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

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.

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]:

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

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

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.

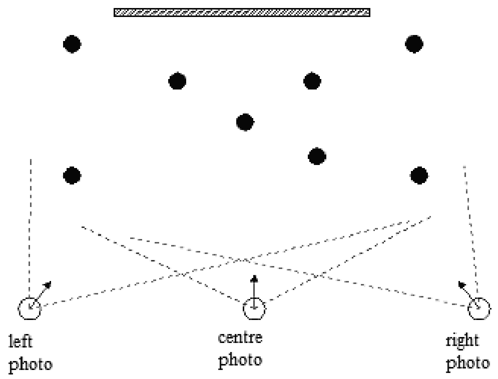

Figure 3: *Handheld gadgets configuration*

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*

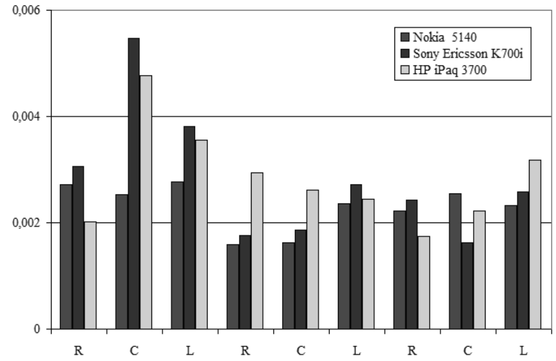

Figure 4: *Normalized range of changes in principal distance*

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.

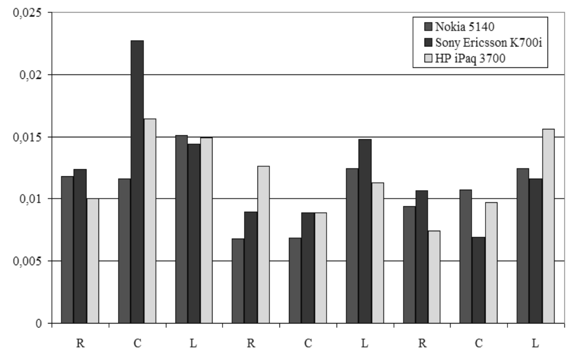

Figure 5: *Changes of principal point (normalized to the image width)*

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.

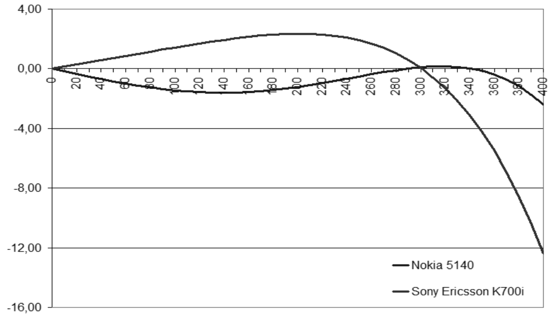

Figure 6: *Balanced radial distortion curves form Nokia 5140 and Sony Ericsson K700i mobile phones*

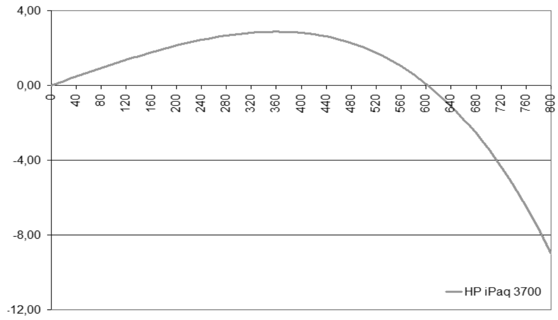

Figure 7: *Balance radial distortion curve from PDA HP iPaq 3700*

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	Stereopair	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.

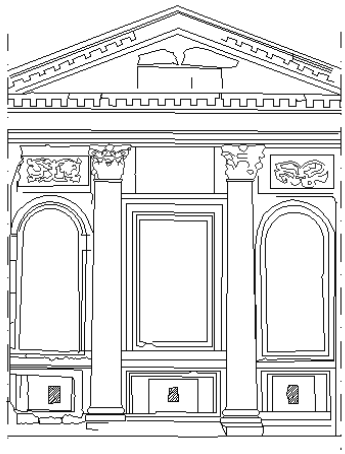

Figure 9: *The 2D façade of "Krini Priouli"*

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).

