. Introduction

The growing interest in the digitalization of ancient remains has opened the way to new approaches in the analysis and dissemination of Cultural Heritage [Bar00] and [Add00]. Together with 3D reconstructions and replicas of archaeological and anthropological finds there is now a big challenge in the rational use of digital data sets for restoration, conservation and general fruition. Several tools, methods and skills need to be shared among different scientific areas and results should highlight the innovations and the discoveries they bring to light. One of the most interesting research areas in this field is the study of mummies. Several considerations arise when applying Virtual Reality to this important historical, cultural and scientific heritage [TSHJi92] and [GRHR06]. Since they are usually very fragile, direct manipulation interventions would further damage the remains of the mummy and cause the loss of small fragments of soft mummified tissue. This means that transportation and restoration are very dangerous for the good conservation of mummies. Moreover, much information is encapsulated under the surface of the mummified tissues or of the bandage. Volumetric exploration of the mummy from inside is a real challenge for researchers who need to build up complete reports on such remains [CMF*03] and [RHB02].

In the next sections a South America mummy is investigated by a multidisciplinary team in the framework of a collaboration between the Second Faculty of Engineering and

Conservation of Cultural Heritage Faculty of the University of Bologna. Materials, tools and methods are described, together with the description of the results achieved.

2. Materials

The mummy under investigation was sent from the Civic Museums of Reggio Emilia to the Department of Histories and methods for the Conservation of Cultural Heritage (DISMEC) for research purpose and restoration interventions [LLO*03] .

Figure 1: *The dismembered mummy.*

The mummy comes from the Necropolis of Ancòn, in the south-central coast of Peru and was shipped Italy in 1893. Due to the lack of equipment it is not possible to exactly date the mummy. Anyway remains from Ancòn area are usually dated between Late Intermediate (900-1440 AC) and Late Horizon Period (1476-1532 AC) of the ancient Peruvian history. Moreover the kind of spinning of a small fragment of cloth found on the neck of the mummy confirms the place of origin and chronologically sets it between the X and XI century AD. Besides, the original tightly flexed position of Figure 1, typical of the Andean mummies, had been reproduced by means of temporary strings, and both internal and external structures had been seriously damaged. After removing the strings the mummy showed six dismembered parts and looked in really bad conditions. Only the left upper limb could be considered in the proper anatomical position, while all the other limbs were separated from the body of the mummy. Six different main fragments are currently available: the part of the bust with the head and the left upper limb, the right upper limb, the part of the rachis, the pelvis (reduced to bony tissue), and the two lower limbs. It is also possible to remark the loss of small fragments of soft mummified tissue due to the fragility of the remains. First anthropological analysis revealed a female subject who died approximately at the age of 14-15 years. She was 144-150 cm high and her head was intentionally and tightly deformed as it would usually happen whitin high society members. Radiographic and tomographic investigations showed radiopaque areas which are related to a natural mummification process inside the skull due to the dry climatic conditions of the Peruvian coasts. A further radiopaque perimeter on the right parietal bone of the skull is related to a calcified tumefaction of soft tissue probably due to a stroke. Furthermore, spectrographic analysis have been performed in order to identify the specific material of metal parts clearly highlighted in the mouth of the mummy by tomographic investigations. These are principally copper fragments, but also silver, iron, chrome and lead have been revealed. The above considerations lead to suppose that the mummy is a sacrificial victim.

3. Methods

A multidisciplinary team in the field of Virtual Reality applied to Cultural Heritage needs to be built upon the contamination of many backgrounds. Experts from the archaeological-anthropological area have a knowledge-based approach and bring their know-how about the past and present practices in the study of remains and on the lack of information now observed. Nevertheless further ideas are expected during the project development process as new potential approaches are foreseen. On the other hand technological skills are required to those who work in the acquisition and the post processing of data. This process can be very complex and requires the construction of design procedures capable to enhance the results and assess the definition of a new generation of methods and metrics. Moreover the process is based on the visualization and interaction of three dimensional models that must be accessible to users. Thus the Human Computer Interface component is also a key factor in the development of this project. Knowledge about design procedures, CAD modelling and innovative human computer interfaces are brought by the team of engineers who posses a significant experience in Virtual Reality and Simulations for industrial applications.

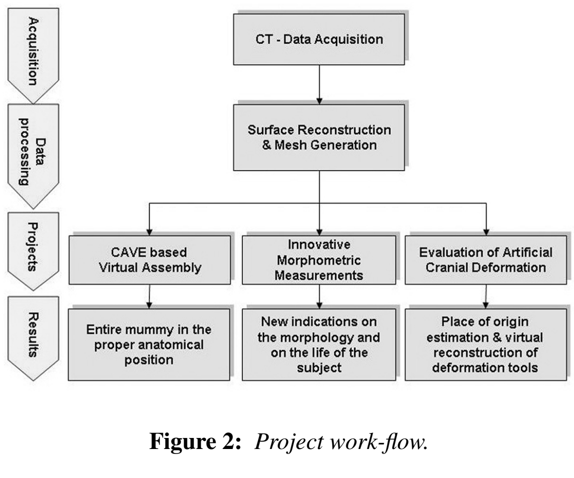


Figure 2: *Project work-flow.*

Figure 2 depicts the work-flow applied to the preincaic mummy. It is seriously damaged and broken in six separate parts. Each of these components has been acquired and 3D models of the single fragments have been obtained from CT (Computed Tomography) image stacks. Once the data processing is performed three single projects have been developed showing important anthropological results.
The first project focused on the visualization and interaction procedures performed in a semi-immersive Virtual Reality environment and provided a unique virtual model of the entire mummy in the proper anatomical position of funerary posture. It is evident that the importance of these archaeological finds, which bear witness to an ancient bio-cultural civilization, requires precautionary measures. Besides the opportunity to analyse the mummy preserving the conservation state, it is worth highlighting the power of communication that the virtual mummy has compared to its single fragments (Figure 3).

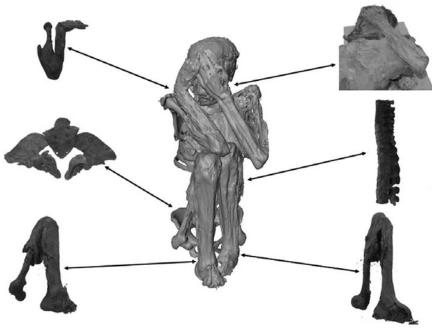


Figure 3: *The Virtual Model of he entire mummy.*

In addition to the external surface of the mummy, the surfaces of both the external and the internal structure of the rare bones have been meshed. The entire skeleton reconstruction provides a unique and extensive data-set to enhance the results of morphometric studies and to propose new potential approaches for morphological applications. A digital-based procedure can seriously limit the influence of the subjective factors related to traditional approach, such as the manual orientation and the application of contact-based instruments. Moreover, the virtual skeleton allows to start up totally new researches. Here we investigate the humerus shape features analysing the specific sections computed from the bone surface, the cortical surface and the marrow canal. Comparing the right and the left humerus according to the geometric features derived from the sections, several indications on the morfological and on the life of the subject are reported.
The last project deals with the evaluation of the artificial cranial deformation observed on the mummy. This kind of practice was common in Pre-Columbian civilizations in South America. Researches in this field refer to the study of the skull morphology mainly based on the comparison of anthropometric indexes. Mapping these modifications is a valid approach for the evaluation of artificial cranial deformation, but in the case of the mummy anthropologists are prevented from measuring the skull at the traditional osteometric landmarks due to the soft tissues that cover the reference points on the bones. Hence, the skull of the mummy has been brought to light from the main fragment disassembling it from the bust and the left hand. Reference landmarks have been selected and outline profiles have been identified on the virtual skull, properly oriented, in order to compute anthropometric indexes. Cranial deformations have been evaluated using the 3D model and comparing with the results of previous scientific works and a virtual model of the hypotised instruments used to induce such deformation is provided.

4. Virtual Reconstruction of the Entire Mummy

It is well-known that the introduction of Computer Graphics and Virtual Reality provided significant benefits to the development of advanced tools and support experts in retrieving additional information on mummies in the framework of Cultural Heritage analysis [HBG04] . This project work aims at the reconstruction of a virtual model of the entire mummy in an interactive computer based environment. Therefore visualization and manipulation techniques were applied in a collaborative approach within a CAVE (Cave Automatic Virtual Environment), a semi-immersive equipment based on three 2.5 x 1.9 m rear projected screens. The CAVE is located at the Virtual Reality lab at the University of Bologna within the Second Faculty of Engineering [LPDC01].
The data-set coming from the surface reconstruction process contains a huge amount of data representing the single components of the mummy with different levels of detail and was segmented at different threshold values. Each fragment is available as an external surface model, a bone model and a combined visualization where the soft tissues are presented at a 50 of transparency superimposed on the bones. In oreder to virtually assembly the mummy and to validate the digital 3D model anthropologists are provided with stereoscopic goggles perceiving the depth models of fragments in a 1:1 or larger scale (Figure 4).

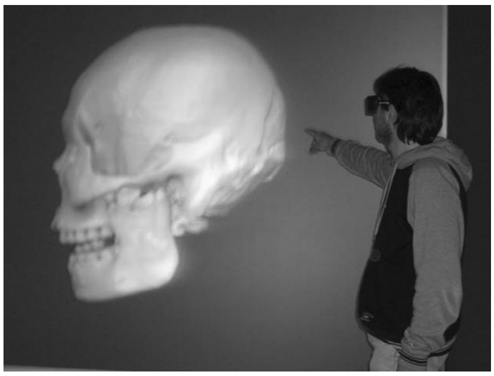


Figure 4: *Exploring the Virtual Model in the CAVE.*

The wide projection area allows to dispose more models and to assemble the entire mummy enhancing the visualization aspect. Actually, the nature of the remains did not allow to locate the exact contact surfaces applying collision detections and the general lay out was determined by visual comparison. Starting from the bust, the pelvis, followed by the rachis and the limbs, has been assembled via a desktop interface until they fit in a unique model (Figure 5).

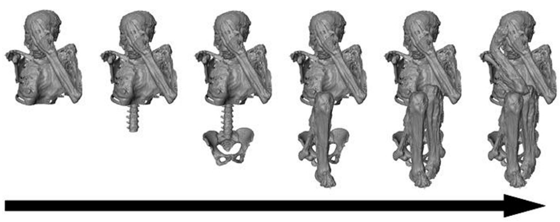


Figure 5: *The Virtual Assembly Process.*

Moreover, other archaeological finds that are classified according to the same place of origin, dated back to the same historical period and are comparable in terms of funerary customs which were used as reference elements. The virtual model of the whole mummy with all the main fragments located in the proper anatomical position of funerary posture is shown in Figure 3. As expected, the final lay out represents the typical tightly flexed position of mummies coming from Andean places and with the same date. By exploring the three-dimensional surface reconstructions the presence of some typical aspects related to funerary customs that had been already noted in the previous radiographic assessment has been more clearly confirmed. Different colours were used in the visualization of the surfaces to highlight the most important information available from the model. In this case it is very easy to identify the calcified tumefaction of soft tissue on the right parietal bone of the skull and the metal artefact put in the mouth of the mummy.

5. Innovative Morphometric and Morphological Approach

The aim of this work is to provide a set of detailed and innovative morphometric measurements of the mummy by properly generating and manipulating the 3D models of its components. In addition to the external surface, the surfaces of the rare bones have been meshed with a volume rendering software (Amira 3.1.1) and the entire skeleton reconstruction has been carried out. Landmarks have been located and measurements have been taken by means of Rhinoceros, a NURBS modelling software.

By measuring the length of the femur it was possible to assess the stature of the female individual before death. Trotter and Gleser created a chart of equations to estimate the living stature of unknown individuals based on the surviving long bones, like the physiological length of femur (LF) [TG52]. In this specific case, for female subject, the stature was calculated by the following equation:

Stature (cm) = 2.47 x LF (cm) + 54.10 +/- 3.72

LF = 36.08

Stature (cm) = 2.47 x 36.08 + 54.10 +/- 3.72

Stature (cm) = 143.22 +/- 3.72.

Further osteometric measures on the virtual models are based on the same points and on the same measurement criteria reported by Martin and Saller [MS59]. This procedure allows to apply methods which are comparable to those developed in previous works to classify real remains.

In addition to the traditional osteometric investigation, a new approach is presented. In particular the right and left humerus have been disassembled from the rest of the skeleton to be oriented in a reference system and characterised by means of not only morphometric but also morphological features. In accordance with the indications presented in the traditional approach, three landmarks have been identified on the humerus to locate it in the XY plane in the space of reference. A fourth point is needed to locate the X axes. Once both the humerus are referred to the same space we followed the approach proposed by Rhodes et al. [RK05], computing a stack of sections profiles and section areas of the humerus. Each step between two following sections measures 5 percent out of the humerus length, taken between 20 percent and 80 percent of the total length (Figure 6). Thus thirteen sections are provided. Comparing the computed areas of total and cortical sections we observe that the left humerus measures larger sections. This is due to a thicker cortical section and a smaller marrow canal. More profiles are computed creating the curves that interpolate homologue centroinds of each section, such as the cortical surface and the marrow canal. Comparing these curves we observed that it is possible to extract useful indications on the morphology of the bone.

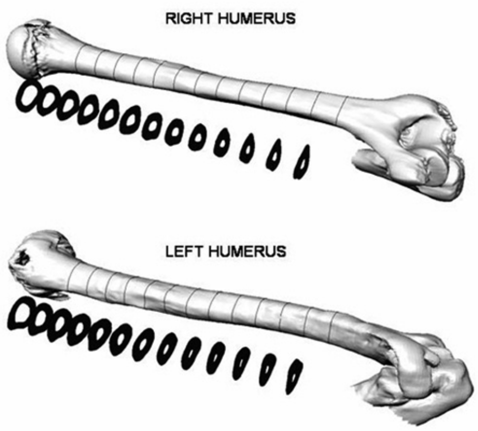
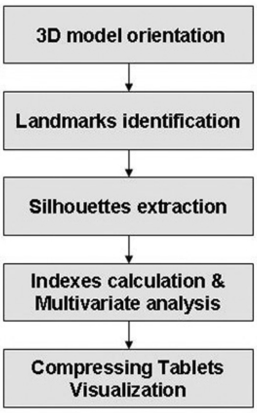


Figure 6: *Virtual sections of the right and left humerus.*

Observing the section taken at the 50 percent of the total length it is easy to perceive the difference between the right and the left side both in the morphology and in the extension of the cortical area. Biomechanical effects of a scarce use of deltoid muscle is also visible in the slight deviation of the axes. Concerning the skull, besides the large and thick tumefaction on right parietal side, morphometric measures reveal that it is comparable to the members coming from the necropolis of Ancòn. This assessment is based on the detailed study in the Peruvian skulls reported by Pardini [Par75] and it is the motivation for the last project.

6. Evaluation of Artificial Cranial Deformation

Pre-Columbian civilizations in South America used to induce artificial cranial deformations on young members of the communities. Researchers have studied modifications to skull morphology mainly by means of comparison of anthropometric indexes which are not applicable on mummies. This is true unless a virtual model of the skull is available. Therefore, once the surface mesh of the skull owning to the mummy under investigation has been generated, we followed the procedure depicted in the following work-flow.



The main aims of this work are the classification of the artificial cranial deformation on the single skull and the three dimensional reconstruction and localization of the compressing tablets. Intentional cranial deformation is a very important aspect of the worldwide culture since the beginning of the history of civilization. Several populations used to apply this practice for different matters, such as political, religious or aesthetic. It is easy to understand why the study of the cranial and facial artificial shape modifications has always been a fundamental area in the field of physical anthropology [RMP06].
There are two techniques to induce deformations on the bones of the skull. The first one used a tight bandage made of stripes (annular), while the second one used tablets tied up the head in order to compress it. A much more detailed classification has been made in previous works about this subject and refers to geographical and ethnic characterizations. Many considerations arise when the anthropologist need to establish if a deformation has been induced on a skull and retrieve such information from it. The surface should be analysed in its morphological features, taking into account that stripes and tablet induce continuous and not discrete modifications of the shape. As far as Peru is concerned, Pardini suggests to classify cranial deformations according to the position of the tablets and the place of origin as depicted in Figure 7 [Par75]. It is believed that in the Andean necropolis compressing tablets were positioned both in the front and in the rear of the head, at different height inducing particular shapes that Pardini reports as:

1. Type I: inion-obelion;
2. Type II: inion;
3. Type III: lambda;
4. Type IV: inion-lambda.

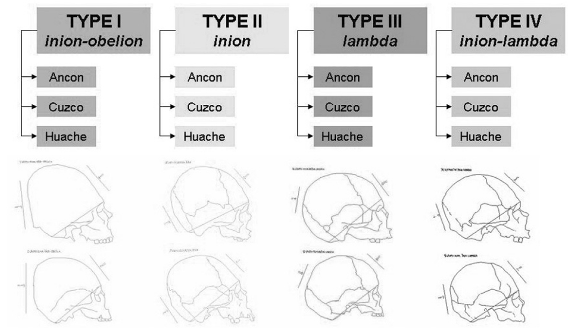


Figure 7: *Artificial Cranial Deformations according to Pardini.*

Pardini characterised the skulls coming from the necropolis of Ancon, Cuzco and Huache by means of a parameter table. This table reports the values of angles, distances and geometric references indexes according to the type of artificial cranial deformation and to the place of origin. In order to assign the skull of the mummy to one of these groups we need to measure the list of parameters in the table and compare it with the twelve groups identified. First of all the virtual skull has been oriented in a space of reference via the Frankfort Plane and the Mid-Sagittal Plane. The Frankfort Plane is the plane passing through three points of right and left porion and left orbitale. The Mid-Sagittal Plane is normal to Frankfort Plane and passes through two points of glabella and midpoint of line between right and left porion (Figure 8).
On the surface and on the sections of the skull a wide set of landmarks has been taken and the value of each parameter has been computed (Figure 9).

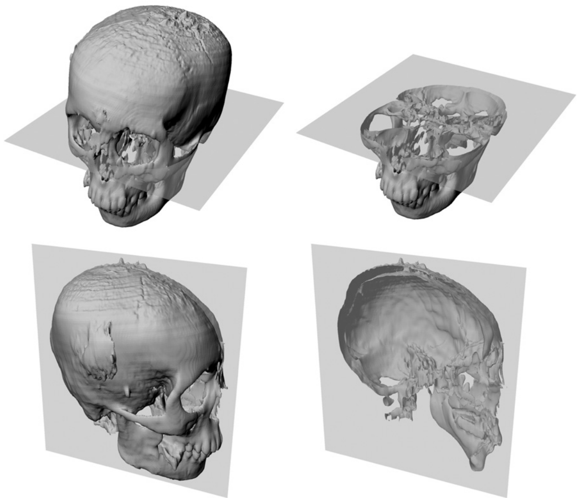


Figure 8: *Frankfort Plane on the top and Mid-Sagittal Plane on the bottom.*

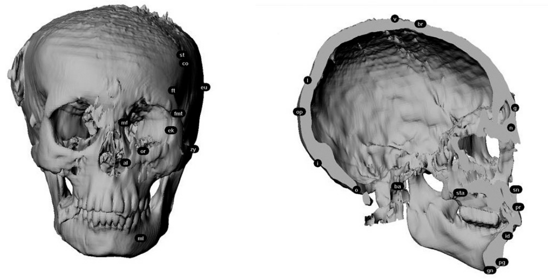


Figure 9: *Landmarks.*

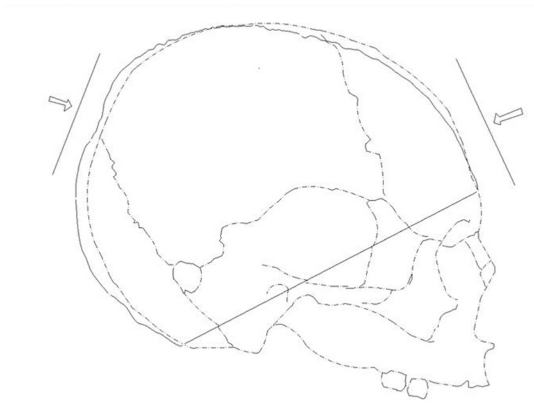


Figure 10: *Silhouette comparison.*

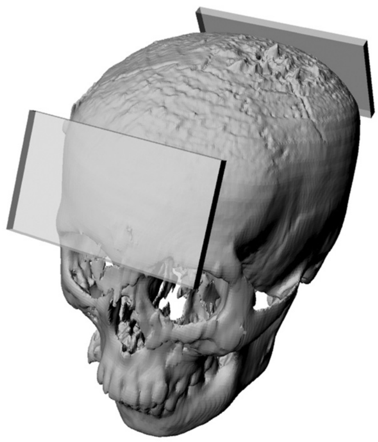


Figure 11: *Visualization of compressing tablets.*

To evaluate which is the group the mummy is more similar to, we performed a multivariate analysis. This quantitative method suggests that the mummy probably belongs to the TYPE III coming from Ancòn. As reported in section 2 the place of origin had been previously identified as Ancòn. Hence it confirms the place of origin which was already known and validates the previous hypoteses. Furthermore, we compared the silhouette of the mummy skull with the one reported in the classification criteria providing a qualitative vision. As depicted in Figure 10 the silhouette extracted from the skull of the mummy (represented in continous line) is very similar to the TYPE III since it matches with the dashed profile.
Finally, three dimensional tablets are built and visualized together with the skull in a virtual environment, where it is clear how they worked to compress the head (Figure 11).

7. Conclusions

In conclusion we can affirm that the collaborative and multidisciplinary interaction between engineers and anthropologists has been very useful. Technological aspects have been exploited and several results have been achieved. The Virtual Environment of manipulation avoided to cause irreversible damages to the remains and the digital model of the whole mummy was validated before the application of further restoration interventions. More information have been brought to light on the life of the subject. Quantitative measurements that can not be performed on the remains were conducted directly on the digital 3D models. The comprehension of anthropological results and the dissemination material on the mummy has considerably increased via 3D visualization and a novel approach to measure the anthropological feartures has been proposed and validated. Finally a physical model of the skull of the mummy has been realized by means of Rapid Prototyping System based on FDM (Fused Deposition Modeling) technology, as shown in Figure 12.

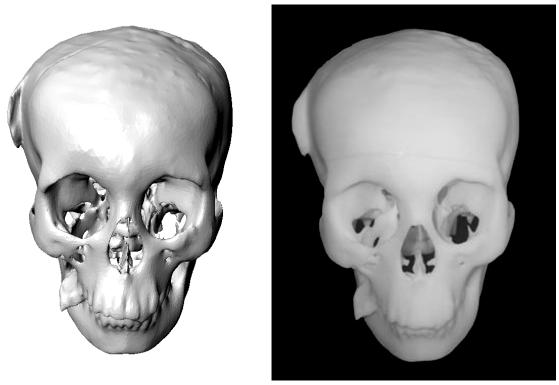


Figure 12: *The Virtual Model on the left and the Physical Model on the right.*

8. Acknowledgments

We wish to express our thanks to the whole staff of the radiology department of Faenza Hospital and Dr. Carlo Orzincolo for the support provided in this project on technical aspects about CT scanning. Moreover we acknowledge Professor Leonardo Seccia for the support on Multivariate Analysis.

References

[Add00] ADDISON A. C.: Emerging trends in virtual heritage. *IEEE MultiMedia 7*, 2 (2000), 22–25.

[Bar00] BARCELO J. A.: *Visualizing what might be. An introduction to virtual reality techniques in archaeology*. ArcheoPress, April 2000.

[CMF*03] CESARANI F., MARTINA M. C., FERRARIS A., GRILLETTO R., BOANO R., MAROCHETTI E. F., DONADONI A. M., GANDINI G.: Whole-Body Three-Dimensional Multidetector CT of 13 Egyptian Human Mummies. *Am. J. Roentgenol. 180*, 3 (2003), 597–606.

[GRHR06] GILL-ROBINSON H ELIAS J B. F. A. T., RD H.: Using image analysis software to create a physical skull model for the forensic facial reconstruction of an akhmimic mummy. *Journal of Computing and Information Technology* (2006).

[HBG04] HUA H., BROWN L. D., GAO C.: Scape: Supporting stereoscopic collaboration in augmented and projective environments. *IEEE Comput. Graph. Appl. 24*, 1 (2004), 66–75.

[LLO*03] LENARES M., LONGHENA M., ORZINCOLO C., VANDINI M., BERNABÒ-BREA M., MACELLARI R., LORUSSO S., GRUPPIONI G.: Studio etno-antropologico su una mummia andina conservata presso i civici musei di reggio emilia. *Quaderni di Scienza della Conservazione 3* (2003), 69–84.

[LPDC01] LIVERANI A., PERSIANI F., DE CRESCENZIO F.: An immersive reconfigurable room (i.r.r.) for virtual reality simulations. In *Proceedings of the XII ADM International Conference* (2001), pp. E1–9/E1–15.

[MS59] MARTIN R., SALLER K.: *Lehrbuch der Anthropologie*. Gustav Fischer, Stuttgart, 1959.

[Par75] PARDINI E.: *I calvari della necropoli di Ancon*. Istituto di Antropologia dellŠUniversità di Firenze, Italy, 1975.

[RHB02] RUHLI F. J., HODLER J., BONI T.: Technical note: CT-guided biopsy: A new diagnostic method for paleopathological research. *Am J Phys Anthropol 117*, 3 (Mar 2002), 272–275.

[RK05] RHODES J., KNUSEL C.: Activity-related skeletal change in medieval humeri: Cross-sectional and architectural alterations. *Am J Phys Anthropol 128*, 3 (2005), 536–564.

[RMP06] RHODE MATTHEW P. A. B. T.: Influence of cranial deformation on facial morphology among prehistoric south central andean populations. *American Journal Of Physical Anthropology* (2006).

[TG52] TROTTER M., GLESER G. C.: Estimation of stature from long bones of American Whites and Negroes. *Am J Phys Anthropol 10*, 4 (Dec 1952), 463–514.

[TSHJi92] TAKAMI Y., SHIGEKI Y., HIROSHI O., JUNICHIRO T.: 3d visualization of an ancient egyptian mummy. *IEEE Comput. Graph. Appl. 12*, 3 (1992), 13–17.

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
VAST (2006)
M. Ioannides, D. Arnold, F. Niccolucci, K. Mania (Editors)

The Application of Interactive Multimedia Technologies for Cultural Heritage Documentation

Maged Farrag

Mega Media Creative Development, Cairo, Egypt

Abstract.
A showcase of various products that were developed using cutting edge multimedia technologies to document cultural heritage content.

Categories and Subject Descriptors (according to ACM CCS):H.5.1 [Multimedia Information Systems] , H.5.2 [User Interfaces] , H.5.4 [Hypertext/Hypermedia]

1. Legacy of Alexandria

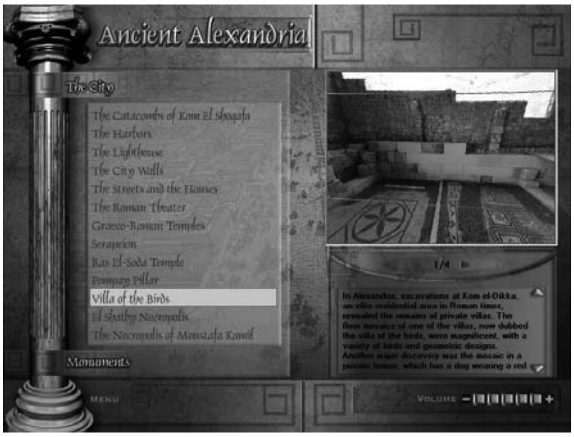
The name of Alexandria recalls the legends of Alexander the Great, Anthony and Cleopatra, and a hall of fame list of Roman Emperors that includes no less than Julius Caesar, Hadrian, and Marcus Aurlieus. The beauty of the city was unrivalled. Planned following a rectangular grid, the city consisted of colonnaded streets with villas and houses surrounding the royal quarter with its palace.

This CD brings to you the magnificent archaeological collection at the Graeco-Roman Museum in Alexandria. The collection gives you a glimpse of life in Ancient Alexandria from the conquest of Egypt by Alexander the Great to the death of Cleopatra. You will be guided through the galleries of the museum, and explore the collection in themes related to Kings, queens and emperors, gods and goddesses, daily life, and the afterlife.

The collection in the museum is linked in this CD to the monuments of Alexandria providing you with a tour of the city in the museum.

The CD-ROM is enriched by numerous virtual tours of the old archaeological sites and 3D reconstruction of the ancient library. The 3D model of the library was utilized in coordination with Cyprus Technical Institute to produce a mock up of the library.

Developed in two languages (Arabic and English) For the National Center for Documentation of Cultural and Natural Heritage in collaboration with the Supreme Council with Antiquities.



2. The Contributions of the Arab and Islamic Civilizations to Medical Sciences

The scholars of the Arab and Islamic civilizations have a long, glorious history abundant with rich contributions in the different fields of knowledge. Their medical writings are probably the most notable of their scientific contributions.

This title documents an impressive selection from the manuscripts of the National Library and Archives of Egypt.

The CD-ROM features seven complete manuscripts that illustrate the contributions of the Arab and Islamic Civilizations to Medical Sciences. The manuscripts

Shedding a spot light on the works of scholars covering wide scope of medicine specialties. To list a few, Bodily Rectification through man’s measures, Galen's Collective work on eye diseases, treatises and anatomy, Book of Antidotes, The Prescription of Ibn al-Baytar and The Collective Abridgement via Questions and Answers

The user could browse through the different pages of each of the manuscripts at two levels of zoom. Information highlighting the biography of the author as well as synopsis of the Manuscript.

It includes as well the bibliographical list of the Arabic, Persian and Turkish manuscripts in the National Library of Egypt.

Developed in three Languages (Arabic, English and French) for the National Center for Documentation of Cultural and Natural Heritage in collaboration with the UNESCO and the National Library of Egypt..

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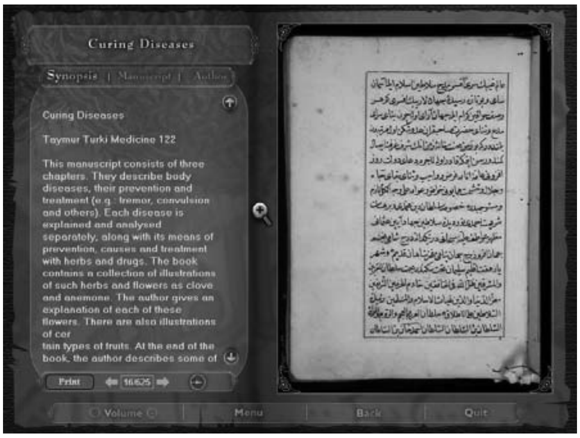
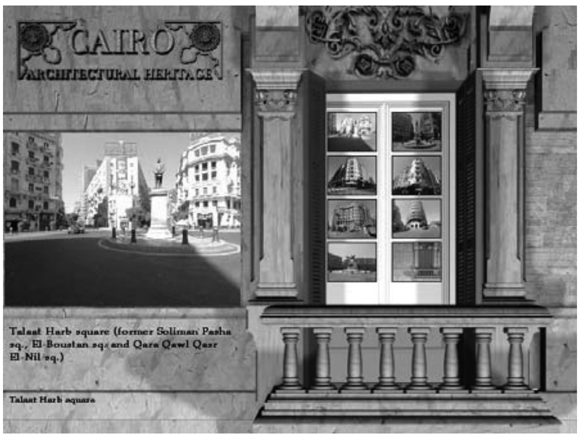


3. The Architectural Heritage of Down Town Cairo

The purpose of this project is to document Cairo’s nineteenth and early twentieth century architectural heritage. Documenting this endangered architectural heritage in the Downtown area of Cairo as a pilot project, this project constitutes of a Geographic Information Systems (GIS) with an easy to browse database that includes extensive photographic documentation, all published material for each inventoried building, in addition to historic documents, maps and archival material.

In the wealth of studies about architecture in Cairo, this is an unprecedented systematic digital approach that crowns the limited attempts of the dispersed few who have documented one aspect or another of Cairene nineteenth and twentieth century architecture. Moreover, it is hoped that this CD-ROM can be an effective cultural awareness tool.



4. The 3D Reconstruction and Virtual Tour of Mar Mina Archaeological Site.

Abu Mena is one of the oldest Christian sites in Egypt (4th to 7th century A.D.). The church, baptistery, basilicas, public buildings, streets, monasteries, houses and workshops in this early Christian holy city of Abu Mena were built over the tomb of the martyr Menas of Alexandria. The site was placed on the UNESCO (United Nations Educational, Scientific and Cultural Organization) World Heritage List in 1979

This project was developed for the National Center for Documentation of Cultural and Natural Heritage in collaboration with a European fund to document ancient cities and sites in the Mediterranean countries. To be published on the World Wide Web, the work conducted offers its viewers the chance to interact with virtual tours (360 degrees panoramic images) of the old city ruins and the new monastery as well as 3D reconstruction of ruined churches.

5. The Contributions of the Arab and Islamic Civilizations to Astronomy

This title documents an amazing selection from the manuscripts of Al Azhar. The CD-ROM Features rare manuscripts that highlight the contributions of the Arab and Islamic Civilizations to Astronomy. It includes as well special section on the Astrolab and Arabic names for the sky map and Zodiac that are still used till today.

6. The Campaign of The sound and light Shows of Egypt.

The legendary shows are playing at world renowned Pyramids of Giza, Temples of Karnak, Philae and Abu Simbel; four of the UNESCO World Heritage sites. Their historical and cultural values are simply beyond description. Latest lighting, laser and projection technologies are utilized to visualize mysteries of the Pharonic civilization. Every year, hundreds of thousands attend these magnificent spectaculars to relive the legend.

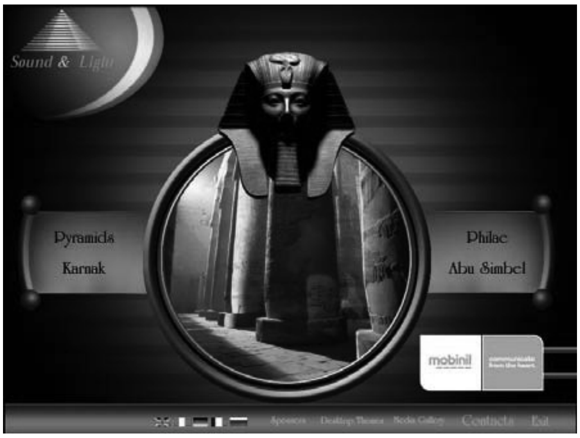
The campaign incorporates breath-taking imagery and a wealth of cultural heritage; a multilingual (5 languages) CD-ROM, Web Portal, Magazine Campaign and a multitude of Touch Screen Information Kiosks.

High quality Digital Video shooting of the shows was produced. 360 degree interactive panoramic images of the sites giving the user the chance to indulge into the mystery of those fabulous monuments. Having the multimedia rich CD content in five languages; English, Italian, German, French and Russian, to guarantee the largest audience.

To ensure maximum exposure 35,000 copies are produced and distributed free of charge in the first phase of the campaign and to guarantee it reaches the target audience, the distribution will be as follows:

- 10,000; Sound and Light Company during international exhibitions and travel trade shows.
- 5,000; sponsors
- 10,000; with selected magazines and publications (Egypt Today, Travel Today).
- 10,000; business and first class guests of a renowned airliner's trips to Egypt (Egyptair).
- 3,000; Egyptian Ministry of Tourism and Travel Authority.

A touch screen information kiosk will be placed at the entrance of the Sound and Light Show of Giza Pyramids, giving a chance for the guests to interact with its content while waiting for admission. Yet more exposure was granted through eight full-page advertisements and four editorials in a magazine campaign.



The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
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MAD: Managing Archaeological Data

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Abstract

MAD is a web-based tool for the management of XML archaeological datasets having the same features of other well-known web-oriented databases (Oracle, MySql, Postgres) but entirely based on XML and W3C technologies. XML is a powerful and flexible language, portable, easy to use and to understand, ideal for representing both structured and unstructured data (e.g. archaeological diaries). The tool is designed as a web application and it is developed on top of eXist, an Open Source native XML database, written in Java, supporting XPath/XQuery features and dynamic XSLT transformation and presentation of documents and query results. Documents are indexed and stored in a UNIX-like file system structure of folders and subfolders: queries can be performed on stored documents by using common web interfaces. Furthermore the W3C XML-based languages simplify the process of interface creation for simple or complex queries definition, record insertion (XPath/XQuery) and update (XUpdate). The application has been tested on a set of archaeological data recorded during the excavation of the site of Cuma (Naples - Southern Italy) in the Nineties. The original archive was created using an archaeological tool called Syslat and Hypecard, an application program from Apple Computer produced until 2001. The conversion of the old archive in XML was a necessary first step, since Hypercard is no longer supported by its developers.

Categories and Subject Descriptors (according to ACM CCS): H.3.5 [Information Storage and Retrieval]: Web-based Services

1. Introduction

Modern archaeological research uses a variety of software to record, analyze and store data collected during the excavation process. But sometimes binary formats seem to be insufficient for particular data encoding (i.e. unstructured data) and to suit one of archaeology's fundamental needs: long term data preservation. Very often, indeed, data are compromised by the proprietary formats in which they are stored. Archaeologists, on the other hand, require more permanent, flexible and easily editable formats. In general, all these tasks are better accomplished by storing archaeological data in text-based formats and encoding them by using international standards.

XML (Extensible Markup Language) is a standard language developed by the World Wide Web Consortium, designed to describe data with human-readable markup, with text enclosed within descriptive tags defining the document structure [XML]. The combination of plain text and descriptive markups makes XML particularly suitable for archival purposes. An XML-encoded data file can be opened and easily read using any text editor. The explicit nature of XML and the use of standard XML formats provide data with the permanency and flexibility particularly required by specific kinds of data, the so-called document-centric documents, very common in every archaeological data recording process. Archaeological documentation, indeed, is often composed by sets of unstructured documents, such as excavation diaries and free text descriptive forms, designed for human consumption, characterized by irregular structure and where the order in which elements and data occur is always significant [CDN02]. XML is also becoming the standard language for data exchange over the Internet since one of its outstanding features is the capability of encoding semantic metainformation to be automatically used by advanced computer tools, like "intelligent" search engines for meaningful data retrieving [BL98].

In future the implementation of the Semantic Web, a vision of a universal medium for exchanging information put in a computer-processable meaning, will need new standards for conceptual models creation (ontologies) and powerful languages for data encoding and complex relations definition (and most of the existing ones are already XML-based, such as RDF [RDF] and OWL [OWL]). It will also need software agents able not only to locate data, but also to "understand" them. This will allow computers to perform, automatically and on the fly, the meaningful tasks that today must be executed manually and episodically by computer users [SW]. Querying heterogeneous collections of XML documents requires a combination of database languages and concepts used in information retrieval. Several XML query languages have been developed for this purpose: all of them use regular path expressions to query XML data but need particular XML-oriented database-like environments, where collections of XML documents are stored, to be executed.

2. XML and Databases

2.1. Native XML Databases

Among XML databases, many solutions have been developed and at present there are mainly two different ways to store XML documents in a database: the first is to map the document schema to a database schema and then transfer data according to that mapping (XML-enabled databases). The second one is to use a fixed set of structures that can store any XML document (native XML databases) [ABS99].

XML-enabled databases are useful when publishing existing data as XML or importing data from an XML document into an existing database. However, XML-enabled databases are not a good way to store complete or unstructured XML documents because they are able to store data and hierarchy but everything else is discarded: document identity, sibling order, comments, processing instructions, and so on [ST01].

Native XML databases, on the other hand, store complete and unstructured documents in their "native" format, without the need for data to be manipulated or extracted from the document and regardless of any database schema, since they were created specifically to overcome the shortcomings of relational databases when dealing with document-centric XML. The benefit of a native solution is that information is always stored and retrieved in an XML format [CRZ03]. Interesting and reliable native XML databases are Tamino, a commercial software developed by Software AG, Xindice, born as part of the Open Source Apache XML Project, and eXist, one of the most complete solutions in this field.

2.2. eXist

eXist is the core of our application since it is one of the most efficient native XML databases available. It is an Open Source software written in Java and developed by Wolfgang Meier at the Darmstadt University of Technology. It can easily be integrated into applications dealing with XML and be deployed in a number of ways, either running in a standalone server process, inside a servlet engine, or directly embedded into applications [EXI].

eXist provides the indexing and storage of XML documents in hierarchical collections and a wide set of features for querying distinct parts of documents and collections hierarchies, or even all the documents contained in the database, by using XQuery and other standard W3C languages. In order to supply a validation mechanism for stored data, one or more XML Schema or DTD can be also included in the collections and dynamically assigned to documents by using the namespace mechanism. The server offers quite a number of different interfaces, including XML-RPC, SOAP, REST-style HTTP or direct access via Cocoon and the XML:DB API [Mei03]. It also provides a graphical user interface allowing users to create and manage collections, to store documents, to create users and to manage permissions. Some backup/restore functions are also provided (figure 1). Through this very useful interface it is possible to organize huge sets of XML documents, to index them and to make them available for further operations.

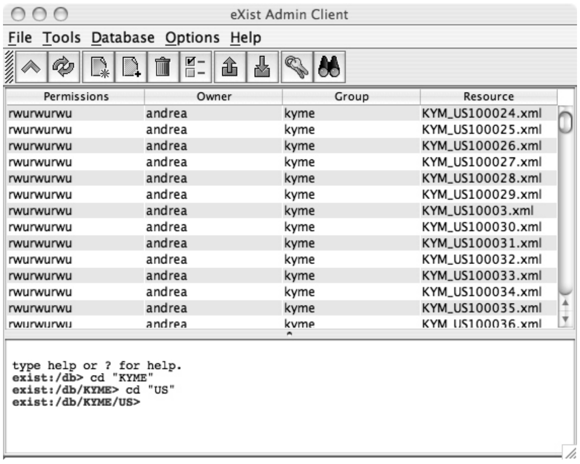

Figure 1: *The eXist Graphical User Interface.*

3. The Application

3.1. The Development Process

A native XML database is assumed to work with XML documents in exactly the same way as relational databases do with data stored in records and tables. But since MAD is intended to be a web application, the database alone is not enough to perform complex operations on data and a set of web interfaces is needed, allowing the user to manage data in a simple and powerful way.

Web-oriented databases such MySql and Postgres usually work well with languages like PHP, PERL or JSP that allow the creation of advanced and user-friendly interfaces combined with CSS, XHTML and JavaScript. For our application we used the standard CSS/XHTML framework for the creation of elegant and accessible web pages, but the

XQuery and XUpdate languages were chosen for script implementation because of their natural way of dealing with the XML data stored in the database. In addition the XSLT language was used for the creation of stylesheets to manipulate the XML results [XSL] and the Cocoon framework was used to organize the logic process of data retrieving and content presentation.

3.2. XQuery and XPath Languages

XQuery is a language very similar to SQL in syntax but specifically designed to query XML data: it is built on top of XPath expressions supporting the same XPath functions and operators. The strength of the XPath syntax is the capability to define and select parts of XML documents, to navigate through them in a file system-like way and to retrieve nodes according to given criteria. XPath is a W3C standard, provides a library of over than 100 built-in standard functions and is a major element in the process of the XSL Transformation operations defined in XSLT stylesheets [XPA]. The way XPath works is quite simple: let's assume we have an XML document like the following:

```
<US_form usn="1022">
  <main_us>
    <US>1022</US>
  </main_us>
  <sector>2</sector>
  <coordinates>X2.87</coordinates>
  <coordinates>Y5.57</coordinates>
  <author>F. Fratta</author>
  <date>Lun</date>
  <materials>Stones</materials>
  <year>1995</year>
</US_form>
```

we can apply on it an XPath expression like this

```
/US_form/coordinates
```

wich selects the `coordinates` elements children of `US_form` elements. The result of this expression would be the following:

```
<coordinates>X2.87</coordinates>
<coordinates>Y5.57</coordinates>
```

The same result would be returned by the expression

```
//coordinates
```

which selects all `coordinates` elements descendants of the root element. Other interesting examples show how useful a syntax like this can be:

```
//main_us[US>100]
```

This expression selects all the `main_us` elements having an `US` descendant with a value greater than 100 and gives, as can be seen, the possibility to specify basic conditions in retrieving XML nodes.

XQuery inherits from XPath the syntax for data model description and all the functions provided for the identification of nodes; but its syntax also has the same powerful query features of the SQL language to write concise and easily understandable queries [XQR]. The basic building block of an XQuery program or script is the expression, a string of Unicode characters which may be constructed from keywords, symbols, operands and some optional functions and definitions. The typical XQuery expression is called FLWOR, an acronym for the words `FOR IN`, `LET`, `WHERE`, `ORDER BY`, `RETURN`, the five expressions that form the core syntax of every XQuery. The `FOR IN` expression is similar to the typical UNIX/Linux shell script iterator and is used to recursively select and analize fragments of data defined by the XPath syntax; the `LET` expression is used to define local variables for future reuse:

```
let $x := 5 let $y := 6
```

the `RETURN` expression returns specific XML fragments and the results found according to the given parameters. The `WHERE` and `ORDER BY` clauses work the same way of the classic SQL instructions for defining conditions and order results. A short XQuery example follows:

```
xquery version "1.0";
declare namespace vl="http://www.vast-
lab.org/kyme.xml";

for $x in //vl:US_form
where main_us/US = "1022"
return <result>{$x}</result>
```

after the mandatory XQuery declaration, the second row shows the use of a classic XQuery function used to declare namespaces bound to specific elements of the XML documents, as shown in the second row for the element `vl:US_form`. The last line exemplifies the power of the `RETURN` expression and its ability to combine query results and additional XML elements necessary, for istance, in the process of content transformation and presentation. Other interesting functions for XQuery are provided by eXist: the fragment below for instance

```
return
<user>
{let $user := request:get-session-
attribute("user") return $user}
</user>
```

shows how it is possible to return elements containing parameters taken from the HTTP Session (the application user in this case). Thanks to the richness of these kind of functions and expressions XQuery is the most complete way to query XML data and to get arbitrary formatted results for following operations.

3.3. XUpdate and eXist's XQuery Functions

A query system, even if complex and elegant, is not enough by itself when the final goal is the creation of a complete application. Features for data modification, deletion and update are also needed for a fully functional management framework to be used by final users and fortunately the technology for the implementation of such features exist. The preferred way to modify, update and manage documents in our application is XUpdate, another very useful W3C-compliant XML-oriented language, together with a set of eXist's built-in functions [Mei06]. XUpdate, like XQuery, is a language based on XPath, usually used to modify XML content by simply declaring what changes should be made in an XML structure [XUP]. The following code

```
<xupdate:modifications version="1.0" xmlns:
xupdate="http://www.xmldb.org/xupdate">
  <xupdate:update select="/US_form[@usn=
'1022']/author">M. Torelli</xupdate:update>
</xupdate:modifications>
```

is used, for instance, to modify the author of the XML document identified by the `usn` attribute `1022`. Other powerful features are directly provided by eXist as XQuery functions: they can be used to create documents from scratch and to delete, move and rename existing documents and collections stored in the database. In this simple example

```
xquery version "1.0";

declare namespace
xdb="http://exist-db.org/xquery/xmldb";
declare namespace
util="http://exist-db.org/xquery/util";

xdb:register-database("org.exist.xmldb.
DatabaseImpl", true()),
let $root := xdb:collection("xmldb:
exist:///db", "admin", ""),
   $out := xdb:create-
collection($root, "CIDOC")

for $rec in /rdf:RDF/* return
  xdb:store($out, concat(util:
md5($rec/@rdf:about), ".xml"),
    <rdf:RDF xmlns:rdf=
"http://www.w3.org/1999/02/22-rdf-syntax-
ns#">
        {$rec}
    </rdf:RDF>
  )
```

a new collection called `CIDOC` is created by using the eXist's `xdb:create-collection` function and a set of RDF documents is stored there by using the `for in` iterator and the `xdb:store` function. This way an improved XQuery can be used in order to work perfectly with the database.

3.4. Content Presentation: The Cocoon Pipeline

One of the most common problems of an XML content based web application is the separation of content, style and management functions, since XML syntax is content-oriented and XML documents do not contain any information on style. Content also needs to be presented in different ways according to its nature: for istance the presentation in a browser of a query result is completely different from the presentation of the details of a document. Also presenting data in HTML format is different from showing them as an XML tree structure. For this reason different XSL stylesheets need to be dynamically applied to XML fragments and documents returned by queries, in order to format the content according to user and application requests. In MAD this process is entirely driven by a pipeline, a set of logic components able to read and understand HTTP Requests and to perform operations accordingly. For the construction of our pipeline we used some of the functions provided by the Cocoon framework, an advanced, flexible and easy to configure Java-based engine for data processing, based on XML technology and using simple XML configuation files to work [COC]. The pipeline mechanism is based on 4 main elements:

- a *matcher* that attempts to match an URI with a specified pattern for dispatching the request to a specific processing pipeline;
- a *generator* used to create an XML fragment from an input source (mainly an XQuery result);
- a *transformer* used to map an input XML structure into another XML structure;
- a *serializer* used to render an input XML structure into some other format (not necessarily XML).

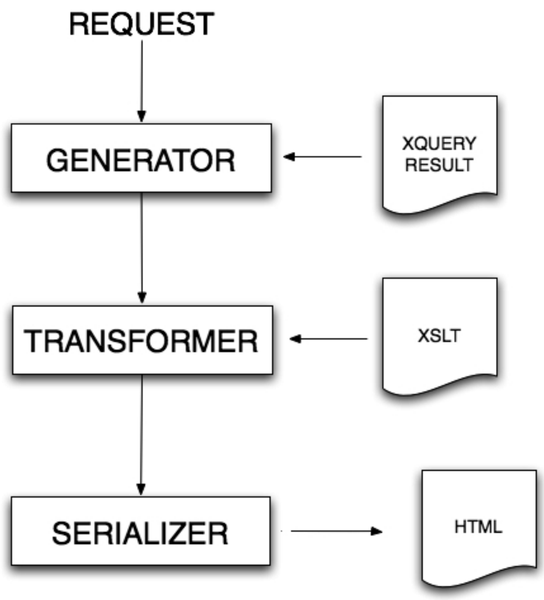

Figure 2: *The Cocoon Pipeline Mechanism.*

All these elements correspond to Java modules that phisically perform each operation. The way to use them is defined in an XML file called `sitemap.xmap` to which every request is sent in order to be processed. By using the instructions contained in this XML file, an HTTP Request like the following:

```
http://www.vast-lab.org/exist/
advanced_search.xml
```

will be dispatched to the following XML fragment of the `sitemap.xmap` and then processed:

```
<map:match pattern="advanced_search.xml">
  <map:generate src="advanced_search.xq"
type="xquery"/>
  <map:transform type="xslt" src="
StyleSheets/advanced_search.xsl"/>
  <map:serialize type="html"/>
</map:match>
```

The matcher corresponding to the request contains all the instructions to generate XML fragments by querying the XML database with the expressions of the `kyme_advanced_search.xq` XQuery file and transforming them by using the `advanced_search.xsl` stylesheet. Finally the serializer tells the application which format to use for the final presentation. In this way it is possible to serialize the content in whatever format is needed, for instance PDF, RDF or XML, with a little change of instructions and an XSL Transformation (XSLT) or XSL Formatting Object (XSL-FO) stylesheet. The pipeline matcher for a PDF document creation looks like this:

```
<map:match pattern="US_*.pdf">
  <map:generate src="kyme_index.xq"
type="xquery"/>
   <map:transform src="context://exist
/style/xsl/page2fo.xsl"/>
 <map:serialize type="fo2pdf"/>
</map:match>
```

As shown, the result generated by the `kyme_index.xq` XQuery is transformed with the XSL-FO `page2fo.xsl` stylesheet. XSL-FO is an XML-based markup language describing the formatting features of XML data for output to screen, paper or other media. Its vocabulary is able to specify structural information such as page length, margins, fonts and so on. A little fragment of this stylesheet shows how simple it can be to prepare a formatted page starting from XML

```
<?xml version="1.0"?>
<xsl:stylesheet version="1.0"
   xmlns:xsl="http://www.w3.org/1999/XSL
/Transform" xmlns:fo="http://www.w3.
org/1999/XSL/Format">
  <xsl:template match="/">
   <fo:root xmlns:fo="http://www.w3.org
/1999/XSL/Format">
     <fo:layout-master-set>
       <fo:simple-page-master master-
name="page"
         page-height="29.7cm"
         page-width="21cm"
         margin-top="1cm"
         margin-bottom="2cm"
         margin-left="2.5cm"
         margin-right="2.5cm">
         <fo:region-before extent="3cm"/>
         <fo:region-body margin-top="1cm"/>
         <fo:region-after extent="1.5cm"/>
       </fo:simple-page-master>

       <fo:page-sequence-master master-
name="all">
         <fo:repeatable-page-master-
alternatives>
           <fo:conditional-page-master-
reference master-reference="page" page-
position="first"/>
         </fo:repeatable-page-master-
alternatives>
       </fo:page-sequence-master>
     </fo:layout-master-set>

     <fo:page-sequence master-
reference="all">
       <fo:static-content flow-name="xsl-
region-after">
         <fo:block text-align="center"
           font-size="10pt"
           font-family="serif"
           line-height="14pt">page <fo:page-
number/>
         </fo:block>
       </fo:static-content>

       <fo:flow flow-name="xsl-region-
body">
         <xsl:apply-templates/>
       </fo:flow>
     </fo:page-sequence>
   </fo:root>
  </xsl:template>

  <xsl:template match="title">
   <fo:block font-size="18pt" space-
before.optimum="24pt" text-align="center">
     <xsl:apply-templates/>
   </fo:block>
  </xsl:template>
```

The first `xsl:template` block, matching the root element of the XML fragment, sets all the information to create a structured page, while the second `xsl:template` block, matching the title of a document or fragment, sets the font size and the text alignment of the `title` element.

4. Testing the Tool

In order to test the application we used a set of data recorded in the Nineties during the archaeological excavation of Cuma, an ancient greek city near Naples (Southern Italy). Stratigraphical Unit data and other related information were originally recorded using Syslat, a system developed on top of a famous application program from Apple Computer: HyperCard. Syslat was in concept a sort of multimedia database application for storing information, creating easy to modify files in quite a flexible way also thanks to HyperTalk, a powerful and easy to use programming language for manipulating data and user interfaces. Unfortunately HyperCard was finally withdrawn from the market in March 2004, although it had not been updated for many years at that time [DN02]. An XML conversion seemed to be necessary to save and preserve data "entrapped" in the old archive.

The first task required in order to get data from Syslat, was the design of a brand new XML Schema describing the old Syslat database organization with an XML structure. In order to encode data in a standard format, the XML Schema has been designed to be fully CIDOC-CRM compliant in order to make data ready to be used in a Semantic Web scenario. The CIDOC-CRM is an International ISO Standard (ISO 21127:2006 under publication as of 06/06/06) developed by an interdisciplinary working group of the International Committee for Documentation of the International Council of Museums (CIDOC/ICOM) under the scientific lead of ICS-FORTH [CRM]. The CIDOC-CRM standard ontology was also choosen for its capability to describe concept and relationships used in cultural heritage documentation in a logical and detailed way. The extraction operation and the XML encoding of the archaeological data were made using a set of HyperTalk scripts, with which it was possible to map the old data to the new XML structure described in the XML Schema. The procedure was able to extract and encode data without loss of details and a set of about 3000 archaeological forms was converted to the new textual format, imported into eXist and organized into collections. Then all the necessary sets of scripts, stylesheets and web interfaces were created in a semi-automated way, starting from the data definitions given by the XML Schema, by using an advanced schema-driven generation process.

Since data are now stored in eXist, a powerful set of operations can be performed from the web interface of MAD: data can be accessed from useful indexes created by advanced XQuery scripts and simple or complex queries can be submitted by specifying one ore more search criteria linked together with boolean expressions. The user can also query the entire database by using one or more keywords, through a "fast search" field present in every page (figure 3). New documents creation and update of existing ones is also provided with a combination of HTML forms and XQuery scripts able to put data coming from the HTTP Request in the choosen XML format and writing or updating them into the database (xdb and XUpdate functions, see figure 4).

One of the most important features of MAD is the ability to transform on the fly the original XML content into whatever format is needed by simply writing the corresponding stylesheets and dynamically applying them to the desired

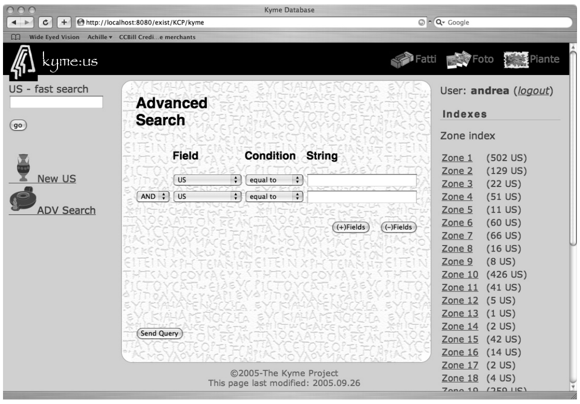

Figure 3: *Indexes and Query Interfaces.*

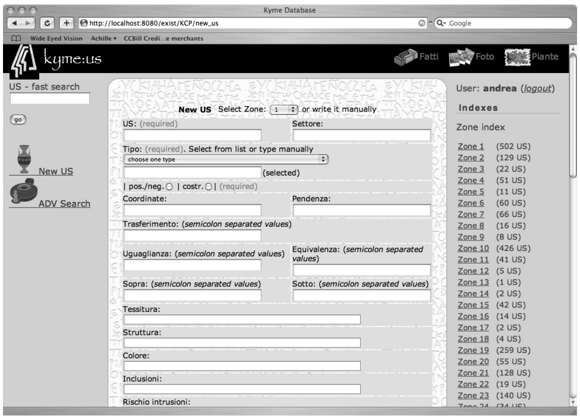

Figure 4: *New Record Creation and Record Update Form.*

data through the pipeline mechanism. It is possible, for instance, to serialize data in the PDF format or export data and their semantic relations in an RDF CIDOC-based document, created using also a particular stylesheet for "mapping" data to CIDOC-CRM on demand (figure 5).

5. The CIDOC-CRM Implementation

Since CIDOC-CRM is becoming the new standard model to document Cultural Heritage data, the creation of tools ready to manage CIDOC-CRM compliant archives will be one of the most important goals of the coming years.

MAD has been conceived to be the most powerful application of this kind because the way it works is already CIDOC-CRM oriented and all its features have been designed to work perfectly with this model. Every institution having documentation in a CIDOC-CRM compliant format will be able to use MAD in order to manage a CIDOC-CRM based documentation archive. Interfaces and queries will be created accordingly in a simple and rapid way. The web oriented nature of the application will also make possible the implementation of systems for data sharing on the web and information retrieval over distributed archives [HN00].

Thus MAD may be considered the natural complement of CIDOC-CRM: the latter establishes data structure, MAD will provide a powerful and user-friendly way to implement it. In our opinion, the availability of a CIDOC-CRM compliant effective data management system may substantially push its acceptance by heritage professionals and practitioners.

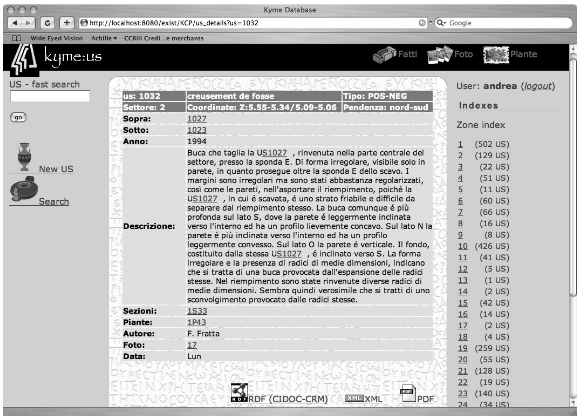

Figure 5: *Record Details and Export Options.*

6. Conclusions and Future Work

MAD has proven to be a fast and reliable web application thanks mainly to the power of the native XML database on which it is based. Advanced query features and the flexibility of languages make easy the process of interfaces creation to adapt the application to any set of data. The tool was entirely developed using Open Source technologies and well known and widely used standards for XML data management and encoding (W3C Languages, CIDOC-CRM ontology).

Future development of the application will provide more support for semantic queries by setting up a complete integration with semantic-web-oriented frameworks like Jena and Joseki. Interoperability with graphical tools for representing archaeological stratigraphy and relations between stratigraphical units, like Jnet, will be also provided as a set of scripts that will extract and analyze spatial information and will deliver them to the application for real time graphics creation. A similar process will be also used for extracting useful information for 2D and 3D modeling of archaeological objects or buildings.

7. Acknowledgements

MAD has been developed as part of EPOCH, project no. IST-2002-507382, and is the result of a fruitful collaboration among PIN (University of Florence - Prato, Italy) and CISA (University of Naples "L'Orientale" - Naples, Italy) which supplied the Cuma archaeological excavation datasets. I would like to thank Franco Niccolucci for the ideas and the many helpful suggestions I received from him throughout all the development process and Andrea D'Andrea, whose perfect knowledge of the archaeological datasets used for creating the test version of this application made many of the improvements done to increase performances and usability possible.

References

[ABS99] ABITEBOUL S., BUNEMAN P., SUCIU D.: *Data on the Web: From Relations to Semistructured Data and XML.* Morgan Kaufmann Publishers, San Francisco, CA, 1999.

[BL98] BERNERS-LEE T.: Semantic Web Roadmap, an attempt to give a high-level plan of the architecture of the Semantic WWW, September 1998. `http://www.w3.org/DesignIssues/Semantic.html`.

[CDN02] CRESCIOLI M., D'ANDREA A., NICCOLUCCI F.: XML Encoding of Archaeological Unstructured Data. *In G. Burenhault (ed.), Archaeological Informatics: Pushing the envelope* (2002). Proceedings of the 29th CAA Conference, Gotland April 2001, BAR International Series 1016, Oxford 2002, 267-275.

[COC] The Apache Cocoon Project. `http://cocoon.apache.org/`.

[CRM] The CIDOC Conceptual Reference Model. `http://cidoc.ics.forth.gr/`.

[CRZ03] CHAUNDRI A. B., RASHID A., ZICARI R.: *XML Data Management - Native XML and XML-Enabled Database Systems.* Addison-Wesley, 2003.

[DN02] D'ANDREA A., NICCOLUCCI F.: Database di scavo ed Internet. L'accesso remoto all'archivio Syslat. *In B. D'Agostino, A. D'Andrea (a cura di), CUMA. Nuove Forme di Intervento per lo Studio del Sito Antico* (2002). Atti della Giornata di Studio, Napoli 12 Febbraio 2001, AION ArchStAnt, Quad. 14, Napoli 2002, 167-175.

[EXI] eXist Open Source Native XML Database. `http://exist-db.org`.

[HN00] HERMON S., NICCOLUCCI F.: The Impact of Web-shared Knowledge on Archaeological Scientific Research. Proc. of Intl' CRIS 2000 Conf., Helsinki, Finland, 2000.

[Mei03] MEIER W.: eXist: An Open Source Native XML Database. *In Web, Web-Services and Database Systems* (2003). NODe 2002 Web- and Database-Related Workshops, Erfurt, Germany, October 7-10, 2002, 169-183. Lecture Notes in Computer Science 2593 Springer, 2003.

[Mei06] MEIER W.: Index-driven XQuery processing in the eXist XML Database. Paper presented at the XML Prague 2006 Conference. http://exist-db.org/xmlprague06.html.

[OWL] W3C Semantic Web Activity, Web Ontology Language. http://www.w3.org/2004/OWL/.

[RDF] W3C Semantic Web Activity, Resource Descpription Framework. http://www.w3.org/RDF/.

[ST01] SALMINEN A., TOMPA F. W.: Requirements for XML Document Database Systems. Proceedings of the 2001 ACM Symposium on Document engineering, November 2001.

[SW] W3C Semantic Web Activity. http://www.w3.org/2001/sw/.

[XML] Extensible Markup Language (XML). http://www.w3.org/XML/.

[XPA] XML Path Language (XPath) Version 1.0. W3C Recommendation 16 November 1999. http://www.w3.org/TR/xpath.

[XQR] XQuery 1.0: An XML Query Language W3C Candidate Recommendation 8 June 2006. http://www.w3.org/TR/xquery/.

[XSL] XSL Transformations (XSLT) Version 1.0. W3C Recommendation 16 November 1999. http://www.w3.org/TR/xslt.

[XUP] XUpdate - XML Update Language Homepage. http://xmldb-org.sourceforge.net/xupdate/.

All web references have been visited on 15-07-2006.

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
VAST (2006)
M. Ioannides, D. Arnold, F. Niccolucci, K. Mania (Editors)

Cultural Heritage Engineering
Measured, Calculated and Computed Color

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Abstract

We present the latest results of a pluridisciplinary work already in progress at Ecole Centrale Paris involving 3D digitization, simulation, rapid prototyping of several museum artifacts. This work is led in the framework of a general collaboration between three academic labs, The Musée National des Arts Asiatiques Guimet, the Centre des Monuments Nationaux, the Louvre museum, and the rapid prototyping center CREATE. The main purpose is to virtually represent the museum objects in high quality rendering, to simulate the visual appearance of their materials based on optical and physical characteristics and to replicate them. The complete process used throughout all the phases of the projects only involves optical devices that ensure no physical contact with the museum artifacts.

This article describes the complete chain of engineering resources and the main models we used for accomplishing our objective. From 3D capture without contact to plaster replica, the complete process will be described and illustrated with images and objects during the conference. Some sequences extracted from the didactic and scientific movies produced will also be presented.

Categories and Subject Descriptors (according to ACM CCS): I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism

1. Introduction

Our approach aim to establish the bases for cultural heritage engineering methods and models from 3d digitization to simulation and replication by rapid prototyping. In this context, we focus particularly on simulating optical behaviour of materials constituting the objects. Our ongoing study concerns a polychrome medieval statue: the recumbent statue of Philippe de France (circa 1222 - 1232 AC) in the Saint-Denis Basilica (royal necropolis in the north of Paris). Previously studied was the modelisation of metals and alloys using the OCRE method (Optical Constants for Rendering Evaluation), developed by Patrick Callet and describing the materials optical behaviour [Cal05]. Plasma physics and spectroscopic ellipsometry were used for that pertinent modelling and the characteristics data extraction from measurements [CZM02]. For metals and alloys we naturally used their complex indices of refraction, either computed or carefully measured, but, in any case always validated by measurements. These previous important results are very useful for the rendering of the golden parts of the statue that consist in an alloy more or less enriched in gold. The metallurgical composition of the gold leaves recovering the visible rests will greatly help in the formulation of the visual appearance for virtual restoration or historical reconstitution.

We now focus on modelling and representing the painting materials (pigments and binders) using spectrophotometry, and extrinsic physical parameters such as the paint film thickness, the concentration of each species of pigments, their mean diameter or the granulometry distribution functions,... Intrinsic parameters, characterizing the nature more than the structure of all the compounds such as complex indices of refraction of all involved materials are used throughout the study. As an extension of the Kubelka and Munk theory, a four-fluxes approach of the multiple scattering of light is used for the simulation. At each step of the study we compare our computed results of simulation with measurements made on handcrafted samples in laboratory or in situ, i.e. on the statue itself. With the knowledge about painted stones during the middle-age, we studied the pigments and binders which were probably used by the artist. Finally we replicated the statue to 1/3rd of its original dimensions.

Figure 1: *The recumbent statue of Philippe Dagobert in Saint-Denis Basilica (13th century AC).*

2. A work on painting materials

Our collaboration with the "Centre des Monuments Nationaux" helps us to elaborate a new project: a polychrome medieval statue, the recumbent statue of Philippe Dagobert de France (13th century AC) in the Saint-Denis Basilica. The CMN being in charge of organizing and managing the public visits in more than one hundred French monuments, is deeply involved in the realisation of the study. The research results are meant to be shown, permanently near the Philippe de France tomb, in order to sensibilized a large public to the scientific research contribution, and for a better understanding of historical heritage.

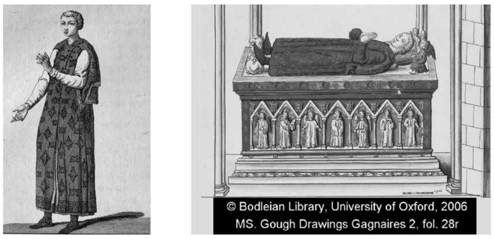

Figure 2: *Philippe Dagobert - (left) Stained glass window drawing, (right) Drawing of the tomb with its recess.*

2.1. Historical context

This recumbent statue has been chosen for its remaining polychrome traces (fig 1) and also because it was representative of the fine middle XIIIth century funeral sculpture. At that time, Louis IX, not yet known as king " Saint Louis", was setting up the Saint Denis Royal necropolis and the "Children of France" necropolis in the Royaumont Cistercian abbey at Asnières sur Oise [EB75]. It concerns the Philippe-Dagobert's tomb, a young Saint-Louis's brother born in 1222, who was designated to be "clericus", i.e. to have an ecclesiastic career, died in 1232 and buried in Royaumont (North of Paris); His tomb has been raised in the abbey-church chancel between October 1235 (consecration date of this church) and middle XIIIth . He is not represented as a child here but as an idealised young man, laying down, opened eyes, joined hands; his head lay on two cushions each of them being held by two angels; his feet are resting upon a lying lion holding in its paws a leg of deer. With the French revolution this tomb encountered several dramatic events [BJV96]. It has been transferred in Saint-Denis in 1791, then damaged in 1793-94 and deserted till 1796 when, it has been preserved in the *Musée des monuments français*. In 1816 it returns to Saint-Denis, where it has been installed in the crypt; then the famous architect Viollet-le-Duc, between 1860 and 1867, inspired by the original pieces, rebuilt entirely the sarcophagus and installed it in the north transept. Concerning the paintings, Baron de Guilhermy published his observations in 1848 [dG48] : "From the restitution of these tombs in Saint-Denis, the whole sculpture has been restored, and the old paintings disappeared under a new covering which after only thirty years were already eroded". It refers to painted work ordered by the architect François Debré in 1820. Luckily, half a century ago, the savant Millin could study and draw the Philippe-Dagobert tomb in Royaumont as it was in 1790, just before it was transferred to Saint-Denis [Mil91]. Millin most likely describes the remnants of medieval paintings namely blue for the surcoat sprinkled with golden squares and lozenges. This pattern is confirmed by a drawing made in 1694 for Roger de Gaignières, which represents a missing stained glass window in the Royaumont abbey-church with the young prince up and wearing the same clothes than his recumbent statue (left figure 2). As for the tomb, Gaignieres made it drawn and painted with great precision. In the right part of figure 2 is exhibited a reproduction of the original coloured drawing conserved in the Bodleain Oxford Library. This research could allow to show once again how colour was present at medieval epoch [Ami00], studying this time the visual appearance of a rich prince funeral monument.

2.2. Data capture

As for previous projects the 3D digitization has been performed *in situ* (in Saint-Denis Basilica) after public hours, without contact using an optical system based on structured light projector and a camera (fig 3) from Breukmann company. A regular light and shadow grid is projected on the object and the distortion of the boundaries between light and shadows on the surface is recorded by the camera and analysed, in order to extract a cloud of 3D points with a good accuracy. This gave us about 120 clouds of 3D points used

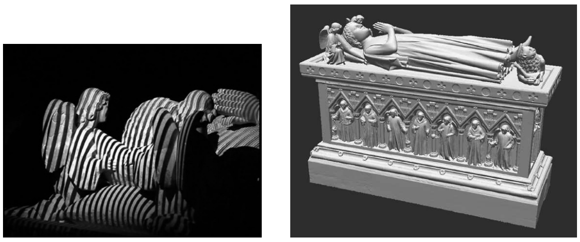

Figure 3: *(left) 3D digitization using structured natural white light. (right) 3D colorless model displayed with Catia (Dassault System software).*

for reconstructing the surface with RapidForm commercial software (Inus Technology). The final 3D shape of the tomb (recumbent statue on the sarcophagus) in full resolution represents about 7,5 Million triangles (fig 3). Also *in situ*, we captured spectral information on the remaining traces of paint thanks to a spectrophotometer with optical fiber useful for further analyses and material characterization. The portable spectrophotometer (USB 2000 series from Ocean Optics company) consists in a set of optical fibers guiding a normalized light source (a halogen lamp for CIED65 illuminant) surrounding the backscattered light guiding fiber. The later is connected to a spectrometer where a 1024 photodiodes array transforms the received light in a signal that the software can sample. We then obtain the diffuse reflectance spectrum of the paint according to visible wavelengths domain (from 380*nm* to 780*nm*). As we need to compare and validate permanently our choices and models, we also used pigments and binder samples prepared in the laboratory. We made our spectral measurements on these samples also (fig. 4).

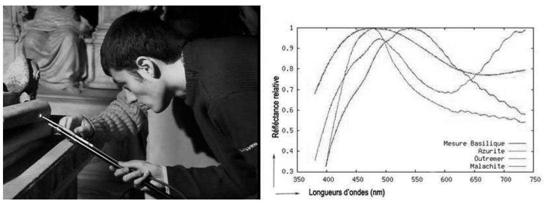

Figure 4: *Spectral data acquisition and analysis.*

2.3. Preparing the data

First we need to specify which part of the global reconstructed shape would be associated to each kind of different materials (meaning pigments and binder or/and gilts here) (fig. 5). As visible on the picture (fig. 1) there are still some traces of paint and gilding on the stone at the contrary of the other graves gathered in the basilica. The robe is blue with red sleeves, he has yellow hair, and he is wearing black breeches. His head rests on a red cushion on top of a green

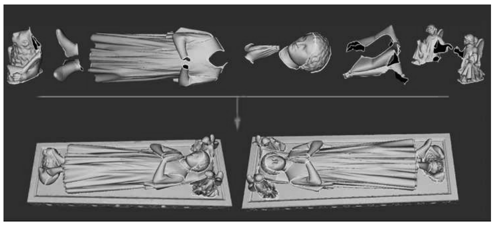

Figure 5: *3D model cut up not completely decomposed in color parts.*

one. The angels' bodies are blue painted and their wings are golden. At his feet lies a golden lion. During the Middle Age and more particularly during the thirteenth century, we already know (thanks to scientific study [Ami00] and litterature [Esc04] what pigments are the most commonly used and also how the paints were applied on the sculpture. First, the artists start with two or three layers of ceruse, made out of water and white lead. This step enables to waterproof the stone but also enables the painters to rectify the surface defects of the stone by coating. Then they apply several layers of paint, consisting of pigments embedded in a binder like egg (tempera technique), animal protein, linseed oil or gum-resin. The most frequently encountered pigments are:

- White : White Lead, White Chalk, Lime
- Black : Wood Smoke, Black Vine
- Blue : Azurite, Lapis-Lazuli, Indigo
- Red : Vermilion, Minium, Red Ochre
- Yellow : Yellow Ochre, Massicot
- Green : Green Clay, Malachite, Verdigris

Which of them were used in the specific case of Philippe Dagobert's recombent statue? The recorded diffuse reflectance spectra, obtained by the only possible analysis involving a non destructive method allow us to compare to the results of a necessary chemical analysis for validation.

2.4. The Kubelka-Munk model extended to Four-fluxes theory

Other works are related to spectral representation of colours ([SFD00], [RP97], [DCWP02], [GMN94]), and pigmented material representations in computer graphics [HM92], [BWL04], using the Kubelka-Munk theory. Our first concern here was, to use an extended Kubelka-Munk to four fluxes approach to better fit a modelisation of paintings and to realize our calculations based on 81 wavelengths sampled from 380nm to 780nm in the visible spectra, as tools to apply on our case study. Our second concern is in our entire process to constantly go back and forth between our theoretical models and our measurements on real materials. And above all, helped with our collaborations to apply these concepts in an archeological, and historical approach. The Kubelka-Munk model is almost well suited for the description of pigmented materials. These are described as a scattering medium, laying on a scattering background. The system is illuminated by a diffuse orthotropic incident light. It can be demonstrated ([VT01]), that an incident orthotropic light flux on such a film of thickness h can be considered equivalent to a collimated directionnal and normal incident flux on a paint film of thickness $2h$. The model gives the reflected and the transmitted fluxes from an incident light, normal to the layers across a paint film of thickness h laid on a substrate. The plain Kubelka-Munk theory ([KM31]) is a 2-flux theory involving two directional fluxes, one going downward L^+ and the other upward L^-. The layer of paint is a macroscopic scattering and an absorbing medium so we consider two coefficients: S and K the scattering and absorption ones. The substrate has a reflectance factor R_g. Thus, we account for

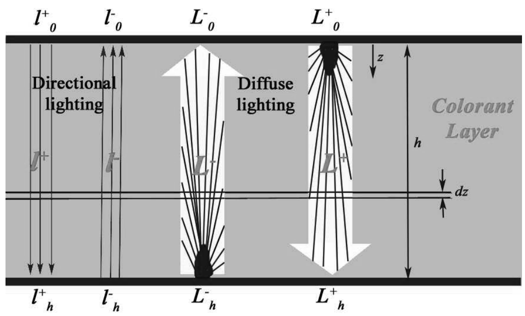

Figure 6: *Four-Fluxes theory: The radiances, directional (l^+,l^-) and diffuse (L^+,L^-), together with the boundary conditions.*

the normal and directional lighting on the outer layer. So the 2-fluxes model is improved with 2 additional fluxes of light l^- and l^+ normal to the interfaces. Including the two previous diffuse fluxes, one downward L^+ and the other upward L^- (as described in [VT01]). The figure 6 shows the scheme of this model. The incident light is then decomposed in a remaining directional reflected light and of an additional scattered light due to volume and surface scattering from the substrate. Two specular components are then added to the classical Kubelka-Munk model. We operate a local radiative balance and write four equations, where k', is the absorption coefficient for directional light, and respectively s^+, the forward scattering coefficient, and s^-, the backward scattering coefficient.

$$dl^+ = -(k+s^+ +s^-)l^+dz \tag{1}$$

$$-dl^- = -(k+s^+ +s^-)l^-dz \tag{2}$$

$$dL^+ = s^+l^+dz + s^-l^-dz - (K+S)L^+dz + SL^-dz \tag{3}$$

$$-dL^- = s^-l^+dz + s^+l^-dz - (K+S)L^-dz + SL^+dz \tag{4}$$

Setting l^+ and l^- equal to zero and solving the above system of equations, leads to the plain 2-fluxes Kubelka and Munk expressions of absorption coefficient K and scattering coefficient S. The results of the measurements leads to :

- h: the layer thickness,
- R_g: the background reflectance,
- R_∞: the reflectance for an infinite thickness (totally opaque layer)
- R: the layer reflectance (what we need)

We successively calculate: R_0, the surface reflectance:

$$R_0 = \frac{R_\infty(R_g - R)}{R_g - R_\infty(1 - R_g R_\infty + R_g R)} \tag{5}$$

S, K the scattering and absorption coefficients:

$$S = \frac{2.303}{h}\frac{R_\infty}{1-R_\infty^2}\log\frac{R_\infty(1-R_0R_\infty)}{R_\infty - R_0} \tag{6}$$

$$K = \frac{2.303}{2h}\frac{1-R_\infty}{1+R_\infty}\log\frac{R_\infty(1-R_0R_\infty)}{R_\infty - R_0} \tag{7}$$

For the four-fluxes model we add the specification of all the terms k, s_i, s_j from the optical coefficients. We shall for this, study a reference sample with a thickness of h_r deposited on a specular substrate.
We set :

$$a = 1 + \frac{K}{S}, \qquad b = \sqrt{\frac{K}{S}\left(\frac{K}{S}+2\right)}$$

$$x = bhS, \qquad A = asinh(x) + bcosh(x)$$

and also deduce the following parameters

$$\tau = \frac{b}{A}, \qquad \rho_1 = a - b, \qquad \rho_2 = \frac{sinh(x)}{A}$$

We obtain from the previous relationships:

$$T_r = e^{-\mu h} = \left(\frac{R_r}{R_{r,0}}\right)^{\frac{1}{2}} = \left(\frac{R_r^*}{R_{r,0}}\right)^{\frac{h}{2h_r}}$$

Then:

$$p = \frac{R_\infty(1-\tau T_r) - R_b}{\rho_1(1-\tau T_r) - \rho_2}$$

$$q = \rho_1 p - R_\infty$$

Next, inverting p and q equations leads to the scattering coefficients:

$$\left\{ \begin{array}{l} s_i = p(\mu - aS) + qS \\ s_j = pS - q(\mu + aS) \end{array} \right\}$$

where $\mu = \frac{1}{h}\ln\frac{1}{T_r}$
Finally we can deduce the absorption coefficient for very weak thickness:

$$k = \mu - (s_i + s_j)$$

These results were specially accurate for gilts: gold leaf polished above a colored paint film. The very small holes observed inside the gold leaf and produced by the polishing process enrich the reflected spectrum with the diffuse component of the underlying paint even when the metallic leaf is thick enough to be theoretically completely opaque.

2.5. Recorded diffuse reflectance spectra and paintings

We analyzed some paint samples made in laboratory and worked on the appearance of the paints depending on the thickness of each deposited film. We also measured the thickness of each sample. First, we notice the change in reflectance as the thickness increases.

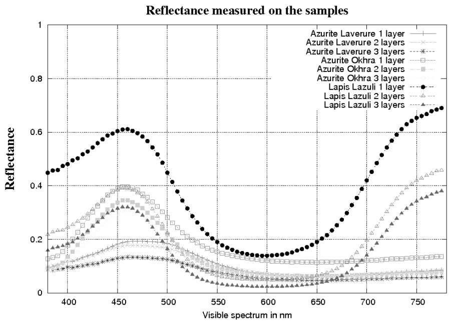

Figure 7: *Reflectance spectra of the blue pigments, azurite and lapis-lazuli.*

The thicker the layer the lower the reflectance. This means that the shade is darker as the thickness is increased, thus masking more and more the white substrate. For several pigments (green clay, malachite, black vine, vermilion, and lemon ochre), the reflectances of two and three layers tend to be quite similar, so we will consider that the diffuse reflection spectra for the three layers sample gives the R_∞ to determine the coefficients K and S of these pigments. Spectral measurements help in differentiating a lapis-lazuli from an azurite film (fig. 7). The first one has two peaks, one in the blue wavelengths near 455*nm* and the other in the red and the near IR wavelengths region (780*nm*). Only one peak appears for the azurite pigments. Lapis-lazuli and its subtle reddish component is known as natural ultra-marine blue, very efficient for reflecting infra-red radiations (ideal paint used for the shutters in the mediterranean countries).

We can also notice that the two pigments have different maxima in the blue region of the visible spectrum. One exhibits a relatively narrow peak while an other has a more flat and extended peak tending to cover the green shades region. Sometimes, a small amount of malachite in natural azurite can explain the reflectance curve aspect and also the greenish color observed on the sample. Now that we have the reflectance spectra of the pure pigments, we want to compare them to the ones we measured at the basilica on the recumbent statue. We have identified some of the pigments used on the statue.

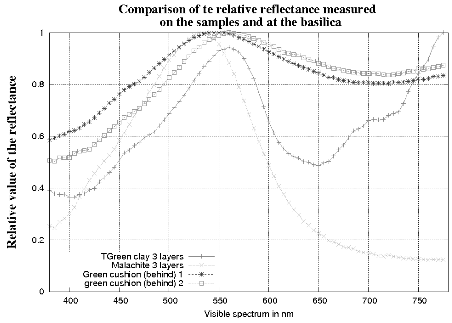

Figure 8: *Comparison of the in situ measured diffuse reflectance spectra with the corresponding spectra of the handcrafted samples.*

It seems that the pigment used by the painter was identify as green clay, according to the reflectance curves. We have done this kind of comparison for every *in situ* spectrum. The blue areas seem to have been painted with azurite. The spectrum of the red cushion approaches the spectrum of the minium. We can notice that the spectra taken at the basilica have a less amplitude between the maximum and the minimum of their reflectance curves than those of the samples. This phenomenon expresses the fact that the colors of the sculpture are now very de-saturated. There are several reasons for that. First, the colors are old and dirty. Then, the deposited dust on the sculpture increases the whitening with the surface scattering of all incident light.
More studies are necessary to exactly determine the composition of each paint used to achieve this sculpture. More samples of different pigments will be elaborated. Therefore we could virtually create mixtures of pigments and compare them to the spectra measured in the basilica, according to the robust color matching methods.

2.6. Spectral simulations

With a correct characterisation of all materials, the surface state (ondulation, roughness), the lighting conditions and standard colorimetric observer (CIE 1964 10°), we can compute the restored visual aspect of the museum artifacts. For metals such as gilts the images are obtained by a parallelized ray-tracing algorithm using 81 wavelengths bands of 5 nm width. The 3D coordinates of the points are hierarchically distributed inside hundreds of bounding boxes, made to speed up ray-surface intersections determination. We use the complex indices of refraction which characterise the intrinsic properties of the materials. Optical constants are then, real part $\eta(\lambda)$ and the imaginary part $\eta(\lambda)\kappa(\lambda)$ of the complex index of refraction of the metals and alloys (eq. 8). This can be measured on samples by *spectroscopic ellipsometry* an optical method based on Fresnel formulas and the analysis of the amount of reflected and polarized light at large

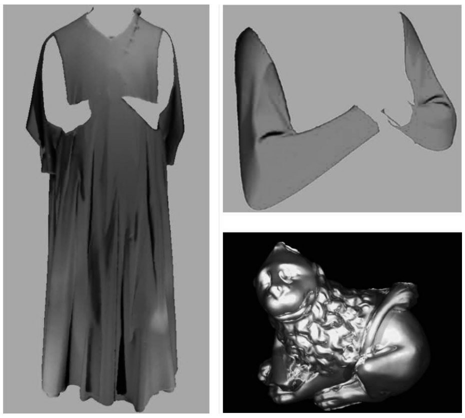

Figure 9: *(left) Philippe-Dagobert's surcoat rendered in lapis-lazuli blue pigment by the radiosity software Candelux. (right) Philippe-Dagobert's sleeves - vermilion pigment rendered with Candelux, gilded lion (spectral ray-tracing).*

incidence on a smooth surface. We use throughout the calculations the Max Born's notation for the complex index of refraction, ie:

$$\eta(\lambda) = \eta(\lambda)\,[1 + i\kappa(\lambda)] \tag{8}$$

The whole theory of reflection of light by a metallic surface is available in optics books such as Born and Wolf's [BW80]. For the rendering of paints we use a spectral radiosity algorithm Candelux to test the appearance of pure pigments as studied on samples in laboratory: for instance lapis-lazuli for the surcoat (fig. 9), or vermillon for the sleeves.

3. Conclusions

We went one step ahead in our knowlege and know-how for cultural heritage engineering and physical models for materials in optical simulation. Till now we worked with normalized lightings such as CIE D65 illuminants. We need and shall pursue these studies in improving our knowledge on natural lighting by stained glass windows and all other anthropogenic lightings used in the medieval era.

References

[Ami00] AMIENS: *La couleur et la pierre. Polychromie des portails gothiques, rencontres internationales sur la polychromie des portails gothiques Amiens, Octobre 2000, ISBN: 2708406280*. A. et J. Picard, 2000.

[BJV96] BARON F., JANKOWIAK C., VIVET C.: *Sculpture française, I, Moyen Age, Catalogue, Musée du Louvre, Département des sculptures du Moyen Age, de la Renaissance et des Temps modernes, Paris, p.110-111 Sculpture funéraire d'Ile de France, deuxième quart du XIIIème siècle.* RMN, 1996.

[BW80] BORN M., WOLF E.: *Principles of Optics, Oxford, sixth edition*. Pergamon Press, 1980.

[BWL04] BAXTER W., WENDT J., LIN M. C.: Impasto: A realistic, interactive model for paint. In *In Proc. NPAR2004,the 3rd Intern. Symposium on Non-photorealistic Animation and Rendering* (2004), pp. 45–56.

[Cal05] CALLET P.: Visual appearance of bronze – simulation and validation. In *International Conference on Color (Association Internationale de la Couleur), Granada, Spain* (2005), Wiley InterScience.

[CZM02] CALLET P., ZYMLA A., MOFAKHAMI A.: Archæology and virtual metallurgy - application to the visualization of a work of art. In *ICCVG'02, Poland* (2002).

[DCWP02] DEVLIN K., CHALMERS A., WILKIE A., PURGATHOFER W.: Tone reproduction and physically based spectral rendering. In *EUROGRAPHICS 2002, STAR - State of The Art Report* (2002).

[dG48] DE GUILHERMY B. F.: *Monographie de l'église royale de Saint-Denis. Tombeaux et figures historiques, Paris, p.240-244*. " ", 1848.

[EB75] ERLANDE-BRANDENBURG A.: *Le Roi est mort, Etude sur les funérailles, les sépultures et les tombeaux des rois de France jusqu'à la fin du XIIIeme siècle, Paris*. Bibliothèque de la Société française d archéologie,7, 1975.

[Esc04] ESCALOPIER C.: *Essai sur divers arts. Théophilus moine artisan du XIIe siècle. Texte intégral traduit du latin par Charles Escalopier*. Paleo, 2004.

[GMN94] GONDEK J. S., MEYER G. W., NEWMAN J. G.: Wavelength dependent reflectance functions. In *Proceedings of SIGGRAPH'94* (1994), pp. 213–220.

[HM92] HAASE C. S., MEYER G. W.: Modeling pigmented materials for realistic image synthesis. In *ACM Transactions on Graphics* (1992), pp. 305–335.

[KM31] KUBELKA P., MUNK F.: Ein beitrag zur optik der farbanstriche, leipzig. *Zeitschrift für technische Physik* (1931).

[Mil91] MILLIN A. L.: *Antiquités nationales, ou Recueil de monuments pour servir à l'histoire, tome 2, Paris, p.10-12,pl.4,fig.2 et pl.5, fig.1.* Antiquités nationales, 1791.

[RP97] ROUGERON G., PEROCHE B.: An adaptive representation of spectral data for reflectance computations. In *Proceedings of the 8th Eurographics* (1997).

[SFD00] SUN Y., FRACCHIA F. D., DREW M. S.: A composite spectral model and its applications, scottsdale, arizona. In *Eighth Color Imaging Conference* (2000), pp. 102–107.

[VT01] VOLZ H. G., TEAGUE B.: *Industrial Color Testing: Fundamentals and Techniques (2nd edition) ISBN: 3527304363*. Vch Verlagsgesellschaft Mbh, 2001.

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
VAST (2006)
M. Ioannides, D. Arnold, F. Niccolucci, K. Mania (Editors)

The Geometric Documentation of the Asinou Church in Cyprus

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Abstract

The Asinou Church, devoted to the Virgin Mary, is a wonderful 11th c. Byzantine Church built up in Troodos Mountain on the island of Cyprus. This Church has been recognised as a World Heritage Monument by UNESCO. A joint effort between the Laboratory of Photogrammetry of NTUA and HTI had as main goal the geometric documentation of this monument, using a combination of modern digital techniques for data acquisition and methodologies for data processing. Digital surveying and photogrammetric instrumentation, as well as a laser scanner were employed, in order to collect the necessary data for producing digital colour orthophotographs for the four exterior facades and six interior crossections of the church.
The methodology is briefly described and assessed for its adaptability to the special requirements of this monument. The results of the data processing are presented and evaluated for their usefulness. Moreover a 3D visualisation of the church is attempted based on the accurate measurements performed. The paper concludes with an appraisal of the products in view of their inclusion in a Monument Information System, which could include all monuments of the particular area of Cyprus.

Categories and Subject Descriptors (according to ACM CCS): I.2.10 [Vision and Scene Understanding]: Representations, data structures and transforms, H.2.8 [Databases Applications]: Spatial databases and GIS

1. Introduction

Monuments are undeniable documents of world history. Their thorough study is an obligation of our era to mankind's past and future. Respect towards cultural heritage has its roots already in the era of the Renaissance. Over the recent decades, international bodies and agencies have passed resolutions concerning the obligation for protection, conservation and restoration of monuments. The Athens Convention (1931), the Hague Agreement (1954), the Chart of Venice (1964) and the Granada Agreement (1985) are only but a few of these resolutions in which the need for geometric documentation of the monuments is also stressed, as part of their protection, study and conservation.

The geometric documentation of a monument may be defined as the action of acquiring, processing, presenting and recording the necessary data for the determination of the position and the actual existing form, shape and size of a monument in the three dimensional space at a particular given moment in time [UNE72]. The geometric documentation records the present of the monuments, as this has been shaped in the course of time and is the necessary background for the studies of their past, as well as the plans for their future. Geometric documentation should be considered as an integral part of a greater action, the General Documentation of the Cultural Heritage. This comprises, among others, the historical documentation, the architectural documentation, the bibliographic documentation etc. The Geometric Recording of a monument involves a series of measurements and -in general- metric data acquisition for the determination of the shape, the size and the position of the object in the three dimensional space. Processing of these data results to a series of documents, i.e. products, at large scales, which fully document the geometric -and other- properties of the monument. Usually such products include two dimensional projections of parts of the object on horizontal or vertical planes, suitably selected for this purpose.

Technological advances in recent years have spectacularly multiplied the variety of sources for collecting metric information at such large scales. In order to fully exploit these data special techniques should be developed. Moreover, the advancements in computer industry have enabled the three dimensional visualizations of the monuments in a virtual world. The compilation of 3D models of historical monuments is considerably facilitated by the use of dense point clouds, which are created by the use of terrestrial laser scanners. Their combined use with photogrammetric procedures, such as the production of orthophotos, allows the realistic 3D representation of complex monuments such as sculptures. In this context virtual reality tours have been created for simple or more complex monuments. This ability has greatly contributed to the thorough study of the monuments, as well as to the creation of virtual visits.

2. The Asinou Church

2.1. Historical issues

The famous Byzantine painted church of Panagia Phorbiotissa of Asinou lies about five kilometers to the south of the village of Nikitari in the pine-clad of the Troodos range of mountains, at an altitude of approximately 450m (Figure 1). The church is dedicated to the Virgin Mary and is considered to be one of the most important Byzantine churches in Cyprus. The main church is the only surviving part of the Phorves monastery from which the name Panagia Phorviotissa originates. The church is dated from the early 12th century AD and the murals inside range from the 12th century through the 17th century [HM02] . The church is recognised as a World Heritage Monument by UNESCO, as it is home to perhaps the finest examples of Byzantine Mural paintings of the island.

Figure 1: *Location of the church of Asinou on the map of Cyprus.*

The church is a rectangular vaulted, humble-looking building with arched recesses in the side walls and transverse arches supporting the vault. It is built with local volcanic irregular stones originally covered with plaster in such a way as to imitate marble revetment. The church is covered with a steep-pitched roof and flat tiles. The original pies with the transverse arches where strengthened with additions at a later date. The apse of the church was also reinforced with additions at a later date (Figure 2). A narthex, with two semi-circular apses and calotte and a drumless dome, and apsidal north and south ends, was added at the west end at about the end of pitched roof with flat tiles, which appear in the model of the church in the donor composition, and therefore is original. The structure was built in the 12th century by the Greeks, who also built the nearby ancient city of Asinou.

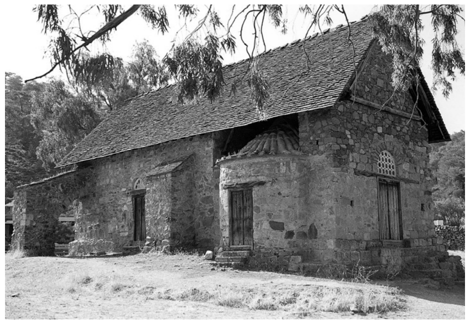

Figure 2: *North-western view of the Church.*

It appears that the church suffered great damage at the end of the 13th, or beginning of the 14th century as the result of an earthquake. The apse was then rebuilt and the apse semi-dome and nave were redecorated. The narthex was redecorated in 1332/3. Thus the frescoes surviving in the church of Asinou today vary in date.

Fortunately, two-thirds of the original decoration of the church of 1100's survive today. Through these murals we are able to determine that the church was probably originally constructed as a family chapel for Nicephoros Magistros (who later died here in 1115 AD). One inscription found in the south-west recess records that the church of the holy mother of God was painted through the donation and great desire of Nicephoros Magistros the Strong, when Alexios Comnenos was Emperor in the year 6614, indiction

Figure 3: *Mural including the oldest inscription of the church.*

14 (Figure 3). This probably means that the church was constructed some time between the year 1099 and 1105.

Another inscription mentions that the founder was also nick-named ”the Strong”, an appellation most probably given to him by the people for his power and severeness as a judge, or taxation officer. Neither of the inscriptions mentions a Monastery, or the appellation ”Phorbiotissa”.

2.2. Specifications

For the proper geometric recording of the Asinou Church it was decided to work towards the production of the minimum necessary 2D and 3D products, which would contain the geometry of the monument, both inside and outside. Hence the final drawings include:

- a horizontal section of the building at a height of approx. 1m, which would, of course, include all necessary details above and below this section,
- the four outside elevations,
- a longitudinal vertical crossection ”looking” at both sides
- two N-S crossesctions, again ”looking” at both sides.

In order to do justice to the wonderful murals inside the church, but also to the unique outside structure, it was decided to produce colour orthophotography for the above drawings, instead of the more traditional and, in any case, quite abstract line drawings. 1:50 was chosen as the scale of the drawings, since it is the most commonly used scale for geometric documentations. This scale requires an accuracy of 15mm for all points and details recorded on the monument, a task which is not that easy. In addition to the above, it was decided to attempt a 3D representation of the Church, in order to convey to the observer part of the majestic impression that the visitor gets, when looking at the monument itself.

3. Geometric Documentation

3.1. Methodology

The Geometric Recording of Monuments at large scale, i.e. larger than 1:100, presents several difficulties and peculiarities, which call for special attention by the users. The need for large scale images, the presence of extremely large height differences compared to the relatively small taking distances and the multitude of details usually present on the surface of the monuments combined with the high accuracy requirements are the main sources of these difficulties for the production of the conventional line drawings. The production of orthophotographs presents even more special problems, as it usually is a case of a highly demanding true orthophoto. Special techniques have been developed to address these problems in the best possible way [DL01], [MPK02], [Wie02].

Recording of monuments often demands the production of special products, quite different from those of conventional photogrammetric applications. Among others the 3D visualizations, supported by technological advancements, have added a significant means of representation of the complex monuments. The combination of available data has enabled the construction of highly detailed 3D models, which could convey the accuracy of the original data. Rendering techniques supported by increasing computing power have significantly contributed to the aesthetic appearance of these visualizations. The next step is to enable the performance of accurate measurements on these 3D visualizations.

In the present case a combination of all available technological advances was used for the optimum result. The irreplaceable conventional surveying measurements support the photogrammetric mapping, which provides the detail and the point clouds from the terrestrial laser scanning cater for the detailed three-dimensional information.

3.2. Data acquisition

Instrumentation of the latest technology has been used for the data acquisition phase. A reflectorless total station Topcon GPT-3003, with 10cc and $\pm$3mm $\pm$2ppm accuracy, a Canon EOS 1D Mark II 8.2 Mpixel digital camera with a pre-calibrated 28-80mm f/3.5-5.6 zoom lens, with a pixel size of 8μm and CMOS sensor size of 3504 x 2336 pixels and a Leica Geosystems HDS-2500 terrestrial laser scanner were the basic instrumentation used.

The contemporary idea of multisource data exploitation [GI05] has been applied in this case, hence the fieldwork included -among others- geodetic network and control point measurements, image acquisition and laser scanning. A careful planning of the fieldwork ensures the successful processing at a later stage, minimizing the need to re-visit the site for additional measurements.

Special care has been given to the initial image scale, or equivalently, to the resulting GSD, in order to cover the requirements of the 1:50 scale. Monoscopic or stereoscopic photography has been planned, according to the properties of the various parts of the object. In total 700 ground control points and 1,500 detail points were measured on the object, from ten traverse stations in and around the church. Moreover 116 photogrammetric images were taken, of which 68 for mono and 48 for stereo compilation (Figure 4). Laser scanninig was applied at a later stage, after an initial processing. This enabled the coverage enhancement of areas where there were gaps or omissions from the initial photogrammetric processing. Such areas included the domes of the three apses, the interior of the Holly and other such complicated parts of the object. In addition general scans were also performed, mainly to cover the outside surfaces of the church; in Figure 4 the blue round signs in the internal side of the church symbolize the scanners set-ups directed towards the ceiling.

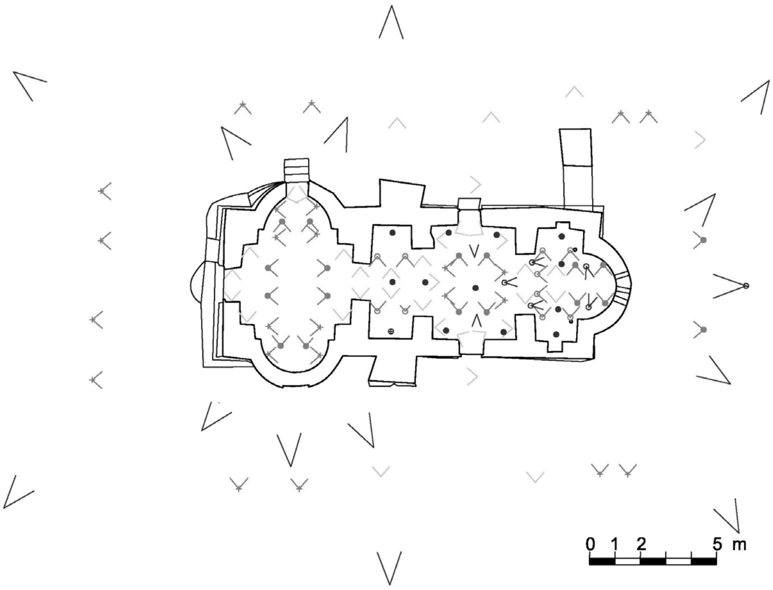

Figure 4: *Plan view of the church, showing scanner set ups (in blue) and camera locations for stereopairs (in red) or monoscopic images (in green).*

3.3. Data processing

Data processing included the individual preprocessing of the various data separately, and later the necessary integration. The geodetic network adjustment ensured the required accuracy in the final products. For the photogrammetric processing, every elevation (Figure 5) should be processed in a separate reference system, which -if desired- may be reversed at a later stage, in order to obtain the final products in a common system.

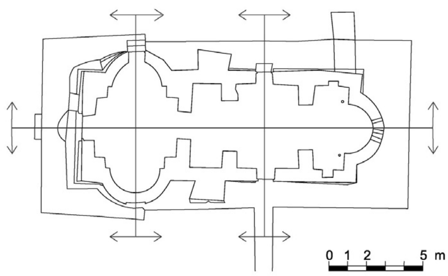

Figure 5: *Horizontal plan of the church showing the positions of the vertical cross sections.*

For the monoscopic processing, i.e. the digital rectification the ARCHIS software by SISCAM was used and for the stereocompilations the digital photogrammetric workstation SSK of Z/I Imaging was employed. DTM, or better, DSM collection was carried out manually on the DPW at an interval of 10cm on the object. In addition all necessary break lines and object edges were also collected, in order to assist the orthophoto production. A GSD of 5cm was chosen for the final orthophotos.

The cloud points from the terrestrial laser scanner were processed within the Leica Geosystems Cyclone software, which provides the possibility of either cloud-to-cloud registration with common points or common features, or the direct reference of a cloud to the desired co-ordinate system. Both possibilities were used and the resulting registrations carried an error of 6mm. The final point cloud (Figure 6) was also exported to dxf format for further exploitation.

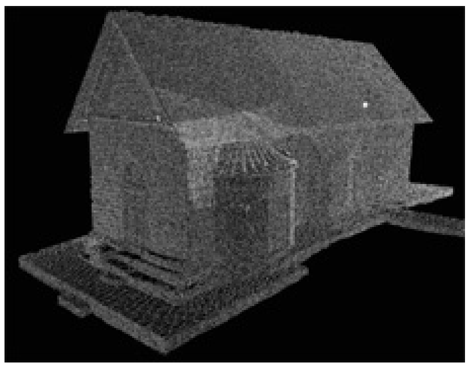

Figure 6: *Registered point clouds.*

4. Products

4.1. Orthophotomosaics

All partial orthophotos belonging to a particular elevation, no matter whether they were produced by rectification or orthophotography procedure, were combined to a unique orthophotomosaic within the AutoCAD environment. For this purpose the measured ground control points were employed. For the radiometric correction and unification of the colours the Adobe PhotoShop image processing software was chosen.

On the resulting orthophotomosaic the inevitable gaps and faults have been located, in order to be completed. (Figures 7, 8, 11, 12)

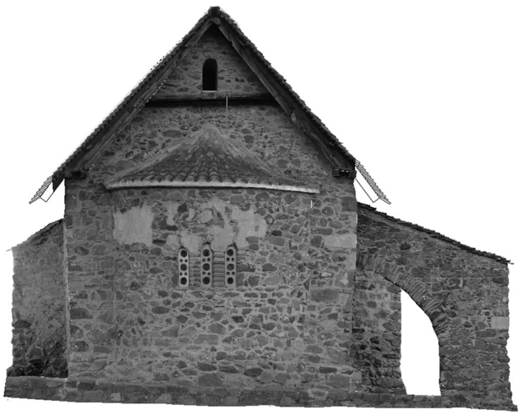

Figure 7: *Ortho-mosaic of the eastern facade.*

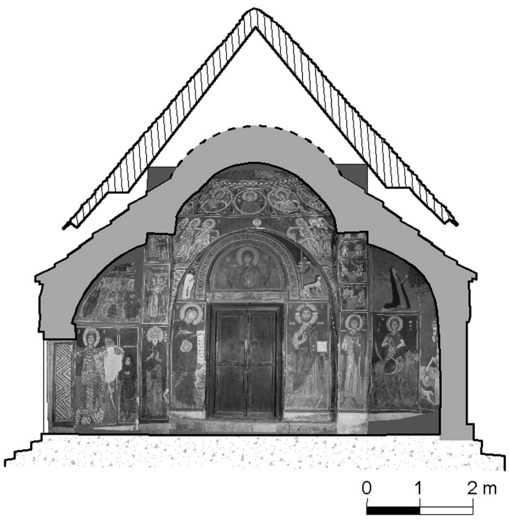

Figure 8: *The N-S cross section "looking" to the west.*

4.2. The three-dimensional model

The creation of a 3D model of the church included first the processing of all dxf files which contain the point clouds, both from the laser scans and the stereo-compilation, for the production of a polygon or triangular network. Geomagic Studio v7 software was chosen for this procedure. The software enables noise removal, as well as data reduction without loss of necessary information. With suitable processing the point cloud was converted to a polygonal mesh, from which the three-dimensional surface model was produced (Figure 9).

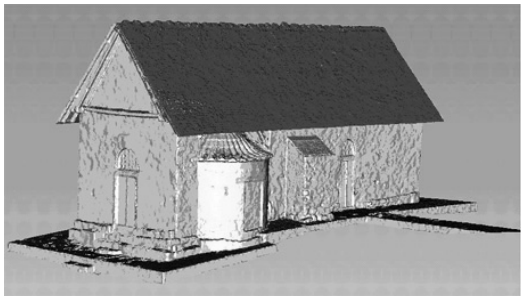

Figure 9: *South-western view of the Church's 3D model produced by the Geomagic software.*

The next step included the production of a 3D textural model of the church. For this purpose the MODO v2.0.1 software was used, which contains a larger variety of more user-friendly tools for texture mapping than the Geomagic software. The orthophotos which had been produced photogrametrically were adjusted to all surfaces of the church instead of using simple images. Thus, an accurate adjustment of raster information on the 3D solid model and high quality results were achieved. Figure 10 shows a view of the internal side of the church with orthophotos as an overlay on the surfaces.

Figure 10: *North-eastern view of the textured 3D model of the Church.*

Figure 11: *Ortho-mosaic of the outer northern facade of the Church.*

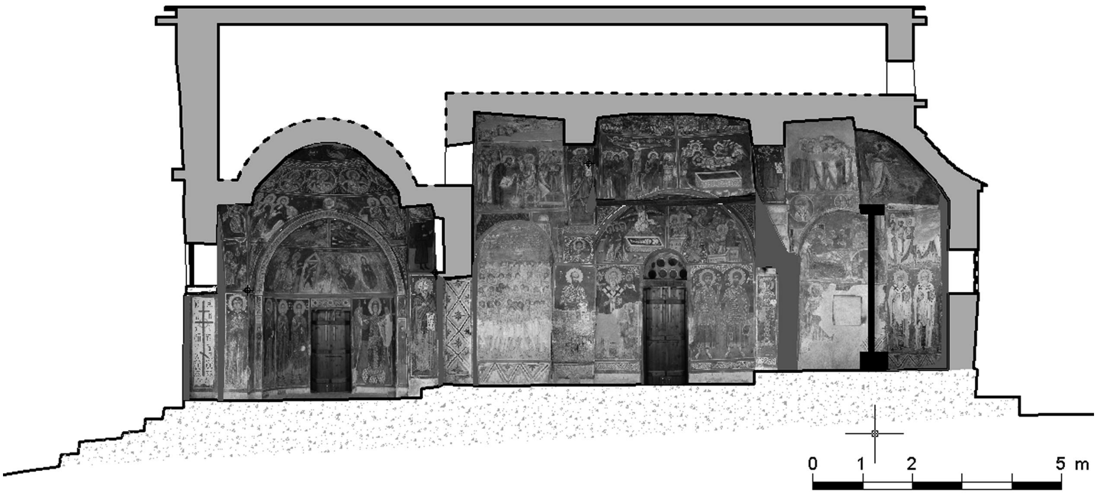

Figure 12: *The longitudinal vertical cross section "looking" to the north.*

5. Monument Information System

A Monument Information System (MIS) is required for an integrated documentation of the Byzantine church of Asinou, in addition to the detailed geometric recording. Historic, archaeological, architectural and other information will be integrated in this system together with the above mentioned geometric information, in text, images, vector and raster format, 3D animations, videos.

The establishment of such a MIS is on-going project, and is part of the proposal for establishing an Information System for all Byzantine Churches in the jurisdiction of the Holly Metropolis of Morfu, where there are eight of the 13 churches that exist in Cyprus which are characterized by UNESCO as "World Heritage Monuments". New techniques are been used regarding Informatics, Graphics, Virtual Reality, and Multimedia. The MIS which will be developed will provide for data collection, storage, analysis, processing, management, virtual representation and animation by use of multimedia technology. The user will be able to make a virtual tour of the whole area of the Metropolis, which will be based on the framework of high resolution satellite images and other necessary data. During this tour the churches-monuments will be georeferenced. The system will also provide services for an individual tour by using multimedia and a virtual guide.

The beneficiaries of this project include students, teachers, scientists, researchers, parents, visitors, and any others interested to have an electronic access and would enjoy an e-tour [Tem06].

6. Conclusions

A combined use of photogrammetric methods and laser scanning techniques was applied for the geometric documentation of the Asinou church. The extraction of accurate and detailed DSM of the surfaces of the monument is necessary both for the production of two-dimensional orthomosaics, and for the creation of 3D model. The combined use of those two techniques allowed:

- the completion of the missing parts of the DSM, where the stereoscopic image acquisition was difficult or impossible
- the creation of a three-dimensional textural model which has good geometric accuracy.

In agreement with the Episcope of Morfu, it was decided that a documentation model will be developed for the Church of Asinou, which will be used for the other churches-monuments of Cyprus, as well. For this purpose the produced geometric recording should be completed with more detailed 2D plans at larger scales, e.g. 1:10 or 1:5; videos with detailed three-dimensional textural models of the surrounding area and the inside of the church should be created and a MIS accessible through the Internet should be in operation.

Acknowledgements

The invaluable help and support of Father Kyriacos Christofi of the Bishopric of Morfou is gratefully acknowledged. The assistance of Ms. M. Ieronimides and Mr. P. Flourenzos from the Archaeological Department is also recognized. The authors wish to also thank Mr. Hadjichristodoulou from the Bank of Cyprus and Cyprus Airways for their support.

References

[HM02] HADJICHRISTODOULOU C., MIRIANTHEFS D.: *Guides to the Byzantine Monuments of Cyprus. - The Church of Our Lady of Asinou.* Cultural Foundation of Bank of Cyprus, 2002.

[DL01] DEQUAL S., LINGUA A.: True orthophoto for architectural survey. In *Proc. of 18th International Symposium CIPA, Potsdam*, (2001), IAPRS, vol. XXXIV-5/C7, pp. 269–276.

[GI05] GEORGOPOULOS A., IOANNIDIS C.: 3D visualization by integration of multisource data for monument geometric recording. In *Proc. of the International Workshop on 'Recording, Modeling and Visualization of Cultural Heritage', Ascona, Switzerland, 2005* `http:www.ascona2005.ethz.ch.`.

[MPK02] MAVROMATI D., PETSA E., KARRAS G.: Theoretical and practical aspects of archaeological orthoimaging. In *Proc. ISPRS Commission V Symposium 'Close-range imaging, long-range vision'. International Archives of Photogrammetry and Remote Sensing, Corfu, Greece*, (2002), vol. XXXIV-5, pp. 413–418.

[Tem06] TEMBRIOU V.: *Welcome to the Church of Our Lady of Asinou.* Diploma Thesis, Higher Technical Institute of Cyprus, 2006.

[UNE72] U.N.E.S.C.O.: *Photogrammetry applied to the survey of Historic Monuments, of Sites and to Archaeology.* UNESCO editions, 1972.

[Wie02] WIEDEMANN A.: Challenges and solutions on the generation of digital surface models of facades using image processing techniques. In *Proc. ISPRS Commission V Symposium 'Close-range imaging, long-range vision', Corfu, Greece*, (2002), IAPRS, vol. XXXIV-5, pp. 479–483.

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
VAST (2006)
M. Ioannides, D. Arnold, F. Niccolucci, K. Mania (Editors)

A Proposed Low-cost System for 3D Archaeological Documentation

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Abstract

To meet the requirements for rapid, accurate and effective recording and documentation of archaeological excavation sites a prototype system is under development. This paper presents the first results from an easy-to-use system that utilizes photogrammetric and computer science methods, as well as tools for on-site recording, modeling and visualization of an archaeological excavation. The software-component is the main focus of our research. Its aim is multifold, such as to provide a three-dimensional reconstruction of the excavation site in a very accurate way, rapid and almost real-time recording and documentation, multiple outputs for various uses and finally to achieve all these tasks requiring minimal knowledge of Digital Photogrammetry and CAD systems, through a sophisticated and user-friendly interface, easy to be used by people, such as archaeologists that are not experts in Photogrammetry or in Information Science. Finally, in the near future it is planned to evaluate and demonstrate under real circumstances the functionality and the effectiveness of the system, so as to be performed the necessary improvements.

1. Introduction

The nature of an archaeological excavation is destructive and therefore recording is a procedure that must be performed at every stage. Not only the different layers of stratigraphy but also all the containing features, such as walls, post-holes, graves, pits, ditches, must be carefully recorded, in terms of size, depth, shape etc. and photographed. Additionally, at various phases an accurate excavation plan must be created, in order to show the location of features and contexts, as well as the spatial interrelation (topology) of the findings for the subsequent archaeological study. All these records will form "the basis of which all interpretations of the site will be made" [RB91]. The aforementioned procedures are not only time-consuming dramatically postpone the excavation time, but also costly, because of the large amount of data to be recorded. Furthermore, they do not provide the level of absolute accuracy that the archaeologists need for their future research.

In the last years, digital photogrammetry became a major tool in archaeology. Specialists in this area recognize the advantage of fast and accurate mapping, Moreover they use photogrammetric techniques in order to record and document the findings of an excavation [GP96]. Digital photogrammetry offers to archaeologists all the powerful tools for fast and accurate recording and mapping of the archaeological sites [HE97]. The new low-cost digital cameras, providing high-resolution images, in combination with the portable Digital Photogrammetric Stations (DPS), constitute powerful tools for the whole mapping process in the period of one day [BLR97], [Miy96]. This is very important since the archaeological image interpretation is performed in the same day.

Unfortunately, DPS are high-end hardware & software devices, mostly in use for aerial Photogrammetry and normally do not tackle correctly the problems of close-range imaging. Additionally they refer to specialized personnel and characterized by high hardware and software cost. In contrast, in a lot of cases, the needs of architects and archaeologists are much more primary and simpler than these of a cartographer [GP02], [PK95]. However they can always take advantage of some of the value added modules of a Digital Photogrammetric Station such as the 3D viewing and measuring subsystems.

To meet the requirements for rapid, accurate and effective recording and documentation of archaeological excavation sites a prototype system (which is already under development) is proposed.

The software-component of such system is the main focus of this research. Its aim is multifold, such as to provide a three-dimensional reconstruction of the excavation site in a very accurate way, rapid and almost real-time recording and documentation, multiple outputs for various uses and finally to achieve all these tasks requiring minimal knowledge of Digital Photogrammetry and CAD systems, through a sophisticated and user-friendly interface, easy to be used by people, such as archaeologists that are not experts in Photogrammetry or in Information Science. Finally, in the near future it is planned to evaluate and demonstrate under real circumstances the functionality and the effectiveness of the system, in order to perform the necessary improvements.

This paper presents the specifications and the requirements of the proposed system that utilizes photogrammetric and computer science methods, as well as tools for on-site recording, modeling and visualization of an archaeological excavation. Both research groups will join forces and former experiences presented in [DG00], [MGT*04], [PST98], [PST*99] to propose low-cost solutions to improve current methods, tools and techniques.

2. General principles of system design

The proposed prototype system will allow the rapid and accurate recording and documentation of archaeological excavations. As it is already mentioned, it's aim is to provide mapping and documentation of the site, using overlapping digital images free of distortions and a user-friendly 3D viewer, providing a realistic view of the archaeological findings, with accurate measuring capabilities, and allowing a simple and interactive access to the recorded data. Moreover, it will provide *in-situ* pre-processing of the data and distribution of the processing tasks to remote users.

The aims of the system are:

- To provide a three-dimensional reconstruction of the excavation site in a very accurate (1-2 cm) way.
- To provide a rapid and almost real-time recording and documentation.
- To provide multiple output for various uses. Such outcomes can be 3D vector graphics, Orthophoto mosaics, 3D digital surface models, real-image rendered 3D objects, visualization of 3D objects, interactive 3D models linked with documentation databases and Geographic Information System input, etc.
- To achieve all these tasks requiring minimal knowledge of Digital Photogrammetry and CAD systems, through a sophisticated and user-friendly interface.

The challenge in this research is to develop automatic or semi-automatic photogrammetric techniques, which could provide the required accuracy with the minimum intervention from the part of the user, compensating thus to the degree of the required knowledge, as well as safeguarding for mistakes. Besides automation and robustness issues, the proposed software will be equipped by user-friendly interface, in order to be easy for the user to navigate through the different tasks and perform them with a low degree of experience.

Additionally, the proposed system must be able to run on desktop and laptop computers. Therefore, it must not use high resources from the hosted computer.

3. System Design

The proposed system will be developed up to a pre-industrial level and will consist of a low-end hardware component, a developed software component and a user-manual. The system consists of the following components.

3.1. Hardware Component

The hardware-component will be low-end and off-the-shelf aiming at minimizing the start-up cost of the whole system. It is planned that the minimum required hardware will consist of a Personal Computer (or a Notebook) with Ethernet and Internet capabilities, enhanced by special 3D-graphics card with (if possible) active polarization or interlaced capabilities. Networking and Internet connections will enable the user to distribute the recording and documentation tasks to remote group-members while active polarization ability will enable the user to see and measure in three dimensions using polarization glasses. Alternative, if the graphics card cannot provide stereoscopic abilities, a stereoscopic view with Blue/Red glasses will be used.

For the recording phase, additional hardware will consist of a (low-end) digital CCD camera. Current technology provides for such a low-cost hardware, which although is very reasonable in price, suffers by often severe distortions either due to electronics or due to the lenses.

3.2. Software Component

The software-component will include all the procedures that are needed in order to achieve the aim of the project, in modules, under a common interface. One of the main targets of the project is to keep the included basic photogrammetric tools as much "hidden" from the user as possible (using automatic or semi-automatic procedures). (Figure 1)

The modules are:
i. Calibration and interior orientation of the camera. Standard calibration techniques for the compensation of the distortions induced by the low-cost digital cameras will be included.

ii. External orientation. This is one of the procedures that usually cannot be fully automated and the help of the final user will be needed. The user must indicate the control points to the system in order to solve the external orientation of the images. This module has already been developed. Further implementation will include the fully automatization of the procedure with the use of pre-defined control points.

iii. Triangulation. Excavation sites usually give very high textured images. This means that triangulation, which will produce a very dense (every 5-10 cm) network of points of the excavation surface, is a procedure that can be easily automated. A new and effective algorithm (low CPU cost) will be embedded in the system for the search of conjugate points on the epipolar images. The new technique differs from the typical approach in a way that can lead fast and easy to the correct x-parallax value of the epipolar images for the desirable ground point. Moreover, manual addition of points will be possible by the user in case of poor textured images. This module has also been developed and is now under accuracy testing.

iv. DTM/Grid creation. The above network of points will be used in order to produce a grid of points for the excavation surface by creating a TIN based on Delaunay Triangulation. This module is not implemented yet.

v. Orthophoto/mosaic generation. The system will give the ability to produce an image or a mosaic of images (Orthophoto) of the excavation site free of rotation and anaglyph errors. With the creation of orthophotos, archaeologists have an accurate (as a map) and complete (as a photograph) background without the need to do any surveying of the sites, other than taking overlapping digital photographs. This background will be used for making the archaeological interpretation in vector format as a layer on top of the Orthophoto. This interpretation will be inserted in CAD programs as a vector file. The sub-component of the Orthophoto generation is already developed.

vi. Basic measurement functions. User will be able to see a pair of images in stereo (using polarization or blue/red glasses) and measure some basic attributes of objects like distance and area. This module will be developed in the final stage of the project, when the final GUI of the software will be known. The major sub-components of the module (e.g. Stereo viewing, 3D measurement functions, etc) are already developed.

vii. Mono-plotting ability. In addition to basic measurement functions, the system will also include a mono-plotting module. That is with the orthophoto as a background, the archaeologist will be able to extract 3D metric information (distances, angles, areas and volumes) as well as 3D vector mappings of the sites, without using stereoscopy. In fact, the planimetric coordinates (x, y) will be picked from the cursor movement, whereas the altimetry (z) will be on-the-fly interpolated by the "underneath" DSM. For drawing purposes, the user will have the ability to measure and draw 3D objects of the excavation site in a CAD environment. For the moment, the implementation of this module is being developed for the Autodesk AutoCAD environment. Further implementation will include other CAD environments (like Bentley Microstation).

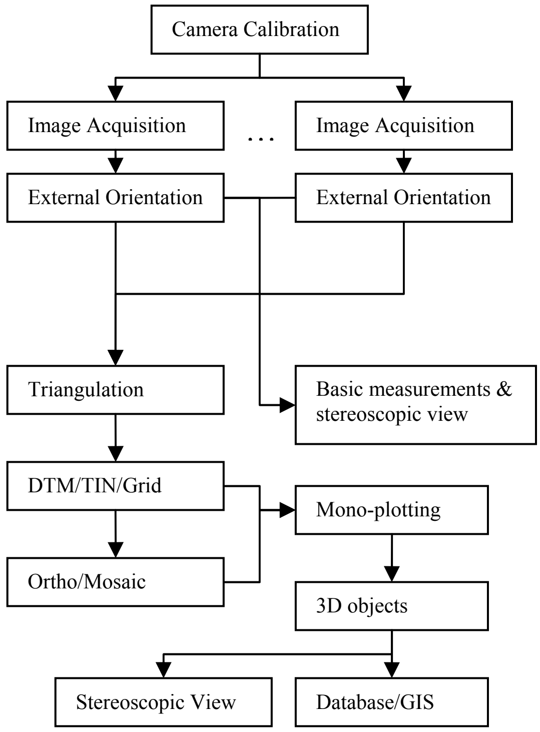

Figure 1: *Basic flow chart of recording procedure*

4. Data handling

Parallel to above procedures and modules, the system will include a complete part for the management and the exploitation of the data accumulated during documentation work on the field. These data can have very different nature (textual, graphical, photographical…). For the storage of the knowledge, databases will be created, with which it will be possible to interact thanks to the creation of an Information System (IS).

We purpose our IS in the form of interactive 3D models (resulting from the three dimensional reconstructions of the excavation site achieved before), which elements will be linked with the records of the databases. Likewise, interactive 2D plans could be generated (in SVG for instance) from maps and drawings done by the archaeologists on the field. These interactive plans could also be an access interface to the information of the database.

This will allow a best spreading and communication of the information about the archaeological site [KS99], as well as a beneficial valorization. This would also be a help for the analysis and the understanding of the site (in permitting quickly to synthesize and to confront very different types of documents) [MGP05].

The system we propose will not be a pure Geographical Information System (GIS), since we will integrate very diverse types of data, but the information search will be done in a localized way via the 3D models and the 2D plans of the site. The 3D and 2D representations serve as access interfaces to the data. For the archaeologists working on the site, they will also serve as interfaces for the modification and the updating of the recorded information [MGP06].

Moreover, we propose to develop a system that will work over the Internet (so that we will be independent of any commercial software), in a simple and clear way, both for the consultation and for the modification of information.
The technical computer platform will be based on free software. Clients will use traditional browsers like Internet Explorer, Mozilla Firefox or Netscape. The main interface will be accessible through a PHP web server like EasyPHP. Web pages of the site could be coded in PHP and JavaScript, with the use of CSS style sheets. Connection to the database could be done thanks to a PHP script language. Queries on the database will be written in SQL language. The database system could be MySQL.

Textual data will be described in XML and automatically recorded in the MySQL database. 3D models will be described in VRML or X3D, widespread languages currently for the visualization of 3D scenes on the Web. And 2D plans will be created in SVG, so that we will work in coherent and standardized formats.

The following schema (Figure 2) illustrates the computer behavior of the platform that will be developed.

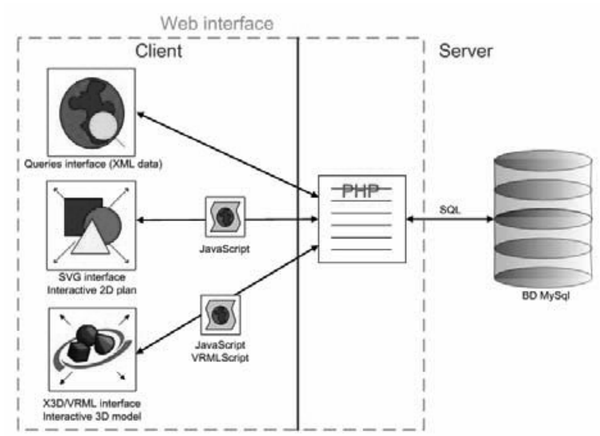

Figure 2: *Schema of the computer behavior of the coming web Information System*

5. Evaluation phase

The major phases are of the proposed research are given in Table 1. The whole system is going to be evaluated and tested under real circumstances to perform the necessary improvements. The testing material will also provide the data for how-to-do-it user manual, which will be developed at the last phase.

Phase	Time Table (months)				Project Work
	06	12	18	24	
1					Acquisition of the necessary hardware Development of the necessary interfaces Development of low level software for major hardware functionalities Testing of hardware component
2					Development of major software components
3					Testing of the software components under simulated and real situation
4					Development of user interface
5					Evaluation and improvement of the system
6					Development of user manual

Table 1: *Major phases are of the proposed research*

6. Conclusions

The proposed research concerns the development of a prototype system for the rapid and accurate recording to improve archaeological excavation and documentation by merging experiences from both research groups.
The hardware component will use digital images free of distortions and a user friendly 3D navigator.
The software component will include automatic or semi-automatic procedures of photogrammetric tools and rethink a prototype system to make it available for non specialists.
For the data handling, we project to use interactive 3D models linked with the records of the databases in an Information System. 3D and 2D representations will serve as access interface to the data and the system will be available to users via browsers.

Acknowledgments

This research is funded by the Greek General Secretariat for Research and Technology and by the French Egide-Platon cooperation program under the Greek-French Bilateral Agreement Program 2005-2007.

References

[BLR97] Boccardo, P., A., Lingua, F., Rinaudo, 1997. Low cost digital acquisition systems for Architectural Photogrammetry, IAPRS, Vol. XXXII, Part 5C1B, CIPA Intern. Symposium, Göteborg, Sweden, pp. 141-146.

[DG00] Drap, P., Grussenmeyer, P., 2000. *A digital photogrammetric workstation on the web,* Journal of Photogrammetry and Remote Sensing, Vol 55 N° 1. Official publication of the International Society of Photogrammetry and Remote Sensing (ISPRS), ELSEVIER février 2000, pp.48-58.

[GTS*00] Georgiadis, C., Tsioukas, V., Sechidis, L., Stylianidis, E., Patias, P., 2000. *Fast And Accurate Documentation Of Archaeological Sites Using In The Field Photogrammetric Techniques*, International Archives of Photogrammetry and Remote Sensing Vol. XXXIII, Part B5, Amsterdam, The Netherlands

[GP96] Grussenmeyer, P., Perdrizet, F., 1996. Archaeological photogrammetry with small format cameras: the survey of the Forum Vetus in Sarmizegetusa (Romania). In: International Archives of Photogrammetry and Remote Sensing, Vienna, Austria, Vol. XXXI, Part B5, pp. 200-204.

[GP02] Grussenmeyer P., Hanke K., Streilein A., 2002. Architectural photogrammetry. Chapter in “Digital Photogrammetry”, Kasser & Egels, Taylor & Francis pp. 300-339.

[HE97] Hanke, K., and Ebrahim, M., 1997b. A low cost 3-D measurement tool for architectural and archaeological applications, IAPRS, Vol. XXXII, Part 5C1B, CIPA Intern. Symposium, Göteborg, Sweden, pp. 113-120.

[KS99] Koussoulakou, A., and Stylianidis, E.,1999. The use of GIS for the visual exploration of archaeological spatio-temporal data. Cartography and GIS, Journal of the American Congress on Surveying and Mapping, Vol. 26, No.2.

[MGP05] Meyer E., Grussenmeyer P., Perrin J.-P., 2005. Evolution of surveying practices in archaeology: a technical overview to introduce new management possibilities for cultural heritage data. In, *The ISPRS International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, XXXVI-5/C34, pp. 923-928. ISSN 1682-1750.

[MGP06] Meyer E., Grussenmeyer P., Perrin J.-P., 2006. First proposals for a web-based information system in archaeology: storage and interactivity for the preservation and the handling of Cultural Heritage data. *Proceedings of the Third Taiwanese-French Conference on Information Technology, Nancy, March 28-30, 2006.* Edited by Yih-Kuen Tsay (National Taiwan University, Taiwan) and Samuel Cruz-Lara (LORIA and INRIA Lorraine, France), pp. 195-211.