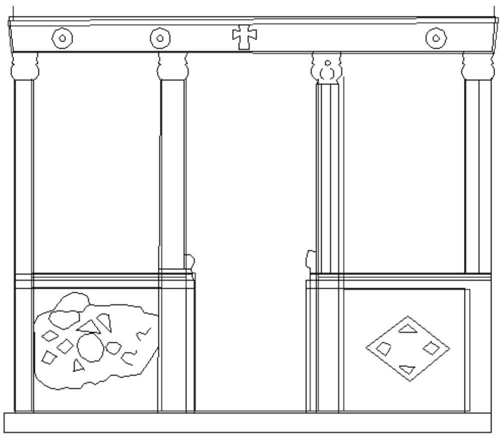

Figure 11: *The 2D facade plan of the iconostasis.*

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.

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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.

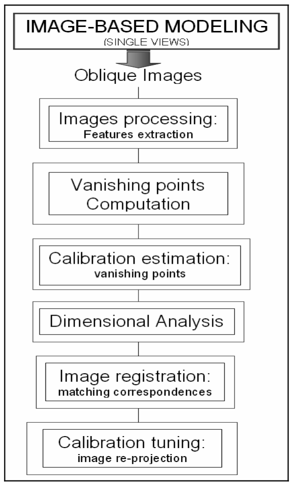

Figure 3: *Multi-sensor registration through single image-based modeling.*

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.

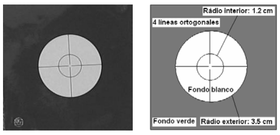

Figure 4: *Special planar targets.*

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:

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

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.

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

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:

$$a^2 = b^2 + c^2 - 2bc\cos\alpha; b^2 = a^2 + c^2 - 2ac\cos\beta$$
$$c^2 = a^2 + b^2 - 2ab\cos\gamma \tag{3.3}$$

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.

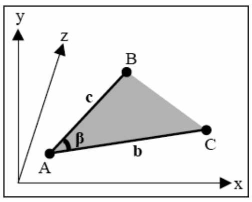

Figure 5: *Search scheme.*

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):

$$C\begin{pmatrix} Ni \\ 2 \end{pmatrix} + C\begin{pmatrix} Nc \\ 2 \end{pmatrix} + Ni \cdot C\begin{pmatrix} Ni-1 \\ 2 \end{pmatrix} + Nc \cdot C\begin{pmatrix} Nc-1 \\ 2 \end{pmatrix} \tag{3.4}$$

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).

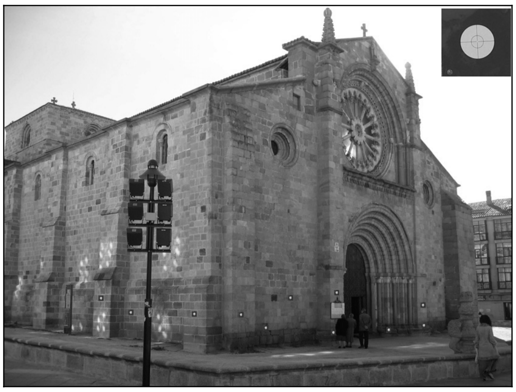

Figure 6: *Original image with special targets (3008x2000 pixels)*

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

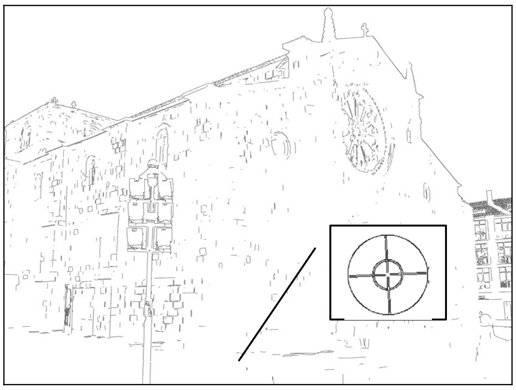

Figure 7: *Image features extraction: vanishing lines and targets.*

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).