[MGT*04] Meyer, E., Grussenmeyer, P., Tidafi, T., Parisel, C., Revez, J., 2004. *Photogrammetry for the epigraphic survey in the great hypostyle hall of Karnak temple : a new approach*, Proceedings of the XXth Congress of the International Society of Photogrammetry and Remote Sensing (ISPRS), Istanbul, Turkey 12-23 July 2004. Int. Archives of Photogrammetry and Remote Sensing, ISSN 1682-1777, Vol. XXXV, part B5, pp.377-382.

[Miy96] Miyatsuka, Y., 1996. Archaeological real time photogrammetric system using digital still video camera. In: International Archives of Photogrammetry and Remote Sensing, Vienna, Austria, Vol. XXXI, Part B5.

[PK95] Patias, P. and Karras, G., 1995. Modern photogrammetric procedures in Architectural and Archaeological applications, Ziti Editions, Thessaloniki, Greece (in Greek).

[PST98] Patias, P., Stylianidis, E., Terzitanos, C., 1998. Comparison of simple off-the-self and of wide-use 3D modeling software to strict photogrammetric procedures for close range applications. In: International Archives of Photogrammetry and Remote Sensing, Hakodate, Japan, Vol. XXXII, Part 5, pp. 628-632.

[PST*99] Patias, P., Stylianidis, E., Tsioukas, V., Gemenetzis, D., 1999. Rapid photogrammetric survey and GIS documentation or prehistoric excavation sites. XVII CIPA Symposium, Recife/Olinda, Brazil.

[PP00] Patias, P. and Peipe, J., 2000. Photogrammetry and CAD/CAM in Culture and Industry – An ever changing paradigm, Proc. and CD of ISPRS XIX Congress, Amsterdam, July 16-23, 2000.

[RB91] Renfrew, C., and Bahn, P., 1991. Archaeology, Theories, methods and practice. London, Thames and Hudson (with Paul Bahn); Madrid 1993; 2nd edn 1996; 3rd edn 2000.

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
VAST (2006)
M. Ioannides, D. Arnold, F. Niccolucci, K. Mania (Editors)

The registration and monitoring of cultural heritage sites in the Cyprus landscape using GIS and satellite remote sensing

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Abstract

In order to protect cultural heritage sites in the landscape from damage and destruction, authorities need to maintain a record (database) of the known sites in the areas for which they are responsible. The better the record, the easier and cheaper it is to minimise conflict between planning and the construction of new roads or any other development. Cultural heritage sites can comprise burial mounds, old settlements, old roads and numerous other features. A good and well-organized cultural heritage database can therefore facilitate sustainable cultural heritage management. The use of GIS and satellite remote sensing tools can assist such task. High-resolution satellites facilitate the development of methods for observing even the smallest features and thus promote a systematic utilization of satellite data in the mapping and monitoring of cultural heritage sites. This pilot project addresses these issues by initiating the development of a basis for a sustainable, up-to-date and cost-effective decision-support methodology which relies upon satellite remote-sensing for mapping and monitoring cultural heritage sites and then the use of GIS for cultural heritage sites registration

1. Introduction

The availability of cloud free images for operational projects is very important and depends on the geographical position and the prevailing weather conditions for the area of interest [KS90]. Countries such as Greece and Cyprus are characterised by good weather conditions and the availability of cloud free images. As shown by [HCR00] the high availability of cloud free images of Cyprus increases the potential of using satellite remote sensing techniques for any application in the Cyprus area. Indeed, satellite remote sensing can be also used as a supporting tool in conjunction with GIS and ground measurements (for example, geophysical, GPS measurements) for the monitoring and registration of cultural heritage sites [HTI05].

This paper provides an overview of the methodology adopted for monitoring cultural heritage sites and then using of GIS for cultural heritage sites registration. Results from the preliminary investigations have been also presented.

2. Satellite Remote Sensing

The basics and the pre-processing steps of satellite remote sensing are briefly presented below.

2.1 Introduction

The recent advances in remote sensing recording systems and image processing techniques, together with the development of high accuracy Global Positioning Systems makes the remote sensing technology as a valuable tool for the retrieval of archaeological information and the management of monuments and sites.

As shown by several other investigators, archaeological research uses satellite remote sensing for assisting the users for:-

- identifying environmental parameters related with the location of the archaeological sites
- identifying the topography of archaeological monuments

- Assessing the spectral signatures of archaeological sites with the ultimate goal of developing predictive archaeological models. In this way, satellite remote sensing constitutes a method of archaeological information retrieval, without the use of excavation or intensive survey procedures [SMG*98] and [Sar00] .

Landsat Thematic Mapper and SPOT satellite images are widely used for deriving information about the earth's land. Especially Landsat TM and ETM image data are widely used for several applications in Cyprus (see Figure 1) due to the fact that almost a single image covers the whole island [HCR00]. High resolution imagery from satellites such as IKONOS and QuickBird has been available for several years, and has proved its usefulness in the mapping and surveillance of remote areas.

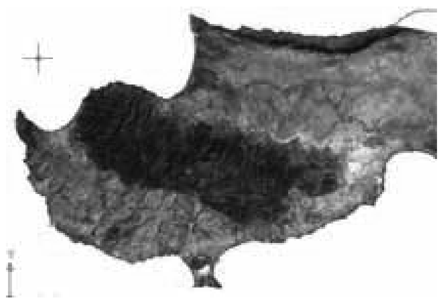

Figure 1: *Landsat-5 TM satellite image of Cyprus acquired on 3/6/1985 (partial scene). Distribution of some cultural sites is shown for Paphos and Limassol District areas.*

2.2 Pre-processing of satellite images

The images that will be used in this project must be pre-processed prior to the use with the GIS data.

Generally the main categories of pre-processing of image data are geometric and radiometric corrections, which are, performed prior to main analysis. Radiometric corrections are distinguished between those effects which are scene-related such as atmospheric, topographic and view angle effects, sensor calibration, illumination and target characteristics and those which are sensor related such as sensor calibration and de-striping [Mat01].

Geometric correction: Remotely sensed images are not maps. The transformation of a remotely sensed image so that it has the scale and projection properties of a map is called geometric correction. Geometric correction was carried out using standard techniques with ground control points and a first order polynomial fit [Mat01]. For the Landsat and SPOT image data of the Cyprus area, twenty well-defined features in the images such as road intersections, corners of large buildings, airport runways, bends in rivers and corners of dams were chosen as ground control points.

Radiometric correction: The use of multi-temporal scenes acquired at different dates or the use of satellite imagery acquired from different satellite sensor for example from Quickbird, IKONOS and Landsat ETM+ 7, radiometric correction must be applied so as to obtain the same comparable units [Mat01].

Calibration in units of radiance or reflectance is an important processing step before atmospheric correction can be applied. Satellite images were converted from digital numbers to units of radiance using standard calibration values. Then the next step was to convert the at-satellite radiance values into at-satellite reflectance using the solar irradiance at the top of the atmosphere, sun-earth distance correction and solar zenith angle.

Radiation from the earth's surface undergoes significant interaction with the atmosphere before it reaches the satellite sensor. The aim of atmospheric correction is to recover, as far as possible, the reflectance at the ground surface. In this study, the darkest pixel atmospheric correction was applied to every image [HCR03].

3. Geographical Information Systems (GIS)

In this project, the participants highlight the need to develop GIS cultural resources, with capabilities of processing and modelling digital images, for the whole island for any further application in which the cultural site is a part of their project. Indeed, this system will reduce the high cost of surface surveying and archaeological site registration and assessment during or prior the course of large scale construction works (for example highway construction, expansion of rural estates, construction of waste dump areas etc). Several other authors in the literature demonstrate the importance of using GIS in conjunction with the use of satellite remote sensing for monitoring cultural heritage sites [Gue99, JC95]. For example, the Laboratory of Geophysical-Satellite Remote Sensing & Archaeo-environment of the Institute for Mediterranean Studies/F.O.R.T.H. launches a WEB site that used to host the results of a project that works with the development of a GIS for the management of archaeological monuments and the mapping of archaeological sites of Lasithi region in Crete (Greece) [Sar00].

Indeed, the partners in this project suggest the following database of the system with the results to be hosted also in a Web-GIS site:-

- digitised geological,

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- topographic and land-use maps, any available thematic mapping information
- road network
- satellite imagery (Landsat, SPOT, Quickbird, Ikonos)
- accurate location of sites (achieved by a systematic GPS survey) and their visible extent and DEM products (for example, see Figure 2)
- accompanied by a dynamic data base regarding the archaeological information of each site, including photographic material and bibliography

The advantage of GIS lies in their ability of updating their geographical information index in a continuous and interactive mode, processing and storing large volume of diverse origin data and creating thematic maps based on specific inquiries. The above can be used in archaeological research for modeling the diachronic settlement patterns of a region, locating and outlining the limits of high probability archaeological candidate sites, studying the communication or defensive networks, specifying cost surface regions used for the exploitation of natural resources, etc. The construction of digital thematic maps that present various cultural and environmental information, could be extremely useful in solving problems resulted by the environmental and development plans, suggesting specific solutions for the protection, preservation and management of ancient monuments.

By using the Landsat TM image of Cyprus shown in Figure 1 and the GIS overlay shown in Figure 2, the thematic map shown in Figure 3 has been produced. The continuous insertion of information will create a complete system of monitoring cultural sites/monuments around the whole island of Cyprus.

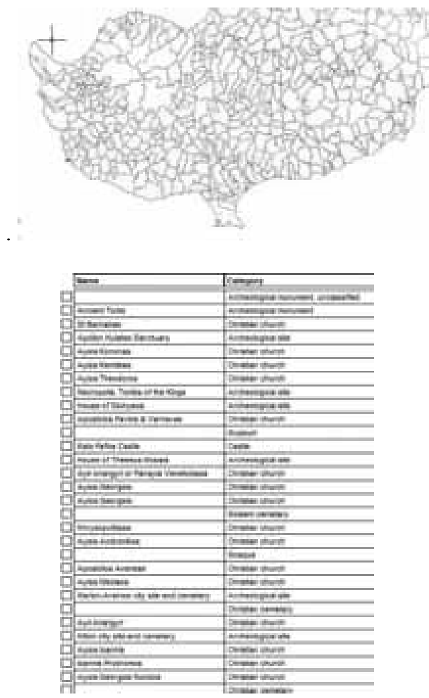

Figure 2: *GIS map of Cyprus including some features from its current database.*

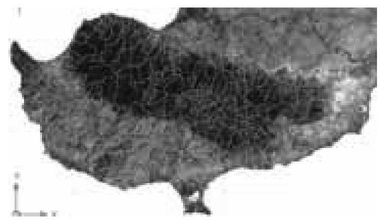

Figure 3: *Overlay of GIS location-information on a Landsat-5 TM satellite image of Cyprus acquired on 3-6-1985: Registration of the selected cultural sites based on the information provided by the developed database*

4. Pilot Studies

The following areas of interests have been registered using the methodology presented in the previous sections using Quickbird high-resolution satellite images:-

- House of Theseous in Paphos (see Figure 4)
- Aphrodite Temple at Kouklia in Paphos (see Figure 5)
- Kourion Theatre in Limassol (see Figure 6 a and b)

Figure 4: *Use of GIS in conjunction with satellite image acquired on 23/12/2003 for the 'House of Theseous in Paphos'*

Figure 5: *Here is a sample figure Use of GIS in conjunction with satellite image acquired on 23/12/2003 for the Aphrodite Temple at Kouklia in Paphos*

Figure 6a: *Use of GIS in conjunction with satellite image for the Kourio Theatre (cultural site in Limassol)*

Figure 7b: *Use of GIS in conjunction with satellite image for the Kourio Theatre (cultural site in Limassol)*

5. Conclusions and Future Work

This paper shows the methodology adopted as well the beneficial use of satellite remote sensing and GIS tools for the registration and managing of cultural sites in the Cyprus Island, as a part of the project themes that have been already agreed by the partners. The high availability of cloud-free images increases the potential for using satellite remote sensing technologies for monitoring and up-dating all the information required to build and enrich our GIS library. Further actions of the project are shown below:-

- Extend and enrich our GIS library with more data regarding information related with the topology, history, land-use changes etc of the cultural sites around the whole Island of Cyprus.
- Obtain spectral signatures using ground spectro-radiometers so as to assist our future satellite image acquisitions in the monitoring and up-dating the information nearby the cultural sites.
- Employ GPS ground campaign for obtaining more accurate locational details of the cultural sites.

6. Acknowledgements

The authors acknowledge the financial and technical support of Cyprus Research Center for Remote Sensing & GIS/CRCRG -Hadjimitsis Consultants, www.cyprusremotesensing.com (Paphos, Cyprus) and ARCHISYSTEMS by Themistokleous LTD (Limassol, Cyprus).

References

[Gue99] GUERMANDI, M.: Protection of the Archaeological Patrimony and G.I.S. Paper presented at the *International Symposium of Computer Applications in Archaeology*, Dublin, Ireland (1999).

EUROGRAPHICS Workshop on Multimedia (2004)
N. Correia, T. Chambel, J. Jorge and Z. Pan (Editors)

[HCR03] HADJIMITSIS D.G., CLAYTON C.R.I., and RETALIS A.: Darkest pixel atmospheric correction algorithm: a revised procedure for environmental applications of satellite remotely sensed imagery, *Proceedings 10th International Symposium on Remote Sensing,* 8-12/9/2003, Barcelona -SPAIN, organised by NASA, SPIE CONFERENCE, p.414 (2003).

[HCR00] HADJIMITSIS, D.G, CLAYTON C.R.I., RETALIS A. and SPANOS K.: Investigating the potential of using satellite remote sensing for the assessment of water quality in large dams, and irrigation demand, in Cyprus, *Proceedings of the 26th Annual Conference and Exhibition of the Remote Sensing Society, RSS2000*, University of Leicester, UK, 2000.

[HTI05] HADJIMITSIS, D.G, THEMISTOKLEOUS K. AND IOANNIDES M.: The use of Satellite Remote Sensing for the management of cultural heritage sites in Cyprus, *XX Symposium of CIPA*, ***The*** *ICOMOS & ISPRS Committee on Documentation of Cultural Heritage*, Torino-Italy, September 2005 (2005), p.356

[JC95] JACOLI, M. and CARRARA A.: GIS-based multivariate model for identifying archaeological sites, Calabria, Southern Italy. *Paper presented at the International Congress on Science and Technology for the Safeguard of Cultural Heritage in the Mediterranean basin*, Catania, Italy, 1995.

[KS90] KONTOES, C., and STAKENBORG, J.: Availability of cloud-free Landsat images for operational projects, The analysis of cloud-cover figures over the countries of the European Community, *International Journal of Remote Sensing*, 11(9), 1599-1608, 1990

[Mat01] MATHER P., *Computer Processing of Remotely-Sensed Images*, John Wiley, UK, 2001

[SMG*98] SARRIS, A., L. MARAGKOU, A. GKIOUROU, CH. KARATHANASIS, M. STEFOULI, TH. MAVROIDIS, E. KARIMALI, E. GIANNOULI, G. GAVALAS, G. ASVESTAS, K. GEORGILA, D. IOANNOU and VRONTAKI E.: The island of Amorgos: micro-scale & macro-scale remote sensing. Paper presented at the 31st *International Symposium on Archaeometry*, Budapest, Hungary, 1998

[Sar00] SARRIS A.: Cultural Resources Management Through the Application of Ground-Based and Satellite Remote Sensing and Geographical Information Systems: A New Digital Cultural World, *ECPR Conference on Culture and Regional Economic Development - Cultural, Political and Social Perspectives,* organized by the Department of Planning and Regional Development (DPRD), Centre for European Studies, University of West of England (UWE), ECPR, Standing Group on Regionalism, School of European Studies, Gardiff University in Wales, University of Thessaly, Volos, 28-30 September 2000.

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
VAST (2006)
M. Ioannides, D. Arnold, F. Niccolucci, K. Mania (Editors)

Cooperative Annotation and Management of Digitized Cultural Heritage: Description of an Integrated and Open Software Environment (SCCM)

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Abstract

Nowadays there is a growing potential for applications enabling Cultural Heritage (CH) organizations to create and annotate digital content. However, available solutions do not always provide a coherent set of comprehensive and accurate techniques to organize large volumes of digital cultural content, and manage related annotations. SCCM (Systema Cultural Content Management) is an integrated software environment that seeks to address these needs. SCCM provides features such as advanced content management capabilities, extensive media format support, watermark techniques and a cooperative annotation environment.

SCCM relies on a Web-Based n-tier architecture that implements standards related to its area of application, such as CIDOC. It offers comprehensive Content and Collection Management Capabilities, using XML - Metadata description techniques. SCCM provides rich media information storage, annotation between different cultural assets and a set of task-based interfaces for extensive search, indexing, content documentation and retrieval functionalities. Currently, SCCM has been successfully used for multiple complex Museum Projects supporting vast online collection catalogues with large volumes of cultural content. By providing advanced features to CH organizations, SCCM offers new capabilities for organizing and publishing scientific information related to CH artifacts to Museums, Researchers and Cultural Communities.

Categories and Subject Descriptors (according to ACM CCS): H.4: Information Systems Applications

1. Introduction

Nowadays there is a growing potential for applications enabling Cultural Heritage organizations to create and annotate digital content. However, available solutions do not always provide a coherent set of comprehensive and accurate techniques to organize large volumes of digital cultural content, and manage related scientific annotations on specific CH artefacts. SCCM (Systema Cultural Content Management) is an integrated software environment that seeks to address these needs. SCCM is a web-based platform aiming to support the digitisation, electronic record storage, scientific annotation and management of digitized cultural heritage artefacts.

The aim of SCCM is to support digitisation and cooperative electronic documentation routines, in order to promote innovative ways of exploiting Cultural Heritage Collections. SCCM has been successfully used in large museum projects, providing to the end-users innovative annotation methods in the context of a collaborative environment. SCCM offers many advanced features to Cultural Heritage institutions, spreading over diverse requirements such as:

- the uniform access to information, retrieval and annotation processes and routines
- mechanisms that enable institutions to create coherent services from disparate projects
- mechanisms for tracking the authenticity and integrity of digital entities
- effective and easily manageable authorization, security and tracking systems
- implementation of organisation-wide mechanisms for managing intellectual property rights
- optimization of cost, effort and resources by providing a centralized organizational structure to monitor the digitisation and annotation processes and routines
- electronic documentation services for the digitisation process
- integration of asset browsing and querying tools
- monitoring the types of entities an organization holds, how users discover and select entities, and what types or specific entities attract the most attention from the users
- multilingual support for the annotation process
- web publishing of cultural content

Support for the digitisation and documentation of cultural files and collections is achieved through an open architecture web-based environment. The environment is user-friendly and widely compliant with established international standards and practices in the field Cultural Heritage information technology applications. In a nutshell SCCM supports the following features:

- Management of Digital Cultural Content
- Compatibility with international standard models of image, audio and video digitisation
- Cooperative environment and services for electronic documentation
- Compatibility with Metadata Support and the international standard of documentation CIDOC/CRM.
- Compatibility with older data-base platforms and documentation systems
- Expandability potential, in order to ensure future compatibility with new and emerging technologies in the area of digitisation and documentation of cultural content

All over the world, there are emerging opportunities for applications that seek to enable Cultural Heritage (CH) organizations to create and annotate digital cultural content [KBD*01]. SCCM is designed from the ground up in order to provide the necessary flexibility in dealing with common challenges, such as:

(i) Adapting to the different degrees of complexity in the context of different digitisation and annotation projects.
(ii) Adapting to the different digitisation and annotation skills and experience of curators and museum personnel (customisation features)
(iii) Adapting to the developing and emerging international standards, and providing extended compatibility and collaboration with other applications of cultural interest.

More specifically SCCM provides:

- combinational access from other platforms in the digital material (migration).
- interconnection of digital material with other collections (integration).
- interoperability of the system with other systems aiming to address similar needs (interoperability).
- intellectual rights protection for registered digital material, by using watermarking techniques

SCCM records elements according to the CIDOC/CRM standard. These include at least the following fields of information for each cultural material:

- Basic elements of identification
- Classification
- Physical form
- Material constitution
- Geographic localization
- Manufacture
- Information regarding correlation with other objects
- Acquisition
- Time-Span Information
- Taxonomic Discourse
- Usage information
- Measurement Information (size, weight, volume, etc.)

2. System Overview

2.1. SCCM Fundamental Subsystems

The SCCM Application Logic is based on four subsystems that collaborate and interact with each other. These are the following:

- Digital Content Documentation Subsystem
- Multilingual Scientific Documentation Subsystem
- Users and User Groups Subsystem
- Communication, Query and Multimedia Database Subsystem

2.1.1. Digital Content Documentation Subsystem. The Digital Content Documentation Subsystem handles all digital content (digitised Museum material) related data. Through this subsystem the data that relates exclusively to digital content is managed. It also enables the user to transform and save the digital material in lower quality formats, in order to use it for the web or for other purposes. For example if the digital content is an image in TIFF (Tagged Image File) format, the user can convert it to a format that can be used for the web (such as JPEG -Joint Photographic Experts Group). The file will be stored in a set location.

Digital watermarking techniques are applied at this point in order to ensure that media content can be distributed online with a copyright notice. Digital content is archived in various file types and resolutions, and can be exported to the web watermarked, allowing the user to share the system's information in a safe manner. The digital content handled in this manner can be in image, audio, video and various three-dimensional formats [HKK*01].

The user is able to store information relating to:

- The procedures regarding the digitisation of the museum item (i.e. name of the person responsible for the digitisation, time of the process, tools used, etc.).
- The technical information regarding the digital content (i.e. data regarding the resolution, the size, the color space etc for images)
- The information regarding the storage of the digital content files and the available qualities in external hard disks, DVDs or in the system.

Part of the data is extracted and stored automatically (Technical Information), while another part can have predefined values, provided by the system administrator. The user can also insert information to a large number of items by a single routine, both across multiple data fields, and across multiple items (even if they belong to different collections).

The data is stored in various formats. Dublin Core standard is used for the metadata regarding the digitisation procedures. The system also uses and stores metadata in MPEG7 format for video and audio and DIG35 for images.

2.1.2. Multilingual Scientific Annotation Subsystem. The Multilingual Scientific Annotation Subsystem manages all the scientific data that relates to a Museum item. The user is able to add new information, edit the existing information and categorize it according to the Museum's needs. The user can also associate scientific annotation with existing digital content and manage translations of the data in at least three languages.

Vocabularies and ISO2788, ISO5964 compliant thesauri can also be managed. Thesauri are vocabularies generally arranged hierarchically by themes and topics. In accordance to international standards, thesauri provide various levels of hierarchy among the listed terms in order to allow a user to be able to specify a particular needed term [ISO2788], [ISO5964]. Users are able to add new terms using the SCCM interface, link terms in various aspects and search the thesauri by semantically orthogonal topical search keys.

The subsystem provides the ability to produce reports of any kind regarding the stored data, to search exhaustively the database by using any data term that is provided, as well as to search combinations of terms.

The same subsystem provides the ability to import and export appropriately annotated metadata from and to other applications. In particular, metadata can be exported in XML files that are CIDOC/CRM standard compliant in order to be used by external systems and organizations. The user can choose which items or collections of items will be exported. In that manner the SCCM system allows the sharing of information with third parties without compromising system security.

2.1.3. Users and User Groups Subsystem. The Users and User Group Subsystem handles all the SCCM user related data and provides various levels of security. User groups are provided with access levels of security and a system administrator can grant or deny rights to specific users and user groups. User statistics are kept in order to track the activity of individual users and also help the process of possible security threats in the system.

System Administrator has access rights to every feature and capability of SCCM and can manage users and user groups by adding new users, suspend user accounts, assigning users to user groups and assigning features of the system to user groups. Users are given a unique username and password. Password can be reset by its owner or by the System Administrator.

2.1.4 Communication, Query and Multimedia Database Subsystem. This subsystem manages all the multimedia database related queries of SCCM. It handles all the data queries from the other three subsystems, as well as the communication between them, the database and other resources. It also tackles metadata and physical files (multimedia storage). Backup capabilities are also provided through this subsystem.

Through the Communication, Query and Multimedia Database Subsystem, one can easily switch to a different database system with minimum effort.

2.2. System Requirements

SCCM is a web based application and its installation can easily be adapted to different intranets. It can be installed according to the needs and the infrastructure of each organization, providing in this way flexibility and extensibility to future needs.

SCCM server operates with the following server requirements:

- Web server for accepting HTTP (Hypertext Transfer Protocol) requests from clients that supports PHP (Hypertext Preprocessor) configured appropriately in order to handle all SCCM features.
- Database server for handling database storage and queries.

The client requirements are intranet access to the servers and a standard web-browser that supports cookies and Javascript.

SCCM server and client can operate in almost every Operating System and thus guarantees interoperability in most intranets. Moreover it can be easily adapted in hardware and software environments updates and the maintenance cost is minimal.

2.3. Archiving Content and Cooperative Annotation

The use of SCCM provides a cooperative annotation environment of Museum items and Cultural Heritage material. There is a clear distinction between annotation of digital content, thesauri and scientific annotation regarding various aspects of multilingual museological and historical information. Yet both types of data can be combined and provide solid information.

In the SCCM application, annotations are notes, comments and data added to a cultural content document to explain and interpret it. But in order to serve as building blocks in a formal representation of the item's attributes, the annotation has to consist of more than unstructured and uncontrolled text which comments on documentation.

Multi-user environment allows the collaboration between users of different scientific background. In this way, scientists of various disciplines which have interest in this item, can provide information about it. This ensures that the different aspects of scientific interest relating to some item are well represented and documented. Data can be enriched by the designated users who carry this responsibility and changes can be tracked in order to ensure that the information stored is valid.

Moreover SCCM provides functionalities necessary for scientific research (search and port capabilities), without compromising the security of the information.

Thus, SCCM also provides a solid framework for co-operative archiving different data in various formats that comply with international standards, guaranteeing that the content can be safely transferred in external systems and applications.

2.4. Standards Compatibility

SCCM provides CIDOC/CRM [Doe03] compliant metadata output in order to allow external heterogeneous applications to use its content. The CIDOC Conceptual Reference Model (CRM) supplies a formal structure and definitions for depicting the implicit and explicit concepts, relationships and hierarchies used in cultural heritage annotation.

The aim of the CIDOC/CRM is to enable wide information exchange and integration of heterogeneous sources. It provides a common and extensible semantic framework in which information about any museum item can be mapped to. Its use intends to promote a shared understanding of cultural heritage information and to serve as a guide for good practice of conceptual modelling.

The CIDOC/CRM has been accepted as working draft by ISO/TC46/SC4/WG9 in September 2000 and is currently in the final stage of the ISO process as ISO/PRF 21127.

The use of CIDOC/CRM in SCCM provides compatibility in the area of information exchange with other institutes and organisations and also a framework for information sharing with external systems and applications.

In order to extend the information range that is described by CIDOC/CRM framework, several extensions of it were used that comply with different standards. Those are described in the following table.

Annotation data Category	Standard used as an extension to the CIDOC/CRM
Digitisation processes	Dublin Core
Management procedures	SPECTRUM
Digitisation documentation of Audio and Video files	MPEG7
Digitisation documentation of Image Files	DIG35

Table 1: CIDOC/CRM extensions used.

3. System Architecture and Functionalities

SCCM application supports functionalities such as:

- Standardization of Scientific Annotation according to the CIDOC/CRM and XML Metadata
- Metadata Management: Management of cultural content metadata (registration, deletion, update). In addition, the mass import of metadata from an existing database, as well as the exporting of metadata in the eXtensible Markup Language (XML) are supported [Gra02].
- Annotation via web: SCCM is a multi-level network application that allows access to the documentation operations performed by remote users, via public Internet. The mechanism is designed in order to provide maximum safety during the data transfer processes.
- Interconnection with other applications: The multi-level open architecture, as well as the implementation approach of the SCCM network features, ensure a growing potential concerning the interconnection and interoperability between SCCM and other applications.
- Management of Users and user-groups: The users should be authenticated, in order to have access to the required services. The access to information and functionalities depends on the user-group in which the user belongs.
- Management of large Cultural Collections: The users can create new collections, import annotations regarding them, and modify them as they wish.

The SCCM platform is based in a 3-tier architecture, which places at different conceptual levels the user interface and presentation properties (Presentation Layer), the information management within the system (Data Access Layer), and the information processing rules (Application Logic). The three levels of system architecture offer the possibility to re-use the software modules in other parts of the system. It allows the system developer to easily adjust various aspects of the system. The following figure depicts the total SCCM architecture.

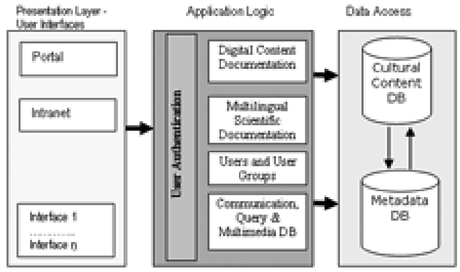

Figure 1: SCCM System Architecture

3.1. Presentation Layer – User Interface

The presentation layer enables users to manage and preview the cultural content. The functionalities of the user interfaces are provided by means of a set of dynamic web-pages, which present the material that has already been stored. Interfaces are user friendly and personalized according to user needs. The system is easy to use, complies with established software ergonomic standards, and provides fast access to individual information via a Main Menu. Messages of direct help are available in all points.

3.2. Application Logic

Application logic layer provides all the essential operations regarding the storage, retrieval, updating and maintenance of information, as well as the mechanisms that ensure the data integrity. In addition, the following operations are implemented at this level:

- Mechanism for importing and updating data, which include the automatic creation and update of metadata.
- Mechanism of data retrieval, which processes the interpellations of the user in text (full text search) and interpellations of SQL queries, based on the produced metadata.

3.3. Data Access Layer

The data access layer consists on the information that has been collected by the aforementioned SCCM layers. The data modelling is based on a structured documents approach (XML), which is a State of the Art model of information exchange and maintenance. It consists of two discrete relational databases, one for the digitized cultural content and documentations, and the other for the media used.

3.4. Web Publishing Techniques

SCCM provides capabilities for metadata export in XML format according to the CIDOC/CRM conceptual model. However, it also supports the creation of files in various formats, suitable for the world wide web. Consequently, it becomes easy to export files which can be interlinked with external applications afterwards, for use in various internet applications: integration with web portals, web sites or other repositories.

The authenticated SCCM user can seek and select the cultural material she/he wishes to publish, and export it via a user-friendly toolbox menu. As concerns the management of collections, the user can group the material that wishes to export, and store her/his choices for the future.

4. Case Studies

4.1. The Averoff Museum of Neohellenic Art case study

The Averoff Museum of Neohellenic Art has operated in Metsovo, district of Ioannina, since August 1988. Its permanent exhibition comprises representative works by the major Greek painters, printmakers and sculptors of the 19th and 20th century, such as Gyzis, Lytras, Volanakis, Iakovides, Parthenis, Maleas, Galanis, Hadjikyriakos-Ghikas, Moralis, Tetsis, and many others. The museum's Collection is regarded as one of the most complete and important of this period.

Up until recently, the Averoff Museum of Neohellenic Art did not make use of any standard application for the annotation procedures of its vast art collection. The annotation data that was collected through the years was in spreadsheets, hard copies and an outdated application that did not provide capabilities of data sharing and multimedia support. The data was also not coherent in many ways, until SCCM was installed and operated in the Museum's premises.

SCCM provided the Museum with an application that supports the scientific annotation procedures and digital material management. It also serves as as an export data tool that allows its users to "feed" external applications with XML files in accordance with the CIDOC/CRM standard format. In that way it became feasible for the Museum to have a coherent annotation tool for its scientific and multimedia management work, and to share selected data with other organisations.

The SCCM installation at the Averoff Museum was carefully designed in order to meet its specific needs, given the fact that every item of the museum (painting or sculpture) required about 66 different data fields. These fields cover almost every aspect of its history, construction, physical state, whereabouts etc. The data fields were categorized according to the CIDOC/CRM standard format in order to produce the XML feeds for external applications.

A CIDOC/CRM compliant Data Type Document was produced and used for this purpose. The objective was to ensure that the annotation data for all Museum items complies with a formal structure that describes their implicit and explicit concepts and interrelationships. The number of the data fields, as well as the semantic areas they cover, made the production of the Data Type Document a complex procedure that involved a detailed annotation for every data field, as well as the relationships between them.

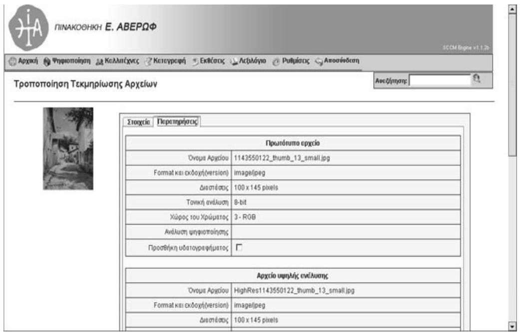

Figure 2: SCCM installation for Averoff Museum Screenshot 1

Nowadays the Averoff Museum uses SCCM as a multi-use application. SCCM provides the interfaces for managing large volumes of scientific data in three languages, as well as multimedia data. Researchers are able to search through the mass of information and produce reports for various uses. In addition, the Averoff Museum can now share its data in accordance to the CIDOC/CRM standard, and use it in its own multilingual web-site, without any risk of the internal data being altered by an intruder.

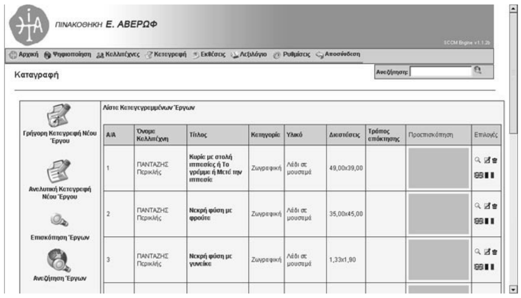

Figure 3: SCCM installation for Averoff Museum Screenshot 2

Figure 4: SCCM installation for Averoff Museum Screenshot 3

4.2. The Hellenic Centre for Theatrical Research – Theatre Museum Case Study

The Theatre Museum was founded in 1938 by the "Greek Playwrights' Society" under the Presidency of the author Theodoros Synadinos. Yannis Sideris, the great historian of the Greek Theatre, was the first Director of the Museum, dedicating his life and work to the meticulous gathering and organizing of a rich selection of theatrical exhibitions and archives, concerning the whole and interesting history of the Hellenic Theatre. In a few years, the Theatre Museum succeeded in becoming and being recognized as a very dynamic and profound "Hellenic Centre of Theatrical Research", possessing a monumental and unique archive of manuscripts and books (dating to the 18th century), theatre programs (since 1880), photographs, negatives, slides, posters, newspaper articles, interviews or theatre critiques, films' archives, audiovisual material (around 2.000 videos of winter and summer theatrical performances of Greek or foreign plays, since 1984, taped exclusively and under the absolute responsibility of the Museum), disks and audiotapes of some of the most famous radio theatrical pieces, operas, theatre or film music etc.

In the past, the Theatre Museum used an outdated custom application that did not support a Graphical User Interface to serve its needs. Every aspect related to the majority of theatrical performances that took place in Greece since 1880 was documented in that application. The Museum also used hard copies in order to document posters, manuscripts, photographs and other material. As a result, it was difficult if not impossible to make proper research through this type of material. The growing needs of the Museum made this custom application obsolete and a need of a new application arouse. The Theatre Museum needed to document performances as well as multimedia content and to archive digitised material in a more sophisticated manner. There was also a need for producing CIDOC/CRM compliant export files in order to be able to interoperate with other organisations.

The SCCM installation for the Theatre Museum required a large effort in data transition. Data collected since 1992 through the old application had to be transferred in SCCM. The custom application used data structures that were specifically designed to meet Theatre Museum's old needs. The volume and the complexity of the stored data, as well as the necessity to add further descriptive fields in order to enrich the content, made the data transition an elaborative process.

The solution for this data transition process was redesigning the Theatre Museum database and using web-services as a means for data transition, in order to ensure the integrity of the data. Interfaces for the annotation of theatrical material were provided, as well as multimedia management consoles, in order to support digitisation procedures of the theatrical material. Moreover CIDOC/CRM compliant export files can be produced in order to serve Museum's needs of co-operation with other organizations.

5. Conclusions

The growing importance and role of cultural institutions in the internet economy must be fostered by the rise of a new generation of software systems. These have to take into consideration the strongly cooperative methodologies used by cultural institutions nowadays for their digitisation and annotation projects, as well as the requirements of usability, user acceptance and user-friendliness, which can ensure the frictionless use of such systems in large digitisation and annotation projects. When these requirements are met, cultural collections present a richer, dynamic and more enjoyable experience to the public, while providing all the necessary power and expressiveness to various curators and scientists all over the world. SCCM fulfils these general objectives, presenting a comprehensive solution for the organization of cultural digital content and thus for the wider dissemination of Cultural Heritage.

6. References

[Col99] COLLATE: IST-1999-20882, Collaboratory for Annotation, Indexing and Retrieval of Digitised Historical Archive Material, http://www.collate.de/, http://istresults.cordis.lu/index.cfm/section/news/tpl/article/BrowsingType/Features/ID/69245

[Dig01] DIGICULT: IST-2001-34898 The Digital Culture Forum, http://www.digicult.info/pages/index.php

[Doe03] Martin Doerr: The CIDOC CRM – An Ontological Approach to Semantic Interoperability of Metadata, AI Magazine, Volume 24, Number 3 (2003).

[Emu99] EMUSEUM: IST-1999-20882, Zetcom AG, publishes multilingual collection information and data into custom-designed web pages and makes your collection accessible around the clock, http://www.museumplus.com/index.php?id=15&L=1

[Gra02] Fabio Grandi: {XML} representation and management of temporal information for web-based cultural heritage applications, Data Science Journal , ISSN 1683-1470, 2002

[HKK*01] Tasos Harissis, George Koutalieris, Constantinos Ksourias, Fotis Karantzis, Christos Douskos: Exhibiting in Shared Virtual Environments: Realistic 3D Museum Representation over the Web, International Cultural Heritage and Informatics Meeting, Milan, Italy, September 3-9 2001

[ISO2788] Documentation - Guidelines for the establishment and development of monolingual thesauri, ISO, International Organization for Standardization, ISO (2788), 1986.

[ISO5964] International Organization for Standardization, Documentation — Guidelines for the Establishment and Development of Multilingual Thesauri, ISO 5964, 1985.

[KBDw*01] J. Keiper, H. Brocks, A. Dirsch-Weigand, A. Stein, U. Thiel: COLLATE – A Web-Based Collaboratory for Content-Based Access to and Work with Digitized Cultural Material, International Cultural Heritage and Informatics Meeting, Milan, Italy, September 3-9 2001 Vol. 1, pp 495 – 511

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
VAST (2006)
M. Ioannides, D. Arnold, F. Niccolucci, K. Mania (Editors)

On the Integration of 3D Models into Digital Cultural Heritage Libraries

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A digital 3D artifact with attached Dublin Core metadata in XML format, rendered in OpenSG.

Abstract

This paper discusses the integration of 3D data in the traditional CH workflow, which is a complex issue with many different aspects. First, the notion "3D data" must be defined appropriately, since 3D may range from raw datasets of individual artifacts to complete virtual worlds including storytelling and animations. Second, a suitable 3D format must be identified among the various, and very different, possible options. Third, the chosen format needs to be supported by all tools and technologies used in the CH tool chain: all the way from the field excavation over presentation in museum exhibitions, over secondary exploitation and database access, to the sustainable long-time archival of digitized artifacts. An integrated solution to this complex problem will be possible only through the tight combination of two basic technologies: 3D scenegraphs and XML.

Categories and Subject Descriptors (according to ACM CCS): I.3.6 [Computer Graphics]: Methodology and Techniques I.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems I.5.4 [Information Interfaces and Presentation]: Hypertext/Hypermedia

1. Introduction

Man-made 3D objects do not exist in isolation. They have a meaning, in particular they have a historic meaning. Historic artifacts are usually involved in a whole number of semantic relations and contexts. Real artifacts are three-dimensional, solid, physical objects, and often very old. Culture on the other hand is an abstract concept. It constitutes itself in the *semantics* of the physical objects: Who has made them, where do they come from, what were they used for, etc.

Small physical differences can lead to great semantic differences when, e.g., the classification of an amphora is based on the shape of its handles, or when the fact that the arm of a statue was created by a different artist is derived just from the chisel marks. Archeology has to understand ancient cultures only from the remaining physical evidence. **Any further loss of information must be prevented.** So accurate documentation of physical artifacts and the faithful recording of all (collected and derived) semantic information are of prime importance for all archeological activities.

Photographs and drawings are the traditional means of archeological documentation. Photos are indespensible for their perspective precision, drawings because they allow the author to *interpret* and *emphasize* what was found. Drawings, together with paintings and with physical replicae, are also the main devices to *hypothesize* about the historic past.

Information technology brings huge benefits to archeology. It helps to organize the traditional workflow more efficiently, but it opens also radically new and innovative perspectives. One great option is advanced knowledge management using *digital libraries* (DLs): All the tiny information fragments, which are so typical for CH, can now be interconnected and related to other pieces, forming versatile semantic knowledge networks that can be queried, filtered, visualized, and presented in various different ways.

Another great progress is marked by new types of *digital artifacts*, from digital photography to 3D laser scanning. Digital replicae have great advantages: They are easy to transport, they consume no archive space, require no maintenance, do not have to be cleaned; they can be studied for any duration, by many people at the same time; and finally, at least in principle, they will never fade away.

2. Motivation

This paper focuses on the technical pre-requisites for the integration of digital 3D models into Digital Cultural Heritage Libraries (DCHLs). The challenge is to connect the three-dimensional digital artifacts ("3D-models") seamlessly with the various other pieces of information. Furthermore we aim at a DL integration of 3D not just as a proof-of-concept, but on an ***infrastructure*** level by providing a reasonably general, broadly applicable software framework.

We argue that it is not sufficient to treat 3D-models as anonymous 'BLOB's (Binary Large OBjects), which is the conventional way to deal with them. A major step forward, and the only satisfactory solution, is to store semantic information *within* the 3D-model, both exploiting and respecting its inherent three-dimensional structure. Only if a markup of parts and regions in a 3D model is possible, then these parts and regions can also be referenced. A reference, in the sense of a hypertext link, needs an URL and an anchor as the link target. Our goal is that a part of a 3D model can be retrieved using a common web search query such as

http://www.epoch-net.org/DL/search?q=venus+milo#head

This query might retrieve the complete 3D model of the *Venus De Milo*, show an overview, and then, smoothly flying, zoom in to its head, which is disceetly highlighted. This requires that the 3D viewer on the client side understands the semantic information. The viewer architecture is therefore a vital part of the infrastructure, its extension the main technical contribution of our paper (see section 5). But first we will shortly explain which kinds of semantic information a 3D model will typically have to accomodate.

2.1. Classical Metadata: Dublin Core (DC)

Different levels of semantic information exist. Commonly perceived as the most basic are the classical metadata. They are very similar in every public library in the world: *author*, *title*, *year of creation*, a unique ID, e.g., the *ISBN* number for books, and a few more. Many different metadata schemes have evolved over the centuries in the various countries. One of the major attempts for standardization is the "Dublin Core Metadata Initiative" (DCMI), or short *Dublin Core* (DC), which defined in 1995 a list of 15 core fields for all bibliographic records. It was subsequently refined [Mil96, dub04].

2.2. Semantic Networks: CIDOC CRM

DC is quite useful, but has severe limitations. Most annoying is the lack of expressiveness w.r.t. relations. This leads to unacceptably "flat" knowledge: A field *author* is fine for a book record, but how can the knowledge be expressed that certain authors are relatives, in order to find all books from one family? One author may have been a student of another, a book was written during a certain period at a certain location. More complex, and much more important, are relations in CH. This is illustrated by the famous CIDOC/CRM example, the network of relations of the 1945 Yalta conference [Doe05]. It involves three allied statesemen, the famous photograph of them, the jointly agreed document, a geographic location, a negotiation period, and the signing date.

The *Conceptual Reference Model* CIDOC-CRM, or just CRM, is the standard for representing such relational semantic networks in Cultural Heritage. It was released in 2000 as working draft by the "International Committee for Documentation of the International Council of Museums" (ICOM-CIDOC). The CRM specification 4.2 [CDG*05] provides 84 *classes* for entities such as actor (person), place, event, time-span, and man-made object, with a sub-class information object that is further differentiated into image and text document etc. It also defines 141 relations, among others participated in, performed, at some time within, took place at, is referred to by, and has created.

2.3. Processing History (PH) Documentation

Digital raw data typically undergo many processing steps before being published or archived: Images are white-balanced, cropped, sharpened or smoothed. Heavy image processing is done without any special notice by every digital photo camera, and by the driver of every digital flat bed scanner. When taking data from an archive it is vital to know how they have been recorded and processed, in order to judge their fitness for a specific purpose: A photo-montage can not be taken as evidence for a historical fact, judging colors without knowing the white balance is pure guessing.

Accurate recording of the processing history (PH) is even more important for 3D objects than for images because the spectrum of 3D editing operations is much wider.

3. The ambiguous notion of 'a 3D model'

The focus of this paper is the integration of 3D models with DCHLs. The term "3D-model" is in fact used for a number of different things. Most of the following entities can have meta-information attached, such as DC, CRM or PH.

- **range map**: single raw scan, basically a photo with depth information. One z-value per pixel: $2\frac{1}{2}D$, heightfield.
- **scanned artifact**: dense triangle mesh. Several range maps merged and edited: fill holes, remove noise, etc
- **synthetic reconstruction**: constructed by an interactive 3D drawing or CAD program, usually very clean model
- **3D scene**: many objects, often structured hierarchically: city→house→floor→room→table→cup→spoon
- **animation**: deforming shapes, solid objects moving along a path, particles, articulated skeletons
- **interactive experience**: anything from the limited interactivity of VRML to high-end computer games

The digital counterpart of a historic artifact from a museum exhibition would be the scanned artifact: an amphora, a sword, a sherd. Two complications arise: First, the scanned artifact is not the natural "atomic unit" as in conventional archeology. It is already the product of a process (range map merging). Second, a range map, and thus the scanned artifact, contains typically a number of objects that are captured in the same "depth photo". So digital acquisition already *starts* with compound objects. Consequently it requires means to distinguish parts of a model. This requires a markup facility on a *sub-object level* (rightmost in Fig. 1).

Multi-object markup, on the other hand, makes sense as well: For grouping similar objects together (columns of a Greek temple), and also to denote whole ensembles of objects; from the arrangement of burial objects to the hypothetical formation of the troups of an ancient battle.

3.1. The great variety of 3D surface representations

Computer graphics provides many different ways to represent one and the same three-dimensional object. This is a fundamental difference to other multimedia formats such as sound, images or video: All bitmap formats describe the same thing, a regular grid of rectangular pixels; and every video format boils down to a stream of images. The difference lies only in the encoding (lossy/non-lossy, etc.).

There is no conceptual "master representation" to which all 3D formats are just an approximation. A short taxonomy reads: point clouds, range maps, triangle meshes, multiresolution surfaces, b-reps, parametric curves and patches (B-splines, NURBS), implicit surfaces (blobs, radial basis functions), volumetric models (voxels, tetrahedral meshes), and CSG of geometric primitives (box, cone, sphere etc). All have their strengths and weaknesses, and also their preferred application domains; furthermore, there is usually no way to convert between representations without loss of information. Furthermore each representation comes with its own set of diagnostic routines and editing operations.

Removal of statistical noise makes sense for discretely sampled surfaces (point clouds, triangles). Continuous surfaces (parametric patches) provide excellent diagnostic tools for high-quality fairing and optimisation, while primitives are very handy to roughly discriminate object parts: A door may be just an anonymous hole in the wall, but it can easily be distinguished with a door frame made of three boxes.

This heterogeinity has important, wide-ranging consequences for 3D markup. First, it is not clear *what* to denote. A notion that is intuitively simple and unambiguous, such as the *cheeks of the Venus De Milo*, can become quite complex on the technical level: Triangles are transient objects, and they provide only a very fragile reference (again see Fig. 1). But the surface representation can also not be neglected: Delicate structures such as ridges, creases, corners etc. are *surface features* that are very important for the semantics of a shape. We formulate this as the following open problem.

Problem 1: Generic, stable, and detailed 3D markup. A method to reference a portion of a digital 3D artifact, irrespective of the particular shape representation used, in such a way that also detailed surface features can be discriminated. The markup should survive simple editing operations (cutting, affine transformations). In case of more complex shape operations there should be a well-defined way to update the reference accordingly, e.g., with a re-computed surface feature.

The drawback of the requested *generic* markup is, of course, that it can not exploit the specifics of a particular shape representation ("the largest triangle", "vertices contained in a box") but only intrinsic surface properties ("the point of maximal curvature").

3.2. The variety of 3D editing and processing methods

It can not always be avoided that a shape is edited that carries a markup. Example: A complex 3D artifact is assembled using parts from different sources (photogrammetry, scanning campains, manual repair). Much later somebody discovers an important shape detail, cuts it out from the larger shape (by manual segmentation), and sends it electronically to an expert. It is of course vital that the expert can trace back the provenance of the different parts of the shape.

It is true that there are probably also huge numbers of *real* artifacts in museums and archives with dubious provenance and processing history. But it is not acceptable that the annoying loss of information that was inevitable with the procedures of the past should still continue with the digital workflows of today. Managing huge amounts of administrative information has become feasible, the challenge is now merely to set the appropriate standards.

Figure 1: *Creating a scanned artifact. Left: Original input data. 3 from 20 noisy range maps are shown un-textured. Right: Simplified versions of the range maps, textured and un-textured. A rectangular region is marked in different triangulations. Rightmost: Several range maps are integrated and smoothed. The gravestone is manually segmented for a semantic markup.*

If a shape is edited that carries a markup, then the shape reference must be updated. How can this be done if the referencing method (solution to Problem 1) is not known beforehand? Well, every referencing method can be evaluated to obtain a list of geometric primitives. **The editing procedure has to keep track of the geometric primitves affected**. Then these primitves can be converted back to a reference (of the same type). Example: Some part of a triangle mesh of a temple is marked “ionic column” using a bounding box. In order to cut out the capital of the column, the triangles inside the box are determined. After the cut, a new bounding box is generated around these triangles to update the reference to restore the “ionic column” markup.

But how can the fact be recorded that the column capital was cut out from the model of a temple?

Problem 2: Provenance and processing history record. First, a standard for describing the sources of digital 3D data. Second, a standard way of recording how the source data have been processed, and how they were combined to obtain the resulting 3D dataset. Ideally the processing history is *complete*, i.e., it has the **re-play property**. This means that it permits to re-generate the result, also with varied parameters.

The enormous complexity of Problem 2 may be not apparent. First, it has to cope with two levels of heterogeneity, namely the various shape representations and the various operations on these representations. Shape editing operations are not canonical: Every 3D software has its own great mesh editing functions, its NURBS intersection routines, and its own CSG implementation. Second, with interactive editing it is barely feasible, and hardly useful, to store each single manual processing step. Third, to actually re-play is extremely difficult: It requires that all tools in the chain maintain and add to the processing history; and this will fail with the weakest link in the chain. Issues such as outdated software versions and incoherent tool chains (operating systems, private solutions, use of scripting languages) are practical problems. More subtle problems have been reported by Pratt in the context of CAD model exchange [Pra04].

This does not mean that Problem 2 is unsolvable. It means only that our infrastructure needs to be particularly flexible w.r.t. future solution(s) to this problem.

4. The notorious issue of the right 3D file format

It is surprisingly difficult to find a 3D file format that is suitable for Cultural Heritage, due to the many demands to meet.

- **Extensibility** to cope with the variety of shape representations, to be open for new shape representations and editing methods that will be developed especially for CH
- **Digital preservation and long time archival** to avoid that the 3D digital artifacts degrade within a few years, whereas the real artifacts have survived centuries
- **Size-efficient encoding** is indispensable since faithfully recorded 3D datasets contain huge amounts of data
- **Well supported and broadly accepted** since the best format is useless if it is neglected by the user community
- **Open standard** that is adaptable to CH requirements

A file can become useless in several ways: by *physical degradation* from an unreadable storage medium, or by *format degradation* when an obscure, undocumented binary format was used, or an outdated format version that no software can decipher any more. Finally *semantic degradation* occurs when data can be read and decoded, but the provenance and processing history is unclear because no metadata are available. A 3D scene may contain many objects from different sources, so that decent metadata are in fact required for each and every object in the scene.

To some extent, well-supportedness and extensibility are contradictive requirements. Commercial standards such as DXF and 3DS are broadly used, but can not be extended. IGES and STEP are open but extremely complex industrial exchange standards, difficult to adapt to the needs of CH and to extend. For similar reasons most other 3D formats can be ruled out. But the example of VRML shows possibly a way out of this dilemma.

4.1. XML based formats: X3D

Today the standard solution for extensible data formats is XML. Its greatest practical advantage is that it makes writing parsers obsolete, which is tedious and error-prone. A single parser, the XML parser, is sufficient to support all XML based data formats. The structural integrity of a file can even be tested automatically when a *document type definition* (DTD) is available.

The history of the VRML standard from 1997 [VRM97] shows its usefulness. Originating from SGI's *Inventor* format, but designed as extensible (via the infamous PROTO), the success of VRML was impeded by the very complex parser it requires. This problem was solved using XML. Yet the result, X3D [X3D03], still carries many legacy concepts.

The main problem is the ambitious intention to create a general language for the description of "virtual worlds". As a consequence, X3D describes many data that are today part of the application. It specifies the navigation (walk/fly/orbit), the event system with triggers and interpolators, and the data flow model (ROUTE). The interaction facilities are rather limited, of course, compared to high-end computer games (Doom, Halflife). Even things like the outdoor background in a 3D computer game are so complex that they are generated by the application. The simple VRML backdrop (color gradient, texture) is insufficient, X3D's generalisation, the *background stack*, nails viewers down to a particular background implementation, a very limiting policy as well.

4.2. XML based formats: Collada

Collada is specifically designed as a content exchange format for "digital assets". It is promoted by the *Khronos industry consortium* as open, royalty-free, XML based standard [Bar06]. Initiated in 2004 by Sony Inc. as exchange format for 3D computer games content, it has quickly gained support from major 3D modelers. Import/export plugins exist for Maya, 3DStudio Max, Softimage, Blender, the primary *digital content creation* (DCC) tools in this sector. Google Earth uses Collada for augmenting the 2D map with 3D models of buildings created, e.g., using *Google Sketchup*.

```
<COLLADA>
 <library_nodes>
  <node id="Pantheon">
   <instance_geometry url="Pantheon_XY5.obj.gz"/>
  </node>
 </library_nodes>
 <scene>
  <visual_scene>
   <node>
    <translate> 1.0 2.0 3.0 </translate>
    <rotate> 1.0 0.0 0.0 90 </rotate>
    <instance_node url="#Pantheon"/>
    <extra>
     <technique profile="Epoch">
      <link rel="schema.DC"/>
      <meta name="DC.creator" content="Smith"/>
      <meta name="DC.subject" content="Temple"/>
     </technique>
    </extra>
   </node>
  </visual_scene>
 </scene>
</COLLADA>
```

Figure 2: *Collada example. Note the attached DC metadata.*

A Collada file has two main parts, the library and the scene (see Fig. 2). The library defines the entities (geometry, materials, lights, etc) for the scene, where they may be used once or multiple times ("multiple instancing").

Almost every major Collada node type, also the scene itself, can have an <extra> element attached. It contains one or more <technique> subtrees, which is the Collada mechanism to cope with different software capabilities: Maya, for instance, can store an object as Collada standard mesh, and attach to it Maya specific information using <technique profile="Maya">. The Collada specification demands that also "unknown" <technique> content has to be preserved, i.e., all attachments must survive import and subsequent export by any Collada compliant software.

4.2.1. Separation of structure from content

Although Collada provides the most common shape representations, it provides certainly not the most efficient encoding for, e.g., huge triangle meshes: The specification says that a Collada file may not contain binary data. However, a reference to binary data stored outside the Collada file is allowed (*external data*), such as the "Pantheon_XY5.obj.gz" in Fig. 2. Note that this reference is a URL. So it may also point to a remote resource, i.e., a web link or even a database query, as was requested in section 2. This is also the key to using more advanced XML technology (discussed in sec. 6).

The decision was taken to store geometric data exclusively as external data, in binary form. This works well since it reflects a clear separation between structure and content. The Collada file contains only the scene hierarchy and transformations, and is typically small. This makes it particularly easy and efficient to create Collada files on-the-fly, e.g., as response to the aforementioned remote database query.

Note that the *digital preservation* requirement (section 4) demands that only well documented binary file formats may be used for CH in order to avoid semantic degradation.

The only problem remaining is to how make Collada support an integral part of the 3D infrastructure of CH.

5. From Collada to OpenSG, and back again

OpenSG is the scene graph system used in the Epoch network of excellence [Epo04]. As part of the 3D infrastructure OpenSG permits to rapidly create 3D applications, e.g., for museum presentations. It is also of avail to quickly add interactive 3D to C++ applications that were previously non-3D. Some of these can be quite demanding with respect to flexible markup and advanced metadata: There are, for instance, management tools for complete archeological sites (e.g., ArchEd, StratiGraph). They would greatly benefit from a striking 3D visualization of the complex three-dimensional structures of an excavation site, and of the various relations between the numerous collected archeological items.

Export, exchange and import of rich CH visualizations requires that 3D objects can be provided with markup and metadata. It should also be possible to edit these attached data, and to send the modifications back. Consequently, it must be possible to store attachments within a Collada file. Then one technical option to extend an application is

1. to include an arbitrary XML parser. When loading a Collada file the parser converts it to a so-called DOM-tree, the in-memory representation of an XML file;
2. to create a 3D scene graph from the DOM tree,
3. and to keep both structures in sync: all editing operations on the 3D scene graph are propagated to the DOM tree,
4. since a DOM tree can easily be exported to an XML file.

The great drawback of this straightforward approach is that the editing operations are application dependent. Thus, the laborious and intricate step 3. has to be implemented anew for each application that is to be extended with 3D.

Is there a more generic way to establish a robust tie between the scene graph engine and CH specific attachments?

5.1. Solution: XML in the scene graph

Our solution is a tighter integration of OpenSG and Collada. This is a delicate decision: A loader usually just parses a file and produces scene graph nodes. Our proposal, however, is to actually preserve certain fragments of the file, and to write these fragments verbatim *into* the scene graph. Of course, this strategy trades greater flexibility with one format against reduced compatibility to other formats: When exporting to a low-level 3D format, a loss of information is inevitable.

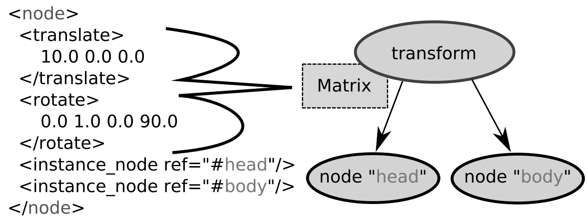

Figure 3: *Collada <node> mapped to OpenSG sub-scene.*

We have found a way, however, to reduce this effect. Instead of implementing just 'yet another' Collada loader, we provide a general, clean, and also concise interface (API) that facilitates adding support for *any* XML based file format. So our module is intended to be used by authors of XML file importers. However, we focus on Collada to illustrate the concepts that might be useful also in other settings.

5.2. Mapping a Collada file to an OpenSG scene

For the reasons described before our Collada importer is deliberately limited. We concentrated on the scene graph aspect and did not include things like animation, shaders or physics, which are also part of the Collada specification 1.4. Neither does it support geometry, since that comes from external sources, from OBJ, 3DS, WRL and, with our addition, also from Collada files. Note that this way also future custom shape representations, which come with their own optimized loader modules, can be accomodated.

The transformation of a Collada scene graph to OpenSG presents some challenges: Some of the Collada elements can not be directly mapped to a corresponding OpenSG object.

5.2.1. Transformations

The <node> element forms the basis of the Collada scene graph. It can have child nodes of many different types. All children that are transformations are accumulated, in the order in which they occur. The resulting transformation affects equally all other, non-tranformation child nodes.

We map one <node> to ≥ 2 nodes of the OpenSG scene graph: One Transform node carries the accumulated matrix, and the non-transformation nodes are children (all siblings), see Fig. 3. It would not help to recreate the chain of transformations since OpenSG knows only one type of transformation (a matrix). The XML text could be conserved, but this runs into trouble when the transformation is changed. As a consequence, the matrix assembly information is lost.

This shows why the *exact import/export property*, stating that import followed by export must reproduce all valid files identically, is unfortunately not a realistic requirement.

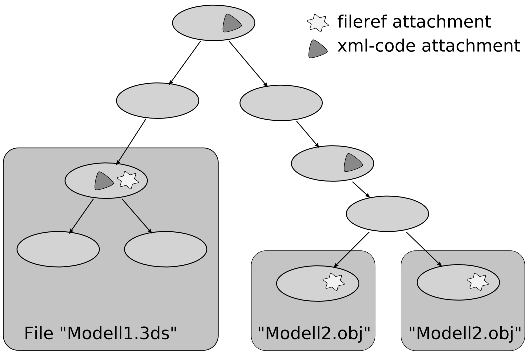

Figure 4: *The use of xml-code and fileref attachments.*

5.2.2. Geometry

Most of the geometry specified in Collada could be directly mapped to OpenSG. The data organization is similar since in both cases state-of-the art realtime rendering is the goal. For a decent support of Collada only advanced things like morphing, animations, shaders might require extensions.

For our external content strategy, however, two Collada elements are sufficient: The <library_node> references the external resource with its URL attribute, and it defines a local name. This name can be referenced in the scene by any number of <instance_node> elements using a *relative* URL (Fig. 2). Unlike an XML file, which is a tree, the OpenSG scene graph is a DAG (*directed acyclic graph*). So sub-scenes can have multiple parents, which comes in handy when a <library_node> references a Collada file. Note that it is vital for nodes resulting from external sources to remember the URL (the file name); otherwise subsequent export will fail.

5.2.3. Attached <extra> and <technique> elements

The <extra> element, which is so useful for CH, can be attached to almost any other Collada element. This is a problem for element types that have no matching OpenSG entity; it is unclear where to store the attached data then. Sometimes dummy nodes can be inserted, like for a <library_node> or for a <visual_scene>, but this strategy does not work in all cases, and it complicates the scene structure.

An <extra> can have children of type <technique> but also <asset>. This is the place for *asset-management information* like <title>, <contributor>, and <keywords>. Although useful in principle this may lead to another complication: CH requires to use much more sophisticated metadata schemes anyways. This makes the <asset> information redundant, and even potentially contradictive.

5.3. The AttachmentContainer facility of OpenSG

A great feature of OpenSG is that arbitrary user data can be attached to almost anything. All major FieldContainer

```
NodePtr torus
 = OSGfilerefManager::the().loadFile("torus.obj");

// create XML annotations
TiXmlElement el_extra      ("extra");
TiXmlElement el_technique("technique");
TiXmlElement el_creator   ("dc:creator");
TiXmlText    text_name    ("John Doe");

el_technique.SetAttribute("profile","epoch:meta");

el_extra     .InsertEndChild(el_technique);
el_technique.InsertEndChild(el_creator);
el_creator   .InsertEndChild(text_name);

// attach XML annotations to the torus
OSGxmlManager::the().setXMLtree(torus, el_extra);
```

Figure 5: *Creating a torus with attached metadata in C++.*

classes such as Node, NodeCore, Image, Material, Camera, etc., are derived from AttachmentContainer. Whereas the set of fields is fixed and the same for all class instances, each individual instance can carry any number of attachments.

Each attachment has a certain type and a unique name under which it can be retrieved using the findAttachment method. This is very useful. For example can all OpenSG objects be named, simply by attaching a character string, a *string attachment*, under the name *"name"*. New attachment types can be defined easily by instantiating a template.

This mechanism can now be used to store additional XML data directly with each object in the scene. For the greatest compatibility, and to be independent of any particular XML library, the XML code is attached as character string. We have defined the custom attachments

- ***"xml-code"*** to store XML data of any kind, and
- ***"fileref"*** to identify external geometry.

The attachments can be manipulated using the functions getXMLcode/setXMLcode and getFileRef/setFileRef.

5.4. The XML manager class

XML in a character string is difficult to access. Greater convience offers the *XML manager* with getXMLtree/setXMLtree. This way XML attachments can be accessed as TiXmlElement tree using *TinyXML*. This is a minimalistic XML "library", in fact just a few cpp files. It offers a very straightforward API to set up and manipulate an XML element tree, as illustrated in Fig. 5. The string attachments are converted to the DOM-like tree structure only *on demand*. This solution combines maximal robustness with the greatest ease of use: The XML manipulation in the scene graph is completely

TiXmlElement∗ getXMLtree(AttachmentContainerPtr container);	convert textual XML annotation to a tinyXML element subtree
void setXMLtree(AttachmentContainerPtr container,	set/overwrite the textual XML annotation in the container object
const TiXmlElement& xmlCodeElem);	by an TinyXML subtree converted back to a character string
void clearPath();	clear the XML access path
void addToPath(**const** string& pathElem,	append one element to the XML access path,
const string& attrib1 ="", **const** string& val1="");	optionally require one attribute to have a particular value

Figure 6: *The most important functions of the XML manager.*

decoupled from whatever XML library may be used in some import/export module.