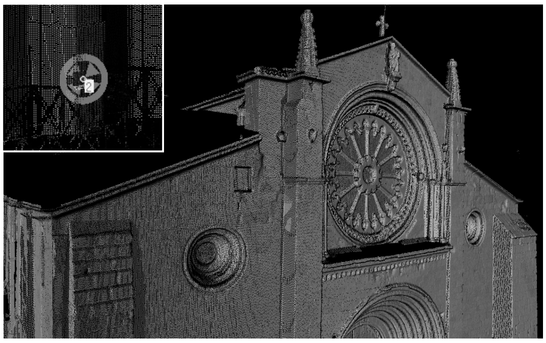

Figure 8: *Laser model and the special targets extracted.*

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.

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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

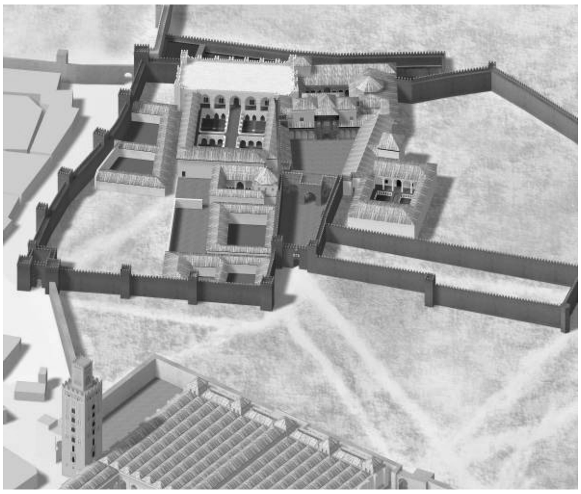

Figure 3: *Aerial vew of the Alcazar in the 14th Century*

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 14th 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.

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

Project Presentations

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.

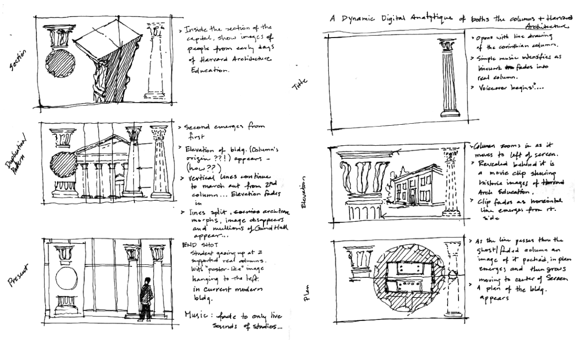

Figure 3: *Storyboard of P.J.*

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.

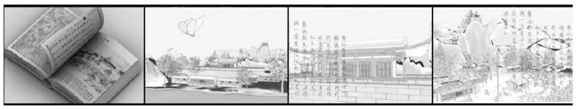

Figure 6: *Snapshots of project from F.G., reconstructing the destroyed summer palace of the Chinese emperor*

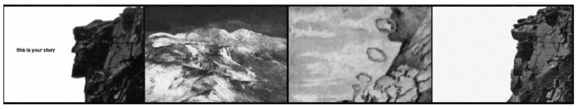

Figure 7: *Snapshots of project from B.H., recording the cultural heritage of the Old Man on the Mountain in New Hampshire*