We found that applications often repeatedly need to access the same elements in the XML attachments of 3D objects. The attachments often have a very similar structure, and the code for traversals is repetitive and tedious to write due to the security queries. The XML manager therefore allows to predefine a path through the XML tree, by node and attribute matching, to provide an easy and robust direct access to a specific element in deeply nested XML attachments. – The API of the XML manager is shown in Fig. 6.

5.5. The Fileref manager class

It is vital to keep track of ***all*** filenames and URLs for two purposes: For a subsequent scene export, and not to import any resources multiple times. This applies also to "node cores" (e.g., geometry) imported through several levels of indirection: A Collada scene might import a Collada "object" scene that imports an OBJ file importing a material file (MTL) loading a jpeg-texture. Even if the texture (e.g., a logo) is used many times it must be loaded only once.

The *fileref manager* takes care of all file related activities. For the above reasons the existing importers (OBJ etc.) were also reorganized to use it. This has the added value of a transparent access to remote resources since URLs are resolved. Files are loaded asynchronously to prevent the application from blocking. A placeholder (a sphere) is temporarily inserted into the scene graph until the loader thread terminates.

Every scene graph node can be exported. The exporter works in either of two modes: It exports references, stopping at nodes with a fileref attachment, i.e., that were imported, or it exports everything, descending down to the leaves of the scene (sub-)graph. In the latter mode ("Save as") the external binary files are simply copied, which implies that they may contain only *relative* references to other files.

6. W3C standards in the light of 3D

Information technology in Cultural Heritage speaks XML. A seamless and efficient adoption of XML is therefore the strategic key to making digital 3D artifacts an integral part of CH libraries and databases. The homepage of the W3C lists more than two dozen XML related technologies. They can open a wealth of new possibilities because many of them are directly applicable to 3D in Cultural Heritage.

XInclude: Transparent inclusion of remotely stored sub-scenes. In case an object is unreachable a locally stored low-res approximation is automatically used.

XPointer / XPath: Flexible referencing of sub-parts of a 3D object. Very general framework for references, e.g., for spatial indexing, for indexing nodes and sub-scenes. Transparent access to objects stored in the file system, in a database, or on a web server.

XSLT: Personalized rendering, context-dependent views, can deal with different versions of objects, can be used to provide information in different languages

XLink: Multi-directional links between several documents, e.g., to relate artifact and interpretation in a bi-directional way. Stored externally, so works also for read-only archives. Link on link, to refer to the fact that a link exists.

Web Services: All sorts of operations on XML: filter, process, create views. Actions to perform can be encoded in a URL. Can generate XML scenes dynamically, as response to a web query. Billing, cookies, user rights management.

XML Encryption To protect *intellectual property rights*: Signing of documents, certificates of authenticity.

7. Conclusions and future work

Historic 3D assets will cease to be an exotic special case. However, much remains to be done. This paper has only attempted to lay out the foundations, which will hopefully prove to be sound.

We are looking forward to applying and testing this technology together with real users in practical CH applications. To have XML support is fine, but much more important is to define how it is used: What are the best solutions for the problems of 3D markup and processing history, which metadata scheme is really useful, and which XML technology should be applied for which purpose.

Acknowledgement

The authors wish to thank the European Commission, in particular the EPOCH network of excellence in cultural heritage (www.epoch-net.org) for their generous support.

References

[Bar06] BARNES M.: *COLLADA Digital Asset Schema*, release 1.4.1 ed. Sony Computer Entertainment Inc. and Khronos Group, June 2006. www.khronos.org/collada. 5

[CDG*05] CROFTS N., DOERR M., GILL T., STEAD S., STIFF M.: *Definition of the CIDOC Conceptual Reference Model*, version 4.2 ed. CIDOC Documentation Standards Working Group, June 2005. also ISO/PRF 21127 (almost). cidoc.ics.forth.gr. 2

[Doe05] DOERR M.: The cidoc crm, a standard for the integration of cultural information. (online), Nuremberg, 2005. Tutorial slides, cidoc.ics.forth.gr/docs/crm_for_nurnmberg.ppt. 2

[dub04] Dublin core metadata element set, version 1.1. ISO ANSI, 2004. ISO/IEC 15836:2002, available from dublincore.org. 2

[Epo04] Epoch – the european network of excellence on ict applications to cultural heritage, 2004. IST-2002-507382. 6

[Mil96] MILLER P.: Metadata for the masses. Ariadne 5 (online), 1996. www.ariadne.ac.uk/issue5/metadata-masses. 2

[Pra04] PRATT M.: Extension of iso 10303, the step standard, for the exchange of procedural shape models. In *Proc. International Conference on Shape Modeling and Applications (SMI04)* (Genova, Italy, June 2004), pp. 317–326. 4

[VRM97] Vrml, the virtual reality modeling language. Web3D Consortium, 1997. Language Specification Version 2.0, ISO/IEC IS 14772-1, available from www.web3D.org. 5

[X3D03] X3d framework and sai (scene access interface). ISO/IEC, 2003. FDIS (final draft international standard) 19775:200x, available from www.web3d.org. 5

[Zsc03] ZSCHAU E.: *Transformation deklarativer Beschreibungsformate für 3D-Anwendungen nach OpenSG*. Tech. rep., (Diplomarbeit) Technische Universität Dresden, 2003.

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
VAST (2006)
M. Ioannides, D. Arnold, F. Niccolucci, K. Mania (Editors)

United we conquer

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Abstract

Databases in Archaeology and Cultural Heritage in general often give extensive information about limited fields, but are isolated and thus fail to exploit synergies that could be found by linking their data to related research areas. Integrating data from a wide range of related fields into a unique network is therefore a very promising task from which all involved parties could profit.

The EU Project BRICKS aims at building a digital library that provides both the necessary infrastructure and a concrete instance of such a network. BRICKS is a peer-to-peer network without central administration. The peer-to-peer structure means that every member organisation is responsible just for their own network node and need not give away their data, while making them available to the whole network. Since the software is free and runs on inexpensive servers, the only cost for the institution is that of setting up and maintaining the network node. To minimize the cost of the setup, BRICKS allows institutions to import metadata in any form they might have via an OAI PMH interface, thus avoiding the costly conversion to a common format.

The software package provides services like content, metadata and collection management, query processing etc. All these services are available via a web service interface, which allows building complex applications on top of them. We present an application to classify archaeological finds as an example.

Joining BRICKS gives institutions increased visibility of their data and the potential to organize research projects with experts in adjacent fields. For individuals, BRICKS provides means to search the whole network with a single query, thus joining data from different institutions; to organize results relevant to a certain project in folder-like structures and to share comments and opinions on individual data items via annotations.

Categories and Subject Descriptors (according to ACM CCS): H3.7Digital Libraries

1. Introduction

Many Cultural Heritage institutions make (part of) their digitized data publicly available, e.g. via web servers. However, in most cases, these data are available only in isolation and synergies from linking them to other material are lost. Digital Libraries (DLs) are a way to overcome this problem. However, there are two fundamental problems with most existing DLs:

- Centralized architecture: most existing solution rely on a central server for tasks like user management, indexing, search etc. Even if the content itself is stored in a decentralized way, the central server requires extra maintenance work (and thus extra costs), and it compromises the robustness of the system because it constitutes a single point of failure.
- Restricted data model: to be able to search and render material from diverse sources, most existing systems require that the metadata / content be mapped to a single schema (or a restricted set of schemas). Such a mapping inevitably either causes the loss of a significant part of the original data (if the mapping constitutes the "least common denominator" between the original schemas), or it requires a substantial amount of work (if the mapping attempts to incorporate most of the information from the source schemas).

BRICKS [BRI] is a EU project to build a DL network in Cultural Heritage that avoids these two problems. It is based on a *decentralized peer-to-peer* architecture, which means that each member institution runs a node in the network (BRICKS node or BNode, for short) and is only responsible for this node. The system maintains a decentralized index which enables searching the whole network. Since there is no central component, there are no costs for a BRICKS member except for the set-up and maintenance of their own

BNode. Also, if any of the nodes crash, only the part of the data stored there is lost – the functionality of the rest of the network is not affected. This is a big advantage over a crash of the central server in a centralized system.

A fundamental decision in BRICKS is to be open to a wide variety of content and metadata models. Thus, existing content and metadata can be imported into BRICKS without losing information and with minimal effort. The idea of BRICKS is not to replace existing content management systems or databases, or to add yet another system to maintain, but to and add extra functionality to existing data.

The rest of this paper is organized as follows: section 2 outlines the architecture of the system, section 3 describes its most important components. Section 4 presents a sample application built on top of the BRICKS infrastructure that demonstrates how BRICKS can be used to fulfill to complex tasks, and in section 5 we give conclusions and outlook.

2. Architecture

The BRICKS architecture consists of two layers: a general-purpose *infrastructure* that provides functionalities like content and metadata management and search via web service interfaces, and a set of *applications* that are built upon the infrastructure and use its components as building blocks. The infrastructure itself is also layered and consists of

- the peer-to-peer layer which handles the communication between the nodes (via the internet)
- a set of core components which must be present on every node, like index, user management, authentication service
- a set of components which provide services for end-users like content and metadata management, collection and annotation services, and the search engine.

End users and applications will mostly use the functionality topmost layer. They will not need to bother about the communication between the peers - all this is handled by the layers below and transparent to them. The user will not see any difference between content that is on his own node and content on remote nodes.

All components in the topmost layer provide web service interfaces and are therefore platform- and language-independent. This facilitates integrating them into existing systems and building new applications on top of them. The components are implemented in Java and tested under Linux and Windows to facilitate the integration of the software with an institution's existing IT infrastructure.

BRICKS offers two GUIs to access the services of the infrastructure: the *BRICKS Workspace*, a web application that can run in any web browser, and the *BRICKS Desktop*, which is based on Eclipse and requires to install the Desktop application on the client computer. The Workspace is targeted mainly at end users and has the advantage that it can be run on any computer with an internet connection and requires no setup; the Desktop is for expert users or administrators and offers extra functionality that could not be implemented in the Workspace because of the limitations of web applications.

The Workspace and the Desktop also demonstrate how to build applications on top of the infrastructure. Other applications built in the framework of the project include a tool to create online exhibitions, an application to manage submissions for the "Museum of the Year" award of the European Musuem Forum, and an application to help untrained users classify archaeological finds (described in sec. 4). These applications illustrate that the infrastructure is not only useful per se, but can also serve as building blocks to accomplish complex tasks. Moreover, using BRICKS components not only provides a library of useful services, but also gives you automatically access to all the data in the network.

3. Main components of the BRICKS infrastructure

The description of components is limited to those that are central either for the setup of a network node or for end users. These are the components that manage content, metadata, collections, and annotations, the search engine, and the importer. Other components include user management and access control, digital rights management, service composition, and a component to map between different metadata schemas.

3.1. Content Management

The BRICKS Content Management system is based on the Java Content Repository [JCR] specification. Essentially, it provides a web service interface to the Apache Jackrabbit system. JCR provides a meta-model, i.e. it does not restrict the content model, but allows to load and use arbitrary models that can be mapped to a tree structure (similarly to the way DOM allows to interact with XML documents). The BRICKS Content Manager comes with an utility that maps XML Schema Definitions (XSD) to a content model, which makes it easy to import custom content models. Alternatively, a set of pre-configured content models for many common cases is also available as part of the BRICKS distribution.

There are two ways to manage content in BRICKS: institutions that already have a content management system in place can import content *"by reference"* i.e. they just supply an identifier by which the content item can be accessed, e.g. by specifying a URL. When a user wants to see the content, the Content Manager will use this reference to get the content from the external system and display it to the user. This has the advantage that there is no need to keep BRICKS and the external system synchronized (as long as the identifiers don't change). The alternative is to *copy* the content into BRICKS. We assume that this will be used mainly by institutions which don't have a content management system in place.

3.2. Metadata Management

Metadata are data which describe the content (e.g. catalog data). In BRICKS, we focus on descriptive metadata, i.e. metadata that can be used to find content items which matches a description (e.g. pictures of roman silver coins minted during the reign of Emperor Hadrian).

The BRICKS Metadata Manager is based on RDF/OWL [RDF, OWL] and built on top of the Jena system. It can manage any metadata schema which can be expressed as an OWL-DL ontology, which is the case for virtually all metadata schemas in use in Cultural Heritage. The Metadata Manager allows to load an ontology (metadata schema), and to create, edit, view, and delete metadata about content items. It does not provide functionality to *modify ontologies*, since we assume that this feature is seldom needed, and there are of free tools available for this task (e.g. Protégé [Pro]).

The internal representation of the Metadata in the Metadata Manager is an RDF graph. However, since the graph can be confusing for end users, we added a *presentation layer* which organizes all information pertaining to one content item and adhering to a certain metadata schema into a *metadata record* (which means that if a content item is described in more than one schema, there are several records for it). This is shown in fig. 1.

Although we support arbitrary metadata descriptions, an unqualified Dublin Core [DC] description is mandatory for every content item. This restriction comes from the use of OAI PMH in the importer (see 3.6). Also, since the DC schema is very simple and all fields in it are optional, we think that providing these metadata does not require substantial effort as it can be automated in most cases. But it provides a basic level of interoperability exploited by the search engine.

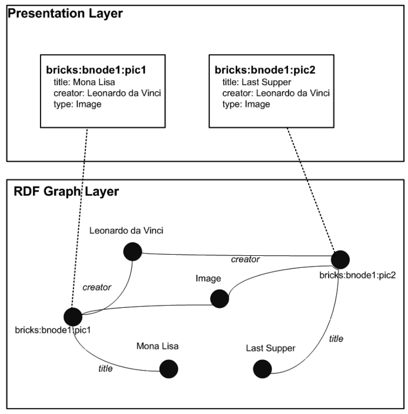

Figure 1: *Two-layered metadata model*

Fig. 2 shows the relation between Physical and Logical Collections.

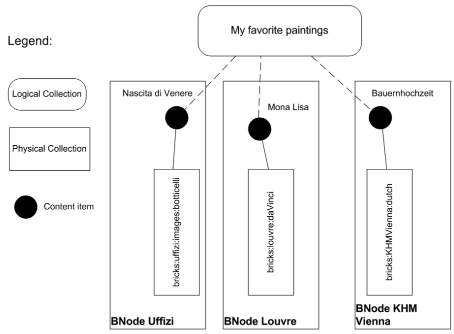

Figure 2: *Physical and Logical Collections*

3.3. Collections

Collections are hierarchal structures to organise the content of BRICKS. They can be nested to an arbitrary level and resemble Windows folders or Unix directories. We distinguish between two types of collections:

- *Physical Collections* describe where the content resides. Each content item is in exactly one Physical Collection. This allows to use Physical Collections to restrict the search space. Also, Physical Collections can include only content from *one* BNode.
- *Logical Collections* contain only *references* to content items. Each content item can be in an arbitrary number of Logical Collections, and they can include information from different BNodes. This allows end users to aggregate information relevant for a certain topic from diverse sources.

3.4. Search

For end users, the search engine is probably the most important component of the entire system. It allows to find content which satisfies certain conditions. The whole BRICKS network can be searched with a single query. BRICKS provides two kinds of search:

- *Simple Search* is keyword-based, i.e. you can enter a number of keywords (e.g. "roman coins Hadrian"), and the search engine will deliver all items that have these keywords in their metadata. This very similar to common search engines like Google, except that the search is based on metadata and can therefore also give meaningful results for non-textual content like images. If an item is described with several metadata schemas, simple search will use all of them.

- *Advanced Search* is more like a database query in that you can specify which field of the metadata should match and that you can also exploit the ordering of numeric or date values (e.g. "`creation_date>2004-01-01`" to search for documents that were created in or after 2004). You can combine conditions with logical `AND` / `OR` and you can also use fields from different metadata schemas. This allows very fine-grained searches, but it requires some knowledge of logic and the metadata schemas involved. To search the whole DL, use the properties of DC (because every item is described in DC). However, if you can restrict your search to data of one or several institutions, and you know which metadata schemas these institutions use, you can use these schemas in a query (and probably obtain more precise results).

To speed up the process, you can limit your search to a set of (Physical and / or Logical) Collections. This is useful especially if you know which institution owns relevant material.

3.5. Annotations

Annotations allow users with sufficient access rights to *comment* on content items or other user's comments. The comment can refer to the whole document or to a part of it (e.g. a section of an image showing a person). The author of the annotation can specify a visibility for his annotations: *private* annotations are visible only to the author (or a system adminstrator), *shared* annotations are visible for a group of users, and *public* annotations are visible for everybody. Shared annotations provide an excellent means to exchange information in research projects; e.g. a researcher could upload a document and ask his colleagues to comment on it.

3.6. Importer

The importer allows to import existing metadata (and content) using the Open Archives Initiative (OAI) Protocol for Metadata Harvesting [PMH]. OAI PMH is a flexible protocol very popular in the DL community. Many existing systems already have an OAI PMH interface to export data. Also, several open source implementations of OAI PMH servers exist that are easy to connect to an existing content management system.

OAI PMH allows to import arbitrary metadata, but mandates that also a DC version of the metadata is given. In most cases, existing metadata schemas can be mapped automatically to DC, so there is not much extra effort. In cases studies performed with our content provider partners, the effort to import metadata was between several hours and a week, depending on the existing system, the complexity of the metadata, and the skill of the technical staff at the institution.

4. A Sample Application: Finds Identifier

One of the sample applications built to demonstrate the usefulness of the BRICKS infrastructure is the "finds identfier", an application to help untrained persons to identify archaeoligical objects they found. Specifically, for the prototype of this application we limit ourselves on coins. The user is guided through the classification process by a wizard-like set of dialogs, where his answers determine the questions he is asked next. Also, the information provided by the user is used to limit possible alternatives in lists (e.g. when the user has specified the material of the coins as silver and given the approximate diameter, in the list of denominations only matching coins will be shown).

When the user has entered all the information he can give, a search will be started and all coins matching the descriptions will be retrieved. If the results exceed a certain number, say 20, they will be organized in a tree structure. The user can now browse the results and select the coin that most closely resembles his find. This application makes use of the distributed search, content and metadata management - all information about coins in the network can be used to help with the classification task.

5. Conclusions and outlook

BRICKS has left the prototype stage and can be used to publish, interlink, and search data from many fields. The effort to set up and maintain nodes is very small, and there are no other costs. The decentralized structure and the active sustainability policy make us hope that this network will remain after the end of the project funding. However, this will also depend on attracting a "critical mass" of members. Already more than 70 Cultural Heritage institutions have joined the project, and we hope to increase this number substantially during the next year.

References

[BRI] The brickscommunity page. `http://www.brickscommunity.org`.

[DC] The dublin core metadata initiative. `http://www.dublincore.org`.

[JCR] Java content repository. `http://www.jcp.org/en/jsr/detail?id=170`.

[OWL] Web ontology language. `http://www.w3.org/2004/OWL/`.

[PMH] The open archive initiative protocol for metadata harvesting. `http://www.openarchives.org/OAI/openarchivesprotocol.html`.

[Pro] Protégé. `http://protege.stanford.edu`.

[RDF] Resource description framework. `http://www.w3.org/RDF/`.

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
VAST (2006)
M. Ioannides, D. Arnold, F. Niccolucci, K. Mania (Editors)

An Integrated 3D Geometric Recording of a Mycenaean Tholos Tomb

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Abstract

The Mycenaean tholos tombs are impressive graves located in several areas of southern Greece. Their components are: the dromos, the doorway, and the main chamber, composed of adjoining parts of conical surfaces, which form a dome. A complete geometric recording and documentation of such a construction pre-assumes the creation of an accurate textured 3D model and 2D plans in vector and raster format. The size of the construction, its complexity and the variety of the necessary products need the combined use of field surveying, photogrammetric and terrestrial laser scanning methods. Laser scanning is the optimum solution for the production of the 3D model and the collection of a detailed DSM. Photogrammetric procedures are necessary for the compilation of the plans: rectification for the side walls of dromos, stereorestitution for feature extraction of section lines, and orthophotos for the raster representation of chamber's stones. The compilation of specific in-house written software is necessary as well as the application of innovative procedures and mainly the production of complete and accurate section orthoimages of the chamber.

This paper describes the application of the above mentioned procedures for the Tomb (Treasury) of Atreus, which is the largest and most impressive of the tholos tombs at Mycenae. The results of the data processing, such as the 3D models of the monument and the 2D plans in raster and vector format are presented.

Categories and Subject Descriptors (according to ACM CCS): I.2.10 [Vision and Scene Understanding]: Representations, data structures and transforms, J.2 [Physical Sciences and Engineering]: Archaeology

1. Introduction

The need for documentation of the most important and characteristic monuments of international cultural heritage has been analyzed by UNESCO and in the resolutions of international congresses and meetings. The damages that monuments suffer through time and their condition require conservation and restoration. Geometric recording is the first fundamental stage in order to achieve the above.

The details, accuracy and type of products of geometric recording depend on the monument's significance, its size, complexity, construction materials, type of intervention, available budget and several other factors. The available techniques and the types of products that can be produced have been enlarged due to the development of digital photogrammetric techniques, digital cameras and automation in data processing, the integration of GPS measurements, laser scanning and other non-contact recording methods, and software for modeling and visualization.

Besides the traditional 2D vector plans, and regardless of the shape and the other characteristics of the monument, it is possible to produce high resolution raster products (ortho-images or developments) and 3D representations, textured models, animations etc [GI05], [TKP01]. Consequently, technical specifications for the works and products of geometric recording are necessary, and may vary for each monument according to the particular needs.

In this paper the methods used and the results of a detailed geometric recording of one of the most significant worldwide archaeological monument are presented: the Mycenaean Tholos Tomb (or Treasury) of Atreus. The Mycenaean tholos tombs are impressive ancient graves constructed by large blocks of ashlar conglomerate, earlier than 1200 BC. Their components are: the dromos (a long straight forward corridor with flat side walls), the doorway, and the main chamber. The chamber has a circular shape of a base diameter of a few meters, and is composed of adjoining parts of conical surfaces, which form a dome.

For the geometric recording and modeling of such a complicated and large object, which consists of flat and curved surfaces, and with a demand for 2D and 3D products in vector and raster format of mathematical and textured models according to the technical specifications, there is a requirement for combined use of surveying, photogrammetric and laser scanning techniques.

2. Tomb of Atreus

2.1. Historic Information

UNESCO has characterized the archaeological site of Mycenae as a monument of international cultural heritage of great significance. It includes several pieces of significant architecture and sculpture. The Mycenean civilization was developed in the mainland of Greece during the Late Copper era.

Architecture in the Mycenean civilization is characterized by the construction of cyclopean fortress works and of tholos tombs, which consist of the graves of the kings. Their shape represents the shape of the primitive house of man, suggesting the concept that the dead continue to live within their graves after their death.

In total nine tholos tombs have been excavated in the area of Mycenae. They are distinguished in three groups, according to their type. The first group has its start approximately close to the year 1520 BC and it includes the grave of Aigisthos. The second group is more sophisticated than the first group and chronologically it belongs to the 14th century BC. In this group the grave of the Lions belongs. The third group (13th-12th century BC) contains the most advanced monuments of that type, the grave of Clytemnestra, the grave of the Genii and the Treasury (grave) of Atreus. [Vas95].

2.2. Object Description

The most magnificent and at the same time the best preserved Mycenean tholos tomb is the Treasury of Atreus, also known as the grave of Agamemnon. It consists of a royal construction with imposing dimensions, perfect technique and rich decoration. It was build southwest from the Citadel at a distance of approximately 100 meters, on the slope of an inhabited (in those days) hill (Figure 1). According to studies, the construction of the tomb is dated approximately in the mid 13th century BC.

Its dromos, with the vertical sidewalls parallel to each other has a length of 36m and a 6m width, and is floored with clay plaster. The walls have normal pseudo-isodromus layers of square stones and its entrance is blocked by a low and thin vertical wall of similar construction.

Figure 1: *Aerial photography, by helicopter, of the area of the Treasury of Atreus.*

The facade, of a height of 10.50m, had a door in the middle; the width of the door is 2.70m at the base and 2.40m at the top, and its height is 5.40m (Figure 2). The facade was decorated with half columns, of red and green stone, placed on a low square base. Above the door there was a relieving triangular opening hidden by a cover layer of multicolor marble (today this is lost except for some broken pieces), between the two half columns, smaller and shorter than those at the lower level. Parts of these columns are today exhibited at the National Archaeological Museum of Athens and at the British Museum [Mar54].

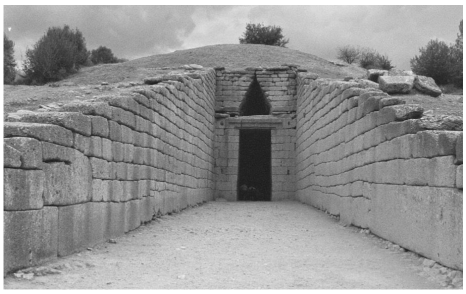

Figure 2: *Photo of the dromos and of the facade of the tomb as they are today.*

The main chamber of the tomb has a diameter of approximately 14m at its base, height of 13.50 m and consists of 33 ring stones of ashlar conglomerate. The stones are piled up in layers so that they create rings, as they become higher in descending size, so that the successive layers will be decreasing continuously (Figure 3). The top is blocked by a large spherical stone. In some of the stones of the tholos there are holes, some of them contain copper nails. It appears that there was some copper decoration on the grave wall.

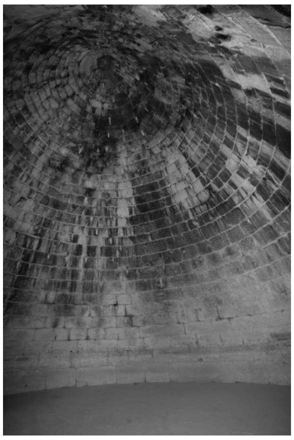

Figure 3: *View of the inner side of the tomb.*

In the northern side of the chamber there is a smaller door which leads to a square side room approximately 6x6x6m. Today there are shown only its naked, in rough walls as they were carved the rock. The inner wall of this room had a cover layer of plaster with a sculptured decoration.

The dome projected above the surface of the hillside and was covered with a mound of earth covered by clay and supported by a poros wall (Figure 4) [Iak03].

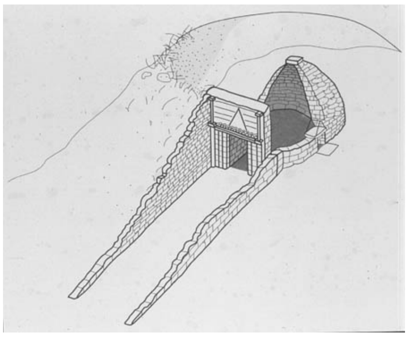

Figure 4: *Schematic representation of the shape of the Grave of Atreus in the antiquity [Wac49].*

3. Data acquisition

The data used were surveying measurements, metric images of the monument and laser scanning point clouds.

Field work included the establishment of the network of 12 points, with two points of known coordinates in the national reference system. Also included were the measurement of:

- Pre-marked control points and characteristic detail points (at the very high parts of the tholos where access was not possible) for the photogrammetric procedures
- Special targets for laser scanning and
- Points along the pre-defined sections of the tholos tomb. Two vertical sections in planes perpendicular to each other and three horizontal sections of the internal of the grave at the levels where the slope of tholos changes were measured.

3.1. Image capturing

Stereoscopical images of the main chamber-tholos were taken using Canon EOS 1D Mark II digital camera (format 28.7x19.1mm, resolution 8.2 Mpixel) from a distance of approximately 12m, with a focal length of 35mm. The image scale is of the order of 1:350. Fourteen stereoscopic models, with overlap of approximately 80% were created. The images arrangement was consisted of two strips: one up to the height of 6m (7 models) and one from the level of 5m up to the 10m from the ground (6 models). One more model was derived from the photography of the dome, with the image axis vertical and directed at the zenith point.

The facade was photographed with the same digital camera with a focal length of 35mm, from a distance of 10m. The image scale is of the order of 1:280 and a stereo-pair was derived with an overlap of 70%.

The corridor was photographed monoscopically using Hasselblad C50 semi-metric analogue camera with a focal length of 50mm, from a distance of 6m. The photo scale is 1:120. For each side of the corridor 12 photos were taken. Using the same camera and lens 4 monoscopic photos were taken in both sides of the doorway from a distance of 5m, at a scale of 1:100. Due to the small opening of the door, the photo axes had large φ angles.

3.2. Laser scanning

Terrestrial laser scanner HDS-2500 of Leica Geosystems was used; it operates with the pulse method and the angular deviation is made by turning mirrors. Each scanning is restricted through a FOV of $40^\circ x 40^\circ$. The scanner has a positioning accuracy of $\pm$ 6mm at a distance of 50m.

Fifteen scans were made, with point density of 1cm. Two of the scans referred to the external of the chamber, that is the dromos and the facade. The other 13 scans were made with the scanner placed at the periphery on the internal of the tholos, in an arrangement of two zones along the height of the object. Every two successive scans of each zone had an overlap of approximately 20%, while the two zones had an overlap of approximately 35%. At each one of these overlaps $3 \div 5$ targets were placed, which besides their scanning with a point density of 1mm, were measured also by field surveying at a unified coordinate system.

4. Data processing

At the beginning of the project a separate processing of each kind of data was made: point coordinates extraction at the national reference system from the field measurements, mono- and stereo-scopic image processing, registration and merging of point clouds of the laser scanning. Then a combined use of the data was applied for the extraction of the best 2D and 3D products.

4.1. Photogrammetric processing

Photogrammetric processing involved the application of various techniques which according to the case gave the best results technically and cost wise, for the geometric recording of the grave. Along the whole length of the dromos sides, at the facade and the sides of the doorway, photogrammetric rectification was applied using ARCHIS software. In total 28 photos were used and 98 presighed control points were needed. Thus, 2D raster products were produced from which through digitization the vector format plans of the monument can be derived. In parallel the shape and the location of all flat surfaces were defined so that they will be used for the creation of the 3D surface model.

For the curved surfaces of the tholos, stereoscopic processing was performed using Digital Photogrammetric Workstation SSK of Z/I Imaging. The requirement for a 2D raster products creation determined the production of ortho-rectified images at the pre-defined levels of vertical and horizontal sections. Consequently, the first stage was the Digital Surface Model (DSM) extraction, and the second the production of the orthophotos.

The parameters of the internal orientation of the digital camera were accurately determined at the Laboratory at a special 3D test field, e.g. c=4,132±3 pixel, xo=9±10 pixel, yo=30±2 pixel. Then a photo-triangulation bundle adjustment was made, using BINGO software, for the simultaneous calculation of the parameters of the external orientation of all the images, which were taken inside the chamber. Yet, these values cannot be used for the restitution of the specific stereo-pairs at DPW due to the circular shape which the image acquisition points of all images create. In order to have stereoscopic observation and creation of stereo-model there is a need to rotate the coordinates of the control points of each pair into a system of which the X axis will create a small angle with the direction of the pair base. So the restitutions of each stereo-pair are made in a different local system.

Under these circumstances it is not possible to produce ortho-rectified images at the DPW, at the pre-defined section levels from all the required stereo-pairs. The procedure selected, instead, is:

- Orientation of each one of the 14 stereo-pairs at the DPW, using appropriately rotated coordinates of the control points.
- DSM extraction from each stereo-pair, at the DPW, at the local coordinate system where the control points are rotated. The uniformity and the highly curved surfaces of the object did not allow the correct operation of the matching algorithms for the automatic extraction of the DSM. So, a manual extraction procedure was followed. A grid of a cell size of 15x15cm on the object was selected, which was proved to be sufficient. In total, more than 58,000 points were digitized from the 14 models.
- Rotation of each one of the DSMs from the local system into a unified coordinate system (the national reference system); merging of all the DSMs
- Ortho-rectified image production using an in-house written software package, described below.

4.2. Special ortho-rectification software

A software package was written, at MatLab programming environment, for the production of ortho-images in close-range applications regardless of the initial image acquisition direction and of the projection plane. This software consists of:

- Photogrammetric resection program. Using as data the coordinates of the control points, at any reference system, their image coordinates and the internal orientation of an image, the parameters of the external orientation are calculated; use of the DLT for the calculation of the initial values.
- Ortho-rectification program, using the XZ plane of the external orientation system as the projection plane. The algorithm of the program includes:
  - determination of the area of the object where the ortho-image will be produced
  - creation of triangular network, with Delaunay method, using all the points of the DSM, and surface creation. The algorithm connects with lines the three closest to-each-other points according to their X, Y coordinates
  - rejection of triangles with sides longer than 1m
  - calculation of the triangles where the centers of the grid cells of the final ortho-image belong. A specific procedure is followed so that the calculation work load will be minimized: the dimensions of a search window for possible triangles are calculated and only within this window the control is made whether the center of the cell lies inside of a triangle or not
  - in the case when the center of a cell belongs to more than one triangles, a control of the Z values of the nodes of each triangle and the selection of the most close triangle to the projection plane is made
  - calculation of the elevation of each center cell with an interpolation from the elevations of the triangle nodes in which it belongs
  - from that point on the typical procedure for ortho-image production is followed.

This software was used for all the images of the inside of the chamber and for all the projection planes of the vertical and horizontal sections, that were planned to be created.

The size of the groundel was determined to be 3 mm. 140 ortho-images were derived, including 28 ortho-images for each one of the 5 projection planes (one is horizontal).

Ortho-images of excellent quality were produced without any distortions even from images whose central axis made a small angle with the projection plane. The method developed was proved to give the best results in comparison with other techniques, such as the coloring of the DSM points through the information included in the initial images and then their projection on the desired plane [GMD05]; this method requires very dense DSM in order to achieve high quality in ortho-image production.

4.3. Laser scanner data processing

The registration, merging and georeferencing of the point clouds were made using Cyclone software. This software provides the means for registration either by using targets which have been scanned (target constraint) or by using common characteristic points between the clouds (cloud constraint) or with a combination of the two techniques. In this application all three possibilities were used, and various combinations were made for georeferencing, either individually for each point cloud or for the final merged unified cloud. It should be mentioned that the space coordinates (in the national reference system) of all targets had been calculated by field surveying.

The application of alternative procedures was made in order to investigate the achieved accuracies. The statistical data from the adjustments prove that in all cases the alignment rms error varied between 2÷5mm, so it was absolutely satisfactory. An accuracy control of the georeferenced point clouds followed by measuring selected check points of known coordinates. As expected, the best registration was derived by using a target constraint and the most accurate georeferencing by using all control points in the merged unified point cloud. Yet, also all the other solutions gave almost similar results; their differences in rms of each axis were less than 3mm. So, fewer targets and field measurements can be used without accuracy loss in the results.

5. Products

5.1. 2D plans

For a complete representation of the Tholos Tomb in 2D plans, the following drawings were produced:

- A horizontal section at ground level, derived from the field surveying measurements
- A horizontal 'aerial view' plan, using aerial photos taken by helicopter with close-range analogue metric camera, and field surveying

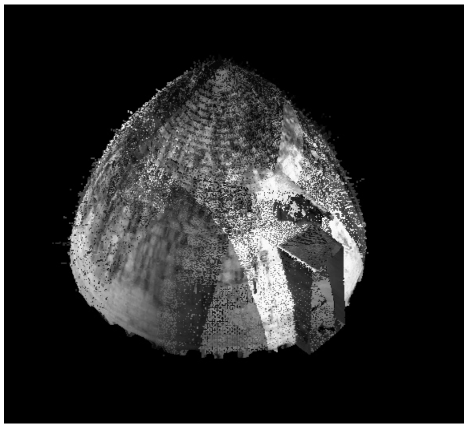

Figure 5: *Registered point clouds of the doorway and the main chamber.*

- Ortho-mosaics (Figure 6 and 7) and vector plans (Figure 8) of four vertical sections through the center of the chamber. For the ortho-images production by the described in-house written software, either the DSM from photogrammetric models or the georeferenced point cloud from laser scanning was used
- An ortho-mosaic of the horizontal section of the chamber with an upward direction.
- The ortho-image of the facade of the grave.

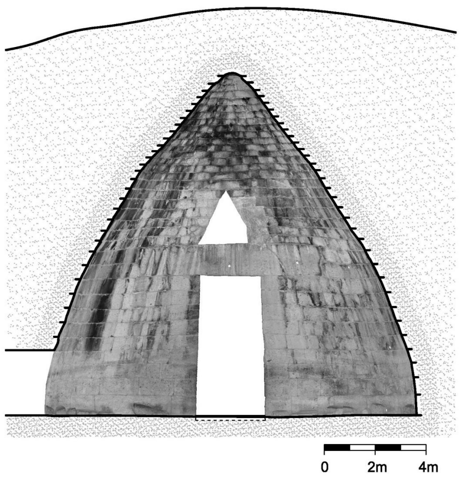

Figure 6: *Eastern facade of the internal of the chamber.*

Of special interest is the effort to create a development plan, in raster format, of the internal surface of the main chamber. From DSM it can be seen that the surface is adjustable in elevation zones from parts of right truncated cones. Through appropriate controls, six (6) zones were defined and the parameters of the relevant cones were defined, so that the deviations of the points of the DSM from the

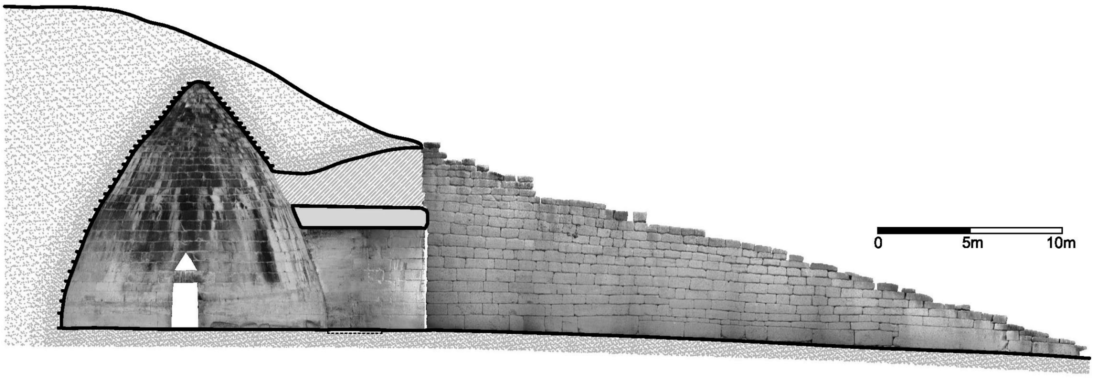

Figure 7: *Section along the axis of dromos, in raster format.*

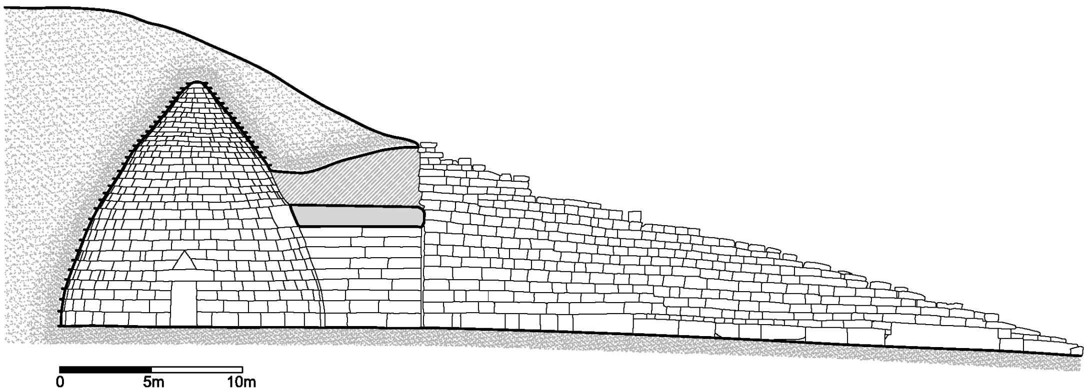

Figure 8: *Section along the axis of dromos, in vector format.*

mathematic surfaces will not be in excess of 2.4cm (rmse = 1.5cm).

The production of developments was made by a software especially written for this purpose, in MatLab environment. It consists of two parts. In the first part the adjustment of a right cone in a 3D point cloud is made; the cone parameters are determined [AJ91] and the parts of the cloud where the adjustment will be made are selected automatically. In the second part the raster development of the best cone is created from the existing images, whose internal and external orientation is known:

- the cones which outline the part of the object that is shown in each image are defined
- the developed conical coordinates which outline the boundaries of the development are calculated; thus the centers of the grid cells on the development are calculated
- for the center of each grid cell the developed coordinates and the coordinates on the conical surface are calculated; then the elevation value through an interpolation on the DSM points and the image coordinates are calculated, from where the information about the color is recorded.

This software was applied for all images of the inside of the chamber, with a groundel size of 5mm. The result, after appropriate georeference, merging and rotation of the six conical developments is shown in Figure 9.

5.2. Creation of 3D models

The initial approach for the production of the 3D model of the tholos tomb was made by Cyclone software. This particular software has limited tools for the creation and editing of solid model; it can adjust to the point cloud only for planes, spheres, cylinders and cones. The analysis of the surface of the chamber into conical surface parts allowed the use of the software. Thus the unified point cloud derived from the laser scanning, at first stage was cleared from the points which did not relate to the surface of the chamber, but were mainly points which lie in the gaps of the surface between the series of stones. Then it was divided into rings, and each one of those was adjusted to a cone, according to the results from the developments processing. The products are given in Figures 10 and 11.

It is obvious that by this method only a general approach

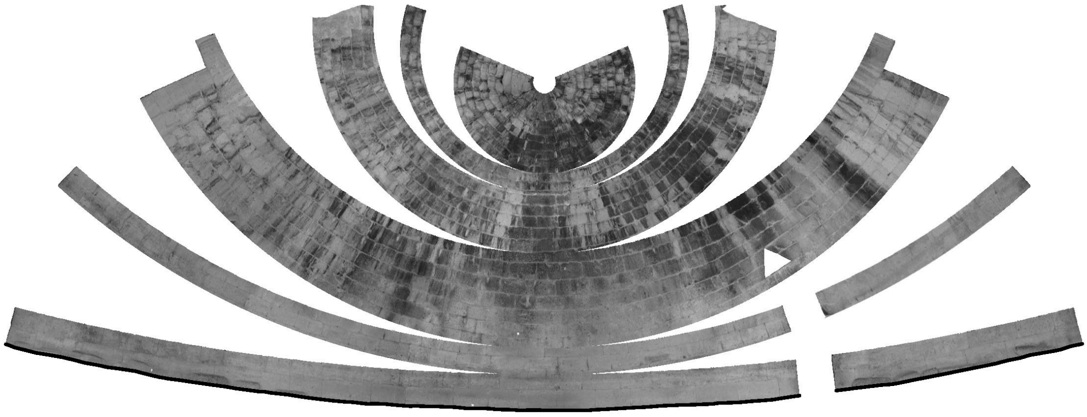

Figure 9: *Developments of conical surfaces of the inside of the chamber.*

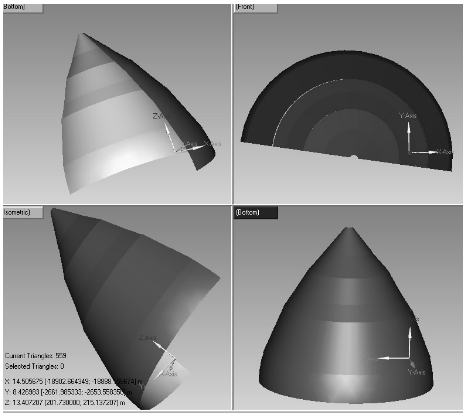

Figure 10: *3D model of the chamber using conical surface.*

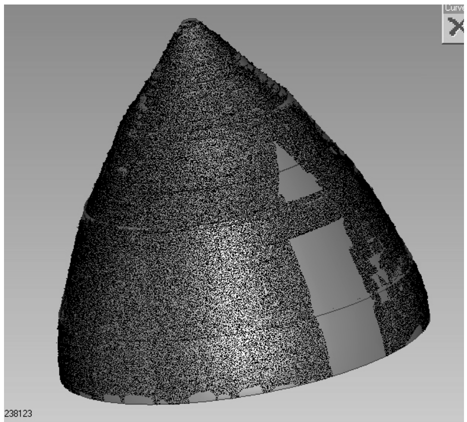

Figure 11: *Simultaneous representation of the point cloud and of the 3D model of the conical surfaces.*

of a 3D model can be made. All distortions, which were a result of the construction, and all the damages that the surface of the monument has suffered, disappear.

For a better representation of the 3D model and a more detailed editing of both the points and the surfaces, the modeling was carried out using Raindrop Geomagic software. The production process involves: in polygon mode the creation of triangles, waterproof solid model and definition of boundaries, and in shape mode curvature detection, creation of contours, patches, grids and fitting of NURBS surfaces.

The total number of the points of the cloud was approximately 9.8 millions. For their better and faster processing, without any noticeable loss of information, the procedure of unified rejection of points from the object was followed. It was proved that 5.5 million points were enough for the needs of the project. The conversion of the points into a polygon network (wrapping) gave approximately 1.8 million triangles

The model processing followed, with the filling of the holes, removing of spikes, and finally the diminishing of the number of triangles by 50%. The final form of the model is given in Figure 12, with the possibility to produce sections with any plane in space Figure 13.

Texture can be applied on this 3D model by covering its surfaces with the ortho-mosaics which have been produced photogrammetrically.

Another process that can be accomplished on the 3D model is the production of the NURB surfaces for a structural analysis of the monument, through the use of 3D finite-element analysis. For the production of the NURBS model: the polygon model should be divided automatically or manually into patches and a grid has to be constructed (for each patch a grid of 20x20 nodes was defined) on which the NURB surface can be adjusted Figure 14.

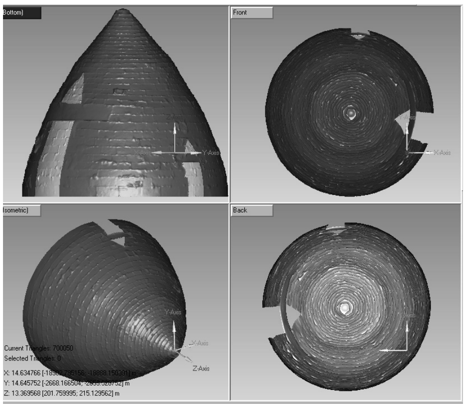

Figure 12: *3D views of the chambers' model, produced using Geomagic software.*

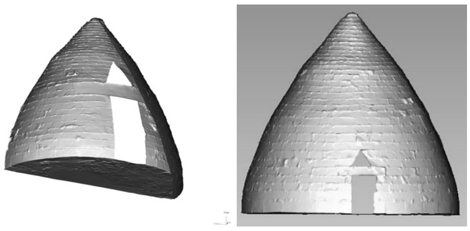

Figure 13: *Representation of the inside of the 3D model: (Left) section in space and (Right) projection on a vertical plane.*

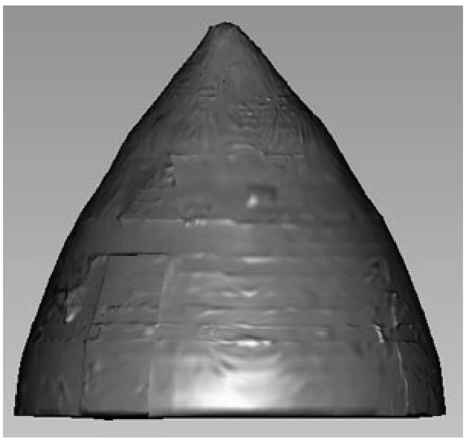

Figure 14: *NURBS model of the chamber.*

6. Conclusions

The combined use of surveying measurements, ortho-rectification and photogrammetric stereo-restitution and laser scanning techniques can give impressive results, regarding quality and accuracy, for 3D geometric recording of historical monuments. All these are non-contact techniques so they are not affected by the topography of the area or by the construction material of the object.

For a complete use of the capabilities of these methods in such demanding close-range applications, the development of special software adjusted to the technical specifications of the particular project is needed. The available commercial software is not planned to cover the demands of the specific cases such as special ortho-rectification using multiple image coverange or the creation of developments and other cartographic projections or combined uses of photogrammetry and laser scanning.

Acknowledgements

We thank the Hellenic Ministry of Culture and the 4th Hellenic Efory of Prehistoric & Classical Archaeology, for giving us the permission to make measurements in the Tomb of Atreus.

References

[AJ91] AHMAD K. AND JAIN P. K.: *Textbook of analytical geometry of three dimensions*. Wiley Eastern Limited, 1991.

[GI05] GEORGOPOULOS A., IOANNIDIS C.: 3D visualization by integration of multisource data for monument geometric recording. In *Proc. of the International Workshop on 'Recording, Modeling and Visualization of Cultural Heritage', Ascona, Switzerland, 2005* (2005). `http://www.ascona2005.ethz.ch`.

[GMD05] GEORGOPOULOS A., MAKRIS G.N., DERMENTZOPOULOS A.: An alternative method for large scale orthophoto production. In *Proc. of the CIPA XX International Symposium, Torino, Italy, IAPRS* (2005), vol. XXXVI-5/C34, pp. 300–303.

[Iak03] IAKOVIDIS S.: *Archaeological Atlas of Mycenae*. The Archaeological Society at Athens Library No 229, 2003.

[Mar54] MARINATOS S.: Short Research Projects in the Mycenae. *Archaeological Ephemeris*, Athens, (1954) (in Greek).

[TKP01] THEODOROPOULOU I., KARRAS G., PETSA E.: Digital surface developments of large cylindrical and conical structures with a single image technique. *Photogrammetric Record*, 2001, vol. 17(97), pp. 25–37.

[Vas95] VASSILIKOU N.: *The Mycenaean Civilization*. The Archaeological Society at Athens, 1995 (in Greek).

[Wac49] WACE A. J. B.: *Mycenae an archaeological history and guide*. Princeton University, New Jersey, 1949.

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
VAST (2006)
M. Ioannides, D. Arnold, F. Niccolucci, K. Mania (Editors)

Enhancement of the Cultural Heritage through an Augmented Reality Based Device

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Abstract

Enhancement of cultural heritage has become one of the most important tasks in built heritage conservation since the Declaration of Amsterdam. This declaration promoted a change in the approach to built heritage conservation and forced to consider the use-value, paying special attention to develop methods and tools to communicate, sensitize and educate users in the values of historical sites. Enhancement of cultural heritage by increasing the accessibility of the available information becomes a great opportunity to promote an historical site as a tourist area. According to this new approach, cultural heritage gives up being a "load" to become a "resource", and ensure its sustainability from economical, social and cultural points of view. One of the main challenges to achieve this goal consists of translating to the citizenship, in an attractive and effective way, the information about the cultural heritage of the site. The diffusion strategy and all methods, products, systems and tools used for this task will be the key in order to reach this objective. It is necessary a real will to promote it, giving priority to the diffusion strategies, and incorporating the new technologies. Information technologies offer the opportunity to make accessible this information in an attractive way, making it suitable for permanent and temporary users. The utilization of virtual and augmented reality technologies for the dissemination of the cultural heritage opens a great number of possibilities to the representation of great volume of information in a simple and direct way. These technologies allow the dynamical visualization and the interaction with the surrounding, as well as add contextual information to the environment, so that it should enhance the experience of the user with the system.

Categories and Subject Descriptors (according to ACM CCS): I.3.1 [Computer Graphics]: Three-dimensional displays, I.3.7 [Computer Graphics]: Virtual Reality, J.5 [Computer Applications]: Architecture

1. Introduction

Enhancement of cultural heritage has become one of the most important tasks in built heritage conservation since the Declaration of Amsterdam [Ams75], in which, for the first time, protection of historical sites was related with its inhabitants. This declaration promoted a change in the approach to built heritage conservation and forced to consider the use-value as well as the traditionally recognised values of cultural heritage (historical, artistic, documental …). Considering this use-value means directly to pay attention to users as the main stakeholders in built heritage conservation: first, because if there are not users, heritage is abandoned with no maintenance; second, because if users don't care about his heritage, its degradation can be accelerated; third, because if users operate in its heritage in a wrong way, they can damage it too. On the other side, users can be the best insurance for a good conservation of built heritage, if they know its importance and if they feel that its protection is a part of cultural identity.

All methods to communicate, sensitize and educate users in the values of historical sites are included in the enhancement strategies of cultural heritage. Enhancement strategies are often directed to two different kinds of users:

- Permanent users: inhabitants or workers of the tourist places or historical sites.
- Temporary users: visitors, tourists.

The aim of these strategies is to make available for the users all the existing information about the historical site and in the same time to allow them to select information they are interested in. Information technologies offer the opportunity to make accessible this information in an attractive way, making it suitable for permanent and temporary users. For this reason, enhancement strategies incorporate very quickly all technological advances in this field.

In this paper we analyse the use of information technologies in general and augmented reality technologies in particular as a mean for enhancement of cultural heritage resources in order to make it sustainable. The main advantages provided by augmented reality technologies as a tool for the dissemination and promotion of cultural heritage are presented as well in this paper. At the end we describe a device based on augmented reality technologies, called Augmented Reality Tourist Telescope, which allows visualization and recreation of tourist singular environments. The description focuses on the selection of the appropriate technology for each of the modules of the Tourist Telescope.

2. Information Technologies for the Enhancement of the Cultural Heritage

The evolution towards the knowledge society will drive an increase of the cultural tourism, which demands global information about the places visited by the tourist; heritage, leisure and culture, hotels and restaurants, city services, etc. Enhancement of cultural heritage by increasing the accessibility of the available information becomes a great opportunity to promote an historical site as a tourist area. According to this new approach, the cultural heritage gives up being a "load" to become a "resource", and ensure its sustainability from economical, social and cultural points of view [Ceb01].

Therefore, it becomes necessary to develop methods, products, systems and tools that allow to approach the cultural heritage to the citizen and the visitors with the purpose of knowing it, to understand it and, thus, to value it. In the last years, multiple tools have been developed in this sense; many of them based on the information technologies, with a great acceptance according to user's opinion. Several initiatives are carried out from different institutions and companies with the aim to promote the tourism of a city, region or country [Rou00]. These initiatives range from advertisements in press and television, to small initiatives of reduced groups that on a smaller scale look for the promotion and dissemination of the tourism.

The use of the information technologies in order to bring the patrimony near the society is becoming more and more usual [GP04]. Multimedia contents, interactive elements, audio-guides, etc. all of them are nowadays elements that have been incorporated, in a natural way, into the world of tourism. Virtual and augmented reality technologies are beginning to be considered as one of the main tools to visualize, imagine and understand relevant aspects of the elements of tourist interest that cannot be perceived usually through the senses or using traditional techniques.

3. Augmented Reality Benefits

In the museums and other cultural heritage exhibitions we can notice the growing demand in the use of new technologies for the development of heritage interpretation tools. Within these new technologies one of the most promising one appears to be the augmented reality. Augmented reality is a novel technology, presented as a variation of the virtual reality, the main difference between them is that the augmented reality allows the user to see the real world augmented with computer generated information [AB01]. Augmented reality makes these applications to be visualized in-situ in contrast to the virtual reality applications which drive the user into a purely digital environment. The augmentation consists of adding any digital information (3D models, images, labels, etc.) to the real elements in the environment. Digital information is presented in the context of the user position and point of view. Ideally the user perceives that real and virtual information coexist in the same place.

The application of augmented reality technologies in the area of cultural heritage is very extensive; they provide a very innovative mean for the dissemination, promotion, education, sensitization, and even preservation of the cultural sites or objects [Arc06]. Dissemination of the cultural heritage is one of the areas in which these technologies are very widespread. Augmented reality technologies provide the way to easily access to the general public to the big amount of technical information available about historical sites. The visualization from inaccessible points of view is also allowed by the augmented reality technologies. The historical phases in the evolution of a building or monument can be also visualized by the use of these technologies without performing any intervention in the real environment. Missing or damaged objects or even historical avatars can be combined with the existing elements in an augmented reality application. Other applications such as augmented reality games are really interesting for the dissemination of the cultural heritage, because of the possibility to access to the information about these sites in an interactive and amazing way. Another application usually well appreciated by the visitors in historical sites consists of using these technologies for guiding people through previously defined paths and oriented to the user preferences.

The promotion and dissemination of the cultural heritage are very much related each other; similar applications to the previously described can be used as a channel for the promotion of an historical site. Although very close related to both promotion and dissemination, sensitization adds the importance to use different means or channels to different audience, while promotion and dissemination is pretty much oriented to the general public. For this purpose, augmented reality can be used with the aim of showing the necessity of taking care about the cultural heritage, as a tool to facilitate the comprehension of a project and the necessity of an intervention, and sensitization of people especially affected by necessary interventions.

Cultural heritage makes use of these technologies for deep research and studies in order to preserve existing heritage by means of digital replicas [Ena06]. With the same purpose, the digital information can be used to access to sites which require restricted access due to their conditions. Education using augmented reality is one of the main areas of application of these technologies. Innovative learning tools for special collectives such as educative games or augmented books for students, simulation tools for professionals or tools for disabled people based on augmented reality have in general a very good acceptance.

The main benefits provided by the augmented reality technologies in the cultural heritage environments are listed below:

- Dynamic, attractive and interactive visualization of the information, supported by the use of multimedia contents (images, videos, animations, 3D models, etc.).
- The representation of great volume of information resulting from historical studies in a way to be accessible and comprehensive to the general public.
- The digital information is provided in the context of the user position and point of view and integrated with the real information captured by the senses.
- Extend the potential users or visitors to collectives who traditionally are not very interested in the cultural heritage (children, teenagers, etc.)
- Facilitate the guidance and support about the places and elements of interest during the visit.
- Provide high degree of realism, since this technology shows digital information added to the real information perceived.
- Allow the visualization from points of view which are inaccessible, too distant or difficult to access.
- Make possible the representation of the evolution of status, use and activity of an historical site.
- Eliminate physical or social barriers, as the language, which traditionally finds visitors in a foreign country.

4. The Augmented Reality Tourist Telescope

In this section we want to present the results in the development of a Tourist Telescope based on augmented reality technologies, as a system to allow the visualization and the recreation of tourist singular environments of the cultural heritage. The augmented reality tourist telescope consist of an augmented reality video-through system, through which the user explore it's surrounding, which is completed with digital information.

The development consists of a hardware device, a software platform and an application that demonstrates the value of the system for that purpose. Digital information is used to complete the perception provided by a traditional panoramic telescope. To complete the above mentioned information consists of adding multimedia contents to the perception obtained by means of a traditional telescope. These multimedia contents provide additional information improving the perception and allowing the recreation of the environment.

One of the main added values of the presented development is based on the possibility of obtaining contextual information according to the user's point of view and in-situ integrated with the real environment. Thus, the user receives information about the objects on which he/she has showed his/her interest every time. This functionality is achieved by means of the augmented reality technologies. The provided information will help the user to know, understand and even to value the place he/she is looking at.

The system described above consists of two well differentiated parts. On the one hand the physical device and on the other one the application developed for this device. The description of the device is focused on the selection of the most suitable elements for each of the components of the device. Regarding the application, the most significant contents for this kind of application are presented.

4.1 Device

One of the main tasks carried out for the implementation of the augmented reality tourist telescope device consists on the evaluation and selection of the most appropriate elements for each of the components of the device. The physical device consists of four basic modules each of them with well defined functionalities. These components correspond with the elements of an augmented reality system (see Figure 1).

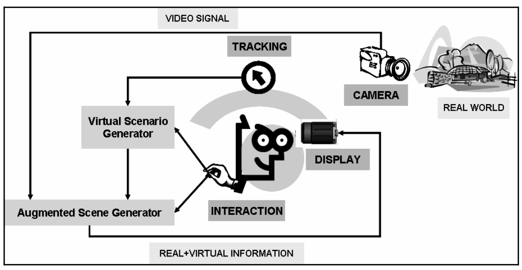

Figure 1: *Augmented Reality System*

Each of these elements has the responsibility of the tasks to it assigned. The following are the modules of the system:

- Image capture module
- Visualization module
- Tracking module
- Interaction module

These modules are integrated in a compact way inside the same external structure of the traditional panoramic viewers, see Figure 2. This structure is the responsible for providing the strength, water-proof and anti-vandalism properties to the system.

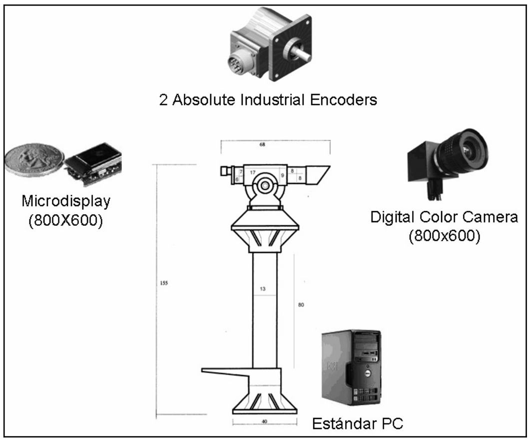

Figure 2: *Modules of the telescope.*

Image capture module

The image capture module is in charge of taking the images of the real environment, the ones that are going to be completed with the digital information. This component is one of the core elements of a video-through augmented reality system. The quality of the image is one of the key requirements for the success of such kind of systems, so as the selection of the camera is crucial for that purpose.

The first approach consists of selecting a webcam as image capture element. This kind of devices is connected to the PC through the standard USB port, is cheap and widespread, and is very easy to configure. Nevertheless, the quality of the image provided is too low (up to 640x480 VGA), no functionalities apart from providing the captured image, no optical zoom and low level of interaction from the PC.

Another alternative is the so called "block camera", they are compact cameras, high resolution and include optical zoom which is controlled as well as the other parameters from the PC through the VISCA protocol. The main drawback of these cameras is that they provide analogue output instead of digital one. In order to use as an input for the software, it is necessary to convert into digital video. For this purpose a video capture card has to be added to the system.

There is also the option of using surveillance video cameras; the cameras used for that purpose provide digital video output (Firewire IEEE 1394), optical zoom and high resolution. Unfortunately, the dimensions of these cameras are generally too big and they are much more expensive than the other alternatives.

With the requirements of dimensions and weight imposed by the external structure, digital video output, high resolution (800x600 SVGA) and USB 2.0 high speed connection, the selected camera is the VRmC-4pro from VRmagic.

Visualization module

The visualization module is the responsible for showing the information to the user. The information to be presented corresponds with the composition of the real image captured by the camera and the virtual scene generated by the system. The solution represents a totally immersive device, when the user observes the environment through the tourist telescope. However the design of the device represents a good solution to swap between the augmented visualization and the real one and vice versa. The selection of the visualization device was done once evaluated the specifications and integration capabilities of each of the detected alternatives. The main requirements for the visualization module concern with the limited size of the device and the high resolution desired.

Three main alternatives have been detected and evaluated to be used as visualization device. Virtual reality binoculars are the most suitable alternative according to the purpose of the solution, however the size and above all the high prices of such devices makes this alternative unsuitable.

Virtual reality/augmented reality HMD is the alternative which presents the most extensive variety of devices, this makes easy to find a device with the expected requirements. Augmented reality HMDs are more expensive but integrate the camera(s) into the same device, this is not an added value in our case because the shape of the external structure makes necessary a distance between the camera and the visualization device. Moreover, both, virtual and augmented reality HMD solutions provide stereoscopic visualization, however ergonomically the design of such devices does not fit with the requirements, so as the devices are too big and must be adapted.

The third and most suitable alternative consists of using one of the new visualization solutions based on reduced size and high resolution displays. These devices are called microdisplays or near-eye solutions. There exist several technologies used for the development of such visualization devices; AMLCD (Active Matrix

LCD), the main features of this technology are: small size, low power, high resolution and low cost. This type of technology has been used widely for the development of visors of small digital image devices as video cameras, photo cameras, mobile phones, etc. LCOS (Liquid Cristal on Silicon) this technology represents a hybrid between the LCD and DLP technologies. This technology has been mainly used for projectors though it is not the only one example of use. The main properties of this technology are: high resolution, low power and reduced time of components life, apart from its small size. OLED (Organic Light-Emitting Diode) the main attribute of this technology is the capability to emit light, opposite to the other technologies based on the modulation of light emitted by an external light source. This technology is very innovative and appears as natural substitute for the visualization devices based on LCD technologies. This technology has the following advantages, more brightness and contrast, high frame rate, lighter, lower power consumption and it is cheaper to produce.

Due to these characteristics and the innovation of the technology we chose this technology for the visualization module. The selected device is the Liteye LE-400 from Liteye. The device represents a solution of immersive visualization provided by a small size and high resolution visor.

Tracking module

The tracking module is in charge of determining the position and orientation corresponding to the user position and point of view. This information is necessary in order to place the digital information relative to the real environment captured by the camera. Positioning is one of the most critical tasks of an augmented reality system. An ideal tracking system is that whose position sensor or positioning module provides a perfect and instantaneous measurement in six degrees of freedom (6 DOF), three for the position and three for the orientation. Of course, the ideal tracking system does not exist and the challenge consists of finding the solution that better fits every real environment.

There exist several technologies for positioning, in our case, the telescope will be placed in a fixed and known position, so only the orientation of the device is necessary in order to determine the 6 DOF. For this reason, the positioning systems that better fits our environment are those based on inertial and mechanical technologies. Both alternatives provide unintrusive, small size and not too expensive systems.

Inertial tracking systems are quite precise and very appropriate for head movement tracking. However, the main drawbacks of this technology are related with the drift, the initial calibration and the sensitivity to the environment. The mechanical positioning systems are the ideal solution for the development of devices where very precise movements are required. For high accuracy positioning and free movement around one or several shafts, the selection of mechanical tracking is a very suitable solution. The tracking module of the telescope consists of two encoders which determine the orientation of the device in two of the axis (pitch and yaw). The market of the industrial encoders is really wide. The main properties of the selected device are the robustness required for the specific environment, as well as the availability to connect the device directly to the PC by the RS232 serial port.

Interaction module

The interaction module allows the user-device communication. This module is the one that mainly differentiates the described telescope from the systems that display movies or pre-recorded multimedia contents. In this case, the system allows the user to personalize the information to be displayed on the device by means of the user interaction.

The alternatives analyzed for this module looks for interaction elements and metaphors that turn out to be intuitive for the user. Elements such as joystick, mice, buttons or even trackballs are commonly widespread as interaction devices in order to communicate with a PC. The use of a tactile screen opens up the possibility to interact with the system without any additional device; however the selection of the microdisplay as the visualization element makes this alternative unavailable. The inclusion of traditional interaction devices such as buttons or mouse will be considered in a future next version of the telescope.

For this version we introduced a basic concept of interaction based on the orientation of the telescope. The user will show his/her interest in an element in the scene by orienting the telescope to the selected element. The application will define interaction elements which will be displayed on the screen as selectable icons. The point of the view of the user will determine the selected icon and so the sequence of the story without any additional interaction devices.

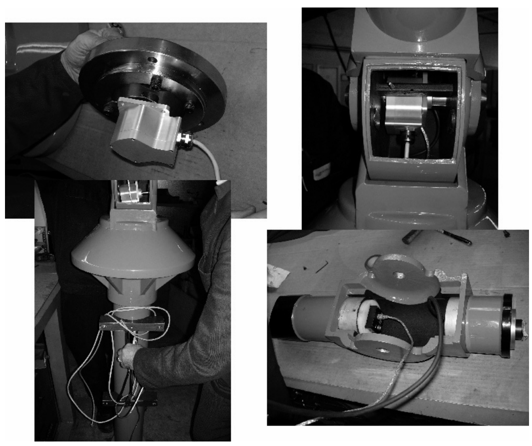

Figure 3: *Pictures from the mechanical assembly*

We decided to use as external structure of the device the same structure of the traditional panoramic visualization devices. This kind of devices are very appropriate for our case because of the robustness, anti-vandalism, resistance to adverse weather conditions and break-down adequate to put inside the selected devices for each module. Apart form its reasonable price.

4.2 Application

Augmented reality applications are based on a software platform that supports the connection and integration of each of the modules through a common interface. The platform works in two different modes, runtime mode, when the user interacts with the application using the telescope, and authoring mode when the application author implements the application. Figure 4 shows the main components of the augmented reality platform.

The three main elements of the software platform are: the graphical engine, the logical engine and the components. Graphical engine manages all related with the creation and visualization of the augmented scene; it represents the way that the logic of the application is presented to the user. Logical engine is responsible for the management and integration of all the components in the application. It is also in charge of the execution of the application providing feedback for the graphical engine to visualize the results. Components are the core elements of an application. There are different levels of abstraction in the components hierarchy, from the low level components which provide the basic functionalities of an augmented reality system, to the medium and high level ones, both application oriented but the first ones correspond with basic and simple components, and the high level ones related to complex functionalities built upon a composition of simple components.

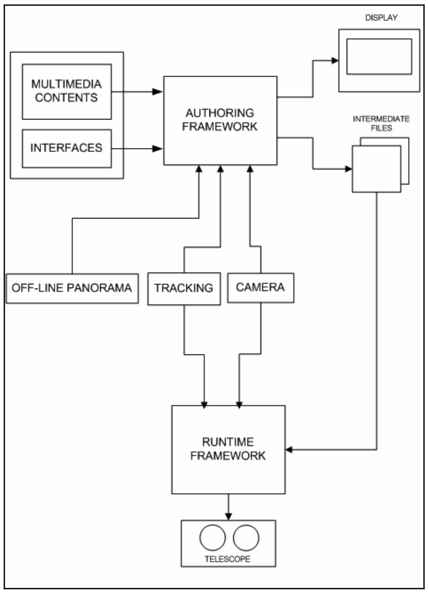

Figure 4: *Augmented Reality Platform*

Authoring tool is the resource developed for the creation and edition of augmented reality applications for the telescope. The development of the application consists of the selection of the appropriated components and contents to be visualized to the user according to the point of view and actions performed. It has been defined two different edition modes; on-line edition and off-line edition. The on-line edition takes place in-situ and uses the camera and the tracking device included in the telescope to capture the real image to be augmented. The off-line edition makes use of a pre-recorded panorama of the scene; this panorama simulates the image capture of the real camera.

Multimedia contents are the main components of an augmented reality application. The most significant contents to be included in the applications are:

- **Multimedia elements**: Almost all kind of multimedia information can be part of an augmented reality application. As a response to a user action or as a result of a internally programmed task any of this content can be shown on the display integrated with the real image captured by the camera. Different formats of multimedia information can be displayed: 2D and 3D images or photographs, text elements, videos, animations, etc.
- **Graphical 3D elements**: As a special kind of multimedia elements, the graphical 3D models are the main resource of an augmented reality application. Any 2D multimedia element can become 3D when they are placed in the 3D position. These elements are really useful to locate elements in the real scene, complement the real video with missing information or show routes

or not visible elements in the images captured by the camera.

- **Interaction elements**: These elements allow the user to interact with the application. Interaction elements are generally displayed as 2D or 3D images or buttons. As a result of the interaction, additional information is shown as any of the previous mentioned types.

Figure 5: *Application example*

Definitively, what the device allows the user is to visualize an interactive multimedia application. The multimedia contents complement the real information captured by the camera and the interaction elements allow the user to personalize the story shown in the device. *Figure 5* shows an application example.

5. Conclusions

Enhancement of cultural heritage has become one of the most important tasks in built heritage conservation. Nowadays the kind of tourism that society demands is quite different from the traditional one. The evolution towards the knowledge society increases the demand of a cultural tourism. This tourism demands information that helps the visitor to understand and know more about the visited places. This kind of information generally exists in a format accessible to experts and professionals but not for the general public. Enhancement of cultural heritage by increasing the accessibility of the available information becomes a great opportunity to promote historical sites. New technologies provide the possibility to bring near the tourist all this information. This is the first step for the citizen to understand the cultural heritage, to value it and even to interest in it. At the end making the heritage is sustainable from economical, social and cultural point of view.

Augmented reality is a novel technology that better fits for the enhancement of the cultural heritage. This technology represents an innovative way of presenting digital information combined with the real environment. Augmented reality is a very appropriate technology for the dissemination, promotion, education, sensitization and preservation of the cultural heritage. Many are the benefits provided by this technology and the acceptance by the audience is very good in general.

As an example of the use of augmented reality technologies for the enhancement of the cultural heritage, we have developed an augmented reality tourist telescope for the recreation of singular tourist environments. The device looks like the traditional panoramic viewers but includes inside all the devices required to build an augmented reality system. These devices are a high resolution digital camera, two mechanical encoders as the basic for the tracking and interaction modules and a compact, very small size and high resolution display. Two applications have been developed in order to validate the telescope.

Acknowledgements

The work described in this paper is based on a project partially funded by the Basque Country Government inside the program of support of the Basque Government to the local enterprises. The project is called BIT and it is a result of the collaboration between two Basque companies Repair Systems and MIESA and the Technological Centre LABEIN-Tecnalia. We also want to thank two institutions in the area of heritage and tourism management, which participate in this project providing the information and the knowledge to demonstrate the availability of this system in two real environments. Bilbao Turismo in Bilbao (Spain) and Oficina del Historiador de La Habana in La Habana (Cuba).

References

[AB01] Azuma, R., Baillot, Y.: Recent Advances in Augmented Reality, Computer Graphics and Application. Nov/Dec 2001.

[Ams75] The Declaration of Amsterdam. Congress on the European Architectural Heritage. 21 - 25 October 1975.

[Arc06] Archeoguide (Augmented Reality based Cul-tural Heritage On-site Guide). http://archeoguide.intranet.gr/ July 2006.

[Ceb01] Cebrian, A.: Turismo cultural y desarrollo sostenible. Análisis de áreas patrimoniales. 2001.

[Ena06] Ename TimeScope 1 Concept. http://www.ename974.org/Eng/pagina/archeo_concept.html July 2006.

[GP04] Geser, G., Pereira, J.: DigiCULT Thematic Issue 7: The Future Digital Heritage Space. December 2004.

[Rou00] Roussou M. Virtual Heritage: From the research Lab to the broad public. In Proceedings of VAST 2000 Euroconference pp 93-100. Arezzo. Italy. 2000

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
VAST (2006)
M. Ioannides, D. Arnold, F. Niccolucci, K. Mania (Editors)

The European (Digital) Library - Overview and Outlook

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Abstract

The European Library (www.theeuropeanlibrary.org) is a multilingual portal offering integrated access to the tens of millions of resources (books, magazines, journals...) of 18 national libraries in Europe. It offers free searching and delivers both digital and non-digital objects. It provides a vast virtual collection of materials from all disciplines. The European Library is currently being expanded with the holdings of the national libraries of the 10 EU New Member States. From September 2006 onwards the remaining EU and EFTA national libraries will be connected to TheEuropeanLibrary.org, bringing the total number of participating national libraries to ±35 by the end of 2008.

In the beginning of 2006 the EC expressed support for The European Library to evolve into a much bigger European Digital Library (EDL), including access to the digital collections of other major cultural heritage institutions, such as museums and archives. The EDL is planned to include the holdings of all European national libraries and a minimum of 2M digital works by the end of 2008. By 2010 the EDL needs to have expanded to include collections of archives, museums and other libraries, with a minimum of 6M digital works.

The European Library aims to remain a major player in the European cultural heritage field and is already strengthening its cooperation with other relevant key initiatives, such as MACS, DELOS, MICHAEL, BRICKS and MINERVA.

K.4.3 Organizational Impacts: Computer-supported collaborative work
K.6.1 Project and People Management: Strategic information systems planning, Systems development

1. Introduction

To date there are 45 official national libraries in Europe. These libraries have been collaborating since 1987, when the Conference of European National Librarians [CENL] was founded. CENL aims to increase and reinforce the role of national libraries in Europe, in particular in respect of their responsibilities for maintaining the national cultural heritage and ensuring the accessibility of knowledge in that field.

Members of CENL are the national libraries of the member states of the Council of Europe and Vatican City. The Conference currently consists of 45 members from 43 European countries (Italy and Russia have two member libraries each).

2. The European Library

The European Library [TEL] was launched on 17th March 2005. It provides multilingual resource discovery facilities for researchers and informed citizens. It offers integrated access to the tens of millions of resources (books, magazines, journals... - both digital and non-digital) of 18 national libraries of Europe. It offers free searching and delivers digital objects - some free, some priced. Besides this, it also gives practical information about the participating libraries.

The 18 participants in The European Library are the CENL members of Austria, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Hungary, Italy, Latvia, Netherlands, Portugal, Serbia, Slovakia, Slovenia, Switzerland and the UK, along with ICCU (the national central cataloguing institute from Rome, Italy).

TheEuropeanLibrary.org has added value

A. For the users, because

- Of the phenomenal depth and quality of trusted deep web resources held in the national libraries.
- It gives easy access to native resources held in other countries.
- It enables types of collection-level searching which would otherwise be impossible.
- It is a major contribution to research both in making resources widely available and by making possible new connections through exploitation of a huge virtual library collection.

B. For the participating national libraries, because

- It provides an international showcase for their collections, products and services.
- It gives them an increased exposure on the world stage with combined political mass providing greater marketing and negotiation power.
- It gives libraries a feedback loop on what users are expecting on a European scale.
- The European Library is a mechanism to extend collaboration (Paragraphs 3 and 6).

C. For the content, because

- It provides feedback on user demands which can prioritise institutional and national digitisation activities.
- The European Library provides a cooperative framework for continuous development, sharing and innovation in metadata, interoperability and other technical standards.

The European Library is targeted at informed citizens world-wide - both professional and non-professional - who want a powerful and simple way of finding library materials. Moreover, it attracts researchers as there is a vast virtual collection of materials from all disciplines. It offers anyone with an interest a simple route to access European cultural resources.

Hence, the vision of The European Library is

Provision of equal access to promote world-wide understanding of the richness and diversity of European learning and culture.

and its mission is

The European Library exists to open up the universe of knowledge, information and cultures of all Europe's national libraries.

3. TEL-ME-MOR – expanding the network

Started in February 2005, the 1.4M€ TEL-ME-MOR project [TELMEMOR] is a two-year project funded by the European Union (EU) with the overall goal of stimulating and facilitating institutions and organisations from the 10 New Member States (NMS) of the European Union to apply for future EU funding in the field of cultural heritage, learning and ICT.

In addition there is a more practical goal to *T*he *E*uropean *L*ibrary: *M*odular *E*xtensions for *M*ediating *O*nline *R*esources: preparing the ten NMS national libraries to become participants of The European Library. The national library of Slovenia is already a participant, so it will only benefit directly from the first objective.

TEL-ME-MOR addresses the cultural, educational, industrial and public sectors. It aims to bring together the various professional networks, the authorities which are responsible for the institutions and their services to the research sector and the research, scholarly & IT communities. In particular, the project targets the following audiences:

- Libraries, museums, archives
- Educational institutions (schools, universities, etc.)
- Researchers
- Government agencies and policy makers
- Local authorities

The activities of the TEL-ME-MOR project are organised into five main areas. They deal with

1. The analysis of research requirements in the NMS
2. The development of the multilingual capacity of the network
3. Awareness building and electronic information space for research partnerships.
4. Management, coordination and evaluation activities of the project.

The fifth area deals with developing the network for access to national resources. In other words: the collections from the NMS national libraries are made ready to be included in TheEuropeanLibrary.org In addition this area aims to raise the profile of this knowledge network in the NMS.

Besides the added values mentioned in Paragraph 2, the benefits of this project to the growth of The European Library are:

- The creation of new quality and trusted resources for end-users. Currently there are around 175 collections available in The European Library portal. The TEL-ME-MOR partners will contribute an extra 52 collections by the beginning of 2007.
- The extension of the existing network and collaborative framework in the field of technology,

open standards and the development & sharing of knowledge.

- The extended profile and increased political mass of The European Library. This might serve as an example for cooperation with and between other European cultural institutions, such as archives and museums (see Paragraph 6)

4. Towards a European Digital Library - A European vision comes to life

In December 2004 Google announced its plans to digitise and publish online 15 million volumes from four prestigious US libraries (Stanford, Michigan, Harvard and New York) and from the Oxford University Library in the UK by the year 2015. This bold initiative sparked a wave of (panic?) activities across Europe.

In an article in the French newspaper Le Monde the President of the French national library, Jean-Noël Jeanneney, expressed his concern that Google's initiative could create a bias towards the English language and Anglo-American culture. He stressed the cultural diversity and multilingualism as basic values of the European culture. His comments were widely picked up in the media, who immediately presented it as a 'cultural war with Google'. In the weeks after the article, Jeanneney weakened his statements, but remained the key figure in awakening decision makers and mobilising funds for the digitisation of European cultural heritage.

Making the holdings of Europe's libraries and archives available online will not be a trivial task. Firstly, there is a wide range of different materials available - books, film fragments, photographs, manuscripts, sheet music, speeches, sounds, etc. Secondly, what materials to select from around 2.5 billion books and bound periodicals in Europe's libraries and millions of hours of film and video in its audiovisual archives?

Things began to speed up when the French call for safeguarding the European cultural heritage got critical backing from the leaders of five countries, supporting French President Jacques Chirac in asking for coordination and funding from the European Union to create a 'European Digital Library'. This initiative found the support of a broad coalition of national libraries from Germany, Austria, Belgium, Cyprus, Denmark, Spain, Estonia, Finland, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, the Czech Republic, Slovenia, Slovakia, Sweden and the UK.

The European Union recognised the vital importance to digitise, preserve, and make Europe's written and audiovisual heritage available on the internet and usable for European citizens, innovators, artists and entrepreneurs for their studies, work or leisure, for now and for future generations. The first concrete action was the launch of an online consultation on 30 September 2005. All interested individuals and organisations were invited to give their views on a number of key issues concerning the creation of a European Digital Library. The consultation closed on 20 January 2006 and received 225 replies. In general, the initiative was welcomed and seen as an opportunity to make Europe's cultural heritage more accessible and usable.

Regarding the technology of a proposed European Digital Library, it was clear from the beginning that any kind of central database would be impossible to achieve, but - similar to The European Library portal - integrated multilingual access to the digitised materials of Europe's cultural institutions (libraries, archives, museums) would be more realistic. The contents of the European Digital Library would thus grow at the same speed as the underlying digital collections in the participating institutions.

It was also stressed from the start that the European Digital Library should not be constructed from scratch, but build on existing initiatives. In fact, the results of the online consultation indicated that The European Library would be a very good starting point, because it not only offers a working technological platform based on common standards, but also provides a firm cooperative organisational framework in which European national libraries already collaborate and have experimented with improving the online accessibility of their digital assets. As for the remaining two ingredients for a successful European Digital Library: the digitisation of many more resources and the challenge of multilingual search & retrieval still require more attention, research and commitment in the years ahead.

On 27 February 2006 the European Commission decided to set up a 20 member High Level Expert Group on Digital Libraries to advise the Commission on how to best address the organisational, legal and technical challenges at a European level and to contribute to a shared strategic vision for the European Digital Library. A few days later the EU announced its next steps for this flagship project, already called 'one of the greatest digital construction projects ever undertaken'. The decision to co-fund the creation of a Europe-wide network of digitisation centres and to address the issues of copyright protection was welcomed by CENL with great enthusiasm.

The proposed timeline of the EU is as follows:

- 2006 - Full EU-wide collaboration between national libraries in the framework of The European Library and the CENL.
- 2008 - Multilingual access to digital collections of national libraries through The European Library portal. The collections must be searchable and usable. A minimum of 2 million digital

works (books, pictures, sound files etc.) should be accessible through the European Digital Library.

- 2010 - The European Digital Library needs to have expanded to include collections of a number of archives, museums and other libraries, and possibly publishers. A minimum of 6 million digital works should be accessible through the European Digital Library. In practice, this number can be much higher, if cultural institutions of different types and at different levels (national, regional, local) participate.

5. The role of CENL and The European Library

As a response to this, CENL had to re-think the position of The European Library within the bigger framework of the European Digital Library. At the time of writing this is very much an ongoing process, but for now The European Library sees itself as the means of providing access. This 'access' is for the long term. It is based on creating, maintaining and conforming to standards in metadata, collection and service descriptions, data harvesting and access protocols. By creating a network across the 45 CENL member libraries there is a practical implementation of standards at an international level. The European Library can also help the priority in digitisation from analysis of user statistics and it can operate as a model organisational structure for cooperation with other cultural heritage institutions, universities, publishers and information providers on a European as well as on a global level.

Starting from the current 18 Full Participants, the first set of measures of The European Library for the years to come are:

- By the end of 2006 the remaining NMS libraries should join as a result of the TEL-ME-MOR project.
- From September '06 onwards work will start to bring another 9 libraries in the EU and EFTA on board by the end of 2007 [EDLPROJECT].
- Continue to work to persuade non-EU libraries to become participants, such as Turkey, Russia and Ukraine, further strengthening and widening the political mass of CENL.

From the point of view of digital content, CENL has started a second set of actions early 2006. In the present European Library portal there are some rich seams of digitised materials, such as maps, music scores, manuscripts and posters. However, there is an emphasis on catalogues, rather than digital resources. Given the fact that currently only 5-10% of the metadata is enriched by digital objects, there is a desperate need for more (digital) content on The European Library.

Because of this, CENL has set an overall goal for the coming years to digitise more content more quickly and to make sure that access is as complete as possible. This includes investigating what means are already or could become available within and across the libraries to make more efficient use of existing content-rich collections and investigating ways to facilitate the creation of virtual content-rich collections across (and within) the libraries (especially via promoting common metadata and access standards).

6. Strengthening the cooperation

As a third series of measures to define and reinforce their position in the scope of the European Digital Library, CENL and The European Library have started working together with a number of relevant key initiatives in the cultural heritage field.

6.1 MACS – *Multilingual Access to Subjects*

To investigate the challenge of multilingual search & retrieval, The European Library is looking at the MACS project [MACS]. This CENL initiative aims to provide multilingual subject access to library catalogues. It enables users to simultaneously search the catalogues of the project's partner libraries in the language of their choice (English, French, German). This multilingual search is made possible thanks to the equivalence links created between the three indexing languages used in these libraries: SWD (for German), RAMEAU (for French) and LCSH (for English). Headings from the three lists are analysed to determine whether they are exact or partial matches, of a simple or complex nature. The end result is neither a translation nor a new thesaurus but a mapping of existing and widely used indexing languages.

6.2 DELOS – *Network of Excellence on Digital Libraries*

The DELOS network [DELOS] intends to conduct a joint program of activities aimed at integrating and coordinating the ongoing research activities of the major European teams working in Digital Library-related areas with the goal of developing the next generation Digital Library technologies.

The cooperation between DELOS and The European Library focuses primarily on the integration of DELOS-provided functionality into the existing The European Library portal and ensures that duplication of activity does not take place. DELOS has also benchmarked version 1.1 of The European Library software against its own benchmark standards.

6.3 MICHAEL – *Multilingual Inventory of Cultural Heritage in Europe*

France, Italy and the UK are working together on, a ground-breaking project that aims to provide simple and quick access to the digital collections of museums, libraries and archives from different European countries. The project [MICHAEL] began in June 2004, with the focus on implementing an innovative multilingual open source platform that will be equipped with a search engine. The Czech Republic, Finland, Germany, Greece, Hungary, Malta, the Netherlands and Poland have also indicated interest. By 2007 the MICHAEL portal should be available in at least 12 European languages and will be capable of retrieving digital collections that are dispersed across Europe.

The European Library has approached MICHAEL to start talks aimed at ways of building on each others knowledge using the expertise within the networks and finding ways of jointly presenting content to the user.

6.4 MINERVA – *Ministerial Network for Valorising Activities in Digitisation*

MICHAEL was launched as spin-off of the MINERVA working group [MINERVA]. MINERVA is a network of EU Member States' Ministries to discuss, correlate and harmonise activities carried out in digitisation of cultural and scientific content for creating an agreed European common platform, recommendations and guidelines about digitisation, metadata, long-term accessibility and preservation. Due to the high level of commitment assured by the involvement of EU governments, it aims to coordinate national programmes, and its approach is strongly based on the principle of embeddedness in national digitisation activities.

6.5 BRICKS – *Building resources for Integrated Cultural Knowledge Services*

At the moment of writing The European Library is also starting talks with BRICKS. This project [BRICKS] works with museums, libraries and other organisations and aims to maximise the impact for the construction of a shared digital heritage, which nevertheless respects the European cultural diversity. Its "bottom-up" approach, which is based on the interoperability of a dynamic community of local systems, maximises the use of existing resources and know-how, and, therefore, national investments. BRICKS will contribute in:

a) tuning the mission of memory institutions in the digital era,

b) developing a shared vision for the exploitation of digital cultural content and

c) encouraging cultural cooperation for the construction of an interoperable cultural capital. BRICKS currently has 50 member organisations, also outside Europe.

7. Conclusion

This short overview shows that there have been many separate beginnings. The big challenge in the years ahead will be to unite the efforts that have started and provide easy and efficient access to the spectrum of collections, not only to European citizens, but also to the rest of the world. It is very unlikely that any of the parties mentioned here can and will have the resources and commitment to do all the work on its own. In the end it will come down to getting the various contributors to cooperate. The organisation that can best manage this collaborative effort is likely have the ace up its sleeve.

References

[BRICKS] Building Resources for Integrated Cultural Knowledge Services
http://www.brickscommunity.org

[CENL] Conference of European National Librarians
http://www.cenl.org

[DELOS] Network of Excellence on Digital Libraries
http://www.delos.info

[EDLPROJECT] EDLProject
http://www.edlproject.eu

[MACS] Multilingual Access to Subjects
http://macs.cenl.org

[MICHAEL] Multilingual Inventory of Cultural Heritage in Europe
http://www.michael-culture.org

[MINERVA] Ministerial Network for Valorising Activities in Digitisation
http://www.minervaeurope.org

[TEL] The European Library
http://www.theeuropeanlibrary.org

[TELMEMOR] The European Library - Modular Extensions for Mediating Online Resources
http://www.telmemor.net

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Problems and achievements in the application of multimedia: cultural heritage and museum presentations in Hungary

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Abstract

Ideas regarding the preservation and visitor-friendly presentation of cultural heritage crop up continuously. These are partly aimed at the reinterpretation of previous, outdated in situ presentations and exhibitions, and partly induce new and progressive developments. In compliance with the Venice Charta, in the decades following WW II, Hungary followed a conservative approach with regard to the preservation of cultural heritage, which approach, although theoretically acceptable, was less successful from the visitors' point of view. However, the last 10-15 years have experienced tremendous changes, although not all of these were unanimously successful attempts. In view of the past decades and the statistical data on the number of visitors, the majority of cultural heritage sites are in need of development, and the require the application of novel methods.

Multimedia-based displays appeared in Hungary simultaneously with their application abroad, yet their content and validity were not always conceptually acceptable. In this presentation we will give an overview of attempts in Hungary – both failed and successful ones –, as well as the concepts and applicability of current projects. As visitor feedback demonstrates, multimedia applications have the potential to complement or freshen up – even as pilot studies – previous exhibitions very successfully. Nevertheless, the targeted and multifaceted application of IT methods, in harmony with the content of the presentation, is the way forward.

Introduction

At first, applied forms of museum presentations in Hungary were extremely simple, one may even say, simplistic. Only basic applications were utilised, that is, traditional museum exhibits of various sorts were illustrated using simple projections as a form of audiovisual presentation.

As a result, multimedia never gained a major emphasis. This would not have been possible at the beginning (some 10–12 years ago) anyway, since it was not only new ideas that had to be propagated, but technical problems also arose. Commercial hardware manufactured for the wider public did not prove to be sophisticated enough for professional use on an everyday basis. Actually, choosing the most appropriate product in this field poses a serious challenge even today. Consequently, the dated equipment with low speed but high maintenance costs hinders IT development in permanent or temporary exhibits in many museums. Most of them have proven useless even in the short run.

This brief review will be illustrated by examples of multimedia applications used in heritage management and museum presentations. By analysing the problems and questions that arose in connection with these examples, one may improve the chances of consciously choosing the most suitable types of multimedia presentation. One of the pioneering projects in presenting cultural heritage in a multi-faceted way was carried out at the Százhalombatta Archaeological Park. To begin with, the excavations of a Hallstatt Period (7th century BC) burial mound were an archaeological sensation in themselves. Many archaeological artefacts were retrieved, and moreover, the timber-structured burial chamber was also extremely well preserved, in a state most suitable for conservation. In 1997 the reconstructed burial mound could be opened to the public. Its modern architecture incorporated characteristic elements of the original, old structure, offering visitors another glimpse on Iron Age culture. Although the burial mound did not have an internal space to begin with, the modern construction was designed for the *in situ* presentation of the burial. This first hand information was supported by a didactic multimedia show, the effect of which was enhanced by the newly formed internal space. Burial rites of this period were presented in a ca. 10 minute film, then local varieties characteristic of Százhalombatta were illustrated for the visitor (the archaeological scenario was written up by E. Jerem and I. Poroszlai, the technical realisation was the work of A. Veres and Gy. Szemadám).

The film was accompanied by a narrated, didactical light show, highlighting relevant, *in situ* parts of the chamber explained by the narrator (*Fig. 1*). Both the architectural reconstruction of the mound and the successful presentation resulted in a heritage management project that may be considered modern even after a decade. The secret of Százhalombatta is that instead of offering only a single option, the multimedia show is an inseparable part of the feature. Without it the structure would not be possible to understand or interpret in the absence of a "real" tourist guide. The viability of this application is demonstrated by the unanimously positive opinion voiced by professionals and, more importantly, the visitors as well, including children. All this directs attention to the fact that it is not sufficient to conserve and protect excavated archaeological monuments. Presentations aimed at both the emotions and the intellect must be spectacular and professionally accurate at the same time, by using modern techniques in the relevant explanation.

Museum applications: problems and results

Experience has shown that the once fashionable and thus widespread *touch screen* technique has become a neglected accessory of several exhibitions. In fact, using this technique is a privilege of the educated few who are also willing to use it. It is usually not an integral part of the message the exhibition wishes to convey, thus its role remains complementary. Unfortunately, this solution cannot be an organic part of any exhibit, since it becomes practically inaccessible during group visits.

This is a conceptual and organisational question of major concern that should be addressed even in the early stages of planning an exhibition. It is of utmost importance to decide whether multimedia solutions can form an organic part of the visual concept or will they remain a mere accessory with only an optional use. Since there is an increasing demand for visitor-friendly and easily perceivable presentations, explanations must be built increasingly on the use of audiovisual aids. Meanwhile, it would be erroneous to suggest that smaller databases and search options used in museum presentations would satisfy the professional demands of specialists. The entire structure and operational algorhythms of professional databases are completely different from those required by an exhibition display, built on the browsing needs of the visitor.

One of the most persistently pursued and updated aims is the creation of audio-guide systems. The latest line of equipment may be activated by either menus or local signals, depending on the visitor's position within the visited space. This method has proven very useful and convenient, since in ideal cases it perfectly coordinates the intellectual capacity of the visitor and the information relevant to a certain location. A good example of this system in Hungary is the recently opened permanent exhibition of the Veszprém Museum (*Fig.2*). The system of information/communication in this exhibit is stratified in the following way:

The general view of the exhibit, a uniform overview of main pathways and exhibition cases.

1. The printed introduction of each thematic unit with any relevant written information.
2. Thematic units of special importance, defined in the basic concept, were illustrated with animated pictures on the monitor. Additional audio links provide commentaries and original soundtracks.
3. The audio-guide operates throughout the entire exhibit.

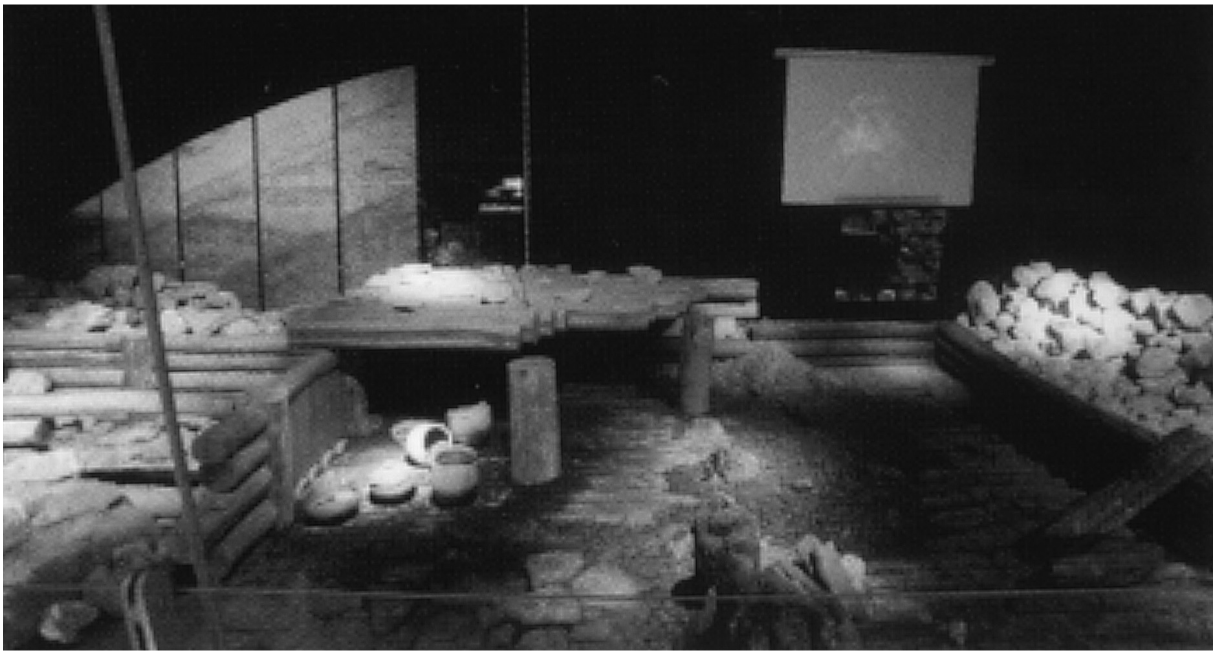

Figure 1: *Inside the Hallstatt Period burial mound including the screen, an integral part of multimedia presentation in the Százhalombatta Archaeological Park.*

A similarly modern solution was pursued in 2005, during the unfortunately short, temporary exhibit of the Budapest History Museum. This show presented the museum's activities during the last 15 years with a special emphasis on rescue excavations. Video screens were placed throughout the exhibit, sometimes even at eye level and above the showcases. The loud and clear audio commentaries were an absolute success. Fortunately, the memory of this short-lived experience has been immortalized in a catalogue, published in both Hungarian and English (Zsidi 2005).

The Hungarian National Museum has also selectively applied multimedia techniques in its permanent exhibit entitled "On the border between East and West". Although their use of this medium is predominantly illustrative in character, the multi-lingual audio-guide facilitates orientation for the increasing number of foreign visitors immensely. One of the main values of this exhibit is the presentation of real-life reconstructions that helps the prevalence of the archaeological material (Vasáros, Zsolt and Rezi Kató, Gábor [eds.] s.a.).

Figure 2: *All purpose use of multimedia equipment in the permanent exhibition of the Bakony Museum, Veszprém.*

Archaeological parks, presentation sites and visitor centres

In the case of previously opened archaeological parks and presentation sites, multimedia techniques serve the updating and modernising of earlier exhibitions. They also have a potential of creating auxiliary programs even more spectacular. One of the most impressive examples of exploiting this potential is the so-called "chronoscope" installed on location in the exhibit that presents virtual images of reconstructed Roman Period streets and buildings amongst the ruins of what was the provincial capital of Roman Pannonia, Aquincum (Zsidi 2006) (*Fig.3*).

Finally, I would like to briefly introduce three projects, still in the planning process, in which multimedia applications have attained a prominent role. One of these is the visitor centre to be built in the aforementioned Százhalombatta Archaeological Park. The final design is to be executed and the location of this centre has been decided on as well. According to the concept, both subterranean exhibition areas and the projection room and the adjacent educational centre near the reception hall would be fully equipped with up-to-date IT facilities.

The Szeleta Museum and Archaeological Park, to be built near the city of Miskolc, is also in the planning phase. However, IT applications also form an organic part of the design concept (Jerem et al. 2002 and 2004). The Palaeolithic period is very difficult to present to the wider public. Even fellow archaeologists involved in the study of later periods have a hard time appreciating this early phase of human history. In addition, during the 2.5 million years of development that is to be presented here, unusually great and significant changes took place. Modern IT technology and virtual reality (VR) in particular solve these problems. Archaeological reconstructions can thus be turned into an animated, life-like visual experience whose popular presentation could be attempted previously only with the help of traditional art (paintings and graphics).

The formation of caves, accumulation and transformation of their depositional layers, as well as the oscillation of the cooling and warming periods along with a north to south shift of climatic belts have taken millennia. These formative processes of the natural environment can be presented in accelerated forms using computerized simulations. Visuality is instrumental in the clear explanation and concomitant rapid perception at the interactive terminals whose software offers a glimpse of scientific research methods to the visitor. The program also provides a puzzle-like interface that shows how reconstructions can be made from various remains. For example, the appearance of extinct animals can be re-created from bones, ancient vegetation can be reconstructed using pollen evidence, and prehistoric human activity can also be simulated using the evidence of archaeological phenomena. Archaeological excavation inevitably destroys the original contexts in which artefacts are found. Using IT

Figure 3: *Virtual reconstruction of the Aquincum Civil Town (detail).*

solutions relationships within such contexts can be virtually reconstructed. Moreover, visitors can carry out virtual excavations thereby gaining familiarity with the work of archaeologists.

Tourism presents a further area of application for virtual reality. Some potential visitors do not want to visit the cultural heritage sites themselves or are hindered by lack of time or difficulties of transportation. Comprehensive multimedia shows and interactive VR tools offered by the visitor centre give a tour of the site, without ever having to leave the museum building. This solution offers a tremendous possibility to the elderly or handicapped, providing access to caves and far-off archaeological sites located away from public roads. Other, more agile visitors, on the other hand, may even be encouraged by virtual tours to actually visit such less accessible sites. Therefore, visual elements and verbal information should be incorporated in virtual tours that make the actual visit to archaeological sites a major experience, even if the site is not particularly spectacular in its present state of survival (*Fig. 4*).

These ideas were also kept in mind during the planning of the Sopron Visitor Centre and observation tower. Among the antecedents of this project it needs to be mentioned that even at the time of the excavations at Sopron-Várhely and Sopron-Krautacker during the 1970–1980s, an idea emerged that the recovered archaeological assemblages should be presented to the public on location, independently of the museum exhibit. In accordance with international practice, it seemed that this aim would be best realised by preserving the most valuable finds of special significance *in situ*. In 1973, the presentation of the then recently excavated Burial Mound (*tumulus*) 131 was initiated by Erzsébet Patek, who also realised the project. Naturally, limitations at the time resulted in solutions that could be called only modest by modern standards. The challenge was the following: a professionally correct presentation had to please both experts and the average visitor; it had to be physically "sustainable" and also serve as an attractive sightseeing feature for mainstream tourism. Since the timber structure of the burial chamber within the mound survived only partially, and its *in situ* preservation was impossible, the depth and shape of the grave pit itself were considered as the starting point in the reconstruction. Covering and guarding the reconstructed burial chamber that contained copies of archaeological artefacts, including pottery and metal objects, as well as human ashes placed back in their original positions also turned out to be a major security task. Finally, a concrete slab was designed that could be

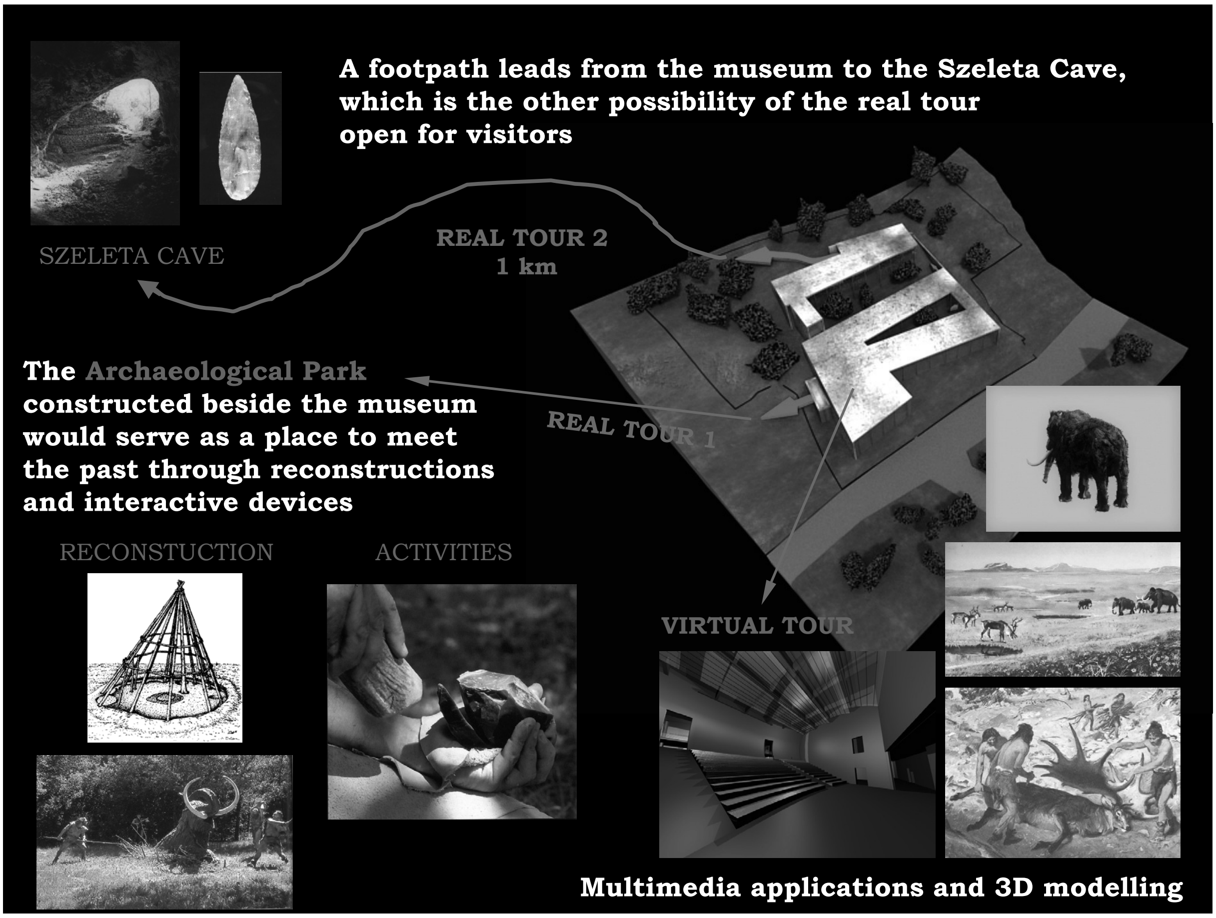

Figure 4: *IT applications (virtual tour and educational films) in the planning of the Szeleta Museum and Archaeological Park project.*

opened using a special winch-and-chain system and locked when out of use. Unfortunately, this construction has proven unsuccessful from a number of aspects. Although it was extremely awkward to open during visits, it was nevertheless robbed several times. After a time reparations made no sense, and the project was abandoned.

Research in the north-western quarters of Sopron was carried out in part parallel with the aforementioned Várhely project, at a location where a section of the so-called Jereván housing complex was planned. The site of Krautacker Baulk contained the remains of a Bronze and Iron Age settlement and cemetery. Excavations were carried out until 1988, and since artefactual assemblages of unusual significance were recovered here, we intended to preserve at least part of the site *in situ*. The first such attempt was supported by the professional argument that a La Tène Period kiln, excavated in 1981 (Feature 199), counted as a find of an outstanding significance. This so-called updraft kiln was found and preserved in a rather good condition and contained pots whose style made the dating of the feature possible. Even today, this find counts as the oldest and one of the most beautiful monuments of Celtic pottery industry in the Carpathian Basin. Since its significance as an industrial monument was recognised already at the time of excavation, professional conservation work was carried out immediately. When the presentation of this find was planned on location, we hoped to show not only the well-preserved kiln, but also wished to offer additional information on Celtic pottery making, presented in billboards and showcases that would have surrounded the archaeological feature. Pressures of reality, however, forced an early end to the excavation. In the absence of theoretical support and financial backing the *in situ* reconstruction of the Iron Age village, or at least one of its main features in what was planned as the Sopron Archaeological Park had to be given up. Finally, houses, workshops, kilns, grain storage facilities excavated at Sopron could be presented in the Százhalombatta Archaeological Park in a reconstructed environment as part of Iron Age farmsteads (Jerem et al. 2001).

When the new archaeological exhibition was built in Sopron in 1999, it became clear that the presentation of world famous archaeological sites would be necessary for the wider public as well. By then, the circumstances had changed, and the requirements of modern tourism justified the planning of a visitor centre where full advantage is taken of multimedia applications. The elaboration of this concept and stages of its planning have already been discussed in two studies (Jerem – Vasáros 2005; Jerem et al. 2006). At this point, it is worth emphasising that this would be the first archaeological information centre and observation tower in Hungary, which would use IT applications exclusively in presenting the attractions of the narrower and broader natural environment and associated cultural heritage. Billboards exhibited on the ground floor of the multifunctional building would help with the orientation of visitors and offer basic information. A coffee shop combined with a bookstore selling cards and maps as well would serve as a rest area. By entering the exhibition area on the way to the observation tower located on the upper level a time journey would begin. Visitors would be guided from prehistory to the present, and a compass would be designed that directs attention to archaeological sites, museums and tourist attractions in the area. Cutting-edge technology thus would offer an opportunity to compare real and virtual images in time and space. Meanwhile, correspondences could be sought between the external panorama visible from the around the observation tower (fortified Iron Age hill-forts of the Sopron Hills, Lake Fertő) and the information presented in the exhibition in the form of projected images, photographs, drawings etc. (*Fig. 5*).

Presenting the landscape and its cultural heritage simultaneously is of utmost importance in this case, since the average visitor would not even know the name of the mountain range along the route. Without an explanation, visitors would have no idea that this hilly landscape was once part of a hill-fort system, the habitation area and burial ground of prehistoric people who occupied the area for centuries.

Planning a visitor centre and an observation tower here are considered as a serious challenge in this case. A successful design would set an international standard, opening new perspectives in dealing with archaeological heritage. Wood and glass were chosen as preferred construction materials for the visitor centre. This decision has been inspired by both the surrounding forests and Sopron's highly respected tradition of wood manufacturing. Therefore, wood would define the basic character of both the façade and the inner spaces. Glass, on the other hand, would offer the best view at every level and would attract the attention of those who have not yet entered real sites or other archaeological complexes.

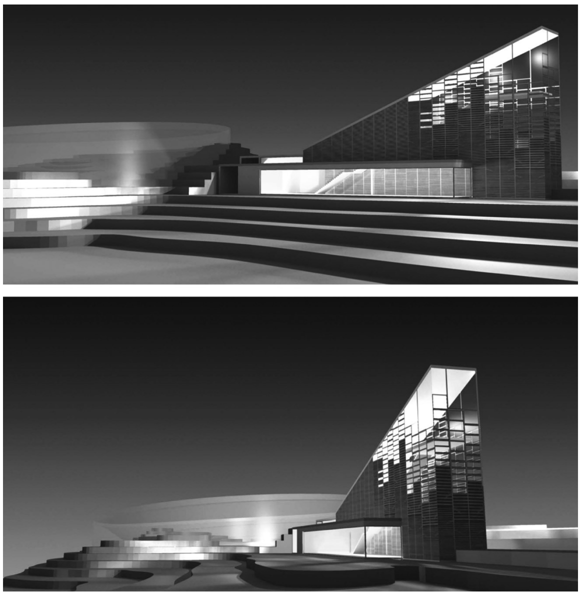

Figure 5: *Virtual design of the Sopron Visitors' Centre aimed at presenting a "time journey" from Prehistory to the present, using entirely cutting-edge virtual technology.*

Closing remarks

Experience with the use of multimedia applications in museum and cultural heritage projects in Hungary have shown that advancement in this field is uneven. The development of neglected or hardly accessible museum collections into "virtual museums" is one of the chief aims that is pursued abroad. Although there is a demand for developing searchable databases in archaeology and fine arts in Hungary, for the time being internet access by the wider public is still limited. In recent years, however, there has been a welcome development in the application of these techniques in exhibitions and even open-air sites. Plans have been drafted in which multimedia applications would play a primary if not exclusive role. These include visitor centres that also play an important educational role in teaching the young and even offering vocational training to older generations. Our aim is to define the operational framework for the realization of such centres and find co-operative partners.

References

Jerem E., Müller K., Vasáros Zs. (2001). Reconstruction of Iron Age houses and their environment in the Archaeological Park of Százhalombatta. *Praehistoria* 2: 173–192.

Jerem, E., Mester, Zs., Ringer, Á., Vasáros, Zs. (2002). Szeleta Museum and Archaeological Park. *Praehistoria* 3: 327–333.

Jerem, E., Mester, Zs., Ringer, Á., Vasáros, Zs. (2004). Back to the Szeletians: A museum project for a virtual and real Prehistoric tour in NE Hungary. In: Stadtarchäologie Wien (ed.), *[Enter-the-past] The E-way into the four Dimensions of Cultural Heritage, CAA 2003*, BAR International Series 1227, Oxford, 2004, CD-ROM

Jerem, E., Vasáros, Zs. (2005). A Soproni Bécsi-dombra tervezett turisztikai látogatóközpont és kilátó. *Soproni Szemle*, 2005/2, 125–137.

Jerem, E., Mester, Zs., Vasáros, Zs. (2006) in print. Projects for the Presentation of the Natural and Cultural Heritage in Hungary. *Beyond the artefacts. Proceedings of the CAA 2004*. Prato.

Vasáros, Zs., Rezi Kató, G. (eds.) (s.a.). *Kelet és nyugat határán – On the Borders of East and West.* Budapest: Magyar Nemzeti Múzeum.

Zsidi, P. (ed.) (2005) *Kincsek a város alatt – Treasures under the city.* Budapest. Budapest Történeti Múzeum.

Zsidi, P (2006) *Az Aquincumi Polgárváros*. Aquincumi Zsebkönyvek 1,128–129. Budapest. Budapest Történeti Múzeum and Archaeolingua Foundation.

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
VAST (2006)
M. Ioannides, D. Arnold, F. Niccolucci, K. Mania (Editors)

Practical experiences in 3D scanning of fossilized remains of the Kikinda Mammoth

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Abstract

3D scanning of fossilized mammoth remains is the first attempt of this kind and magnitude in the Southeast Europe. A part of the Kikinda Mammoth project envisaged as the backbone for the development of culture tourism in the region, scanning of individual bones is still a work in progress. More than 40 bones are already scanned ranging in size from 20 to 140 centimeters. This paper explains experiences and problems that our team encountered having to deal with a field new to us.

Categories and Subject Descriptors (according to ACM CCS): I.4.8 [Image Processing and Computer Vision]: Range data, I.3.3 [Computer Graphics]: Digitizing and scanning

1. Introduction

Ten years ago, in clay outcrop of the Toza Markovic factory in Kikinda, northern Serbia, at the depth of 21 meters, almost complete skeleton of a prehistoric *Mammuthus trogontherii*, has been discovered. Very well preserved (cc. 90% of overall bone mass) the Kikinda Mammoth [Figure 1] represents a unique find of this kind in Europe.

Figure 1: *The Kikinda Mammoth in its present state*

Found *in situ*, this 64 years old female, suffering from spondylosis and rheumatism, probably got stuck in marshy mud and became an easy prey for hyenas and other predators. Analyses done at the time of discovery showed that, when alive, the animal was cc. 4.7 m tall, 7 m long (including 3.5 m long tusks), had 7 tons of weight and probably lived some 600 000 years ago. Since then, the mammoth remains have been conserved, missing and broken bones partially reconstructed and housed on shelves (except for the scull which is mounted with tusks) in a small room on the factory grounds. [Figure 1]

In 2006, almost forgotten mammoth skeleton has become a focus of five institutions and organizations aimed at using their expertise potential in order to protect, but also to revitalize and incorporate it through adequate presentation, into everyday life of Kikinda. These partners are: the Municipality of Kikinda, National Museum of Kikinda, Regional Chamber of Commerce in Kikinda, Nature History Museum in Belgrade and the Center for Digital Archaeology of the Faculty of Philosophy in Belgrade Their partnership is aimed at defining the complex project of The Kikinda Mammoth as the backbone for the development of culture tourism in the region, based on the contemporary world practices and focused at the affirmation of this important find and the town of Kikinda. The Kikinda mammoth project has been approved for realization within the Programme for socio-economical development of the Northern Banat region by the European Agency for Reconstruction and is funded by the EU through the EAR and co-financed by the Municipality of Kikinda.

2. Related work

3D scanning is becoming increasingly popular, especially for sciences that need to work with artifacts that are fragile, not easily accessible or extremely valuable. Archaeology [MGL*04] [BRM*02] , Paleontology [Wil03] [BGW*02] [JBL*04] [LRP00], Palaeoanthropology [Maf01] have all been more than interested in developments in the field of 3D scanning applications, new forms of digital documentation and its safekeeping. Recently, 3D laser scanners have been used for digitalization of large fossil skeletal elements [Wil03] [JBL*04], the study of dinosaur locomotion [BGW*02] and for 3D modeling of macrofossil material from a *mosasaur* [LRP00].

3. Project Aims

Production segment of the Kikinda Mammoth project comprises the creation of: interactive presentation in 3D stereo technique, guide for interdisciplinary exploration of the find in the form of a CD and brochure, internet presentation and finally, production of a life-size, mounted replica of the skeleton. All of these will be based on 3D laser scanned models of the fossilized mammoth bones.

3D scanning as a new form of scientific documentation is logical evolutionary step from photography which conserves two-dimensional image of an object. 3D scanning substitutes photographs with a full three-dimensional representation of an object, where one of the most important feature is volume data itself. Such data provides basis for further scientific analyses, possibly using a single computer, where objects can now be easily analyzed, manipulated and shared over vast distances. For purposes of safekeeping, 3D scanned object has incomparably larger amount of useful data than a regular photograph or a series of photographs. With digital documentation in a form of scanned 3D objects, it is now possible to do manipulation of digital data only, instead of handling real objects or artefacts. Of course, real object is still priceless, however, large number of researchers, by handle digital instead of original objects, can now disseminate knowledge and research results more easily.

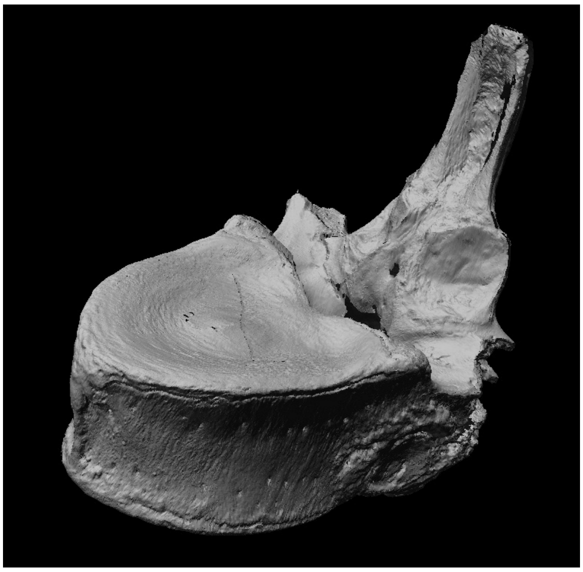

Figure 2: *Scanned vertebra bone before merging*

Exceptionally important aspects of the project is that the first reconstruction of the complete mammoth skeleton will be done virtually, inside a computer. This could prove to be a new approach in handling fossils, as it is much easier to manipulate and experiment with 3D objects in a virtual environment than with original finds. If finds are first 3D scanned and then virtually reconstructed, three important results are achieved:

1. Firstly, every bone is digitally preserved and available for further analyses.
2. Secondly, the ability arises to articulate the skeleton virtually, even experiment with different position of bones, bone angles, pressure areas of the skeleton, mounting scaffold, etc.
3. Thirdly, data can be shared with colleagues around the world without limits, and used in teaching and educational purposes.

After 3D scanning is finished, aim of the project is to produce a replica of each bone using rapid prototyping technologies, or so-called 3D printing. Using 3D printing enables us to indistinctly modify the bones which will allow easy placement on or even over mounting scaffold, without the need to drill or damage the replica bones. Important aspects are also weight difference and durability. Hollow casting in polymer material will make replica bones much lighter than the originals and much less susceptible to physical damage. 3D printing will finally enable us to present the whole articulated skeleton of the Kikinda Mammoth to a wide audience.

4. Methodology

One of the project challenges was also to test the 3D scanning process itself, being used in “real-life” situation with limited amount of available resources. It came as a solution to the problem of presenting the mammoth remains since mounting the originals and placing them in a space of appropriate size and climatic conditions proved to be impossible with the funds available. Producing moulds from the original bones was also out of the question because of their delicate nature and the absence of digitalized data for further utilization. The Center for Digital Archaeology therefore pulled up the resources, knowledge and will and embarked on this pioneering task in this part of the world.

Two technicians were assigned to carry out the scanning, none of which had previous experience with 3D scanning process except in the few weeks of the preparatory phase before the actual work. They were also familiarized with the material at hand while documenting all of the bones and photographing them. Total number of bones was 55, including the mounted scull as one. Large bones (see below) include femurs, tibiae, humeri and ulnae (fibulae and radii are not preserved), while the scull and pelvis still remain unscanned. With the courtesy of Archaeoware LLC we were able to use their prototype model of 3D laser scanner and software tools.

Algorithm for extracting 3D profiles from scans was updated three times during the preparation and scanning process. We started with classical Gaussian fitting algorithm and then moved to time-space algorithm [CL95]. Time-space promised much better results and was introduced as we had many problems with “lip-artifacts” [Figure 3] that appear as a side-effects of imperfections in laser line peak. Lip-artifacts cause significant time-delays as the technician doing sweep registering must look for and delete all them "manually" before registering the sweep. Time-space algorithm, when first implemented, showed that the approach of treating time dimension in scanning process brings better results in the scanned surface. Unfortunately, time-space algorithm failed in providing suggested reduction of lip-artifacts, and proved to be misleading in providing mathematically accurate solution for interpretation of laser line mean value. After realizing this a new, modified time-space algorithm was constructed that used time and space, but changed the principles of the original approach. This new algorithm proved to be better and more accurate, solving lip-artifacts successfully, thus speeding-up the registration process and providing much better surface details overall.

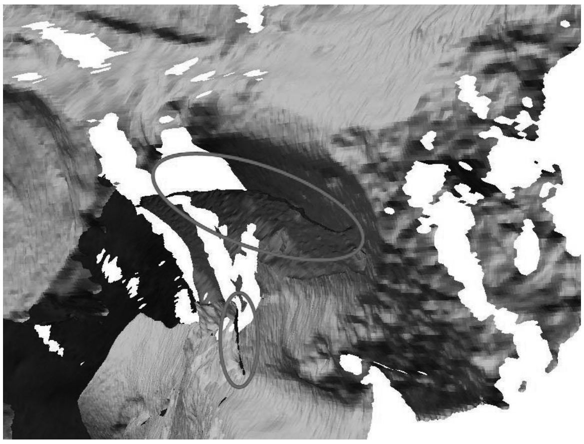

Figure 3: *"Lip-artifacts" at the ends of a sweep*

Two computers were used, one desktop machine with Intel Celeron™ 3 GHz processor, ATI X800™ Graphics card and 2 GB of RAM memory, and a laptop with Intel Pentium M™ processor, ATI Mobility Radeon 9700™ graphic card and 512 MB of RAM memory. Desktop computer was used as the "scanning computer" for acquiring data and producing point clouds and the laptop as the "registering computer" for registering i.e. aligning together different scanner sweeps. Both technicians were quickly familiarized with the entire scanning process so they could swap places at the computers if for no other reason then to interrupt monotony. Polygon based approach was chosen for registering [BM02] sweeps [Figure 4] due to the impossibility of placing reference markers that would be gentle enough not to damage the bones or to leave residue (glue for example) but sturdy enough to remain on a bone during the scanning process and many repositioning by hand in the near dark. Additionally, small size, irregularity of bones and relatively limited sweep radius meant that proportionally many reference markers would be needed which would either seriously compromise scanned surfaces or take up too much time to fill in later.

Finally, it was decided that there was no need to photo texture final models since the conservation method left them all in artificial brown color [Figure 1].

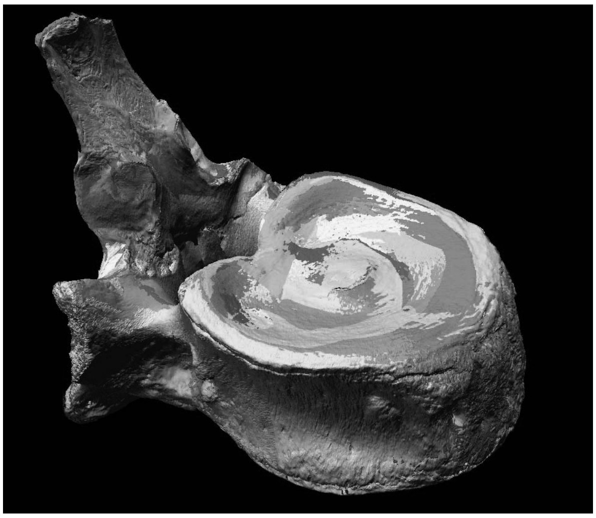

Figure 4: *Registered scan sweeps (vertebra)*

5. Experiences

5.1. Scanning setting

Before the scanning process of the mammoth remains could start, a few requirements needed to be met. Firstly, a suitable room with enough working space for equipment and above all controllable light conditions due to the nature of scanner's data capturing method – darker environment yields better contrast between the laser line and its surrounding and thus better results. The problem was solved with thick curtain over the windows and a lamp with a dimmer. A heavy, large table was chosen as the working surface for the scanner and object being scanned in order to ascertain enough space and minimum vibrations or accidental nudges. It also showed important to have a number of different "gadgets", objects of different size and shape that could be used for positioning scanned bone at the most appropriate angle to the scanner. Our arsenal consisted of: clamps, lifting platform, heavy ashtrays, notebooks, Swiss army knife, computer CD unit, modeling clay etc., to name a few. Finally, the two computers needed to be networked to enable exchange of data.

5.2. Scanning process

Already the first week of scanning showed the importance of experience of the scanning technicians. Literally every day brought new improvement to the process, whether time, effort or quality wise. Following are our experiences drawn from the scanning procedure, after more than 40 bones scanned and countless trial-and-error steps, which were shown in practice to be the best for the material at hand.

On average, a single rib bone [Figure 8] of moderate complexity (number of negative surfaces, sharp edges and holes) took 2 to 3 hours and a vertebra [Figure 2,4] 3 to 4 hours to scan fully. 30-40 sweeps were required for each object. Each sweep took 4-6 minutes and included positioning the object, scanner run, generating point cloud and final valorization. The overall time also includes sweeps for “filling-up gaps” i.e. completing the entire reachable (visible to the scanner) surface of the object. Compromise between the desired level of detail on the one hand and manageability and size of acquired data on the other was reached with the interpolation step of 0.04 cm and maximum edge length of polygon created of 0.2-0.3 cm, depending on the visibility of scanned area (hard to reach areas with scarce obtained data needed edge lengths of 0.3 cm in order to produce more polygons i.e. more completed surfaces). However, these settings were not reached without a price, since at first we started with the interpolation step of 0.02 cm and suffered computer crashes or extremely long times (of even 20-30 hours) in the final stages of registering sweeps and merging models.

Well trained team of two technicians was able work completely synchronously, where every point cloud is transferred from “scanning computer” to “registering computer” sweep-by-sweep via network, meaning that 5 minutes after the last sweep has been done the entire object is provisionally registered and ready for final, low-convergence aligning process. Synchronous work also provide another advantage where “registering technician” was able to guide the “scanning technician” by pinpointing missing and problematic areas thus reducing the overall number of sweeps taken i.e. time needed.

Large bones, of course, needed more sweeps, up to 70 or a whole working day of 8-10 hours to complete, and some physical strength to position the bone correctly (largest ones are over 30 kg in weight), but also proved more straight-forward to scan. This is due to larger size and uniformity of their surfaces so that minimum amount of overlapping areas and “filling-up gaps” sweeps was needed. At this stage individually scanned bones organized in separate projects were taking up space of around 1 GB or more.

Final registration process, with the parameters: sub-sampling step = 1/1 (every polygon is considered for comparison) and convergence < 0.000001 cm (allowed discrepancy between different sweeps) needed more processor time and no human intervention except for setting up the parameters beforehand and saving the result afterwards. This stage was therefore done on both the computers during the night i.e. in non-working hours and it took from 2 to 8 hours per bone depending on the complexity of the bone (i.e. number of sweeps i.e. overall number of polygons) and the quality of sweeps. [Figure 4]

Lack of the third computer resulted in having to leave the merging process of all scanned bones for the end of the scanning campaign and return to the offices in Belgrade where five computers could be used simultaneously for merging, managed by one technician only. The final step in producing what is known as “watertight” 3D models of individual bones consisted of automated filling-up of smaller gaps, and some additional filling-up i.e. modeling “by hand” for larger gaps that were left in unreachable holes on the bones (in most cases hardly or completely unreachable to the naked eye). It is hard to give an estimate of time needed for individual bone in this stage considering the work methodology and nature - parallel work on 5 machines and 2 technicians, one for merging and the other one for gap treatment, and unattended computer work on the merging process - but it amounted to 3 working weeks.

6. Common problems

6.1. Gaps

Figure 6: *Gap due to not accessible surface (vertebra)*

Gaps where a big problem in scanning mammoth bones. Most of the bones have extremely “unpleasant” angles, holes and negative surfaces that are just not accessible/visible. After a few bones scanned it was possible to determine best approach in filling up these gaps. Happy coincidence was that most of the bones could be divided into groups: vertebrae, ribs and long bones thus mastering one bone from a group gives us a methodology for scanning the rest of the group. This practically means that every first bone from one group is most difficult to scan, and as we go to each new bone from the group each scanner position is already tested and it’s easy to anticipate the results. This is specially important for filling up the difficult negative surfaces and holes, as you have to experiment with a lot of angles and get as much data from the sweeps as possible. Doing this a couple of times in a row with similar bones, brings better results and allows the team to better plan the whole process.

6.2. Unnecessary overlapping sweeps

Having no previous experience with large amount of objects needed to be scanned, we started off with a sort of “orthogonal reasoning” (often present in technical photography, where bones were placed with their larger surfaces or planes of symmetry at the near-right angle to the laser line) and after all of those have been scanned we would additionally scan edges, holes and omitted gaps. Edges between two surfaces were most problematic here since they were invisible to the camera lens from this viewing angle and yet extremely important for an accurate and fast final registering process. When finally registered, these models showed many overlapping areas on most of the larger surfaces of the bone with the number of overlaps sometimes even larger than 15.

The new strategy was opposite, a sort of “isometric reasoning” where the whole bone was scanned, with full scanner passes, from the least number of predefined or speculated positions possible, with the emphasis on edges. After all of those sweeps had been registered provisionally this gave us a sort of a “skeleton” to which remaining sweeps or “detail sweeps” could easily register (aligned). New detailed sweeps never required the whole scanner pass, but instead we would focus only on gaps or problematic parts that were missing. Having less sweeps to perform, there was enough time left to focus on the smallest details and still not increase the overall number of sweeps or time per bone.

6.3. Color difference and laser glow

Color differences and laser glow of bones’ sections present significant problem especially if shutter speed of the camera CCD is adjusted to record darker colors. With such setting, laser line crossing part of the surface that is brighter (spots, stains, damaged areas,), glows on the camera CCD [Figure 7]. This results in error [DHH94] when generating the true 3D surface on that spot, and the whole scan must be repeated. It is lesser problem to scan brighter surface that have darker areas, as the laser will not glow, but instead will just not show, resulting in a valid scan. At the end you must somehow scan these darker areas, but at least you made lots of valid scans before addressing this problem.

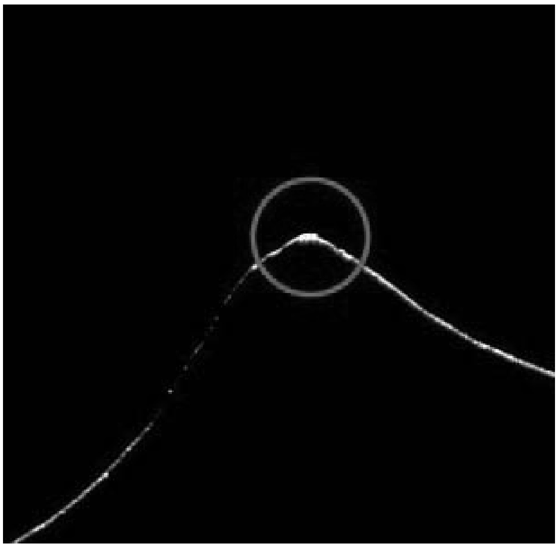

Figure 7: *Laser line glow*

6.4. Laser speckle

Laser speckle problem [BR91][Goo84] is a common in all laser 3D scanning of not perfectly diffuse surfaces. Mammoth bones where only partially reflective and there was no rule to this, but every bone was different. Laser speckle brings artifacts and distorted surfaces onto the 3D model, using any previously mentioned algorithm, even in a case of modified time-space. Bone surface looks jittered and there are small ripples that appear on completely flat surfaces in nature. These abnormalities look different on different sweeps and it is hard to tell the best angle for scanning of such reflective surfaces. There is no real solution to this, unless you interfere with the physical bone surface and cover it with diffusing powder. Instead, we simply made couple of overlapping scans from different angles, left the best one, and deleted the rest. This of course results in more time spent on such scans and thus slowed scanning of such bones, resulting in further delays especially when surface produces a lot of laser speckle.

Figure 8: *Scanned and merged rib bone*

6.5. Vibrations

Moving of the scanner head unavoidably produces vibrations which are transmitted to the working surface it is placed on (table in our case). If the object being scanned is placed on the same surface there exists a possibility that these vibrations might affect the object and make it move or slip slightly, which will result in invalid sweeps. This is especially true when scanning hard to reach areas with the object in an odd position. Nearly every bone we scanned had at least one of the sweeps repeated due to this problem. There is no real solution to it except to try and minimize the transmission of vibrations by placing a damping material underneath the scanner (a piece of cloth or rubber for example) or to securely fix the scanned object (which can prove to be less possible than perceived). Valorization of sweeps by technicians remained the only reliable solution.

7. Building a virtual skeleton

Brining all the bones together proved to be more than just a simple task. The whole skeleton is made out of 55 preserved bones where each scanned bone has minimum 1 million polygons, bringing the whole skeleton model, in case of fully detailed bone models, to more than 100 million polygons. This number is still too high even for the best graphics cards on the market, and we had to do reduction in details in order to work with the full skeleton. When resolution of 3D model of a bone is reduced, details that are previously visible disappear and thus it is not possible to do full analyses on the whole skeleton. Still, in this moment in time, lowering details of 3D models is necessary for successful competition of the project, as the primary aim is not immediate analysis of the whole skeleton. Reductions of this kind could be done either during the merging stage, where merging process is run twice, or later in some of the 3D optimization software. Merging operation is taking more time then standard 3D optimization, but is bringing significantly better results, so the real question is what will the reduced model be used for. Our impression was that manipulating the full resolution models would be a better solution than reducing the quality, but this request would require specialized software package that would be used in these kind of projects. Extensive Level Of Details (LOD) options together with additional tools, archiving options and other scientifically build features would allow new forms of digital documentation and further science developments in this field.

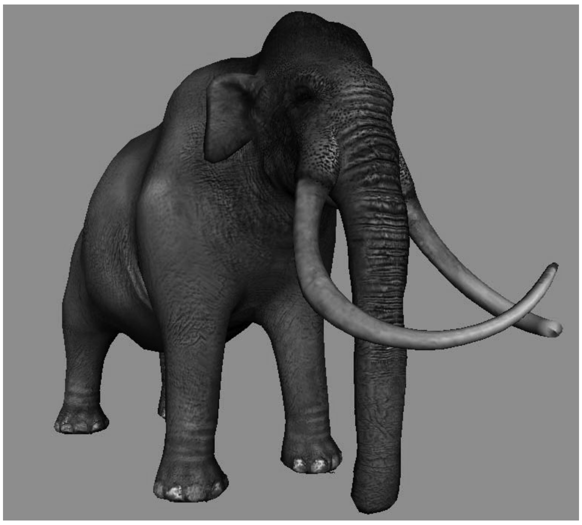

Figure 9: *Mammoth reconstructed*

8. Conclusion

Presented results show that many small factors determine the quality and time-consumption of the scanning process, directly affecting the price and planning, especially in larger projects that have strict deadlines or limited budget available. Shown here are all the major problems a scanning team encounters when first starting a 3D scanning project. Results of the project are scanned mammoth bones, virtually reconstructed skeleton and a full-size replica, where this paper is here to show that if you want to finish the work started, knowledge of the scanning process and experience are often more important than a good will, enthusiasm or budget itself.

References

[BGW*02] O. BIMBER, S.M. GATESY, L.M. WITMER, R. RASKAR AND L.M. ENCARNACAO: Merging Fossil Specimens with Computer-Generated Information. *Computer, 35(9),* (2002) 25-30.

[BM02] P.J. BESL AND N.D. MCKAY: A method for registration of 3-D shapes. *IEEE Trans.Pattern Anal. Mach. Intell.* 14(2) (1992) 239-256.

[BR91] R. BARIBEAU AND M. RIOUX: Influence of speckle on laser range Finders. *Applied Optics, 30(20):2873–2878,* July 1991.

[BRM*02] F. BERNARDINI, H. RUSHMEIER, I. M. MARTIN, J. MITTLEMAN, AND G. TAUBIN: Building a Digital Model of Michelangelo's Florentine Pietà, *IEEE Computer Graphics and Application,* Vol. 22, No. 1, 2002, pp. 59-67.

[CL95] B. CURLESS AND M. LEVOY: Better Optical Triangulation through Spacetime Analysis, *Proc. Int'l Conf. Computer Vision*, pp. 987-994, 1995.

[DHH94] R.G. DORSCH, G. HAUSLER, AND J.M. HERRMANN: Laser triangulation: fundamental uncertainty in distance measurement. *Applied Optics, 33(7):1306–1314*, March 1994.

[Goo84] J.W. GOODMAN:. Laser Speckle and Related Phenomena, chapter 1 - Statistical properties of laser speckle patterns, *pages 9–76. Springer-Verlag*, 1984.

[JBL*04] R.A. JOHNSTON , K. BARNES, T. LOVELL-SMITH 1 AND N.B. PRICE: Use of a Hand-held Laser Scanner in Palaeontology: A 3D Model of a Plesiosaur Fossil, `http://www.polhemus.com/CaseStudies.htm` (2004)

[LRP00] P.D. LYONS, M. RIOUX, AND R.T. PATTERSON: Application of a Three-Dimensional Color Laser Scanner to Palaeontology: an Interactive Model of a Juvenile Tylosaurus SP. *Basisphenoid-Basioccipital, Palaeontologia Electronica, Vol. 3, No. 2, art.4: 16pp..* `http://palaeo-electronica.org/2000_2/neural/issue2_00.htm`

[Maf01] B. MAFART.: 3D Imaging in Paleoanthropology and Prehistoric Archeology: a New Tool for Old Sciences or an Emerging Science. *XIV International Congress of Prehistoric and Protohistoric Science, Liège (Belgium)*, September 2001.

[MGL*04] B. MAFART, G. GUIPERT, M.A.DE LUMLEY, G. SUBSOL: Three-dimensional computer imaging of hominid fossils: a new step in human evolution studies.*Can Assoc Radiol J.* 2004 Oct;55(4):264-70.

[Wil03] R. WILHITE: Digitizing Large Fossil Skeletal Elements for Three-Dimensional Applications. *Palaeontologia Electronica 5(2),* (2003) 10pp, 619KB, http://palaeo-electonica.org/paleo/2002 2/scan/issue2 02.htm

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
VAST (2006)
M. Ioannides, D. Arnold, F. Niccolucci, K. Mania (Editors)

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

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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.

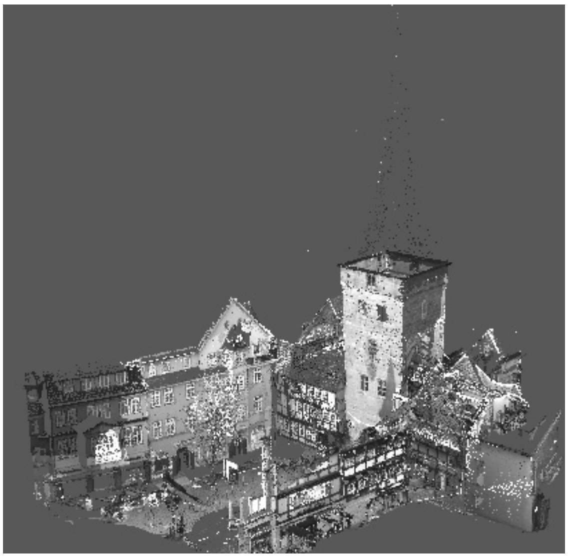

Figure 7: *Entire point cloud of West Tower ensemble*

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.

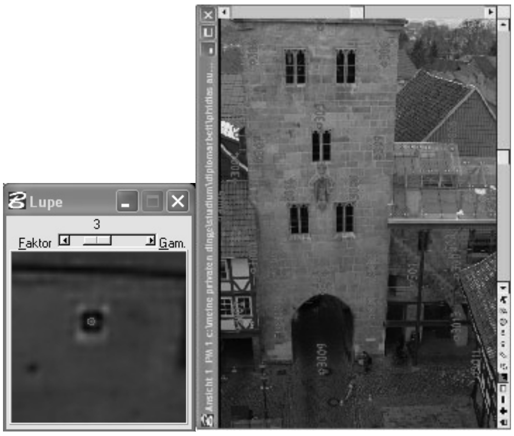

Figure 8: *Photogrammetric point measurements*

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.

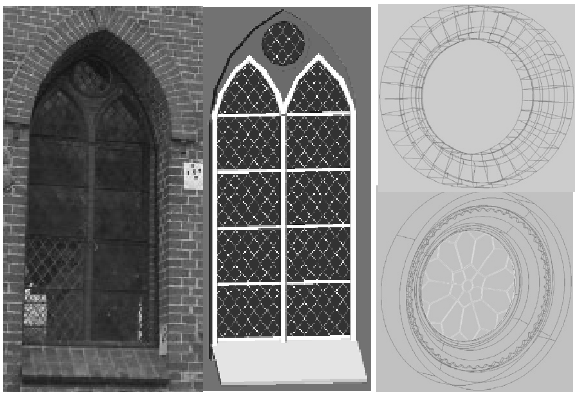

Figure 9: *Reconstruction of a window by photogrammetric 3D point measurements (left, centre) and a window detail (right) in comparison, generated from photogrammetric data (bottom) and from laser scanning data (top)*

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.

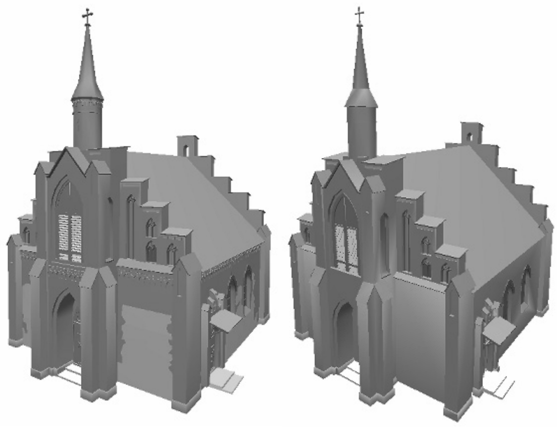

Figure 10: *3D volume model of church Raduhn in comparison: photogrammetry (left) vs. laser scanning (right)*

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.

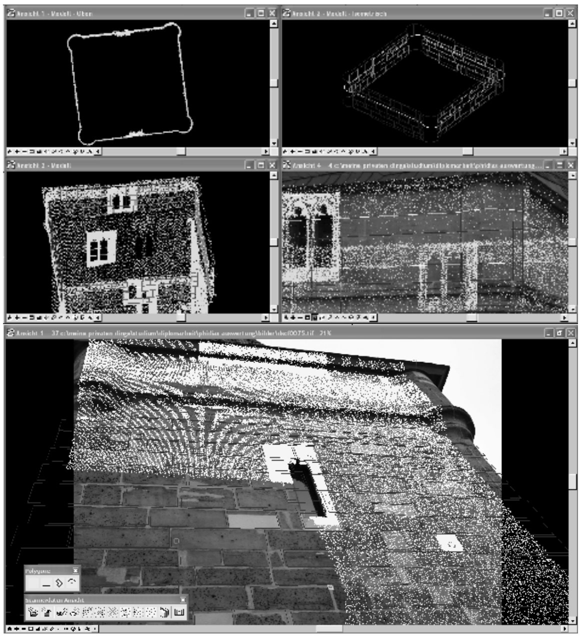

Figure 11: *Representation of the point cloud in combination with image data (top) and monoplotting of stones using information of an image and laser scanning (bottom)*

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].

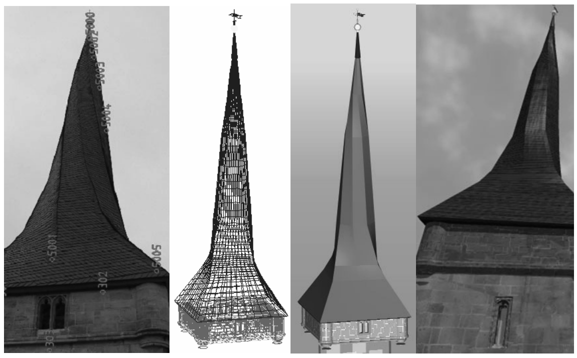

Figure 12: *Generation of the top of the West Tower: photogrammetric image, wire frame, rendered model in AutoCAD and visualisation in Highlight pro*

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.

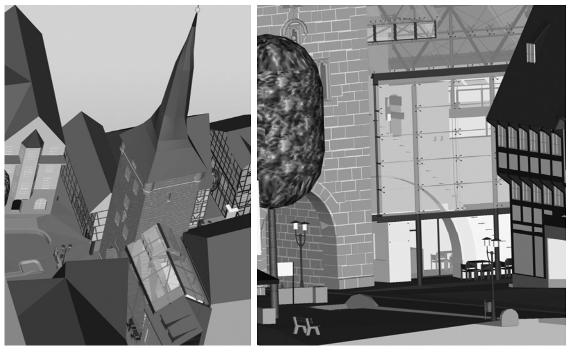

Figure 13: *Rendered perspective scenes of West Tower ensemble Duderstadt generated by AutoCAD*

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.

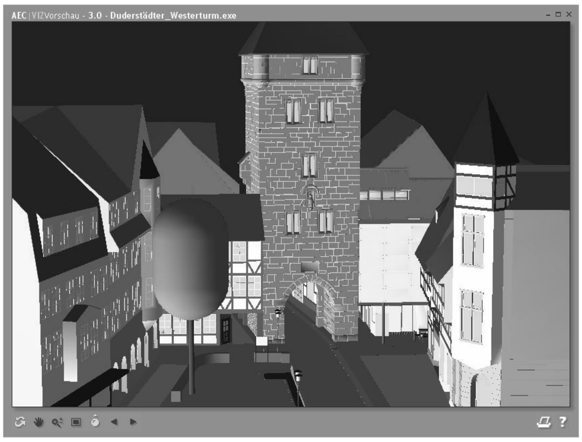

Figure 14: *Interactive virtual model of West Tower ensemble Duderstadt generated by AECViz*

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*

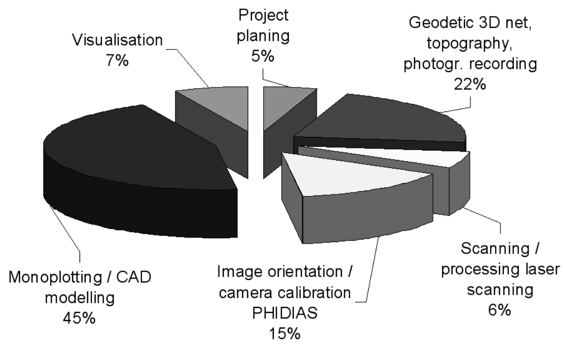

Figure 16: *Expenditure of human labour for project West Tower ensemble Duderstadt in percent*

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.

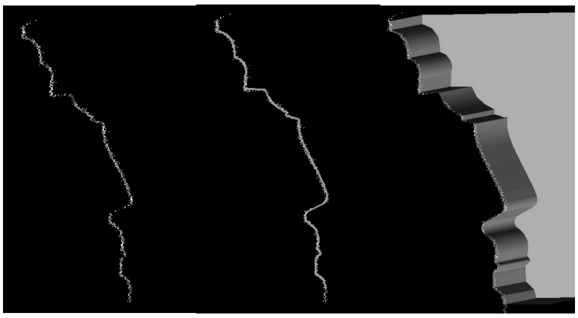

Figure 17: *Modelling of ornaments by laser scanning data: cutting of the point cloud (left), CAD line derived from the laser scanning data (centre), extrusion of the CAD line (right).*

8. References

[BS05a] BECKER, R., SCHWERMANN, R.: Bestandserfassung durch kombinierte Auswertung von Laserscanner- und Bilddaten. *Photogrammetrie, Laserscanning, Optische 3D-Messtechnik – Beiträge der Oldenburger 3D-Tage 2005,* Th. Luhmann (Hrsg.), Wichmann Verlag, Heidelberg, pp. 134-141.

[BS05b] BIEBERMANN, M., SCHNEIDER, M.: 3D-Erfassung und Modellierung des Duderstädter West towerensembles durch Kombination von digitaler Architekturphotogrammetrie und terrestrischem Laserscanning. *Unpublished diploma thesis*, HafenCity University Hamburg, June 2005.

[Hof05] HOFFMANN, R.: Vergleichende Untersuchung bei der 3D-Erfassung und Modellierung der Kirche von Raduhn durch digitale Photogrammetrie und terrestrischem Laserscanning. *Unpublished diploma thesis*, HafenCity University Hamburg, June 2005.

[IDST05] IOANNIDIS, Ch., DEMIR, N., SOILE, S., TSAKIRI, M.: Combination of Laser Scanner Data and Simple Photogrammetric Procedures for Surface Reconstruction of Monuments. *CIPA 2005 XX Int. Symposium, 26 Sep. – 01 Oct., 2005, Torino, Italy. http://cipa.icomos.org/index.php?id=356*

[KAL04] KERSTEN, TH., ACEVEDO PARDO, C., LINDSTAEDT, M.: 3D Acquisition, Modelling and Visualization of north German Castles by Digital Architectural Photogrammetry. *The Int. Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences,* Vol. XXXV, Commission V, Part B2, (July, 2004), pp. 126-132.

[KSM05] KERSTEN, TH., STERNBERG, H., MECHELKE, K.: Investigations into the Accuracy Behaviour of the Terrestrial Laser Scanning System Mensi GS100. *Optical 3D Measurement Techniques VII,* (Eds. Gruen/Kahmen), Vol. I, Vienna, (Oct. 2005), pp. 122-131.

[LIN05] LINSINGER, W.: "3D Laser" versus "Stereo Photogrammetry" for Documentation and Diagnosis of Buildings and Monuments (Pro and Contra). *CIPA 2005 XX Int. Symposium, 26 Sep. – 01 Oct., 2005, Torino, Italy. http://cipa.icomos.org/index.php?id=356*

[Men04] MENSI: GS 100 3D laser scanner. http://www.mensi.com/website2002/gs100.asp, 2004.

[NDSR05] NEUBAUER, W., DONEUS, M., STUDNICKA, N., RIEGL, J.: Combined High Resolution Laser Scanning and Photogrammetrical Documentation of the Pyramids at Giza. *CIPA 2005 XX Int. Symposium, 26 Sep. – 01 Oct., 2005, Torino, Italy, http://cipa.icomos.org/index.php?id=356*

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
VAST (2006)
M. Ioannides, D. Arnold, F. Niccolucci, K. Mania (Editors)

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

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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 8^{th}, 9^{th} and 10^{th} 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*).

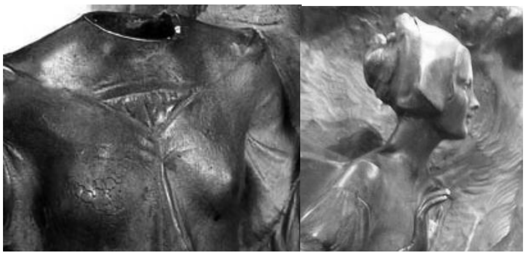

Figure 6*: The fairy's head had been removed (left), and the replica in-situ (right).*

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.

9. Acknowledgements

Sam Sportun, Christopher Dean and the sculpture conservation section of National Museums Liverpool, Office of Science and Technology (UK Government) PSRE fund for financial assistance, Prestbury Parochial Church Council, Jan Stubbe Ostergaard (NY Carlsberg Glyptotek), Vinzenz Brinkmann, Ulrike Brinkmann (Staatliche Antikensammlungen und Glyptothek), Hothouse Centre for Art and Design, CRDM Ltd, Victoria and Albert Museum, and Castle Fine Art Foundry.

10. References

[B04] Byers, F.: *Natl. Inst. Stand. Technol. Special Publication,* 500-252 (2004).

[BG03] Blais, F., Godin, G.: *Natl. Research Coun. of Canada Tutorial notes 4th Int. Conf. on 3D Dig. Imag. And Mod.,* 6 (Oct 2003), 4-5.

[BHMS02] Boehler, W., Heinz, F., Marbs, A., Siebold, M.: *Proceedings of the CIPA Workshop 6 Int. Workshop on Scanning for Cult. Heritage Recording, Corfu, Greece,* (Sept 2002).

[BPEG*02] Beraldin, J.-A., Picard, M., El-Hakim, S., Godin, G., Valzano, V., Bandiera, A., Latouche, D.: *Proceedings of VSMM 2002 Gyeongju, Korea, NRC 44959,* (Sept 2002), 3-14.

[BRMM*02] Beraldini, F., Rushmeier, H., Martin, L., Mittelman, J., Taubin, G.: *IEEE Computer Graphics and Applications,* 22 (2002), 59-67.

[BRTL88] Boulanger, P., Rioux, M., Taylor, J., Livingstone, F.: *12th international symposium on the conservation and restoration of cultural property, Tokyo national research institute of cultural properties,* (1988), 131-147.

[BVM03] Boehler, W., Bordas Vincent, M., Marbs, A.: *XIXth CIPA Symposium, Antalya, Turkey,* (Sept 2003).

[CDP04] Cappellini, V., Damiani, G., Piva, A.: *DEXA Workshops* (2004), 57-61.

[Cho97] Chow, J.: *Int J Adv Manuf Technol.,* 13 (Oct 1997) 723-728.

[EF03] Eklund, J., Fowles, P., *Conservation and Management of Archaeological Sites,* 6 (2003), 11-22.

[F00] Fowles, P.: *J. Cult. Heritage,* 1 (2000), S89-S91.

[Lar94] Larson, J.: *Conservation News*, (July 1994), 10-11.

[Lar95] Larson, J.: *The Art Newspaper,* 46 (March 1995) 19.

[LPC*00] Levoy, M., Pulli, K., Curless, B., Rusinkiewicz, S., Koller, D., Pereira, L., Ginzton, M., Anderson, S., Davis, J., Ginsberg, J.: *Proc. of ACM SIGGRAPH 2000,* (2000), 131-144.

[MWBV96] Milroy, M., Weir, D., Bradley, C., Vickers, G.: *Int J Adv Manuf Technol.,* 12 (1996), 111-121.

[RGG*02] Rushmeier, H., Gomes, J., Giordano, F., El Shishiny, H., Magerlein, K., Bernardini, F.: *IBM Corporation,* (2002), http://graphics.cs.yale.edu/holly/ACVA_07.pdf.

[STHM*03] Stumpfel, J., Tchou, C., Hawkins, T., Martinez, P., Emerson, B., Brownlow, M., Jones, A., Yun, N., Debevec, P.: *VAST* (2003).

[SLZB*04] Slattery, O., Lu, R., Zheng, J., Byers, F., Tang, X.: *J. Res. Natl. Inst. Stand. Technol.,* 190 (2004) 517-524.

[TBBC*99] Taylor, J., Boulanger, P., Beraldin, J.-A., Cournoyer, L., Blais, F., Rioux, M., Domey, J.: *Proceedings of the Canada-Italy Workshop: Heritage Applications of 3D Digital Imaging, Ottawa, Ontario, Canada,* (Oct 1999), NRC 43631.

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
VAST (2006)
M. Ioannides, D. Arnold, F. Niccolucci, K. Mania (Editors)

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

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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, ...).

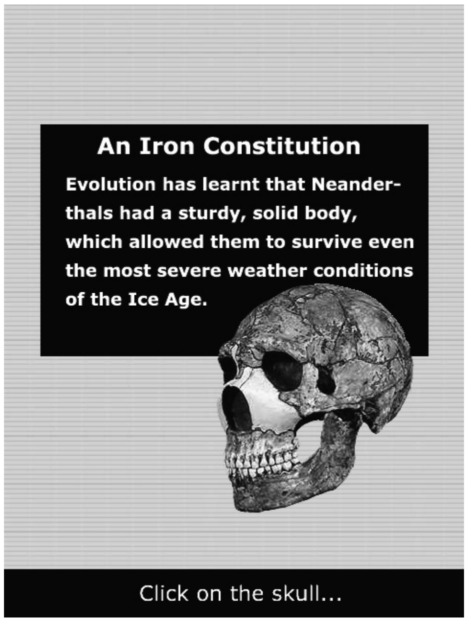
3.2. Personalization and visualization

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.

Acknowledgments

This work was partly funded through EFRO, as part of 'Objective 2 - Programme Limburg 2000-2006 and the Phasing-out Programme 2000-2005, Measure 2: Technology and Innovation, Action 4: Stimulating the product development in the field of multimedia applications concerning culture and cultural heritage'.

We would also like to thank the museum staff of the Gallo-Roman Museum for close cooperation.

References

[Ang06] ANGLISS S.: Talking Sense. *Museum Practice Magazine*, 34 (2006).

[BBZB05] BRUNS E., BROMBACH B., ZEIDLER T.,

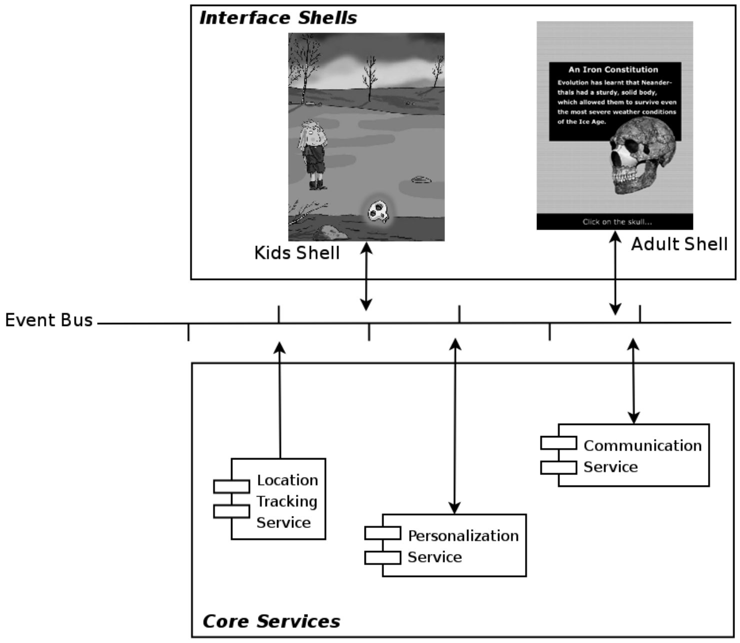


Figure 2: *Framework overview*

BIMBER O.: *Enabling Mobile Phones To Support Large-Scale Museum Guidance*. Tech. rep., Bauhaus University Weimar (Media Faculty), 2005.

[BCLN05] BORRIELLO G., CHALMERS M., LAMARCA A., NIXON P.: Delivering real-world ubiquitous location systems. *Commun. ACM 48*, 3 (2005), 36–41.

[CCC*06] CHAN L.-W., CHIANG J.-R., CHEN Y.-C., NAN KE C., HSU J., CHU H.-H.: Collaborative Localization: Enhancing WiFi-Based Position Estimation with Neighborhood Links in Clusters. In *Pervasive* (2006), pp. 50–66.

[CP03] CIAVARELLA C., PATERNÒ F.: Design criteria for location-aware, indoor, pda applications. In *Mobile HCI* (2003), pp. 131–144.

[Exp05] Exploratorium Electronic Guidebook Forum, 2005.

[FD00] FALK J., DIERKING L.: *Learning from Museums: Visitor Experiences and the Making of Meaning*. Altamira Press, Walnut Creek, 2000.

[Fis05] FISHER S.: *An Evaluation of Learning on the Move and Science Navigator. Using PDAs in Museum, Heritage and Science Centre Settings*. 2005.

[HFL*04] HAEBERLEN A., FLANNERY E., LADD A., RUDYS A., WALLACH D., KAVRAKI L.: Practical robust localization over large-scale 802.11 wireless networks. In *MobiCom '04: Proceedings of the 10th annual international conference on Mobile computing and networking* (New York, NY, USA, 2004), ACM Press, pp. 70–84.

[KBGB*05] KUFLIK T., B. CALLAWAY C., GOREN-BAR D., ROCCHI C., STOCK O., ZANCANARO M.: Non-intrusive User Modeling for a Multimedia Museum Visitors Guide System. In *User Modeling* (2005), pp. 236–240.

[Mor02] MORRISSEY K.: Pathways Among Objects and Museum Visitors. In *Perspectives on Object-Centered Learning in Museums* (2002), Paris S., (Ed.), Lawrence Erlbaum Associates.

[PGR05] Provincial Gallo-Roman Museum. Quantitative learning target group research, 2005.

[PT03] PROCTOR N., TELLIS C.: The State of the Art in Museum Handhelds in 2003. In *Museums and the Web 2003* (Toronto, Canada, 2003), Archives & Museum Informatics, pp. 227–238.

[PW02] PISCITELLI B., WEIER K.: Learning With, Through, and About Art: The Role of Social Interactions. In *Perspectives on Object-Centered Learning in Museums* (2002), Paris S., (Ed.), Lawrence Erlbaum Associates.

[VH05] VOM LEHN D., HEATH C.: Accounting for New Technology in Museum Exhibitions. *International Journal of Arts Management 7*, 3 (2005).

[YA05] YOUSSEF M., AGRAWALA A.: The Horus WLAN Location Determination System. In *MobiSys '05: Proceedings of the 3rd international conference on Mobile systems, applications, and services* (New York, NY, USA, 2005), ACM Press, pp. 205–218.

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
VAST (2006)
M. Ioannides, D. Arnold, F. Niccolucci, K. Mania (Editors)

SemanticArchaeo: A Symbolic Approach of Pottery Classification

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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.

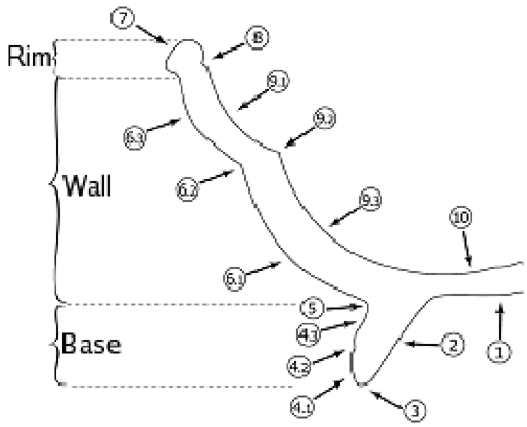

Figure 1: *The relevant description of the* Dragendorff 27b*(done by archaeologists).*

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.*

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

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]
- 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

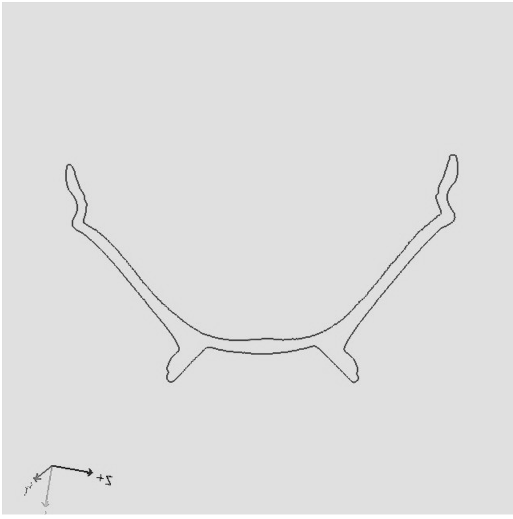

Figure 4: *The* Ritterling 5 *2D double profile.*

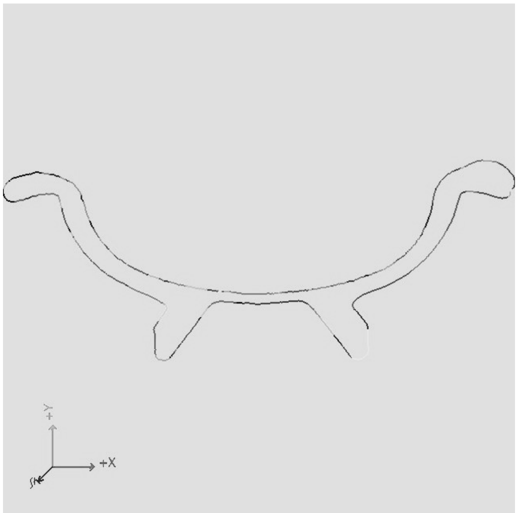

Figure 5: *An over-segmented profile of a* Dragendorff 35.

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.

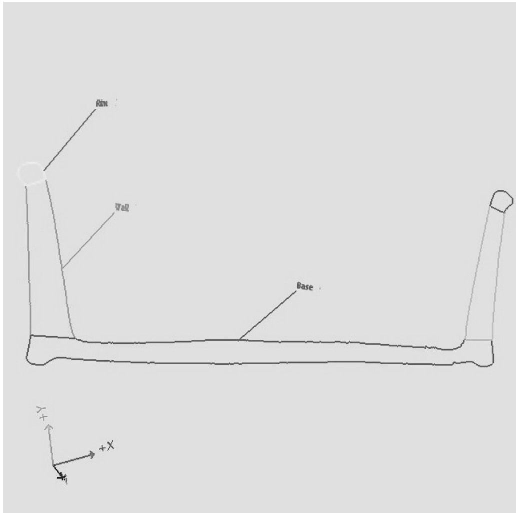

Figure 6: *A relevant profile segmentation of a* Dragendorff 22.

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

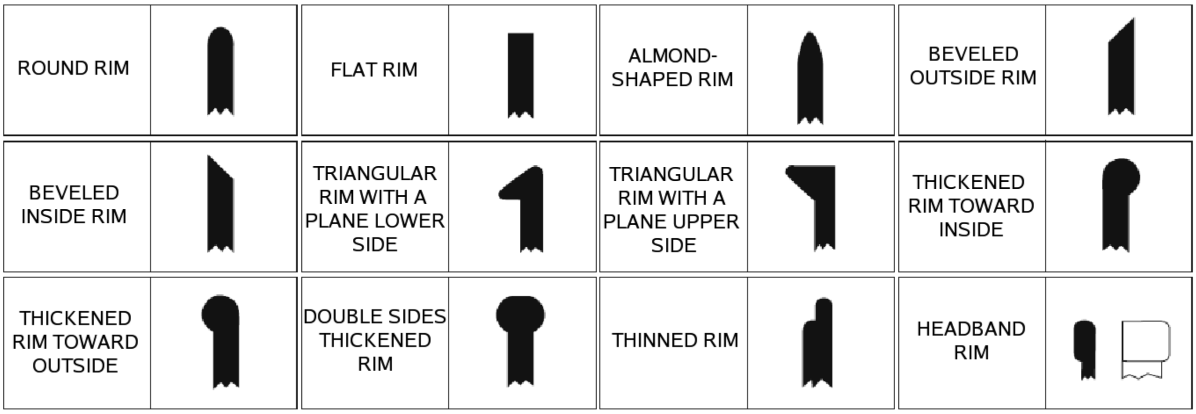

Figure 7: *Some possible rims for the "*sigillées*" potteries.*

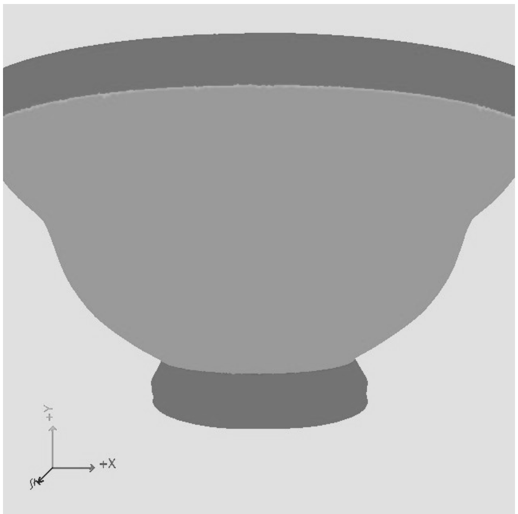

Figure 8: *A* Dragendorff 27 *mesh segmentation.*

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).

References

[BJ86] BÉMONT C., JACOB J.-P.: *La terre sigillée gallo-romaine: Lieux de production du Haut Empire: implantations, produits, relations*. Documents d'Archéologie Française, 6, Paris, 1986.

[CM02] CAO Y., MUMFORD D.: Geometric structure estimation of axially symmetric pots from small fragments. In *Signal Processing, Pattern Recognition, and Applications, IASTED International Conference* (Crete, Greece, June 26 wednesday 2002).

[D0́4] DÉCHELETTE J.: *Les vases céramiques ornés de la Gaule romaine*, vol. 2. Paris : Picard et fils, 1904.

[Dra95] DRAGENDORFF H.: *Terra Sigillata, ein Beitrag zur Geschichte der grieschischen und römischen keramik*. No. 96. Bonner Jahrbücher, 1895.

[Far96] FARIN G.: *Curve and Surface for Computer Aided Geometric Design*, fourth edition ed. Academic Press, Boston, 1996.

[FKS*04] FUNKHOUSER T., KAZHDAN M., SHILANE P., MIN P., KIEFER W., TAL A., RUSINKIEWICZ S., DOBKIN D.: Modeling by example. *ACM Transactions on Graphics (SIGGRAPH 2004)* (Aug. 2004).

[Hal99] HALÍŘ R.: An automatic estimation of the axis of rotation of fragments of archaeological pottery: A multi-step model-based approach. In *Proc. of the 7th International Conference in Central Europe on Computer Graphics, Visualization and Interactive Digital Media (WSCG'99)* (1999), Skala V., (Ed.).

[HF97] HALÍŘ R., FLUSSER J.: Estimation of profiles of sherds of archaeological pottery. In *Proc. of Czech Pattern Recognition Workshop '97* (Praha, Czech Republic, February 1997), Pajdla T., (Ed.), Czech Pattern Recognition Society, pp. 126–130.

[Kno19] KNORR R.: *Töpfer und Fabriken verzierter Terra Sigillata des ersten Jahrhnderts*. Stuttgart, 1919.

[KS03] KAMPEL M., SABLATNIG R.: An automated pottery archival and reconstruction system. *Journal of Visualization and Computer Animation 14*, 3 (July 2003), 111–120.

[KS04] KAMPEL M., SABLATNIG R.: 3d puzzling of archeological fragments. In *Proc. of 9th Computer Vision Winter Workshop* (Piran, Slovenia, 2004), Skocaj D., (Ed.), Slovenian Pattern Recognition Society, pp. 31–40.

[KSC01] KAMPEL M., SABLATNIG R., COSTA E.: Classification of archaeological fragments using profile primitives. In *Computer Vision, Computer Graphics and Photogrammetry - A Common Viewpoint, Proc. of the 25th Workshop of the Austrian Association for Pattern Recognition (ÖAGM)* (Oldenburg, Wien, München, 2001), Scherer S., (Ed.), vol. 147 of *Schriftenreihe der OCG*, pp. 151–158.

[KSM05] KAMPEL M., SABLATNIG R., MARA H.: Robust 3d reconstruction of archaeological pottery based on concentric circular rills. In *WIAMIS05: The 6th International Workshop on Image Analysis for Multimedia Interactive Services* (Montreux, Switzerland, 2005), N. M.-T., J.H. R., (Eds.), pp. 14–20.

[Mar96] MARTIN T.: *Céramiques Sigillées et Potiers Gallo-Romains de Montans*. édition Archéosite, 1996.

[MG05] MAIZA C., GAILDRAT V.: Automatic classification of archaeological potsherds. In *The Eight International Conference on Computer Graphics and Artificial Intelligence, 3IA'2005* (MSI Laboratory, Faculté des sciences, Limoges, France, May 11-12 2005), Pléménos D., (Ed.).

[MS05] M.T. SUZUKI Y. YAGINUMA Y. S.: A partial shape matching technique for 3d model retrieval systems. SIGGRAPH 2005 POSTER (The 32nd International Conference on Computer Graphics and Interactive Techniques), July 2005.

[MSKS04] MARA H., SABLATNIG R., KARASIK A., SMILANSKY U.: The uniformity of wheel produced pottery deduced from 3d image processing and scanning. In *Proc. of EVA04: Electronic Imaging and the Visual Arts* (2004), Cappelini V., Hemsley J., (Eds.), Pitagora Editrice Bologna, pp. 250–255.

[MTL03] MELERO F., TORRES J., LEON A.: On the interactive 3d reconstruction of iberian vessels. In *4th International Symposium on Virtual Reality, Archaeology and Intelligent Cultural Heritage, VAST'03* (November 5-7 2003), D. Arnold A. Chalmers F. N., (Ed.).

[MW99] MANGAN A., WHITAKER R.: Partitioning 3d surface meshes using watershed segmentation. In *IEEE*

Transactions on Visualization and Computer Graphics (1999), no. 5 in 4, pp. 308–321.

[PRF02] PULLA S., RAZDAN A., FARIN G.: Improved curvature estimation for water-shed segmentation of 3-dimensional meshes. IEEE Transactions on Visualization and Computer Graphics, 2002.

[RLB*01] RAZDAN A., LIU D., BAE M., ZHU M., FARIN G., SIMON A., HENDERSON M.: Using geometric modeling for archiving and searching 3d archaeological vessels. In *CISST, Las Vegas* (June 25–28 2001).

[Sim02] SIMON A.: *Advances in 3D Knowledge and Ceramic Vessel Morphology*. Tech. rep., PRISM / Archaeological Research Institute, October 01 2002.

[SMK98] SABLATNIG R., MENARD C., KROPATSCH W.: Classification of archaeological fragments using a description language. In *Signal Processing IX, Theories and Applications* (Rhodes, Greece, 1998), Theodoridis S., Pitas I., Stouraitis A., Kalouptsidis N., (Eds.), vol. II, EURASIP, pp. 1097–1100.

[SMM*05] SABLAYROLLES R., MAIZA C., MARAVAL M.-L., GAILDRAT V., BAROIN G.: *Système d'Imagerie et d'Analyse du Mobilier Archéologique, Rapport Final*. Tech. rep., IRIT-UPS, 2005.

[WC04a] WILLIS A., COOPER D.: Alignment of multiple non-overlapping axially symmetric 3d datasets. In *ICPR* (August 2004), vol. IV, pp. pp. 96–99.

[WC04b] WILLIS A., COOPER D.: Bayesian assembly of 3d axially symmetric shapes from fragments. In *CVPR* (June 2004), vol. I, pp. pp. 82–89.

[WOC03] WILLIS A., ORRIOLS X., COOPER D.: Accurately estimating sherd 3d surface geometry with application to pot reconstruction. In *CVPR Workshop : ACVA* (June 2003).

[YM97] YACOUB S., MENARD C.: Robust axis determination for rotational symmetric objects out of range data. In *21th Workshop of the Oeagm* (Hallstatt, Austria, May 1997), Burger W., M. Burge e., (Eds.), pp. 197–202.

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
VAST (2006)
M. Ioannides, D. Arnold, F. Niccolucci, K. Mania (Editors)

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

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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.

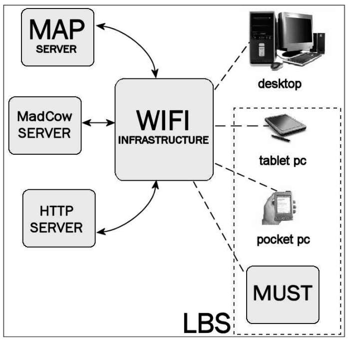

Figure 1: *Architecture overview.*

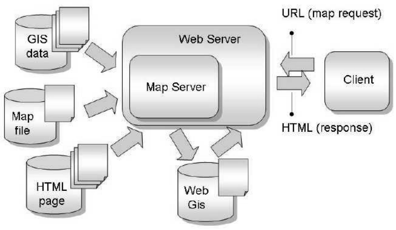

Figure 2: *MapServer architecture.*

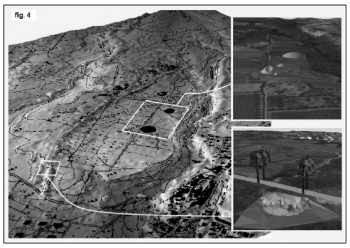

Figure 3: *3D models.*

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)

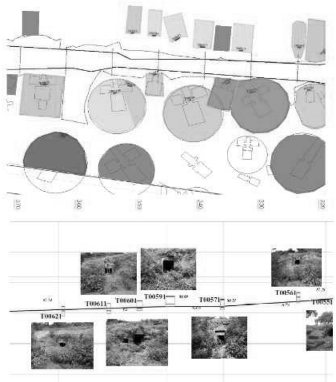

Figure 4: *Vertical iconometric views.*

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-

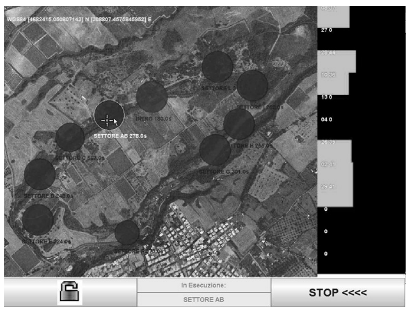

Figure 6: *The MUST user interface.*

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.

5. ACKNOWLEDGEMENTS

The panel that presented the project here mentioned is composed by the City of Cerveteri, the Soprintendenza Archeologica per l'Etruria Meridionale (SAEM), the Fondazione Archeologica per l'Etruria Meridionale (FAEM), the Galatour company as local tourist agency, the ECOmedia company as technological partner and the Department of Informatica of the University "La Sapienza" (Rome) as scientific partner.

References

[BCL*05] BOTTONI P., CIVICA R., LEVIALDI S., ORSO L., PANIZZI E., TRINCHESE R.: Storing and Retrieving Multimedia Web Notes. In *Databases in Networked Information Systems, 4th International Workshop, DNIS 2005, Aizu-Wakamatsu, Japan, March 28-30, 2005, Proceedings* (2005), Bhalla S., (Ed.), vol. 3433 of *Lecture Notes in Computer Science*, Springer, pp. 119–137.

[BFL*06] BOTTONI P., FARALLI S., LABELLA A., MALIZIA A., SCOZZAFAVA C.: Chambre: integrating multimedia and virtual tools. In *AVI '06: Proceedings of the working conference on Advanced visual interfaces* (New York, NY, USA, 2006), ACM Press, pp. 285–292.

[CMR06] CINNIRELLA A., MAURELLI P., ROSA F.: GIS to Improve Knowledge, Management and Promotion of an Archaelogical Park: the Project for UNESCO Etruscan Site in Cerveteri, Italy. In *ASIAGIS 2006* (2006).

[IBM] IBM: Videoannex annotation tool. http://www.research.ibm.com/VideoAnnEx/.

[KM95] KOTANI A., MAES P.: An environment for musical collaboration between agents and users. In *Proc. of Lifelike Computer Characters* (1995).

[Mit05] MITCHELL T.: Web Mapping Illustrated. *Using Open Source GIS Toolkits. O'Reilly Media inc.* (2005).

[OGC03] OGC: OGC reference model (version 0.1.2), document 03040 . *Technical report* (2003).

[PT03] PENG Z., TSOU M.: Internet GIS: distributed geographic information services for the Internet and wireless networks. *John Wiley and Son* (2003).

[SHK03] SCHROETER R., HUNTER J., KOSOVIC D.: Vannotea - a collaborative video indexing, annotation and discussion system for broadband networks. In *K-CAP Wks. on "Knowledge Markup and Semantic Annotation"* (2003).

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
VAST (2006)
M. Ioannides, D. Arnold, F. Niccolucci, K. Mania (Editors)

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

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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

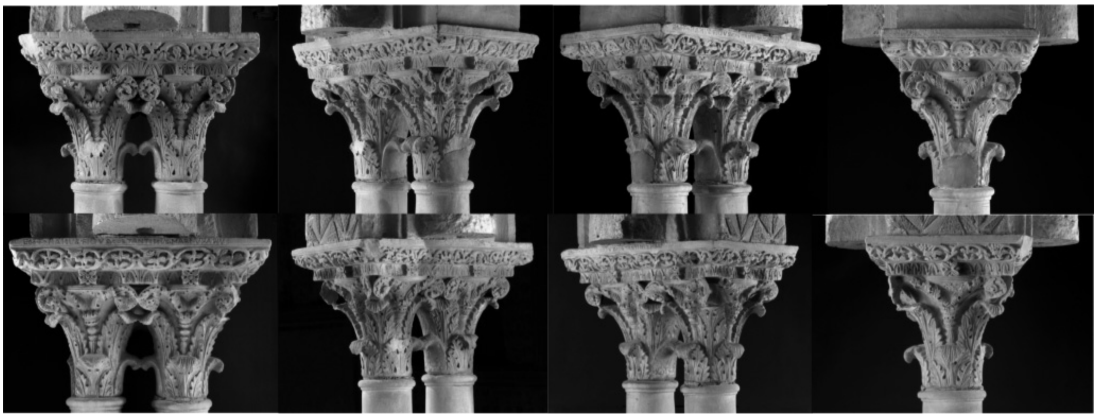

Figure 2: *An example of the set of photos acquired for sampling the color of each capital.*

(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

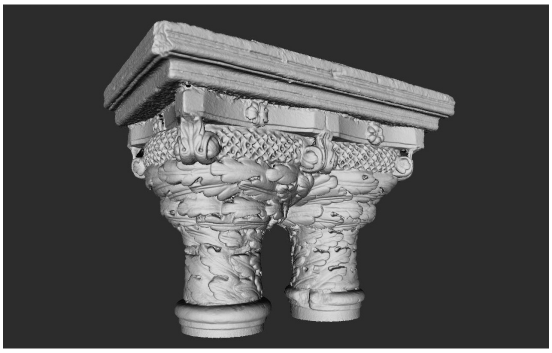

Figure 4: *The "Sh10" capital: ornamental leaves .*

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.

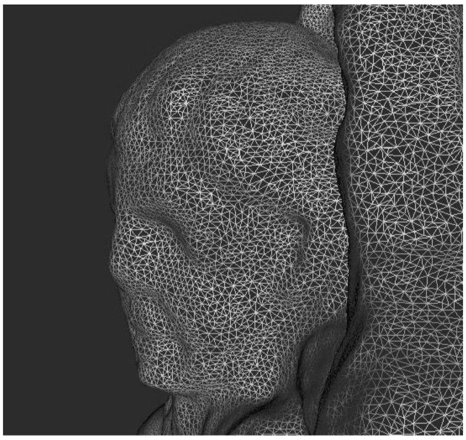

Figure 6: *A wireframe rendering of a small section of the "Sh23" capital (section height 5 cm.).*

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

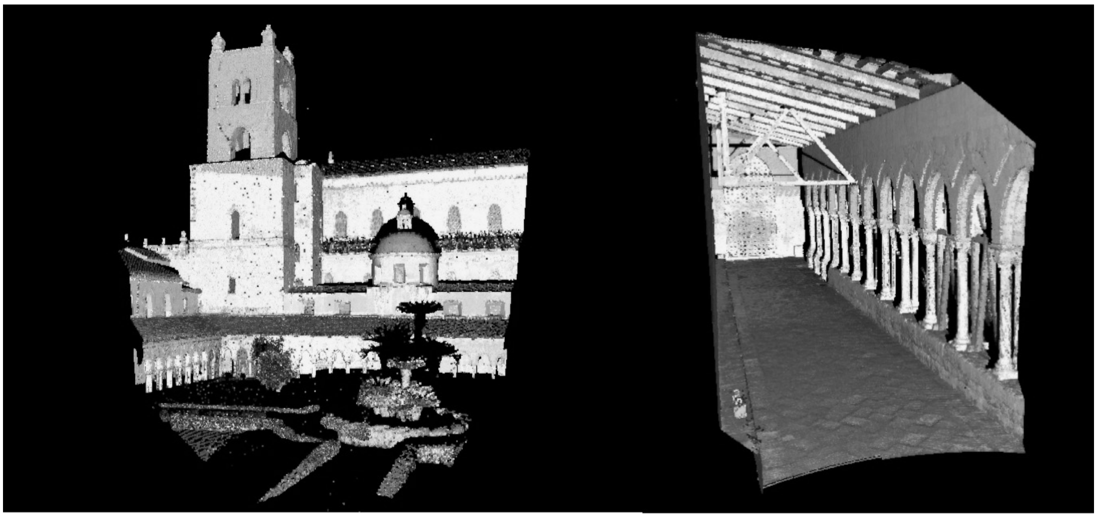

Figure 8: *Examples of time-of-flight scannings.*

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

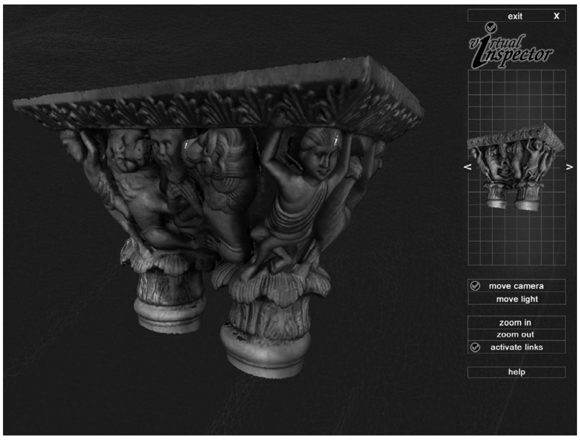

Figure 9: *Visualization of a capital using Virtual Inspector.*

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.

References

[BBC*04] BARACCHINI C., BROGI A., CALLIERI M., CAPITANI L., CIGNONI P., FASANO A., MONTANI C., NENCI C., NOVELLO R. P., PINGI P., PONCHIO F., SCOPIGNO R.: Digital reconstruction of the Arrigo VII funerary complex. In *VAST 2004* (Bruxelles, BE, Dec. 7-10 2004), Y. Chrysanthou K. Cain N. S., Niccolucci F., (Eds.), Eurographics, pp. 145–154.

[BCC*05] BALZANI M., CALLIERI M., CAPUTO G., CIGNONI P., DELLEPIANE M., PINGI P., PONCHIO F., SCOPIGNO R., TOMASI A., UCCELLI F.: Using multiple scanning technologies for the 3d acquisition of torcello's basilica, 2005.

[BCF*04] BALZANI M., CALLIERI M., FABBRI M., FASANO A., MONTANI C., PINGI P., SANTOPUOLI N., SCOPIGNO R., UCCELLI F., VARONE A.: Digital representation and multimodal presentation of archeological graffiti at Pompei. In *VAST 2004* (Bruxelles, BE, Dec. 7-10 2004), Y. Chrysanthou K. Cain N. S., Niccolucci F., (Eds.), Eurographics, pp. 93–104.

[BR02] BERNARDINI F., RUSHMEIER H. E.: The 3D Model Acquisition Pipeline. *Computer Graphics Forum 21*, 2 (March 2002), 149–172.

[BRM*02] BERNARDINI F., RUSHMEIER H. E., MARTIN I., MITTLEMAN J., TAUBIN G.: Building a Digital Model of Michelangelo's Florentine Pieta'. *IEEE Comp. Graphics & Applications 22*, 1 (Jan-Febr. 2002), 59–67.

[BWK02] BOTSCH M., WIRATANAYA A., KOBBELT L.: Efficient high quality rendering of point sampled geometry. In *Proceedings of the 13th Eurographics Workshop on Rendering (RENDERING TECHNIQUES-02)* (Aire-la-Ville, Switzerland, June 26–28 2002), Gibson S., Debevec P., (Eds.), Eurographics Association, pp. 53–64.

[CCG*03] CALLIERI M., CIGNONI P., GANOVELLI F., MONTANI C., PINGI P., SCOPIGNO R.: VCLab's tools for 3D range data processing. In *VAST 2003* (Bighton, UK, Nov. 5-7 2003), D. Arnold A. C., Niccolucci F., (Eds.), Eurographics, pp. 13–22.

[CCS02] CALLIERI M., CIGNONI P., SCOPIGNO R.: Reconstructing textured meshes from multiple range rgb maps. In *7th Int.l Fall Workshop on Vision, Modeling, and Visualization 2002* (Erlangen (D), Nov. 20 - 22 2002), IOS Press, pp. 419–426.

[CGG*04] CIGNONI P., GANOVELLI F., GOBBETTI E., MARTON F., PONCHIO F., SCOPIGNO R.: Adaptive tetrapuzzles: Efficient out-of-core construction and visualization of gigantic multiresolution polygonal models. *ACM Trans. on Graphics (SIGGRAPH 2004) 23*, 3 (2004), 796–803.

[CMRS03] CIGNONI P., MONTANI C., ROCCHINI C., SCOPIGNO R.: External memory management and simplification of huge meshes. *IEEE Transactions on Visualization and Computer Graphics 9*, 4 (2003), 525–537.

[CS00] CURLESS B., SEITZ S.: 3D Photography. In *ACM SIGGRAPH 00 Course Notes, Course No. 19* (2000).

[FDG*05] FRANKEN T., DELLEPIANE M., GANOVELLI F., CIGNONI P., MONTANI C., SCOPIGNO R.: Minimizing user intervention in registering 2d images to 3d models. *The Visual Computer 21*, 8-10 (sep 2005), 619–628. Special Issues for Pacific Graphics 2005.

[FGM*02] FONTANA R., GRECO M., MATERAZZI M., PAMPALONI E., PEZZATI L., ROCCHINI C., SCOPIGNO R.: Three-dimensional modelling of statues: the minerva of arezzo. *Journal of Cultural Heritage 3*, 4 (2002), 325–331.

[GH97] GARLAND M., HECKBERT P.: Surface simplification using quadric error metrics. In *SIGGRAPH 97 Conference Proceedings* (Aug. 1997), Annual Conference Series, Addison Wesley, pp. 209–216.

[Hop99] HOPPE H.: New quadric metric for simplifying meshes with appearance attributes. In *Proc. IEEE Conference on Visualization (VIS99)* (New York, Oct. 25–28 1999), ACM Press, pp. 59–66.

[LKG*03] LENSCH H. P. A., KAUTZ J., GOESELE M., HEIDRICH W., SEIDEL H.-P.: Image-based reconstruction of spatial appearance and geometric detail. *ACM Transaction on Graphics 22*, 2 (Apr. 2003), 234–257.

[LPC*00] LEVOY M., PULLI K., CURLESS B., RUSINKIEWICZ S., KOLLER D., PEREIRA L., GINZTON M., ANDERSON S., DAVIS J., GINSBERG J., SHADE J., FULK D.: The Digital Michelangelo Project: 3D scanning of large statues. In *SIGGRAPH 2000, Computer Graphics Proceedings* (July 24-28 2000), Annual Conference Series, Addison Wesley, pp. 131–144.

[PGV*01] POLLEFEYS M., GOOL L. J. V., VERGAUWEN M., VERBIEST F., TOPS J.: Image-based 3d acquisition of archeological heritage and applications. In *VAST 2001 Conference Proc.* (Athens, Greece, Nov. 28-30 2001), Arnold D., Chalmers A., Fellner D., (Eds.), ACM Siggraph, pp. 255–261.

[STH*03] STUMPFEL J., TCHOU C., HAWKINS T., DEBEVEC P., COHEN J., JONES A., EMERSON B.: Assembling the sculptures of the parthenon. In *VAST 2003* (Bighton, UK, Nov. 5-7 2003), D. Arnold A. C., Niccolucci F., (Eds.), Eurographics, pp. 41–50.

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
VAST (2006)
M. Ioannides, D. Arnold, F. Niccolucci, K. Mania (Editors)

Integration issues for tools to create interactive Cultural Heritage experiences

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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):

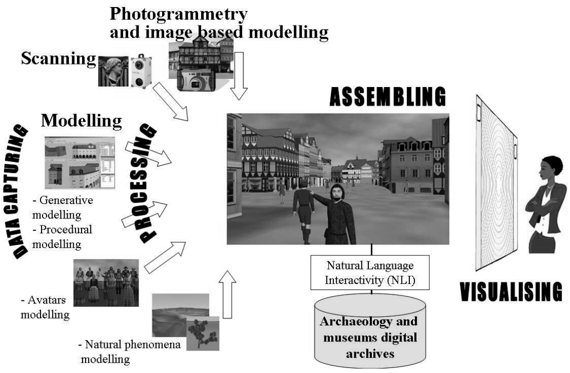

Figure 2: *Framework for the creation of a virtual CH environment*

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

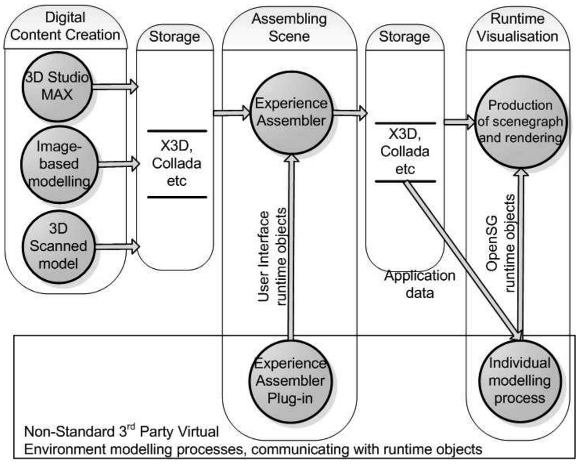

Figure 3: *Runtime object exchange*

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.

Acknowledgement

This work has been conducted as part of the EPOCH network of excellence (IST-2002-507382) within the IST (Information Society Technologies) section of the Sixth Framework Programme of the European Commission. Some of the 3D models were created by the Epoch 3D webservice, developed by the VISICS research group of the K.U.Leuven in Belgium.

References

[AB88] ARNOLD D. B., BONO P.: *CGM and CGI: Metafile and Interface Standards for Computer Graphics*, isbn 3-540-18950-5 ed. Springer-Verlag, Heidelberg New York, March 1988, p. 279. 3

[AD90] ARNOLD D. B., DUCE D.: ISO Standards for Computer Graphics: The First Generation. *Computer Graphics Standards Reference Series - Butterworth's Scientific 1* (March 1990), pp264. 3

[BLE] BLENDER: http://www.blender.org/cms/Home.2.0.html. 2

[CC] CIDOC-CRM: http://cidoc.ics.forth.gr/. 3

[CSA04] CH'NG E., STONE R. J., ARVANITIS T. N.: The Shotton River and Mesolithic Dwellings: Recreating the Past from Geo-Seismic Data Sources. In *Proceedings of the 5th International Symposium on Virtual Reality, Archaeology and Intelligent Cultural Heritage (VAST)* (Brussels, December 2004). 1

[GCP04] GAITATZES A., CHRISTOPOULOS D., PAPAIOANNOU G.: The Ancient Olympic Games: Being Part of the Experience. In *Proceedings of the 5th International Symposium on Virtual Reality, Archaeology and Intelligent Cultural Heritage (VAST)* (Brussels, December 2004). 1

[GML] GML: http://www.generative-modeling.org/GenerativeModeling/DOCUMENTS. 2

[LB04] LADEIRA I., BLAKE E.: Virtual San Storytelling for Children: Content vs. Experience. In *Proceedings of the 5th International Symposium on Virtual Reality, Archaeology and Intelligent Cultural Heritage (VAST)* (Brussels, December 2004). 1

[MVcSL05] MUDGE M., VOUTAZ J.-P., CARLA SCHROER, LUM M.: Reflection Transformation Imaging and Virtual Representation of Coins from the Hospice of the Grand St. Bernard. In *Proceedings of 6th International Symposium on Virtual Reality, Archaeology and Intelligent Cultural Heritage (VAST)* (Pisa, Italy, November 2005). 4

[Opec] OPENSG: http://www.opensg.org/. 3

[VvG06] VERGAUWEN M., VAN GOOL L.: Web-Based 3D Reconstruction Service. In *Machine Vision Applications* (2006). 2

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
VAST (2006)
M. Ioannides, D. Arnold, F. Niccolucci, K. Mania (Editors)

Interactive Simulation of Ancient Technology Works

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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 walkthroughs 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.

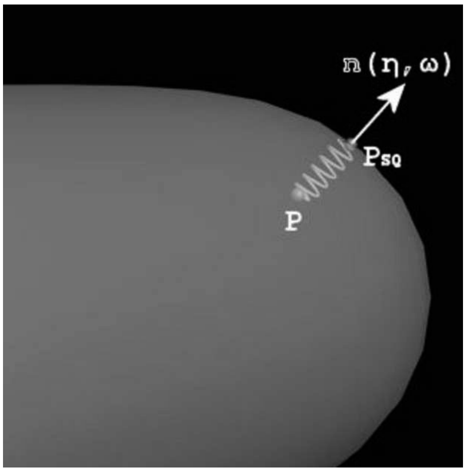

Figure 1: *Force feedback evaluation*

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:

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

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:

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

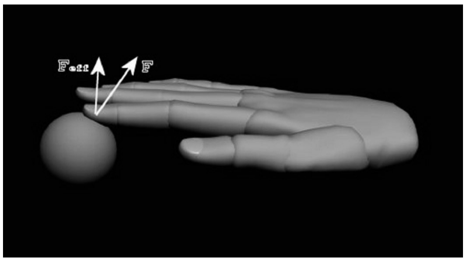

Figure 2: *Force feedback for the CyberGrasp*

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.

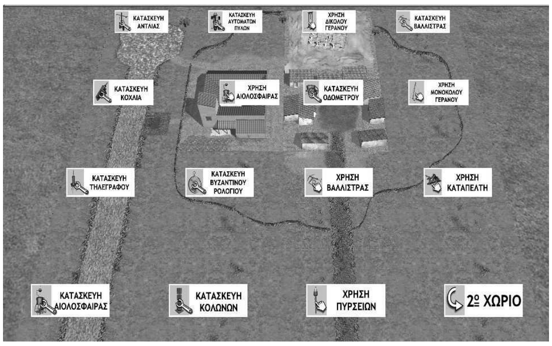

Figure 3: *The ancient village.*

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,

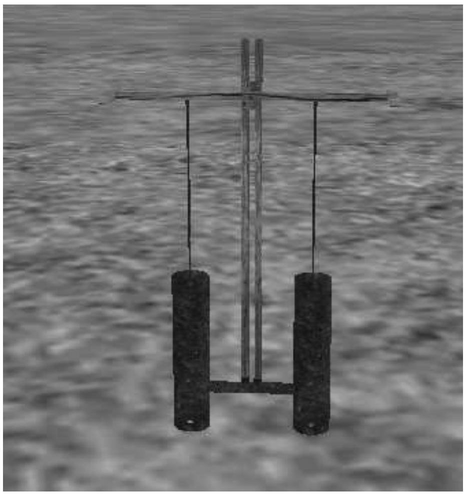

Figure 5: *Ktisivios pump.*

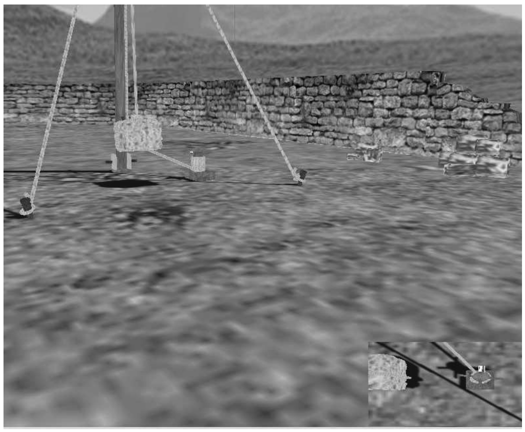

Figure 6: *Single pulley crane.*

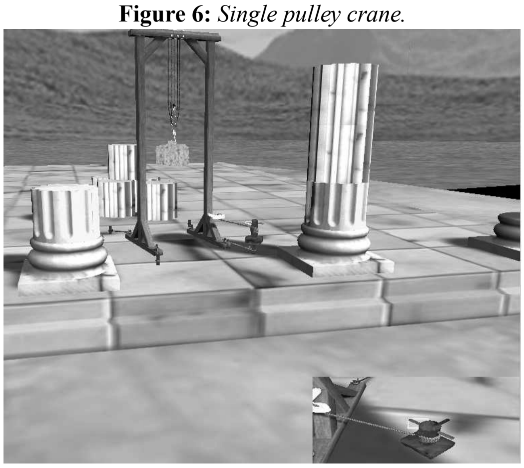

Figure 7: *Double pulley crane.*

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.

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.

References

[BP01] BARBIERI T., PAOLINI P.: Reconstructing leonardo's ideal city - from handwritten codexes to webtalk-ii: a 3d collaborative virtual environment system. In *Proceedings of the 2001 conference on Virtual reality, archeology, and cultural heritage* (2001), ACM Press, pp. 61–66.

[GPC03] G. PAPAIOANNOU A. G., CHRISTOPOULOS D.: Enhancing virtual reality walkthroughs of archaeological

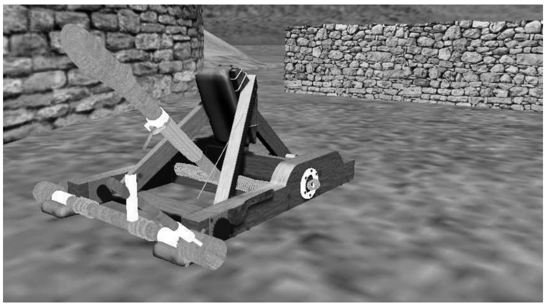

Figure 8: *Catapult.*

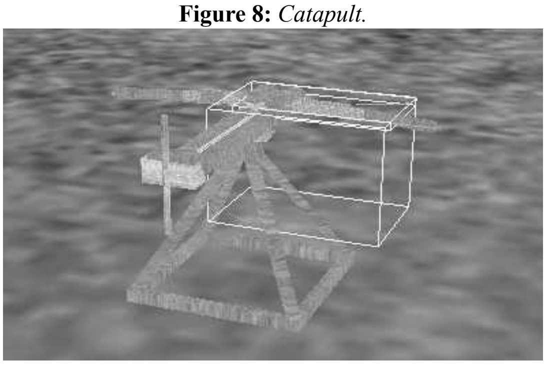

Figure 9: *Crossbow.*

Figure 10: *Sphere of Aiolos.*

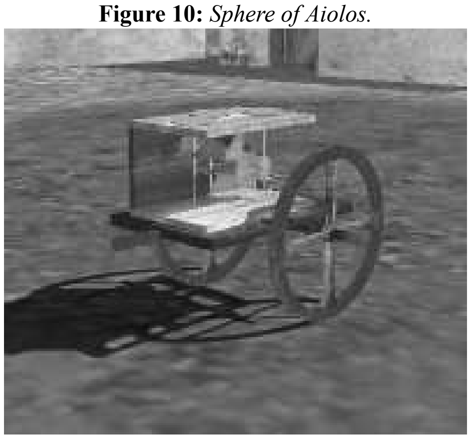

Figure 11: *Odometer mechanism.*

sites. In *Proceedings of the 2003 conference on Virtual reality, archeology, and cultural heritage* (2003).

[Ili02] ILIADIS N.: *Learning Technology Through the Internet*. Kastaniotis Publisher, Athens, 2002.

[LS03] LEDERMANN F., SCHMALSTIEG D.: Presenting an archaeological site in the virtual showcase. In *Proceedings of the 2003 conference on Virtual reality, archeology, and cultural heritage* (2003).

[Mal78] MALEY D.: *The Industrial Arts teachers handbook: Techniques, principles and methods*. Allyn and Bacon, Boston, 1978.

[Mal79] MALEY D.: *The Maryland plan. In American Council on Industrial Arts Teacher Education, Indus-trial Arts education:Retrospect, prospect*. Bloomington, Illinois, McKnight, 1979.

[MAS02] MALASSIOTIS S., AIFIANTI N., STRINTZIS M. G.: A gesture recognition system using 3d data. In *IEEE 1st International Symposium on 3D Data Processing Visualization and Transmission* (June 2002).

[NFT03] NIKOLAKIS G., FERGADIS G., TZOVARAS D.: Virtual assembly based on stereo vision and haptic force feedback virtual reality. In *in Proc. HCI International* (June 2003).

[NFTS04] NIKOLAKIS G., FERGADIS G., TZOVARAS D., STRINTZIS M. G.: A mixed reality learning environment for geometry education. In *in Lecture Notes in Artificial Intelligence* (June 2004), Springer Verlag.

[NTMS] NIKOLAKIS G., TZOVARAS D., MALASSIOTIS S., STRINTZIS M. G.: Simulation of ancient technology works using haptic interaction and gesture recognition. (Proc. VAST 2004).

[SB90] SOLINA F., BAJCSY R.: Recovery of parametric models from range images: The case for superquadrics with global deformations. *IEEE Trans. Pattern Anal. Mach. Intell. 12*, 2 (1990), 131–147.

[SDP00] SPARACINO F., DAVENPORT G., PENTLAND A.: Media in performance: Interactive spaces for dance, theater, circus and museus exhibits. *"IBM Systems Journal" 39*, 3 (2000), 479–510.

[TNF*04] TZOVARAS D., NIKOLAKIS G., FERGADIS G., MALASIOTIS S., STAVRAKIS M.: Design and implementation of haptic virtual environments for the training of visually impaired. *IEEE Trans. on Neural Systems and Rehabilitation Engineering 12*, 2 (June 2004), 266–278.

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
VAST (2006)
M. Ioannides, D. Arnold, F. Niccolucci, K. Mania (Editors)

Project Presentations

Digital Documentation of Cultural Heritage Objects using hybrid recording techniques

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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.

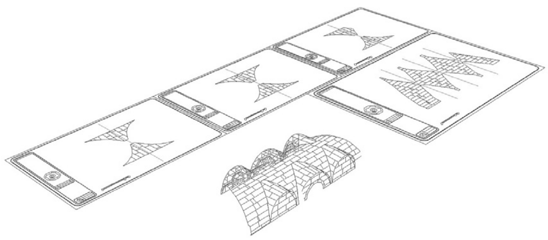

Figure 4: *Collage of a 3D CAD model and the associated 2D joint graphics*

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.

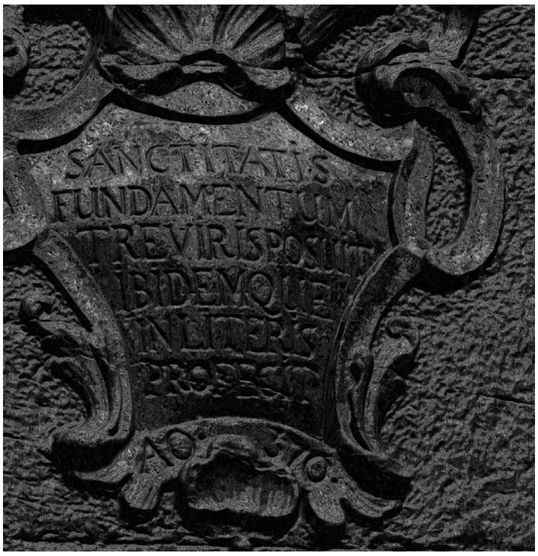

Figure 9: *High resolution 3D surface model of a relief*

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.

References

[BBH04] Böhler W., Bordas Vicent M., Heinz G., Marbs A., Müller H: High Quality Scanning and Modeling of Monuments and Artifacts - Proceedings of the FIG Working Week 2004, May 22-27 - Athens, Greece. Published by FIG. - 2004

[BBY04] Böhler W., Bordas Vicent M., Yule P.: Documentation of Sisupalgarh in Coastal Orissa - GIS Development, The Asian GIS Monthly, June 2004, Vol.8, Issue 6. pp. 30-32 – 2004

[BOO03] Boochs F.: DISCA und DISTA - ein stereophotogrammetrisches Aufnahme- und Auswertesystem für einfache Messaufgaben - Denkmäler 3D, Universität Essen - Essen - 2003

[HEI02] Heinz G.: Combination of Photogrammetry and easy-to-use non-metric methods for the documentation of archaeological excavations. ISPRS, Commission V Symposium; Close-Range Imaging, Long-Range Vision - Corfu, Greece - 2002

[MAR02] Marbs A.: Experiences with laser scanning at i3mainz - CIPA, Heritage Documentation - International Workshop on Scanning for Cultural Heritage Recording, pp. 110 – 114, Corfu, Greece – 2002

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
VAST (2006)
M. Ioannides, D. Arnold, F. Niccolucci, K. Mania (Editors)

An Introduction to the London Charter

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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.

7. Acknowledgements

The present paper has been partially supported by EPOCH, project no. IST-2002-507382. However, this paper reflects only the authors' views and the European Community is not liable for any use that may be made of the information contained herein

References

[Bar00] BARCELÒ J. A.: Visualizing what might be: an introduction to Virtual Reality techniques in Archaeology. In *Virtual Reality in Archaeology* (Oxford, 2000), Barcelò J. A., Forte M., Sanders D. H., (Eds.), Archaeopress, pp. 9–37.

[BFS00] BARCELÒ J. A., FORTE M., SANDERS D. H. (Eds.): *Virtual Reality in Archaeology*. Archaeopress, Oxford, 2000.

[CHA] http://www.international.icomos.org/charters.htm (accessed 18/09/06).

[CRM] http://cidoc.ics.forth.gr/ (accessed 18/09/06).

[EFHR03] EITELJORG II H., FERNIE K., HUGGETT J., ROBINSON D.: *CAD: A Guide to Good Practice*. Oxbow Books, Oxford, 2003.

[ENA] http://www.enamecharter.org/ (accessed 18/09/06).

[FNRB02] FRISHER B., NICCOLUCCI F., RYAN N. S., BARCELÓ J. A.: From CVR to CVRO: the Past, Present and Future of Cultural Virtual Reality. In *Virtual Archaeology — Proceedings of VAST2000* (Oxford, 2002), Niccolucci F., (Ed.), Archaeopress, pp. 7–18.

[FR03] FERNIE K., RICHARD J. (Eds.): *Creating and Using Virtual Reality: a Guide for the Arts and Humanities*. Oxbow Books, Oxford, 2003.

[GG00] GOODRICK G., GILLINGS M.: Constructs, simulations and hyperreal worlds: the role of Virtual Reality (VR) in archaeological research. In *On the theory and practice of archaeological computing* (Oxford, 2000), Lock G., Brown K., (Eds.), Oxford University Committee for Archaeology, Institute of Archaeology, pp. 41–58.

[JKS03] JABLONKA P., KIRCHNER S., SERANGELI J.: TroiaVR: a Virtual Reality Model of Troy and the Troad. In *The Digital Heritage of Archaeology — Proceedings of CAA2002* (Athens, 2003), Doerr M., Sarris A., (Eds.), Hellenic Ministry of Culture, pp. 13–18.

[LC] http://www.londoncharter.org (accessed 18/09/06).

[NH06] NICCOLUCCI F., HERMON S.: A Fuzzy Logic Approach to reliability in Archaeological Virtual Reconstructions. In *Beyond the Artifact — Proceedings of CAA2004* (Budapest, 2006), Niccolucci F., Hermon S., (Eds.), Archaeolingua.

[Nic99] NICCOLUCCI F.: Virtual reality in Archaeology: a useful tool or a dreadful toy? In *Proceedings of the Medi@terra Symposium, Athens* (1999), pp. 238–239.

[RD03] ROUSSOU M., DRETTAKIS G.: Photorealism and Non-Photorealism in Virtual Heritage Representation. In *VAST2003 The 4th International Symposium on Virtual Reality, Archaeology and Cultural Heritage* (Aire-La-Ville, 2003), Arnold D., Chalmers A., Niccolucci F., (Eds.), Eurographics, pp. 51–60.

[RR96] ROBERTS J. C., RYAN N. S.: Alternative Archaeological Representations within Virtual Worlds. Available at: `http://www.cs.kent.ac.uk/people/staff/nsr/arch/vrsig97/vrsig.html` (accessed 18/09/06), 1996.

[Rya96] RYAN N. S.: Computer based visualisation of the past: technical realism and historical credibility. In *Imaging the Past* (London, 1996), Higgins P., Main P., J. L., (Eds.), British Museum Press, Occasional Paper 114, pp. 95–108.

[ZCG05] ZUK T., CARPENDALE S., GLANZAMAN W. D.: Visualizing Temporal Uncertainty in 3D Virtual Reconstructions. In *VAST2005 The 6th International Symposium on Virtual Reality, Archaeology and Cultural Heritage* (Aire-La-Ville, 2005), Mudge M., Ryan N. S., Scopigno R., (Eds.), Eurographics, pp. 99–106.

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
VAST (2006)
M. Ioannides, D. Arnold, F. Niccolucci, K. Mania (Editors)

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

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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

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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

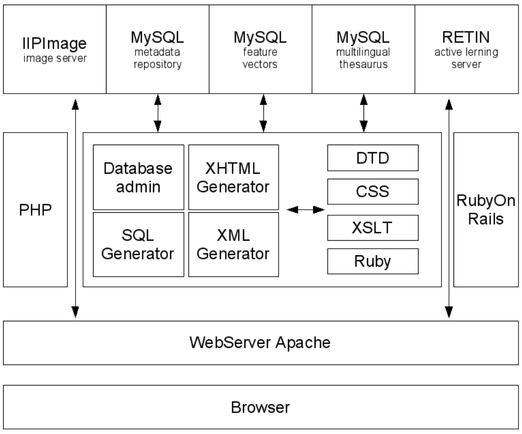

Figure 1: *EROS database organization.*

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*

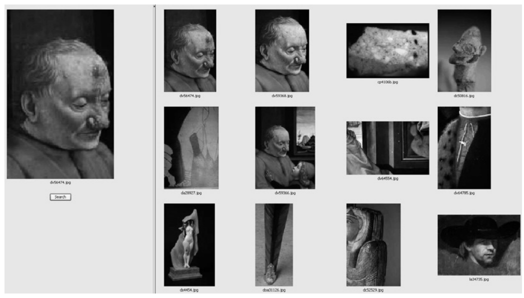

Figure 3: *PORTRAIT OF AN OLD MAN WITH A YOUNG BOY - GHIRLANDAIO Domenico (1449-1494), Louvre Museum, Paris, inv. RF266*

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.

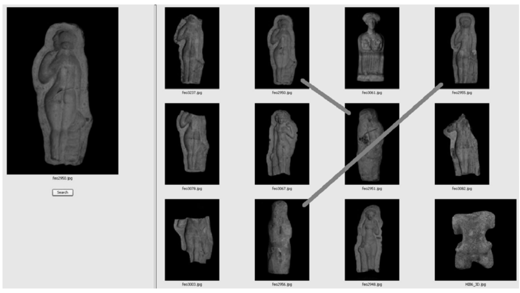

Figure 5: *ANADYOMENE VENUS - PRISCUS, France, Moulins, Anne de Beaujeu Museum, inv. 5.3.20*

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

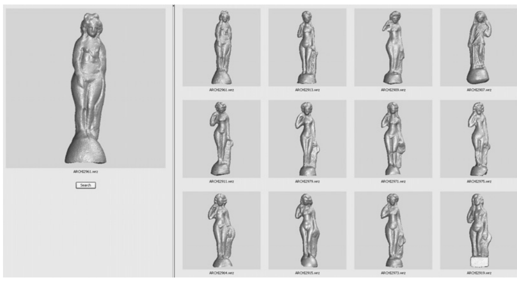

Figure 6: *PRUDISH VENUS - France, Moulins, Anne de Beaujeu Museum, inv. 5.7.6*

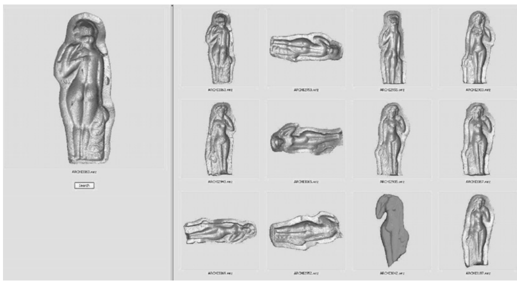

Figure 7: *ANADYOMENE VENUS - France, Moulins, Anne de Beaujeu Museum, inv. 5.3.33*

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.

References

[ALPP05] AITKEN G., LAHANIER C., PILLAY R., PITZALIS, D.: EROS : An Open Source Database For Museum Conservation Restoration. In *Preprints de la 14ème réunion triennale du Comitè International pour la Conservation ICOM-CC*, 2005, pp. 15–23. 2

[ALPP06] AITKEN G., LAHANIER C., PILLAY R., PITZALIS, D.: Database Management and Innovative Applications for Imaging within Museum Laboratories. emph7th European Commission Conference "SAUVEUR", Prague, Czech Republic, 2006 2

[AML*05] ADDIS M., MARTINEZ K., LEWIS P., STEVENSON J., GIORGINI F.: New ways to search, navigate and use multimedia museum collections over the web. In *Proceedings of Museums and the Web* (2005). 2

[FP02] FEKETE, J., PLAISANT, C.: Interactive Information Visualization of a Million Items. *IEEE Symposium on Information Visualization*, Boston, October 2002 2

[FTT05] FELIPE J. C., TRAINA A. J. M., TRAINA C. J.: Global warp metric distance: Boosting content-based image retrieval through histograms. *ism 0* (2005), pp. 295–302. 2

[GBT*02] GODIN G., BERALDIN J. A., TAYLOR J., COURNOYER L., RIOUX M., EL-HAKIM S., BARIBEAU R., BLAIS F., BOULANGER P., DOMEY J., PICARD M.: Active optical 3d imaging for heritage applications. *IEEE Comput. Graph. Appl. 22*, 5 (2002), pp. 24–36. 1

[IJL*05] IYER N., JAYANTI S., LOU K., KALYANARAMAN Y., RAMANI K.: Three-dimensional shape searching: state-of-the-art review and future trends. *Computer-Aided Design 37*, 5 (April 2005), pp. 509–530. 3

[LAC*04] LAHANIER C., AITKEN G., COTTE P., PILLAY R., PITZALIS, D.: Digital capture of archive, objects and paintings for research and conservation. In *EVA* (2004). 1

[LDP02] LAHANIER C., DUFRESNE J. L., PILLAY R.: Acohir: a system for 3d digitization applied to conservation and research imaging. In *The 13th Triennial Meeting, ICOM, J&J* (2002). 1

[LFJ*05] LAHANIER C., FEIHL O., JEANLIN M., PITZALIS D., SCHMITT F.: 3D modelling of archaeological objects for conservation, visualisation, colour and shape characterisation, details comparison In *Preprints de la 14ème réunion triennale du Comitè International pour la Conservation ICOM-CC*, 2005, pp. 43–51. 1

[PPLA05] PILLAY R., PITZALIS D., LAHANIER C., AITKEN G.: Eros: New development in digital archiving for research in conservation. In *EVA* (2005), pp. 192–197. 2

[TS06] TAE P. K., SHIK M. Y.: Object-based image retrieval using dominant color pairs between adjacent regions. In *Computational Science and its Applications - ICCSA 3984* (2006), pp. 404–411. 2

[TV04] TANGELDER J. W. H., VELTKAMP R. C.: A survey of content based 3d shape retrieval methods. In *SMI '04: Proceedings of the Shape Modeling International 2004 (SMI'04)* (Washington, DC, USA, 2004), IEEE Computer Society, pp. 145–156. 3

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
VAST (2006)
M. Ioannides, D. Arnold, F. Niccolucci, K. Mania (Editors)

Modeling and Digital Fabrication of Traditional Japanese Lacquer Ware

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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.

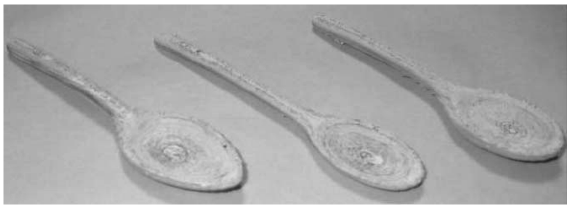

Figure 2: *Spoon models fabricated by a rapid prototyping KIRA Solid Center machine using the paper laminating process.*

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.*

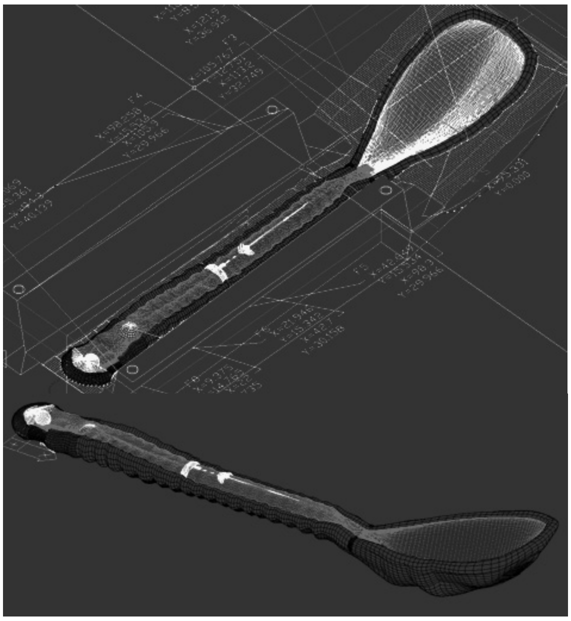

Figure 5: *New "organic" spoon design.*

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

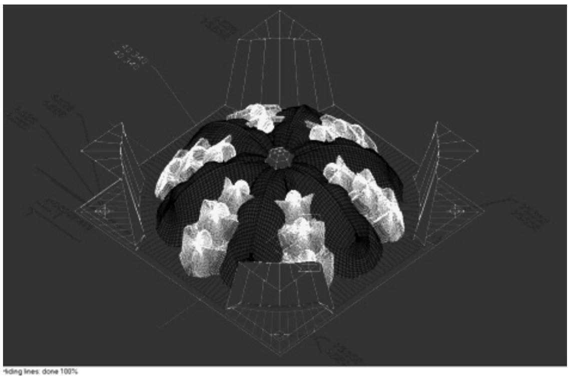

Figure 7: *New bonbonniere design.*

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.

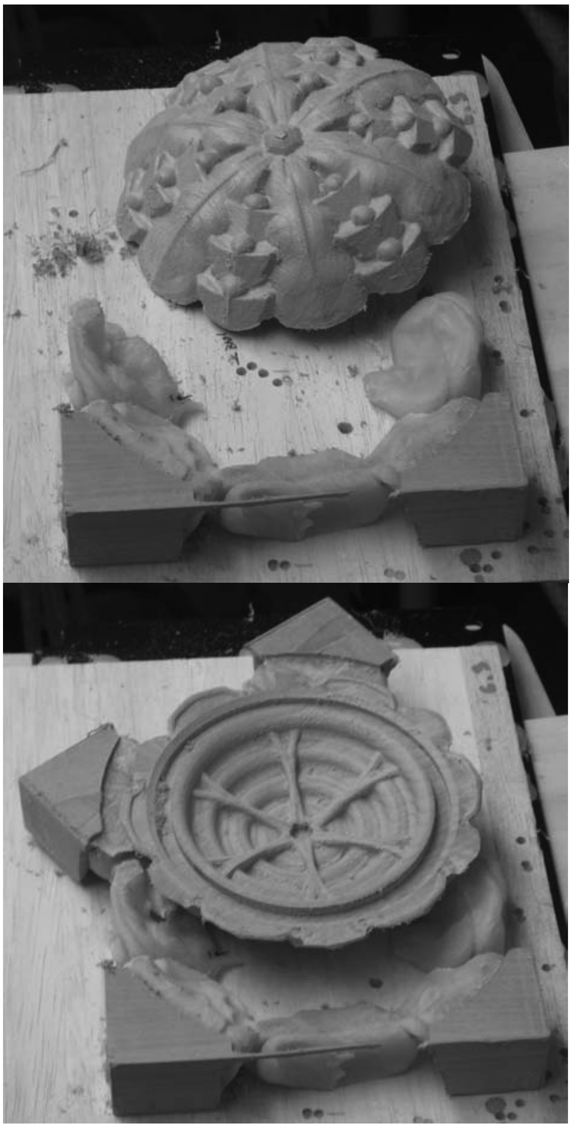

Figure 8: *A fabricated wooden bonbonniere lid with tooling for a Modela machine*

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.

References

[ACF*99] V. ADZHIEV, R. CARTWRIGHT, E. FAUSETT, A. OSSIPOV, A. PASKO, V. SAVCHENKO, HyperFun project: a framework for collaborative multidimensional F-rep modeling , Implicit Surfaces '99, Eurographics/ACM SIGGRAPH Workshop, J. Hughes and C. Schlick (Eds.), pp. 59-69.

[CAP*05] R. CARTWRIGHT, V. ADZHIEV, A. PASKO, Y. GOTO, T. KUNII, Web-based shape modeling with HyperFun, IEEE Computer Graphics and Applications, vol. 25, No. 2, 2005, pp. 60-69.

[PA04] A. PASKO, V. ADZHIEV, Function-based shape modeling: mathematical framework and specialized language, Automated Deduction in Geometry, Lecture Notes in Artificial Intelligence 2930, Ed. F. Winkler, Springer-Verlag, Berlin Heidelberg, 2004, pp. 132-160.

[PAS*95] A. PASKO, V. ADZHIEV, A. SOURIN, V. SAVCHENKO, Function representation in geometric modeling: concepts, implementation and applications, The Visual Computer, vol.11, No. 8, 1995, pp.429-446.

[VPP*04] C. W. VILBRANDT, G. I. PASKO, A. A. PASKO, P.-A. FAYOLLE, T. I. VILBRANDT, J. R. GOODWIN, J. M. GOODWIN, T.L. KUNII, Cultural heritage preservation using constructive shape modeling, Computer Graphics Forum, vol. 23, No.1, 2004, pp. 25-41.

[VS] VIRTUAL SHIKKI, Web site http://cis.k.hosei.ac.jp/~F-rep/App/shi/Shikki.html

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
VAST (2006)
M. Ioannides, D. Arnold, F. Niccolucci, K. Mania (Editors)

Project Presentations

Digital Preservation and Promotion of the Architectural Heritage of Attica

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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.

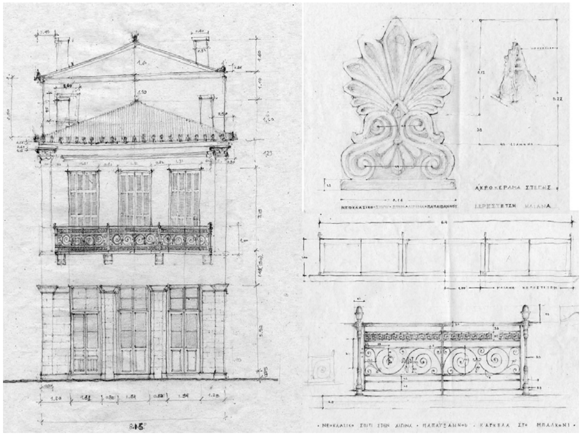

Fig 1: *An example with sketches of a neoclassical building*

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.

5. References

[AB01] Adami M., Biris M.: *Neoclassical Architecture in Greece,* Melissa 2001

[Bir95] BIRIS K. H.: *Athens from 19th to the 20th Century,* Melissa 1995

[Bir87] BIRIS M.: *Half a Century of Athenian Architecture: 1875 – 1925.* Athens 1987

[Cla01] Clark K.: *Informed Conservation: Understanding Historic Buildings and their Landscapes for Conservation*, London: EH 2001

Council of Europe 1995 *Core Data Index to Historic Buildings and Monuments of the Architectural Heritage (Recommendation R (95) 3 of the Committee of Ministers to member states on co-ordinating documentation methods and systems related to historic buildings and monuments of the architectural heritage), Strasbourg: Council of Europe*

[DSV02] Dierckx T., Stellingwerff M., Verbeke J.: *Relating to the „Real", Theories for and Experience with Educational Database Systems* eCAADe 20 Education and Curricula, Tradition and E-ducation Areas, Session 02

[Mik01] Mikrou T. *Digital Representations of Historic Buildings: The case Study of the Tron Kirk in Edinburgh.* Master Thesis for the degree of MSc in Design and Digital Media University of Edinburgh, 2001

[Nov98] Novitski B. J.: *Rendering real and imagined buildings : the art of computer modeling from the palace of Kublai Khan to Le Corbusier's villas,* Gloucester, MA : Rockport Publishers , c1998

Web references

http://buildmemory.arch.ntua.gr,

http://dynamo.asro.kuleuven.be

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
VAST (2006)
M. Ioannides, D. Arnold, F. Niccolucci, K. Mania (Editors)

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

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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.

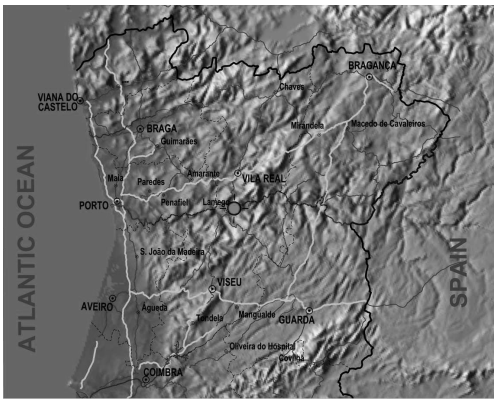

Figure 1 – *Map of the northern region of Portugal with location of Monastery of Santo António de Ferreirim (red spot).*

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.

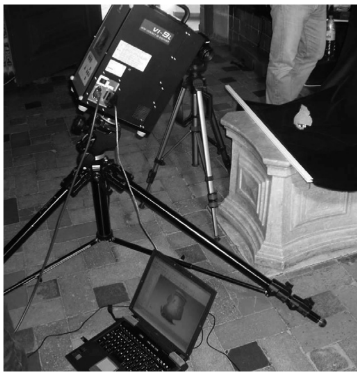

Figure 4 - *Laser Scanner System Konica-Minolta Vivid 9i 3D non-contact digitizer.*

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.

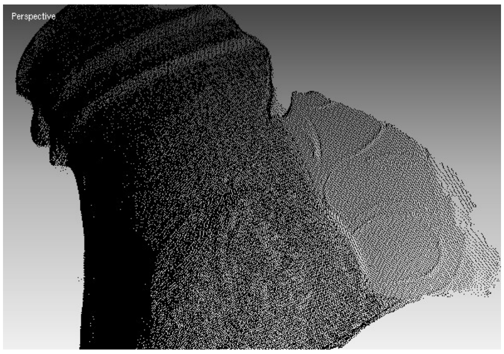

Figure 5 – *Point cloud from the biggest fragment.*

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.

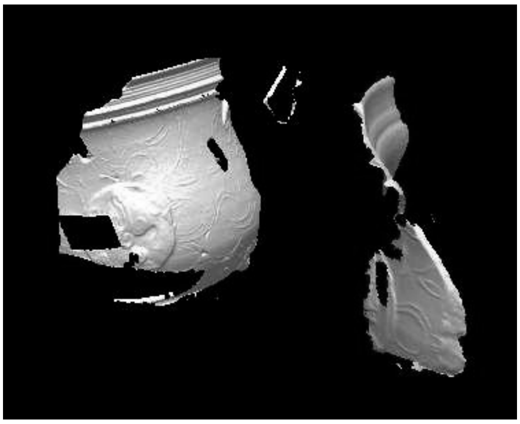

Figure 7 – *Resulting meshes from scanning with a flat mirror.*

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.

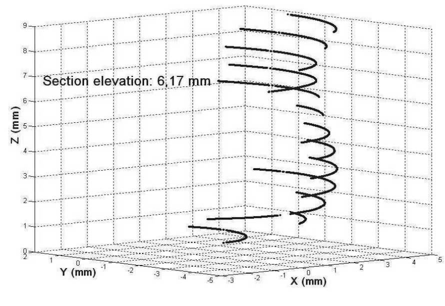

Figure 8 – ***Horizontal sections.***

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.

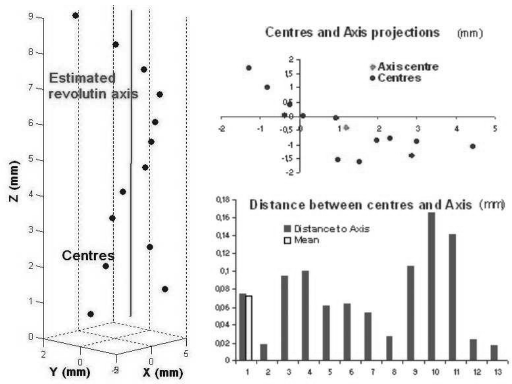

Figure 9 – *Axonometric representation of all the centres of the adjusted circles and the calculated rotation axis (left); centres and rotation axis horizontal projection (top right); distance from centres to the rotation axis and the respective mean distance (0.072 mm) (bottom right).*

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.

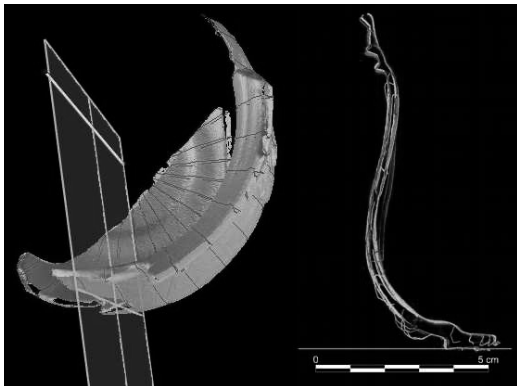

Figure 10 – *3D model radial sections (left) and overlay of sections (right).*

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.

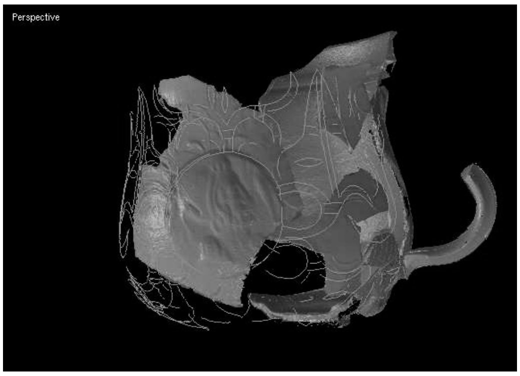

Figure 13 – *Fragments placement and decorative pattern restitution.*

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

The authors would like to thank the contribution and collaboration of Javier Larrazabal in this work, the kind permission from IPPAR to study this artifact and to Paraglobal, L.da for the use of the Konica-Minolta laser scanner. Last, we would like to express our gratitude to our colleagues at Superfície, L.da for their support and encouragement.

References

[Abd03] ABDI H., Least Squares. Encyclopedia of Social Sciences Research Methods. Thousand Oaks, USA (2003);

[BM02] BOEHLER W., MARBS A.: 3D Scanning instruments. CIPA, Heritage Documentation. *International Workshop on Scanning for Cultural Heritage Recording – Corfu, Greece* (2002);

[DBA*04] DEMIR N., BAYRAM B., ALKIS Z., HELVACI C., ÇETIN I.: Laser scanning for terrestrial photogrammetry, alternative system or combined with traditional system? *XX ISPRS Congress, Istanbul, Turkey* (2004);

[EB02] EL-HAKIM S. F., BERALDIN, J.-A.: Detailed 3D reconstruction of monuments using multiple techniques. Proceedings of the International Workshop on scanning for cultural heritage recording. *Complementing or replacing photogrammetry, Corfu, Greece*, (2002);

[GVP05] GUARNIERI A., VETTORE M., PONTIN M.: A volumetric approach for 3D surface reconstruction, *CIPA 2005 XX International Symposium, Torino, Italy* (2005);

[GPPV05] GUARNIERI A., PIROTTI F., PONTI M., VETTORE A.: Combined 3D surveying techniques for structural analysis applications. Commission V Symposium, Image Engineering and Vision Metrology, Dresden, Germany (2006);

[HCMV05] HARR F. B., CIGNONI P., MIN P., VELTKAMP R. C.: A comparison of systems and tools for 3D scanning. 3D Digital Imaging and Modelling: Applications of Heritage, Industry, Medicine and Land, Workshop Italy-Canada (2005);

[KSM05] KAMPEL M., SABLATNIG R., MARA H.: Robust 3D reconstruction of archaeological pottery based on concentric rills. In *Magnenat-Thalmann N. and Rindel J. H. (Eds), WIAMIS05: The 6th International Workshop on Image Analysis for Multimedia Interactive Services - Montreux, Switzerland,* (2005);

[Lar06] LARRAZABAL J.: Una taza de cerámica fina procedente del convento franciscano de Sto. António de Ferreirim (Lamego). *Publicação das actas do VI Encontro de Olaria Tradicional de Matosinhos, Matosinhos, Portugal,* (2006);

[LG02] LETELLIER R., GRAY C.: Bridging the gap between information users and information providers, RecorDIM Initiative, Report of roundtable 1, Los Angeles, USA (2002)

[OSPP06] ORTIZ P., SÁNCHEZ H., PIRES H., PÉREZ J. A.: Experiences about fusioning 3D digitalization techniques for cultural heritage documentation. *ISPRS Commission V Symposium – Image engineering and vision metrology, Dresden, Germany* (2006);

[San05] SANTAGATI C.: 3D laser scanner aimed to architectural heritage survey: from the point cloud to the geometrical genesis determination. *3D-Arch "Visual Reconstruction and Visualization of complex Architectures"* (2005);

[TL94] TURK G., LEVOY M.: Zippered polygon meshes from range images, *Computer Graphics* Proceedings, Annual Conference Series, Orlando, USA (1994);

[WOC03] WILLIS A., ORRIOLS X., COOPER D. B.: Accurately estimating sherd 3D surface geometry with application to pot reconstruction. *Conference on Computer Vision and pattern recognition workshop,* (2003) Vol. 1, pp. 5.

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
VAST (2006)
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Marketing the Past: Ethics and Values in the Archaeological Heritage Management of Greece

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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.

References

[App86]. APPADURAI A.:Introduction: commodities and the politics of value. In A. Appadurai (ed.) *The Social Life of Things: Commodities in Cultural Perspective.* Cambridge. Cambridge University Press, 1986.

[Bau 81]. BAUDRILLARD J.: *For a critique of the Political Economy of the Sign*, trans. C. Levin. St Louis, MO: Telos Press, 1981.

[Bou84]. BOURDIEU P.: *Distinction :A Social Critique of the Judgement of Taste.* London : RKP, 1984.

[Dig94]. DIGGLE K. : *Arts Marketing.* Rhinegold. London, 1994.

[Ho'So'S04]. HILL L., O'SULLIVAN C., O'SULLIVAN T.: *Creative Arts Marketing.* Elsevier, England, 2004.

[Lip84]. LIPE W.: Value and Meaning in Cultural Resources. In H. F. Cleere (ed.) *Approches to the Archaeological Heritage.* CambridgeUniversity Press, 1984.

[Tho79]. THOMPSON M.: *Rubbish Theory: The Creation and Destruction of Value.* Oxford: Clarendon, 1979.

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
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M. Ioannides, D. Arnold, F. Niccolucci, K. Mania (Editors)

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

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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).

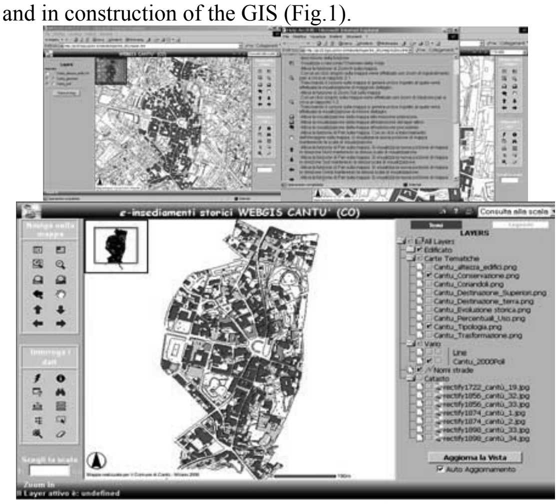


Figure 1: *E-**Historical** site of Cantu*'.
*HOME page, HELP Menù (Zooming, Info,…), Legend description of the thematic raster map published.
The SHEMA GUIDE of the possible functions structured on different levels of access: from the easier built on raster thematic map with sensitive area for local 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.

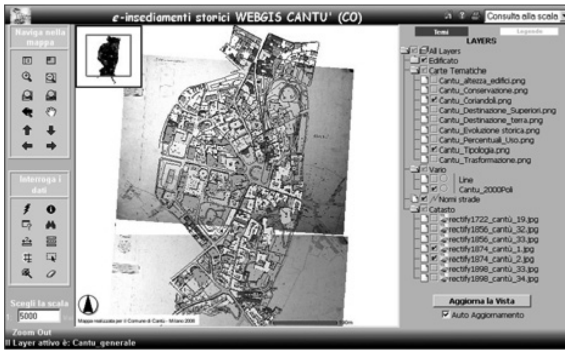


Figure 2: *The cadastral ancient map are georeferenced inside the GIS map of the historical site.*
E-sharing Geo-Information function to the resident community (easy info related to the ancient and actual maps) and to professionals through downloading services and GeoDbase querying (first, second, third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

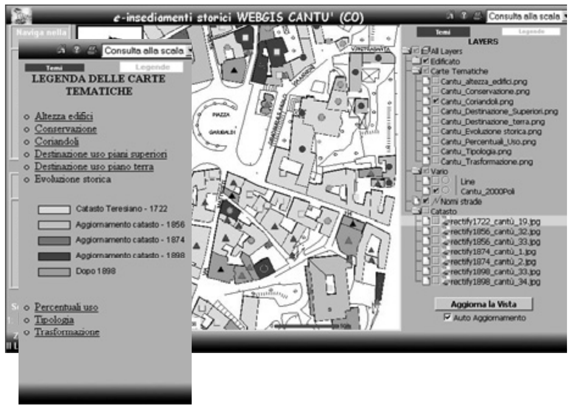


Figure 3a: *Web-GIS of the historic centre of Cantù, the thematic map of historic evolution and transformation of the historic centre read on the historic cadastral pre-existence map.*
Here is the legend related to the GIS thematic table.
The polygonal empty hatch colour refers to the period threshold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

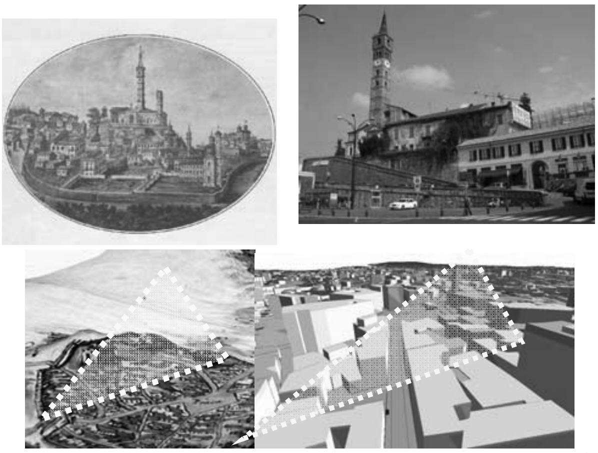


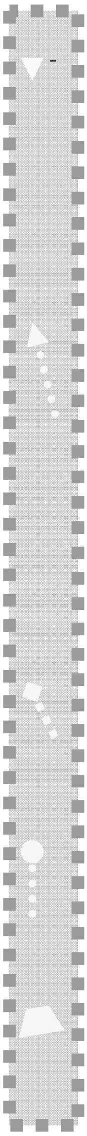
Figure 4: *An ancient 3D view of the historical walled site of Cantù, seen from the west (circa 1800) to the east. It is the View of the Basilica of S. Pauli, constructed in the late 11th century, which became in 1584 the 'Head church of the Cantù'. Relating and comparing the historic and the actual (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

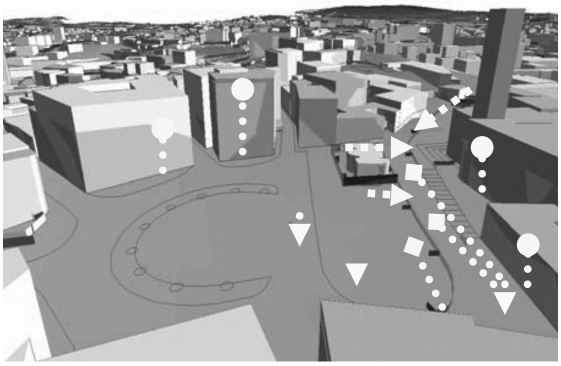


Figure 5: *Lacking 3DGeo-info sample. The skyline is reconstructed within the 3DGIS Map from the historical perspective. The 3D model return back 'flat' for less information if zoomed from a lower point of observation.*

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.

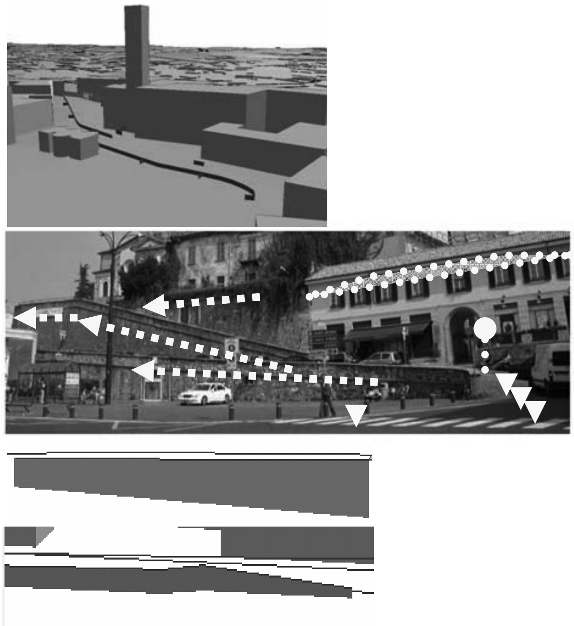


Figure 6: *Sequences of building 3DGIS object. From the flat 3D model to the advanced 3D model implemented in SketchUp (r.5.0) with technical map data integrated by absent data as explained (GPS survey, 3D ring poly – Complex surface). Here it is the case of the reconstruction of the staircases system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

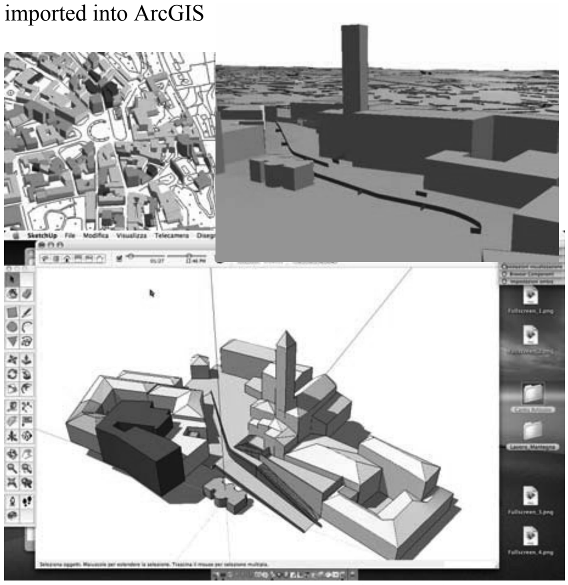


Figure 7: *The3D model implemented from the base technical map(bottom side): the Geo3D model can be integrated with the other GIS data, perhaps the historical analysis: it is constructed in SketchUp, and re-imported into ArcGIS*

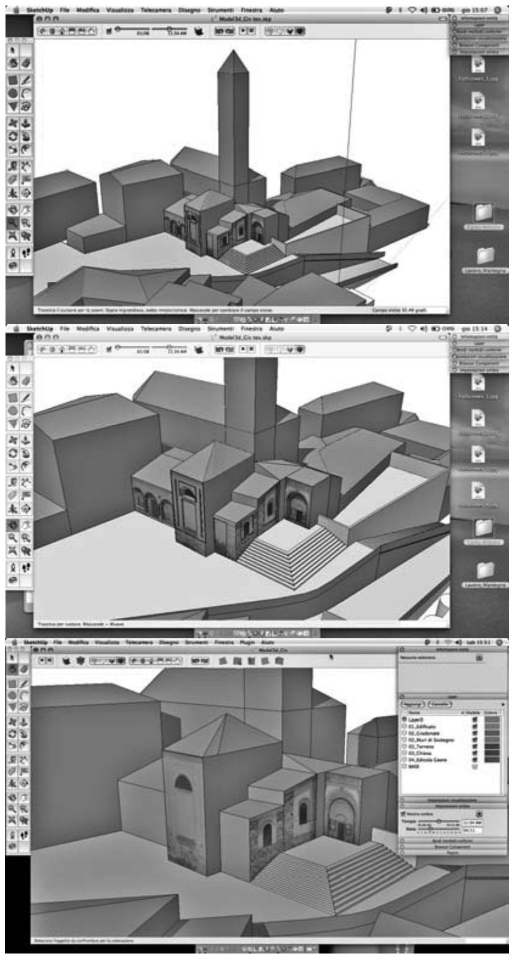


Figure 8: *Texture mapping of the 3D GEOModel inside SketchUp can be re-imported into ArcGIS*

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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

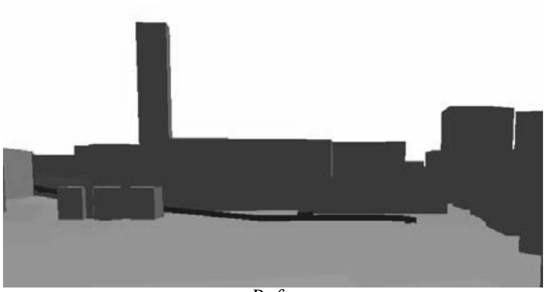
The model as described can be accessed locally, in ArcGIS. The problem is that we need more information and need to improve the following functionalities:

- 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,…).

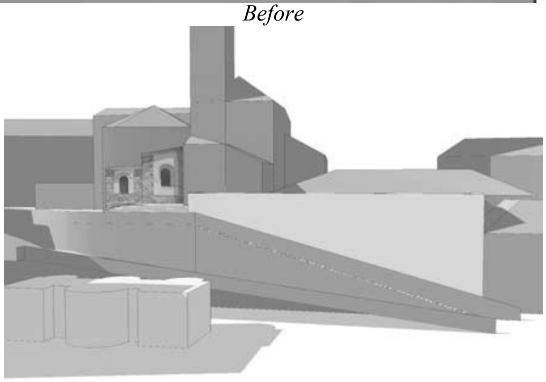
Which e-3Dsharing levels can act as a bridge between GIS technology and virtual reality through the web?

- 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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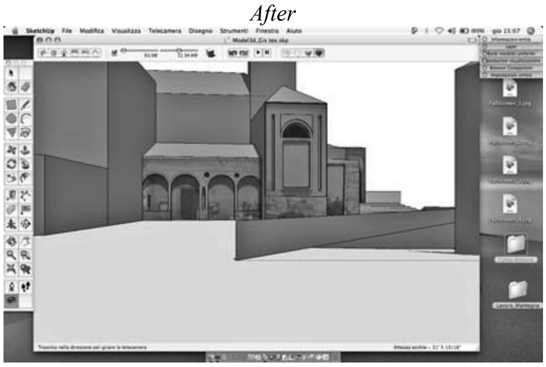

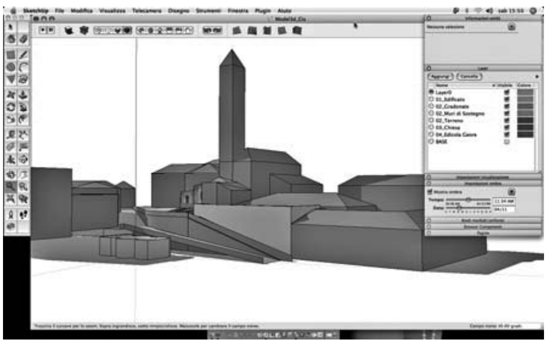

Figure 9: *E-3Dsharing GEO-info.*
Implementing 3d base model coming from technical large scale map is possible to relate paste to the future with historical info, ancient map views, state of the art of the fronts, staircases ancient systems, and so on.
This allows to improve the level of protection of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

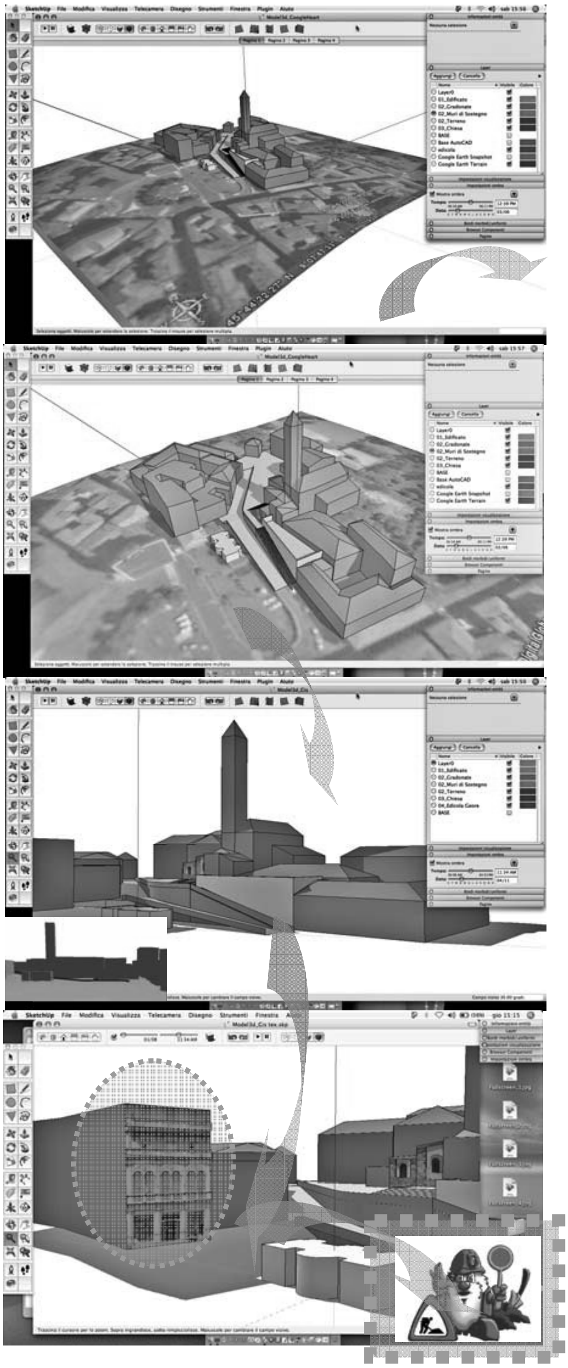

Figure 10: From *Public Administration (P.A.) to the citizens and to the professionals. E-3Dsharing Historical sites on Google Earth: Navigating, Downloading, Implementing Geo3d by external user, by the community of specialists, professionals and citizen. Interoperability between P.A. and professionals 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*

References

AA.VV.,. Polo regionale della Carta del rischio del patrimonio culturale: dalla catalogazione alla conservazione programmata. (2000) Regione Lombardia, Milano

[AG05] AKCA D., GRUEN A.: Fast correspondence search for 3D surface matching. *In: ISPRS WS "Laser Scanner 2005"*(2005) Enschede, Sept. 12-14

[Bae03] BAEHR, H. P.:. Documentation of Cultural Heritage Integrated. In *Proc.3D Urban Information System*. (2003) Int Arch. CIPA, XIX, Antalya

[BKJ*06] BODUM L., KJEMS E., JAEGLY M., KOLAR J.: Focus for 3D city models should be on interoperability; not verisimilarity!. In *Proc. UDMS '06* (2006). I, C. 9.I.1

[DLZ*05] DU Z., LI D., ZHU Y., ZHU Q.: 3D GIS based digital reconstruction and dynamic visualization of timber-frame building. In *Proc CIPA XX Int. Symposium '0*5 . Vol 2, pp 783-787

[EWG05]EL-HAKIM S., WHITING E., GONZO L., , 3D Modelling with Reusable and Integrated Building Blocks. In *Proc. Optical 3-D Measurement Techniques VII*. (2005) Grun A./Kahmen H. (eds.), Wien

[MS05] MERLO S., SHELL C.A.: Developing a multidimensional GIS framework for archeological excavations.In *Proc CIPA XX International symposium '05* (September 2005). Vol 2, pp 783-787

[MP*06] MUSSIO L., POZZOLI A.: New tools for sptio-temporal Database. In *Proc. UDMS '06* (2006). I, C. 9.I.3

[OSQ*02] OOSTEROOM VAN P., STOTER J., QUAK W., ZLATANOVA S.: The Bilance Between Geometry and Topology, (2002). In *Advances in Spatial Data Handling* Dianne Richardson and Peter van Oosteroom (eds.), 10 Int. Symposium on Spatial Data Handling, Springer-Verlag, Berlin

[Por05] PORTELE C., 2005. The Geography Markup Language. Geo-Information Standards in action. (2004) *NGC/GIN Farewell seminar Henri J.G.L. Aalders*. Delft, 17 November

[Sch*06] SCHRODER L.: Cultural Heritage and multidimensional representation of buildings-A semiotic approach to GI-ontologies. In *Proc. UDMS '06* (2006). III, C.3.III.3

[ST04] SPANAKI M., TSOULOS L.: Desing and implementation of a WEB-Based application for the visualization of large scale photogrammetric and cartographic data. In *Proc. XXth ISPRS congress '04* (July 2004). P 147 ff.

[TKA04] TUNC E., KARSLI F., AYHAN E.: 3D City reconstruction by different technologies to manage and reorganize the current situation. In *Proc. XXth ISPRS congress '04* (July 2004). Commission 4, P 147 ff.

[Ulm05] ULM K.: 3D city Model from aerial images, *Geo-informatics* January-February (2005).

[ZRS02] ZLATANOVA S., RAHMAN A.A., SHI W.:. Topology for 3D spatial objects. (2002) *Int. Symposium and Exhibition on Geoinformation,* Kuala Lumpur, Malaysia,pp 7

[VS03] VRIES DE M., STOTER J.: Accessing a 3D geo-DBMS using Web technology, (2003) *ISPRS, Joint WS on "Spatial, Temporal and Multi-Dimensional Data Modelling and Analysis"*, Quebec, Canada.

[VV04] VRIES DE M., OOSTEROOM VAN P.: The third GML relay. Geo-Information Standards in action, *NGC/GIN Farewell seminar Henri J.G.L.* (2004) Aalders, Delft

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
VAST (2006)
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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

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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.

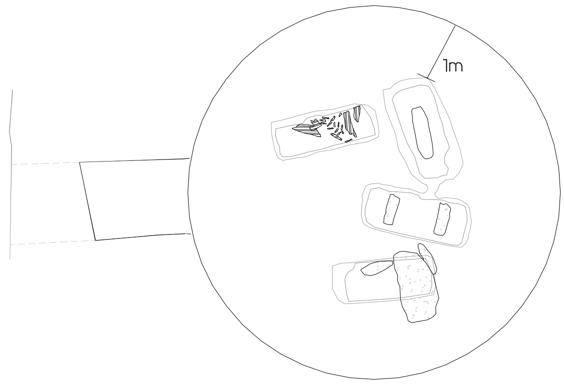

Figure 1: *Space restrictions inside the tomb*

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.

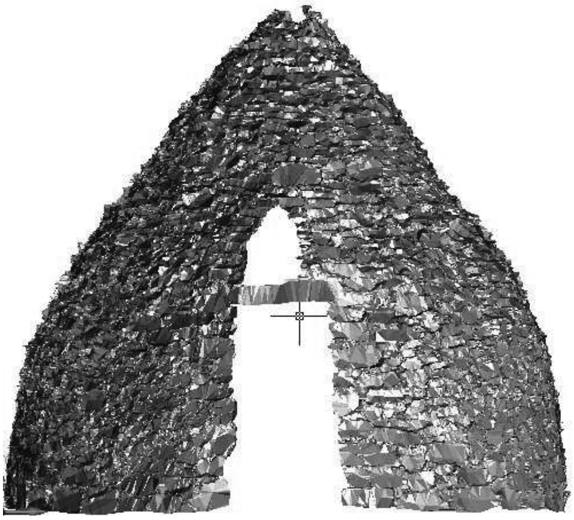

Figure 3: *Photorealistic plan of the west (entrance)*

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 ($c=\tan(\omega/2)$)	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:

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

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

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

$$c = \tan \omega$$

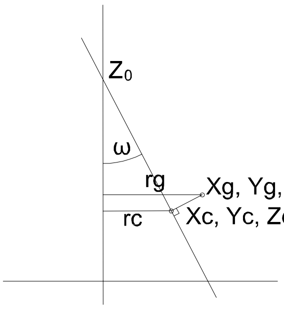

Figure 5: *Geometry of Cone Projection*

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:

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

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

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

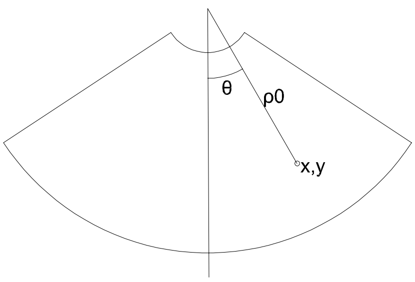

Figure 7: *Developed cone*

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

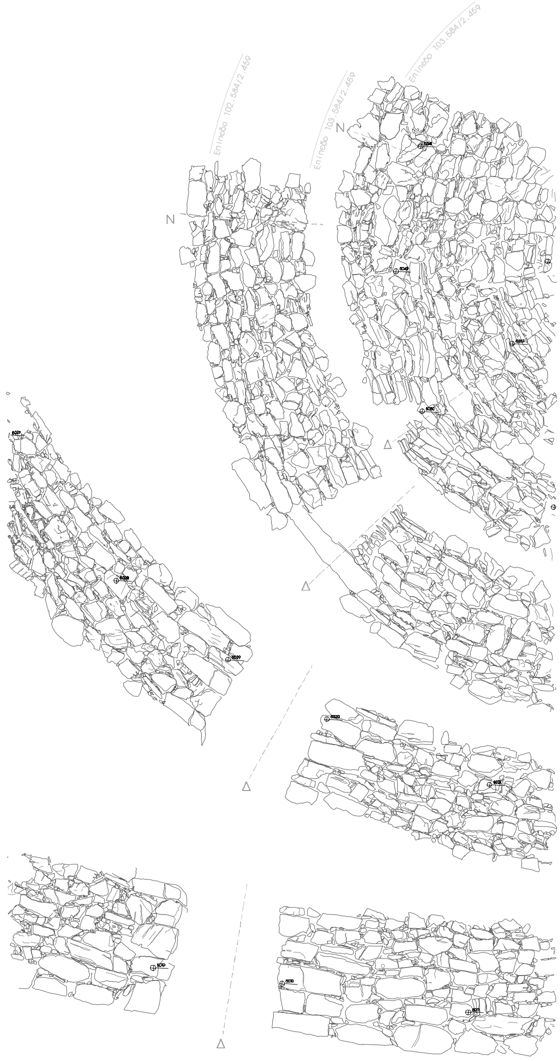

Figure 8: *Part of the final plan depicting 4 distinct cones*

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.

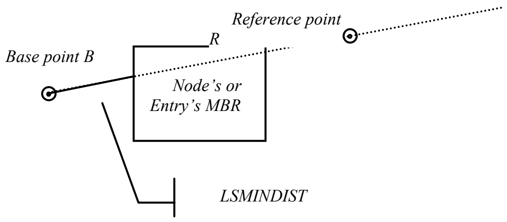

Figure 9: *LSMINDIST Definition.*

```
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.

References

[CL81] CAVANAGH W. G., LAXTON R.R. : The Structural Mechanics of The Mycenean Tholos Tomb. *The annual of the british School At Athens No. 76* (1981).

[BKSS90] BECKMANN, N., KRIEGEL, H.P., SCHNEIDER, R., AND SEEGER, B. The R*-tree: An Efficient and Robust Access Method for Points and Rectangles. *Proceedings of ACM SIGMOD*, 1990.

[Gut84] Guttman, A.: R-Trees: A Dynamic Index Structure for Spatial Indexing. *Proceedings of ACM SIGMOD*, 1984.

[RKV95] Roussopoulos, N., Kelley, S., and Vincent, F., Nearest Neighbor Queries, *Proceedings of ACM SIGMOD,* 1995.

[MA76] Mikhail E. M., Ackermann F., Observations and Least Squares, *Dun Donnelley* (1976)

[Kre91] Kreyszing E. Differential Geometry, *Dover Publications* (1991)

[Cla90] CLARKE, K. C. Analytical and Computer Cartography*, Prentice Hall, Engelewood Cliffs* (1990)

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

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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

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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.

References

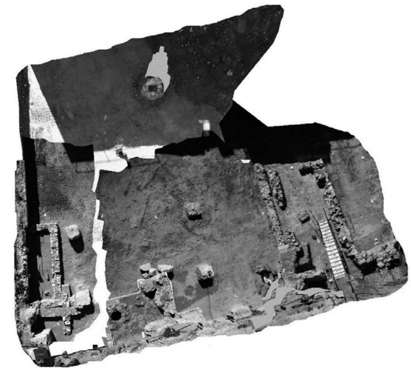
[BPH*03] Beraldin, J. A., Picard M., El-Hakim S. F., Godin G., Valzano V., Bandiera A., Latouche D.: Virtualizing a Byzantine Crypt by combining high-resolution textures with Laser Scanner 3D data. In: *Proceedings of VSMM* (2003), pp. 3-14.

[Hak02] El-Hakim S. F.: Semi-automatic 3D reconstruction of occluded and unmarked surfaces from widely separated views. In: *Proceedings ISPRS Commission V Symposium* (2002), pp. 143-148.

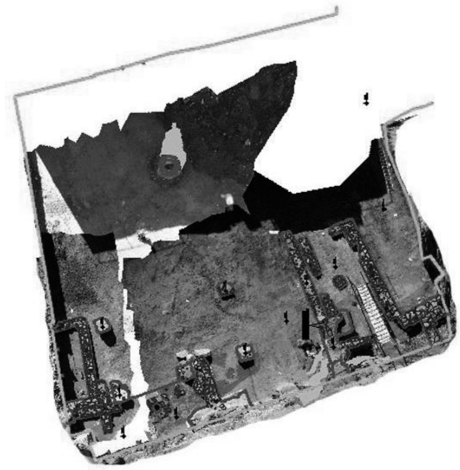
[KFK*03] Kadobayashi R., Furukawa R., Kawai Y., Kanjo D., Yoshimoto J. N.: Integrated presentation system for 3D models and image database for Byzantine ruins. In: *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* (2003), Vol. XXXIV, Part 5/WI2, pp. 187-192.

[Pil00] Pilides D.: A 19^{th} century view of St. George's Hill in Nicosia. Fact or Fiction'. *Cyprus in the 19^{th} Century A.D. Fact, Fancy and Fiction, 22^{nd} British Museum Classical Colloquium,* (2002), pp. 80-92.

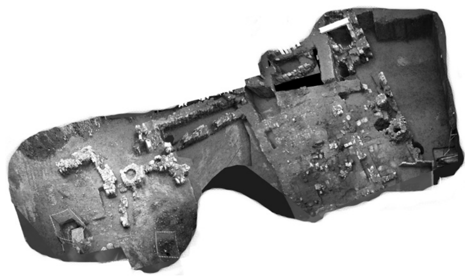
[SCIP04] Stylianidis E., Chrysanthou Y., Ioannides M., Pilides D.: 3D reconstruction and visualization of Agios Georgios site in the city centre of Nicosia-Cyprus. *CIPA International Workshop on vision techniques applied to the rehabilitation of city centres* (2004).



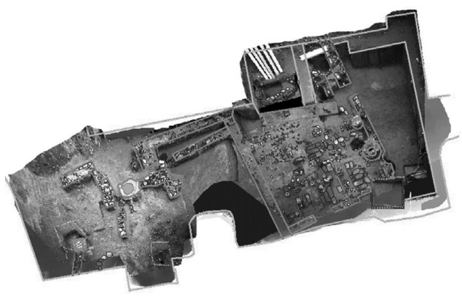
Orthoimage of the north part of the excavation site



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*

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
VAST (2006)
M. Ioannides, D. Arnold, F. Niccolucci, K. Mania (Editors)

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

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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.

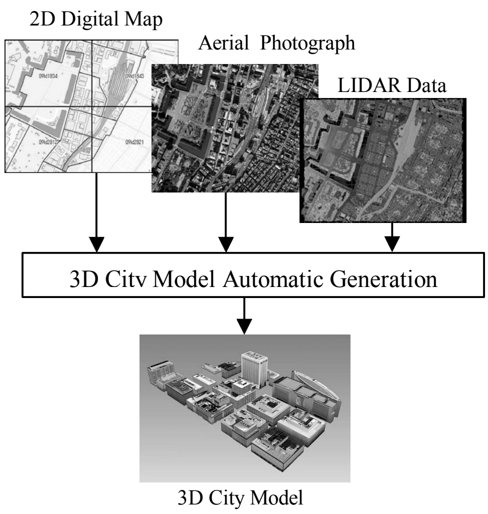

Figure 1: *Automatic generation of 3D city model*

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).

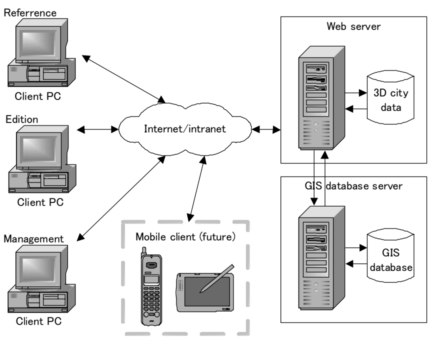

Figure 4: *System structure*

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).

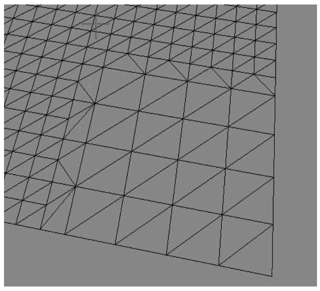

Figure 5: *Connection of DEM meshes with different density*

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).

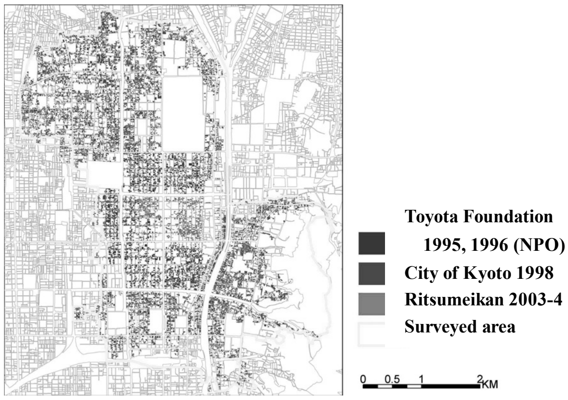

Figure 9: *Machiya surveys*

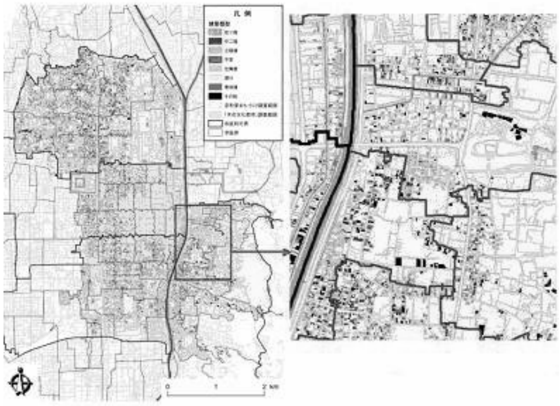

Figure 10: *Distribution of machiyas in Kyoto by types (left), and the detail of Gion area (right)*

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.

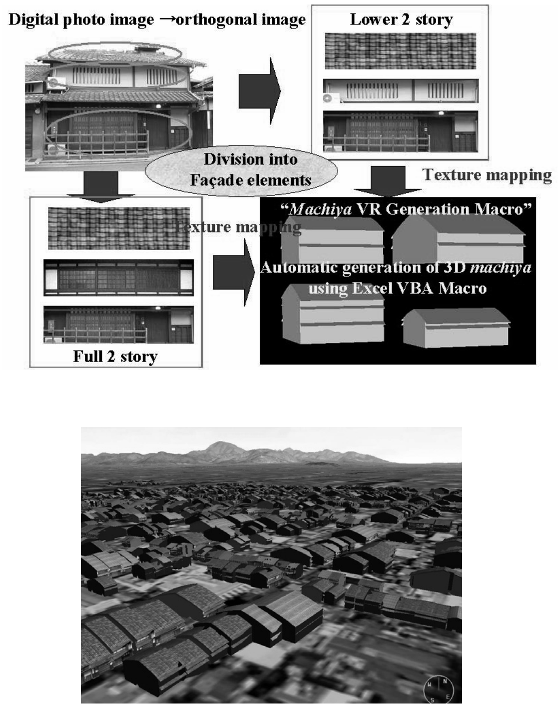

Figure 11: *Automatic generation of Machiya VR model*

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).

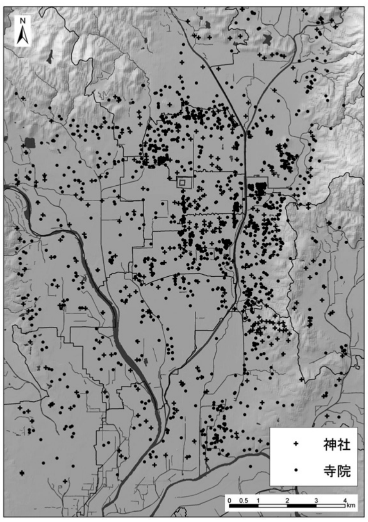

Figure 12: *Distribution of temples and shrines in Kyoto*

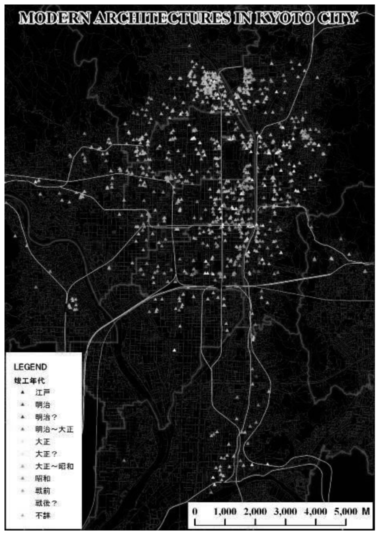

Figure 13: *Distribution of western-style heritage buildings in Kyoto*

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).

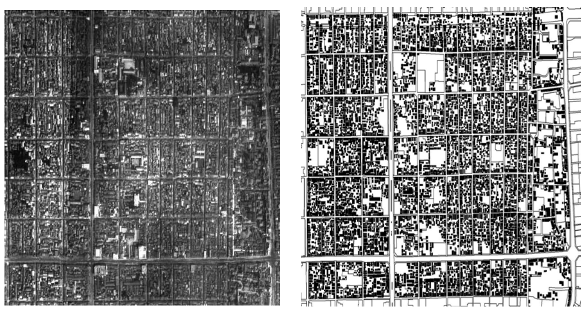

Figure 18: *Identification of machiyas in aerial photograph of 1928*

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).

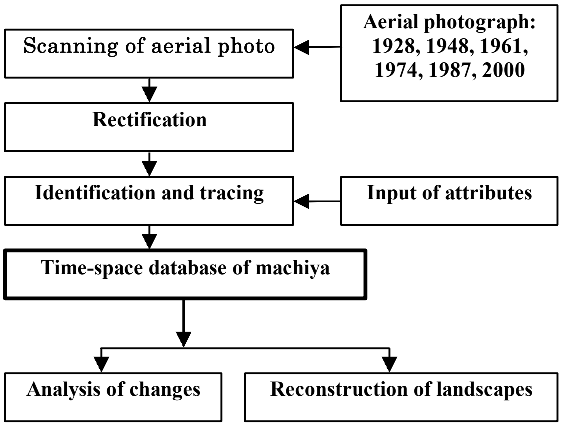

Figure 19: *Time-space database of machiya*

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).

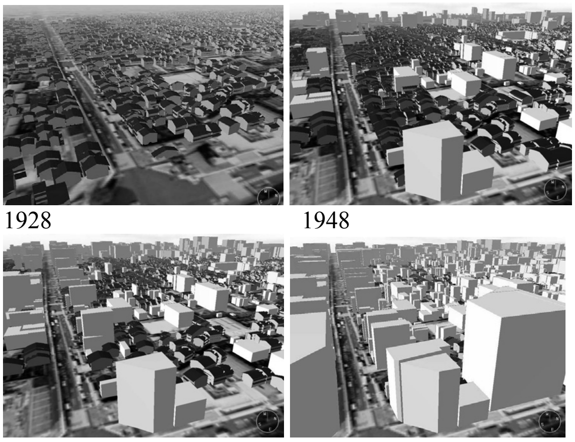

Figure 20: *Changes of landscape*

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.

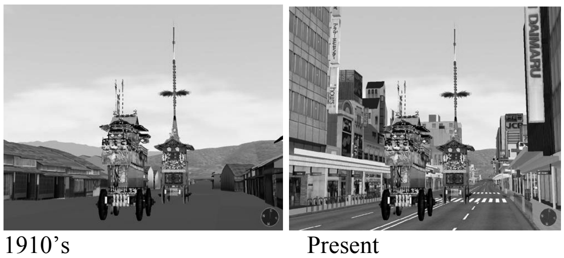

Figure 21: *Changes of Gion Festival through time*

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).

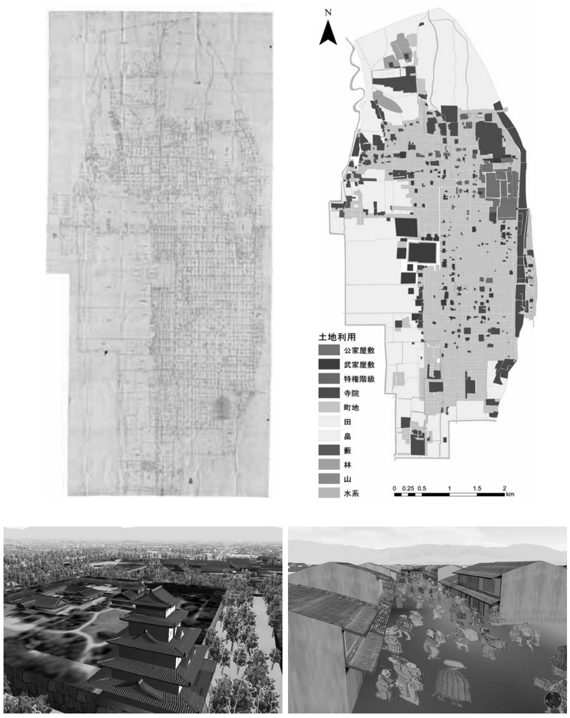

Figure 21: *Map of Kyoto in 1640's (upper left), land use map (upper right), and reconstructed Kyoto in Edo era*

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).

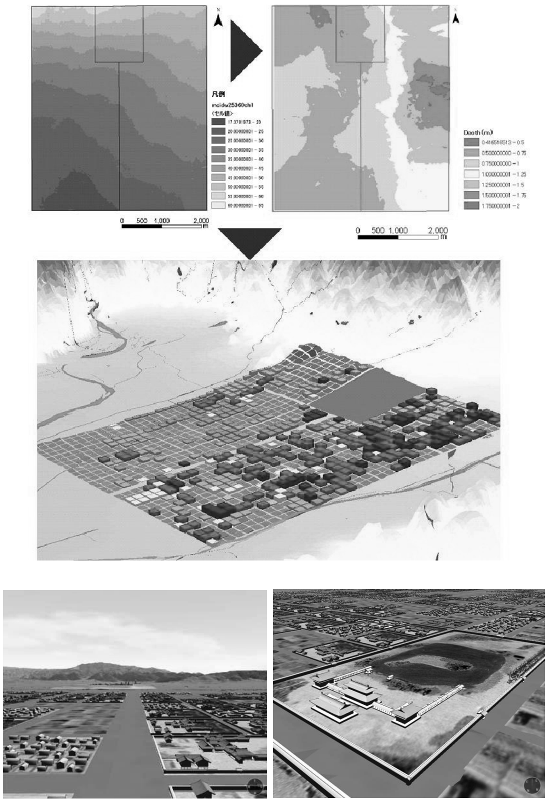

Figure22: *3D Reconstruction of Heian-kyo*

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.

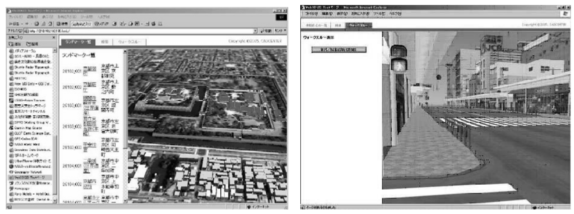

Figure 23: *"Kyoto Virtual Time-Space" on web*

References

TAKASE, Y., SHO, N., SONE, A. and SHIMIYA, K.: Automatic Generation of 3-D City Models and Related Applications, *International Workshop on Visualization and Animation of Reality-based 3D Models*, Tarasp-Vulpera, Switzerland, 2003.

TAKASE, Y., SONE, A., HATANAKA T. and SHIROKI, M.: A Development of 3D Urban Information System on Web, *International Workshop on "Processing and Visualization using High-Resolution Imagery,"* Pitsanulok, Thailand, 2004.

YANO, K., NAKAYA, T., ISODA, Y., KAWASUMI, T., KAWAHARA, D., INOUE, M. and TAKASE, Y.: Time Travel in a Historical City: Virtual Kyoto Using 4D GIS and VR Technologies, *The 30th Congress of the International Geographical Union*, Glasgow, UK, 2004.

TAKASE, Y., YANO, K., ISODA, Y., KAWASUMI, T., TANAKA, S., NAKAYA, T., KAWAHARA, N., KOGA, S., INOUE, M., KAWAHARA, D., SONE, A., SHIROKI, M., MOTOJIMA D. and OHMOTO, N.: "Virtual Time-Space of Kyoto" a Visualization with 4D-GIS, Virtual Reality and Web Technologies, *The 1st Forum on the Promotion of European and Japanese Culture and Traditions in Cyber-Societies and Virtual Reality*, Laval, France, 2005.

References from websites

Sample site of Web3D-GIS by Ritsumeikan University
http://www3.rits-coe.jp/ritsumei_kyoto/main.html

CAD CENTER Corporation
http://www.cadcenter.co.jp

Acknowledgements

Our gratitude goes to the City of Kyoto, and NPO Machiya-saisei-kenkyukai, who allowed us to use Machiya Surveys results, as well as to Shochiku Co., Ltd., who allowed us to use design drawings of Minami-za theater. All brand names and product names are trademarks or registered trademarks of their respective companies.

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
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CREATIVE HISTORIES - THE JOSEFSPLATZ EXPERIENCE

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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-

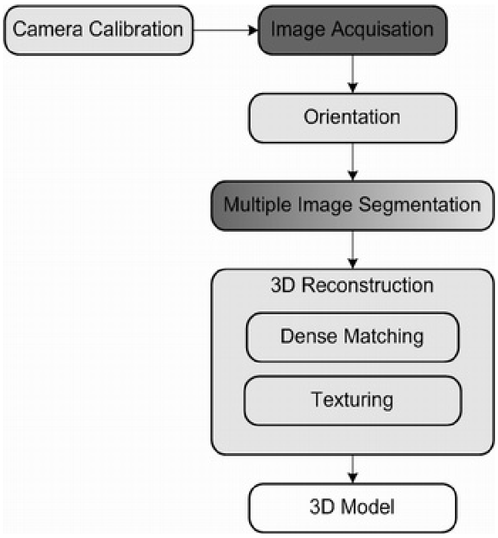


Figure 1: *Overall reconstruction pipeline. The dark grey shaded tasks are interactive whereas the light grey shaded procedures are fully automatic.*

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).

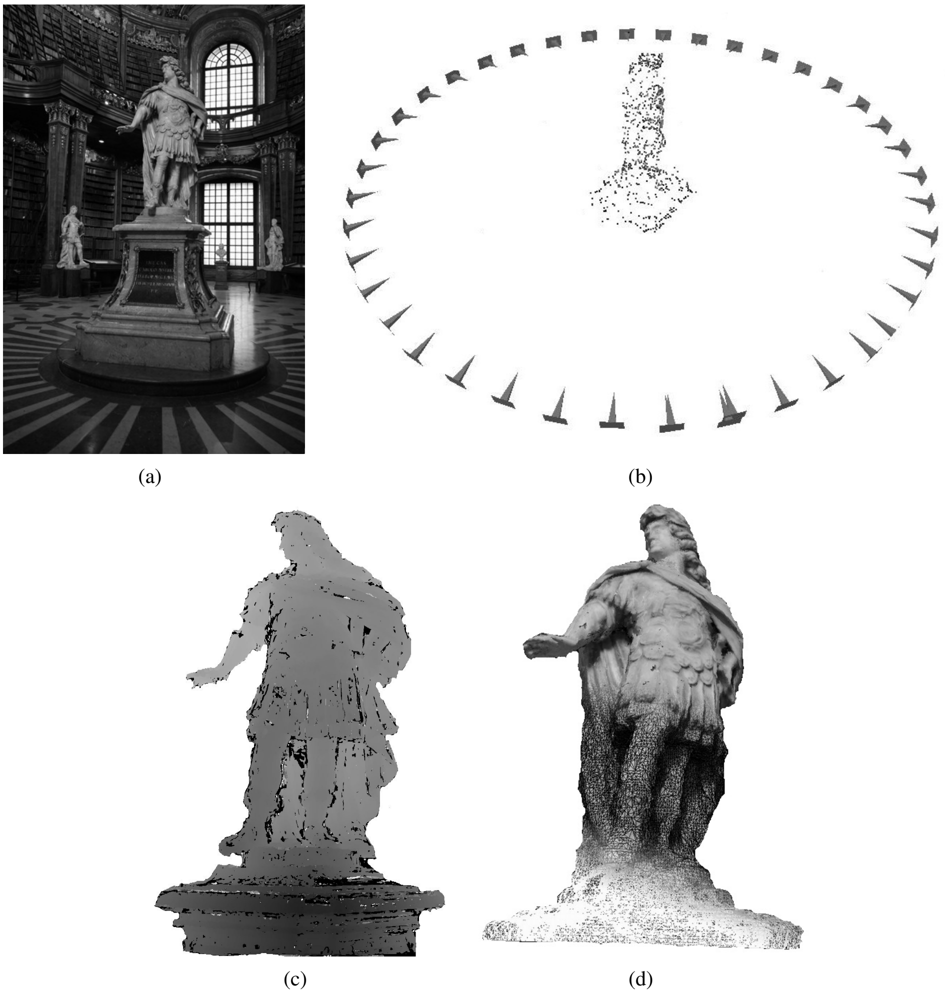


Figure 2: *Illustration of all results achieved with our 3D reconstruction approach and demonstrated on the emperor Kaiser Karl VI located in Austrian National Library in Vienna. The statue of Emperor Karl VI. is 2.3 meters high and the data-set consists of 45 images.* ***(a)*** *One original image of the data-set.* ***(b)*** *Obtained camera positions and colored 3D tie points.* ***(c)*** *Acquired depth map.* ***(d)*** *Reconstructed 3D model.*

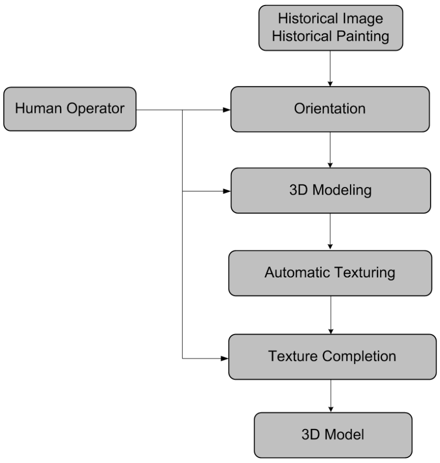
4. Navigating Creative Histories

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.

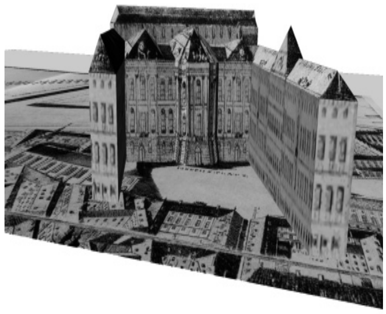
Information Categories

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-



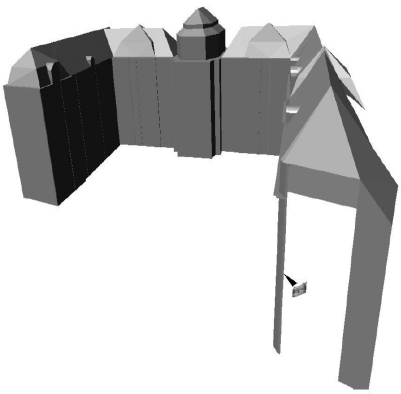
(a)

(b)

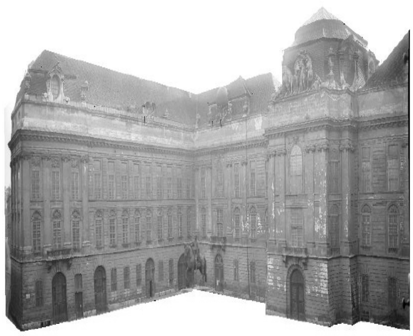


(c)

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-

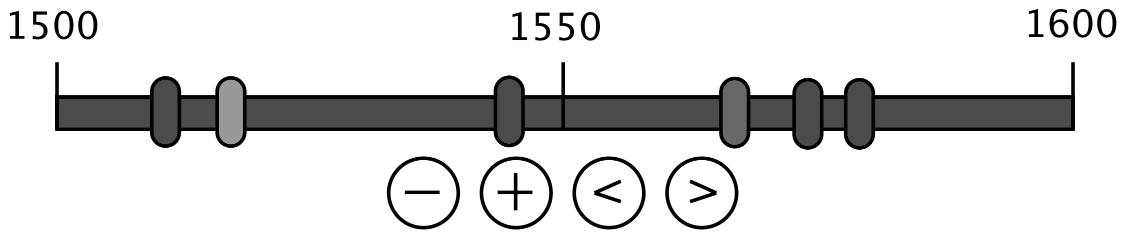


Figure 7: *Possible design for the timeline with marks for anchors and user elements for zooming and scrolling.*

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.

References

[DF01] DEVERNAY F., FAUGERAS O.: Straight lines have to be straight: Automatic calibration and removal of distortion from scenes of structured environments. *Machine Vision and Applications 53*, 1 (June 2001), 14–24.

[Hei00] HEIKKILÄ J.: Geometric camera calibration using cicular control points. *IEEE Transactions on Pattern Analysis and Machine Intelligence 22*, 10 (October 2000), 1066–1077.

[LPRM02] LEVY B., PETITJEAN S., RAY N., MAILLOT J.: Least squares conformal maps for automatic texture atlas generation. *ACM Transactions on Graphics 21*, 3 (July 2002), 362–371.

[SZK06] SORMANN M., ZACH C., KARNER K.: Graph cut based multiple view segmentation for 3d reconstruction. In *International Symposium on 3D Data Processing, Visualization and Transmission* (North Carolina, USA, June 2006).

[ZSK06] ZACH C., SORMANN M., KARNER K.: High-performance multi-view reconstruction. In *International Symposium on 3D Data Processing, Visualization and Transmission* (North Carolina, USA, June 2006).

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.*

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
VAST (2006)
M. Ioannides, D. Arnold, F. Niccolucci, K. Mania (Editors)

From Landscape to Object: The Evolution of Digital Recording for Multi-Disciplinary Investigations and Site Management at Chersonesos in Crimea, Ukraine

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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].

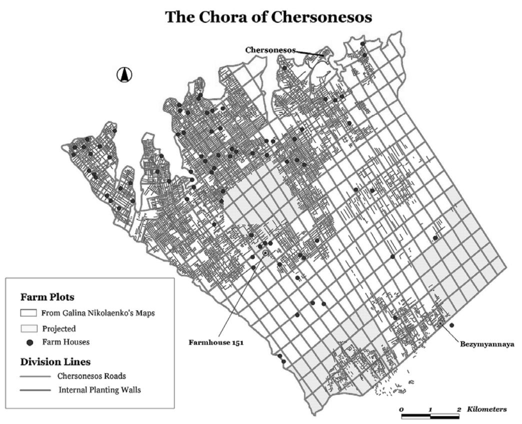

Figure 3: *The divided chora.*

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 19th 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]

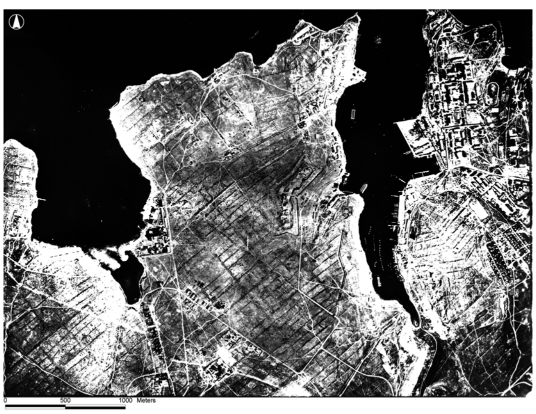

Figure 4: *Historical aerial photograph showing traces of ancient cadastral system.*

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.

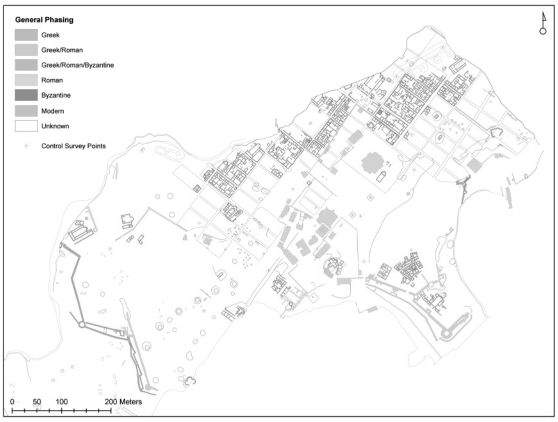

Figure 5: *General plan, the ancient city.*

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.

References

[CAR2006] Carter, J. C.: *Discovering the Greek Countryside at Metaponto.* University of Michigan Press, 2006.

[CCL*2000] Carter, J. C., Crawford, M. C., Lehman, P., Nikolaenko, G. M., and Trelogan, J. T.: The Chora of Chersonesos in Crimea, Ukraine. *American Journal of Archaeology104.4* (October 2000), 707 – 742.

[CTE2006] Cleere, C. G., Trelogan, J. A., Eve, S. J.: Condition recording for the conservation management for large, open-air sites: a pilot project at Chersonesos (Crimea, Ukraine). *Conservation and Management of Archaeological Sites 7* (2006), in press.

[ERT2006] Eve, S. J., Rabinowitz, A. T., Trelogan, J. T.: Precision, Accuracy and the Fate of the Data: Experiments in Site Recording at Chersonesos, Ukraine. *Computer Applications and Quantitative Methods 2006* (April, 2006).

[MC2003] Mack, G. R., Carter, J. C.: *Crimean Chersonesos*. Institute of Classical Archaeology, 2003.

[RYN2005] Rabinowitz, A. T., Yashaeva, T., Nikolaenko, G. M.: Chora of Chersonesos: Excavations at Bezymyannaya, 2002. *Archaeology in Ukraine 1* (2005).

[SZM2000] Sorochan, S. B., Zubar, V. M., Marchenko, L. V.: *Zhizn' I gibel' Khersonesa.* Maydan, 2000.

[TCC2001] Trelogan, J. A., Crawford, M. C., Carter, J. C.: Monitoring the Ancient Countryside: Remote Sensing and GIS at the Chora of Chersonesos (Crimea, Ukraine). Proc. UNESCO/EURISY Conference of Space Applications for Heritage Conservation (November, 2001).

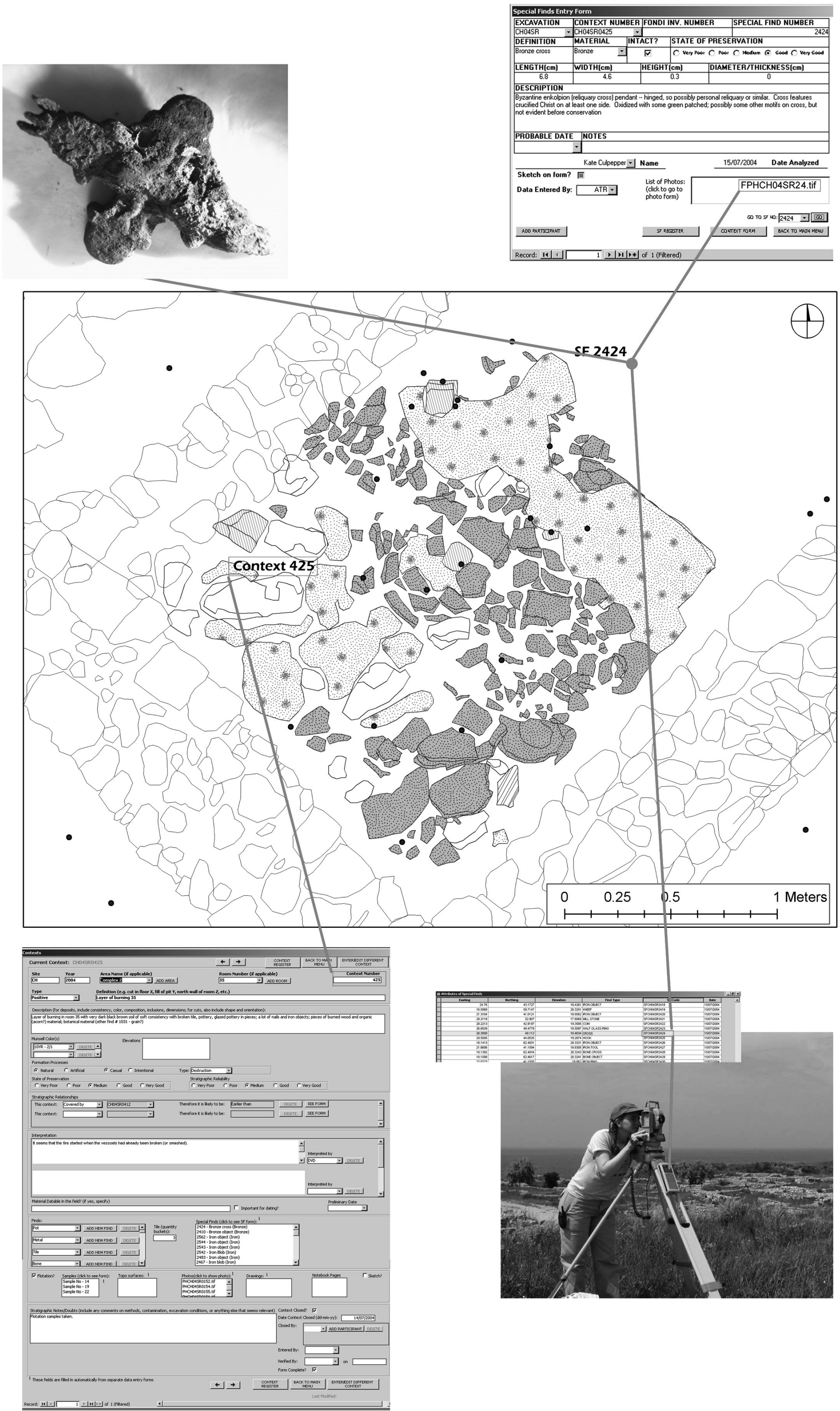

Figure 6: *Special find from field to conservation lab.*

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
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M. Ioannides, D. Arnold, F. Niccolucci, K. Mania (Editors)

Interactive and Real-Time Interpretation: New Boundaries for Cultural Heritage

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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.

5. References

AAVV, "A Cultura das Redes", Revista de Comunicação e Linguagens, Lisbon, Edições Cosmos, May 2002

Azuma, R., Bailot, Y., Behringer, R., Feiner, S., Julier, S., and MacIntyre, B. (2001). Recent Advances in Augmented Reality. IEEE Computer & Graphics 21(6), pp. 34-47;

Azuma, R., Lee, J., Jiang, B., Park, J., You, S., and Neumann, U. (1999). Tracking in Unprepared Environments for Augmented Reality Systems. Journal of Computers & Graphics, 23 (26), pp. 787-793; [3] Berger, M.O., Wrobel-Dautcourt, B., Petitjean, S., and Simon, G. (1999). Mixing Synthetic and Video Images of an Outdoor Urban Environment. Machine Vision and Applications, 11(3), pp. 145-159;

Azuma, R.T. (1997). A Survey of Augmented Reality. Presence-Teleoperators and Virtual Environments, 6(4), pp. 355-385;

Bragança de Miranda, José, CRUZ, Maria Teresa, org., "Crítica das Ligações na Era da Técnica". Lisboa, Tropismos, 2002

Debevec, P.E. (1998). Rendering Synthetic Objects Into Real Scenes: Bridging Traditional and Image-Based Graphics with Global Illumination and High Dynamic Range Photography. Proceedings of SIGGRAPH'98, New York, NY.

Kutulakos, K.N. and Vallino, J.R. (1998). Calibration-free Augmented Reality. IEEE Transactions on Visualization and Computer Graphics, 4(1), pp. 1-20;

Laurel, Brenda, "Computers as Theatre". Addison-Wesley, 1993

Livingston, M.A. and State, A. (1997). Magnetic Tracker Calibration for Improved Augmented Reality Registration. Presence-Teleoperators and Virtual Environments, 6(5), pp. 532-546;

Parente, André (org.), "Imagem Máquina – A Era das Tecnologias do Virtual", Rio de Janeiro, Editores 34, 1993

Piekarski, W., Thomas, B., Hepworth, D., Gunther, B., and Demczuk, V. (1999). An Architecture for Outdoor Wearable Computers to support Augmented Reality and Multimedia Application. Proceedings of the 3rd International Conference on Knowledge-Based Intelligent Information Engineering Systems, Adelaide, Australia;

Rokita, P. (1998). Compositing Computer Graphics and Real World Video Sequences. Computer Networks and ISDN Systems, 30(20-21), pp. 2047-2057;

Roseblum, L. (2000). Virtual and Augmented Reality 2020. IEEE Computer Graphics and Applications, 20(1), pp. 38-39.

Starner, T., Schiele, B., Rhodes, B., Jebara, T., Oliver, N., Weaver, J., and Pentland, A. (1998). Augmented Realities Integrating User and Physical Models. First IEEE International Workshop on Augmented Reality (IWAR '98)", San Francisco, CA;

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
VAST (2006)
M. Ioannides, D. Arnold, F. Niccolucci, K. Mania (Editors)

Analysis – reconstruction – design: case studies on ongoing projects

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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.

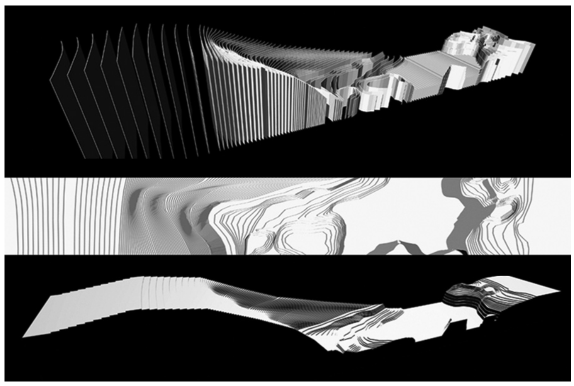

Figure 2: *The terrain model of vertical and horizontal layers*

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.

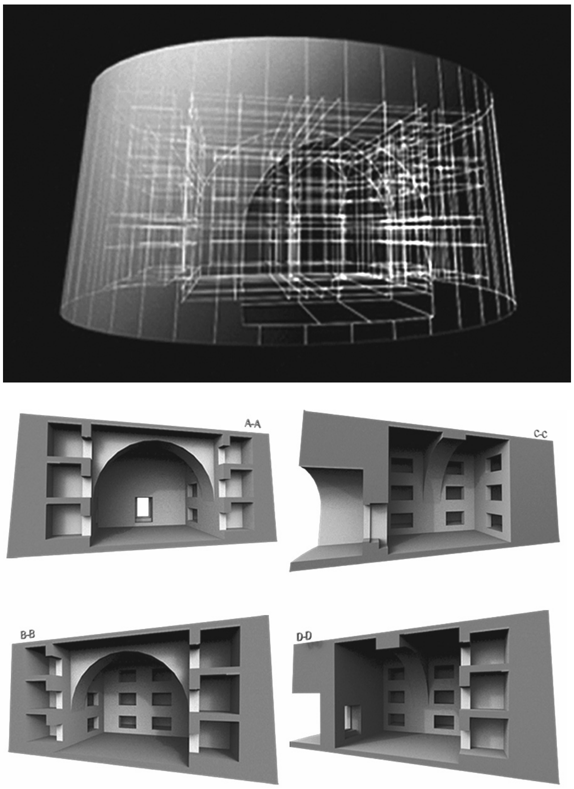

Figure 2: *3D view and sections of a Roman tomb structure*

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.

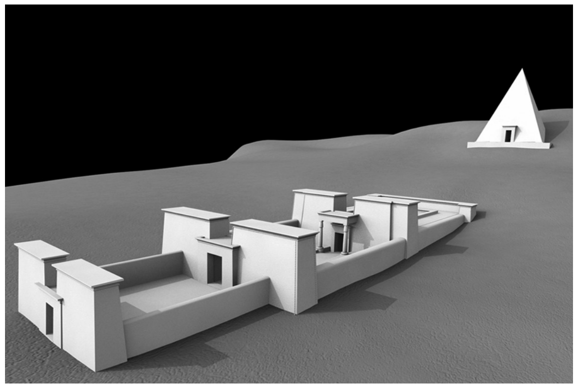

Figure 3: *3D view of the forecourts and the pyramid of the tomb of Djehutymes*

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.

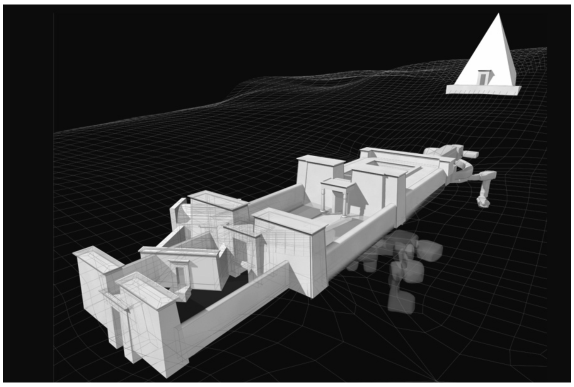

Figure 5: *3D reconstruction of the architectural superposition of Tomb 32 and Tomb B*

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.

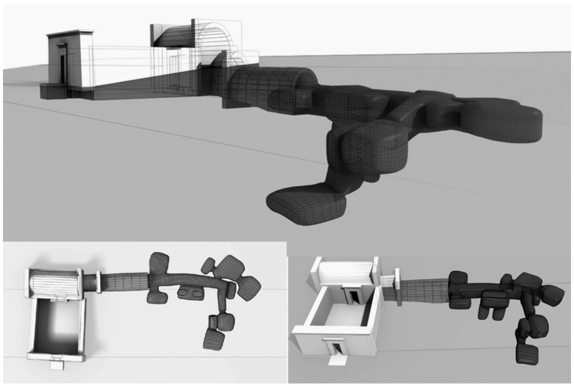

Figure 6: *Tomb B and its reconstructed architectural features*

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.

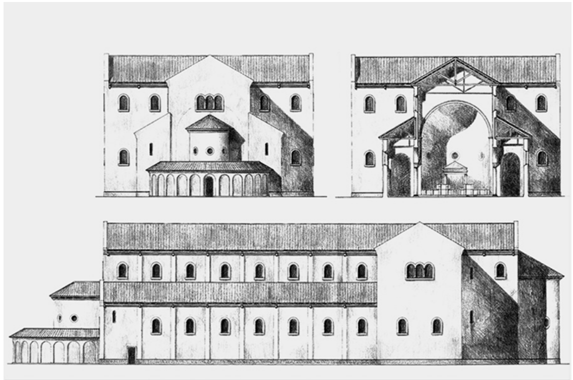

Figure 7: *Reconstructed views of the Cologne Dome - pencil drawings by the author*

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.

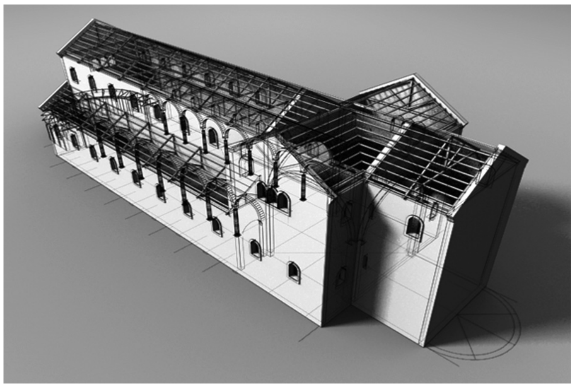

Figure 8: *3D view of the 7th century phase of the Dome*

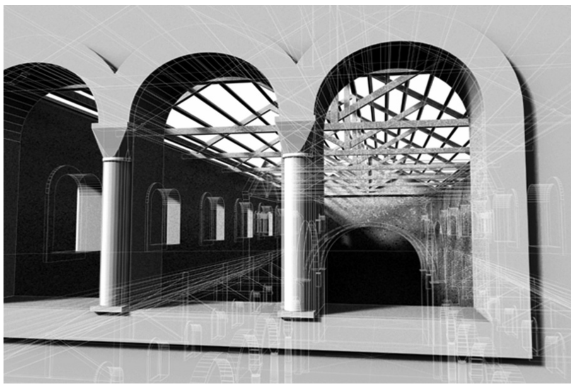

Figure 9: *Detail of the 3D model*

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.

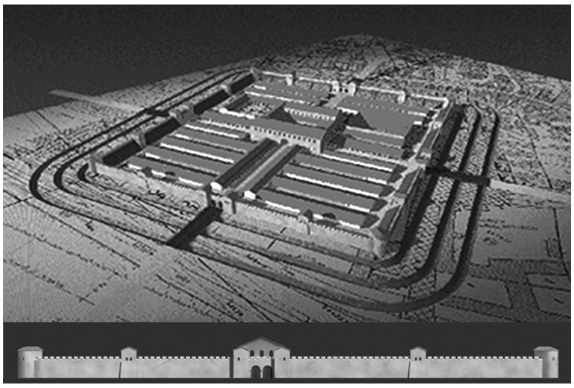

Figure 10: *3D reconstruction of the Roman cavalry fort Campona/Budapest Nagytétény*

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.

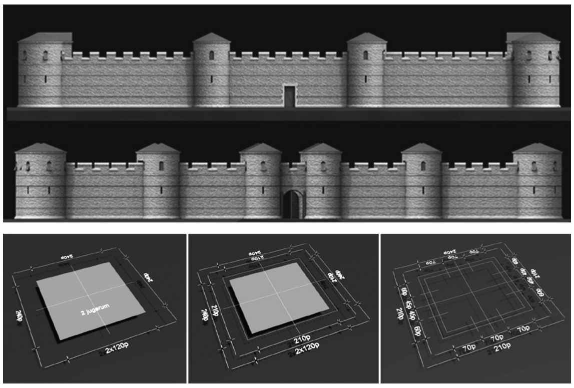

Figure 11: *Reconstruction of the Roman fort Haus Bürgel/Monheim, Germany*

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.

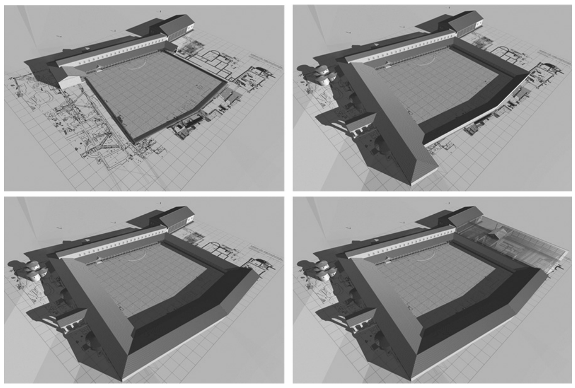

Figure 12: *3D reconstructions of the proposed restoration phases of the late Roman building complex*

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.

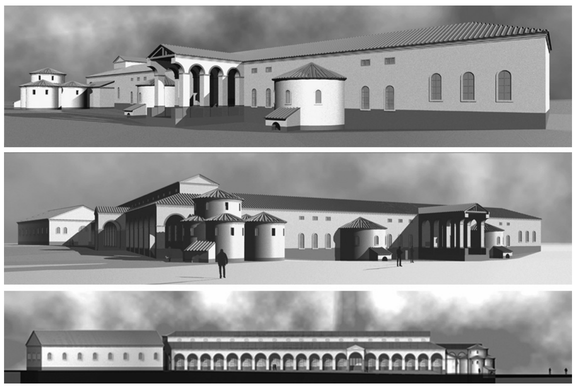

Figure 13: *3D views of the building complex*

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

This study forms part of the EC, FP6 Network of Excellence IST-2002-507382 EPOCH. The author would like to thank the developers of the technologies examined in this study for their contributions; and the European Union for their substantial financial support, without which this project would not have been possible. Special thanks to Sarolta Bihary, Ákos Vasáros, Erzsébet Jerem, Ádám Holicska, Mária Iván, Zsolt Megyesi, Ádám Pásztor, Zsolt Nagy, Katalin Hauszknecht and Gábor Kállay for their help in designing and editing the materials presented in this paper.

References

[Bar00] BARCELÒ J. A.: Visualizing what might be: an introduction to virtual reality techniques in archaeology. In BARCELÒ J. A., FORTE M., SANDERS D. H. (eds.), *Virtual reality in Archaeology (BAR Int. Ser 843)*, pp. 9-46.

[BFS00] BARCELÒ J. A., FORTE M., SANDERS D. H., The diversity of Archaeological virtual worlds. In BARCELÒ J. A., FORTE M., SANDERS D. H. (eds.), *Virtual reality in Archaeology (BAR Int. Ser 843)*, pp. 3-6.

[KBB*04] KÁKOSY L., BÁCS T. A., BARTOS Z., FÁBIÁN Z. I., GAÁL E.: The Mortuary Monument of Djehutymes (TT32). *StAEg I*, Budapest, 2004.

[Luf01] LUFT U., et al.: Preliminary Report on the Fieldwork at Bir Minih, Arabian Desert. *MDAIK 58*, pp. 373-390.

[NC03] NICCOLUCCI F., CANTONE F.: Legend and Virtual Reconstruction: Porsenna's Mausoleum in X3D. In *Proc. CAA 2002*, Heraklion, Crete.

[Oen00] OENBRINK W.: Qanawat. Untersuchungen zu den Nekropolen und Grabbauten. Ein Vorbericht. *Damaszener Mitteilungen 12* (2000), pp. 231-243.

[Red02] REDKNAP M.: *Re-creations. Visualizing Our Past*. Cardiff 2002.

[Ris02] RISTOW S.: *Die frühen Kirchen unter dem Kölner Dom. Befunde und Funde vom 4. Jahrhundert bis Bauzeit des Alten Domes*. Köln 2002.

[Rou02] ROUSSOU M.: Virtual Heritage: From the research Lab to the broad public. In: NICCOLUCCI F. (ed.), *Virtual Archaeology: Proceedings of the Vast Euroconference, Arezzo, Italy, November 2000 (BAR Int. Ser 1075)*, pp. 93-100.

[Rya01] RYAN N.: Virtual Reality for archaeological explanation: Beyond "picturesque" reconstruction. *Archeologia e Calcolatori 12*, 2001.

[SV05] SCHREIBER G., VASÁROS Zs.: A Theban Tomb of the late third intermediate period on El-Khokha. *Acta Archaeologica Academiae Scientiarum Hung. 56* (2005), Budapest, pp. 1-27.

[VD04] VASÁROS Zs., DIVINYI G.: Progressive 3D Modelling of the Theban Tomb 32. In *Proc. CAA 2003* (2001), Vienna, pp. 555-557.

[Vas05] VASÁROS Zs.: Bauforschung-Rekonstruktion-Präsentation: Konzepte für die Beamtennekropole Theben-West, Ägypten. *Bauforschungsperspektiven – DAI Kolloquium*, 17.-19. Nov, 2005.

[Vit04] VITI S.: Between Reconstruction and Reproduction. The Role of Virtual Models in Archaeological Research. In *Proc. CAA 2003* (2001), Vienna, pp. 525-528.

[VLB04] VASÁROS Zs.,. LUFT U., BIHARY S.: Bir Minih 3D – reconstruction of an archaeological landscape in the Eastern Desert of Egypt, oral presentation in *CAA 2004* Florence

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
VAST (2006)
M. Ioannides, D. Arnold, F. Niccolucci, K. Mania (Editors)

The Use of 3D Reconstruction Applied to the Study and Spatial Analysis of Architectural Heritage: The Palace of the Aljafería in Zaragoza, Spain.

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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.

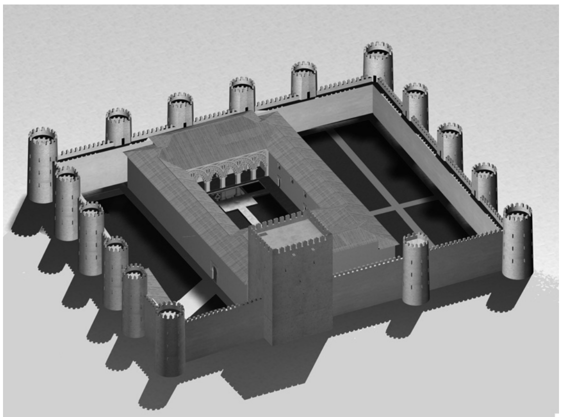

Figure 2: *View of the 3D reconstruction of the whole fortified palace*

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 photorealistic 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.

References

[Bla01] BLASCO, C., *El Palacio del Buen Retiro de Madrid. Un Proyecto hacia el pasado* (2001)

[AA02] ALMAGRO GORBEA, A., ALMAGRO VIDAL, A.: La expresión gráfica en el análisis del patrimonio: el Patio del Crucero del Alcázar de Sevilla. In *Proc. IX International Congress EGA'02* (2002), pp. 517-522.

[Alm98] ALMAGRO GORBEA, A.: La imagen de la Aljafería a través del tiempo. Evolución morfológica, *La Aljafería* (1998), vol. II, pp. 407-421.

[Bet06] BETHUNE, J., *AutoCAD 2006 avanzado* (2006)

[Boa05] BOARDMAN, T., *3ds max 7* (2005)

[Bou04] BOULLOSA GUERRERO, N. *Proyectos multimedia: imagen, sonido y vídeo (*2004).

[Bou05] BOUSQUET, M., *Modelado, rendering y animación con 3ds max 7* (2005)

[Cha05] CHANES, M., *AutoCAD 2006* (2005)

[Con00] CONTRERAS, F. R. *Nuevas fronteras de la infografía. Análisis de la imagen por ordenador* (2000).

[CP00] CORAY, D.; PELLEGRINO, P., *Arquitectura e informática.* (2000).

[Ewe77] EWERT, C.: Tradiciones omeyas en la arquitectura palatina de la época de los taifas. La Aljafería de Zaragoza. In *Proc. XXIII International Congress of Art History* (1977), vol. II., pp. 62-75

[Ewe78] EWERT, C.: *Spanisch-Islamische Systeme sich kreuzender Bögen. III Die Aljafería in Zaragoza* (1978), vol. 1&2.

[Fai00] FAIRCHILD RUGGLES, D.: *Gardens, landscape, and vision in the palaces of Islamic Spain* (2000).

[Fer01] FERNÁNDEZ RUIZ, J. A.: Scientific and Ethical Scope of Digital Modelling in Architectural Heritage. In *Proc. VAST 2001 Virtual Reality, Archaeology and Cultural Heritage* (2001). http://www.ugr.es/~jafruiz/Big%20paper%200019.pdf

[Fer97] FERNANDEZ RUIZ, J. A., *La restauración del patrimonio por la imagen de síntesis.* PhD Thesis. Departamento de Expresión Gráfica Arquitectónica y en la Ingeniería, Universidad de Granada (1997).

[FNRB02] FRISCHER, B., NICCOLUCCI, F., RYAN, N., BARCELÓ, J. A.: From CVR to CVRO: The past, present and future of Cultural Virtual Reality. In *Proc. VAST 2000 (*2002) pp. 7-18.

[Kol03] KOLAREVIC, B., *Architecture in the Digital Age* (2003)

[Mal01] MANOVICH, L., *The language of new media* (2001).

[Moa06] MOLERO VERA, J., 3ds Max 6-7 (2006)

[Mon99] MONEDERO ISORNA, J., *Aplicaciones informáticas en arquitectura* (1999).

[Pis04] PISCITELLI, M. *La rappresentazione nell'era digitale. Nuove tecnologie per disegnare e comunicare* (2004).

[Rah06] RAHIM, A. (Ed*.), Contemporary Techniques in Architecture* (2006)

[Sal99] SALEH UDDIN, M., *Digital Architecture* (1999)

[Ser01] SERRATO-COMBE, A., *.Aztec Templo Mayor* (2001)

[Sob98] SOBRADIEL VALENZUELA, P.: *La arquitectura de la Aljafería. Estudio histórico documental* (1998)

[Str05] STRAUB, K., Creative *Suite. Proyectos básicos versión dual* (2005)

[Vin00] VIÑAS LIMONCHI, M., *Técnicas de infografía: variables creativas metodológicas en el desarrollo de la imagen digital* (2000).

Figure 4: *View of the South portico*

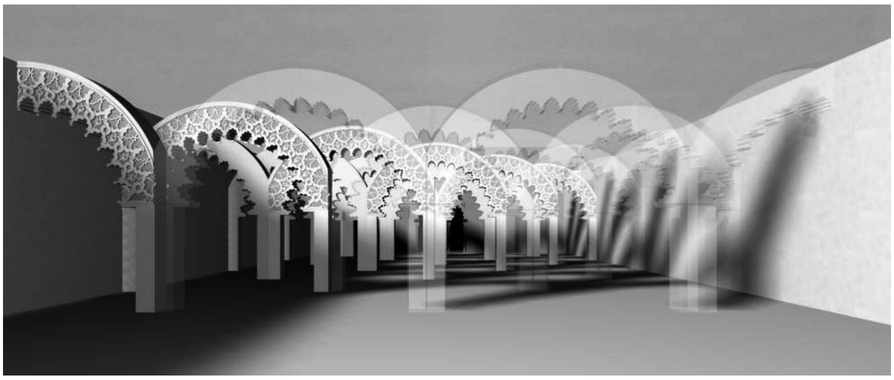

Figure 5: *Ideal front view of the space created by the superposition of porticos*


Figure 6: *View of the South portico and the decorative programme there represented*


Figure 7: *Ideal oblique view of the represented space*

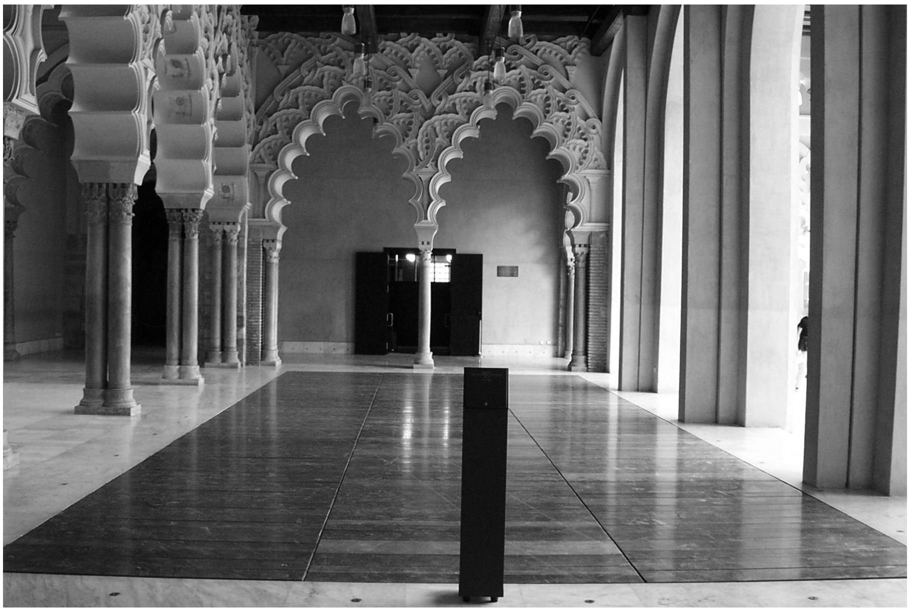

Figure 8: *The right side of the U-shaped portico nowadays. Reconstruction work made in the 1970s*

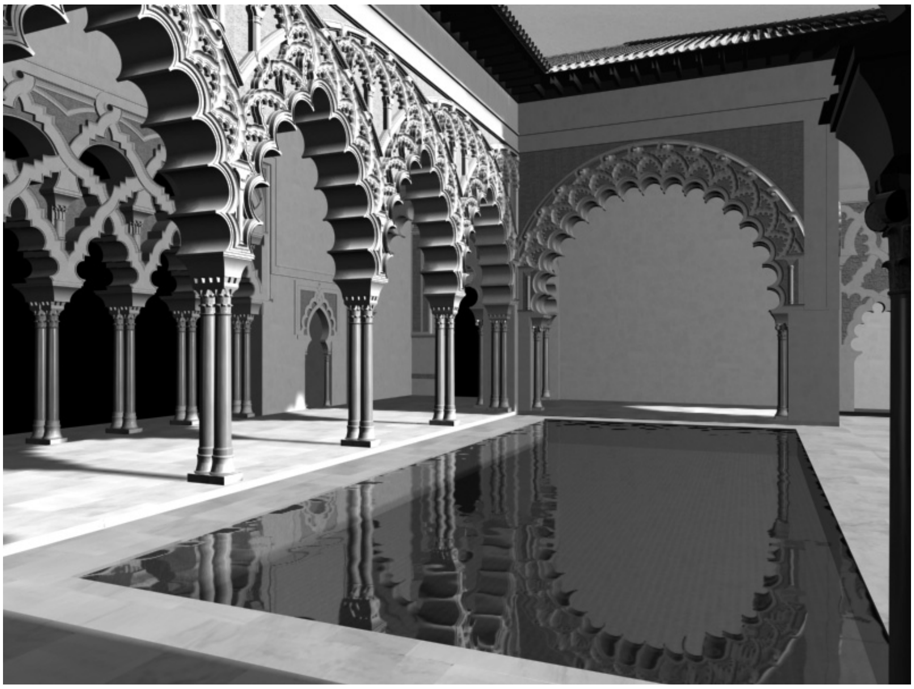

Figure 9: *The U-shaped portico following the reconstruction hypothesis of the 3D model*

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