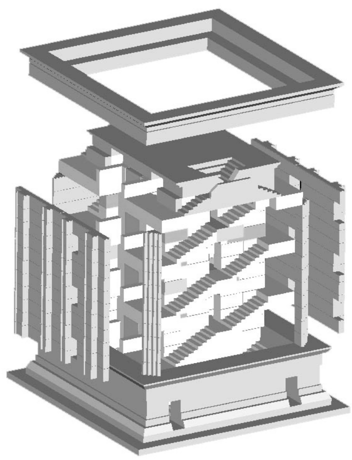

Figure 8: *Project of N.P., assembling the Great Altar*

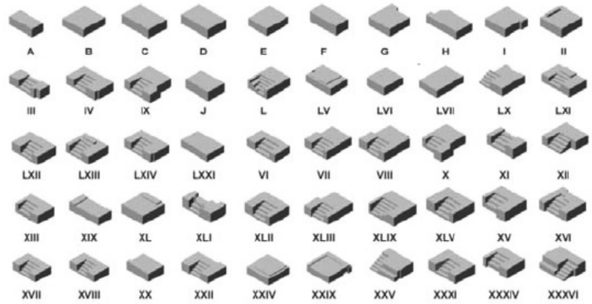

Figure 9: *Project of N.P., the individual stone components of the Great Altar*

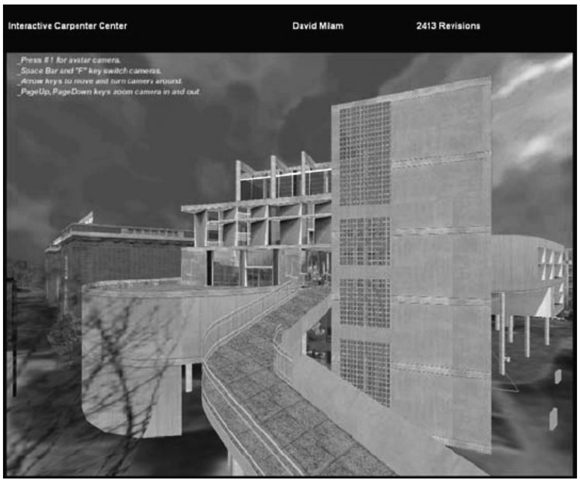

Figure 10: *Snapshot of project from D.M., interactive Carpenter center*

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/

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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

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).

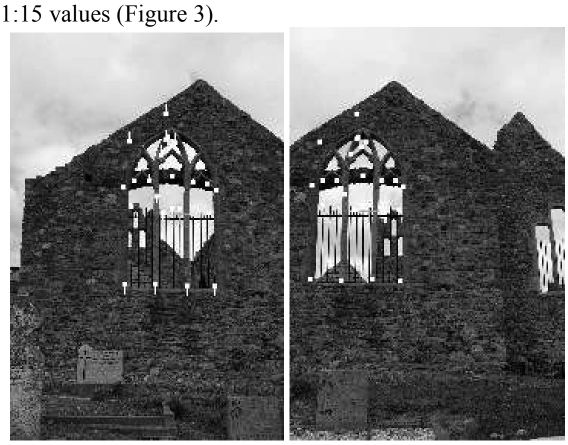

Figure 3: *Left and right stereo images*

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.

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The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
VAST (2006)
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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.

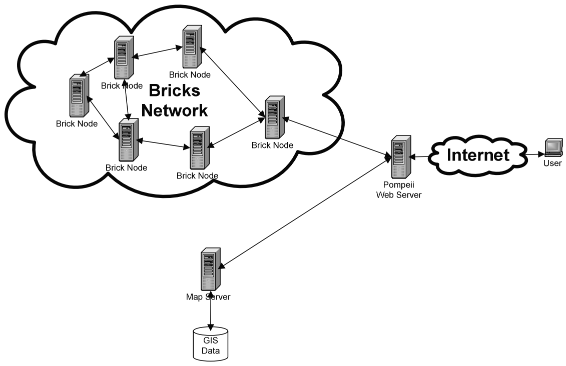

Figure 6: *the "Fortuna visiva of Pompeii" BRICKS Application. Architecture.*

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>**
Date <dc:date>	Availlable <dcterms:available> Created <dcterms:created> Date accepted <dcterms:dateAccepted> Date copyrighted <dcterms:dateCopyrighted> Date submitted <dcterms:dateSubmitted> Issued <dcterms:issued> Modified <dcterms:modified> Valid <dcterms:valid>	Periodo (Period) <dcterms:period> W3CDTF <dcterms:W3CDTF>
Type <dc:type>	**Standard <pico:standard>**	DCMI Type Vocabulary <dcmitype:DCMItype> **PICO Type Vocabulary <pico:PICOtype>** **CLDT <pico:CLDT>** **PRISM Resource Type Vocabulary <pico:prismRT>** **PRISM Resource Category Vocabulary <pico:prismCT>** **ICCD - Oggetto Definizione – Artistic Objects – OA <pico:iccdODoa>** **ICCD - Oggetto Tipologia – Artistic Object – OA <pico:iccdOToa>** **ICCD - Tipologia dell'Oggetto – Architectonical Objects <pico:iccdTOao>**
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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.

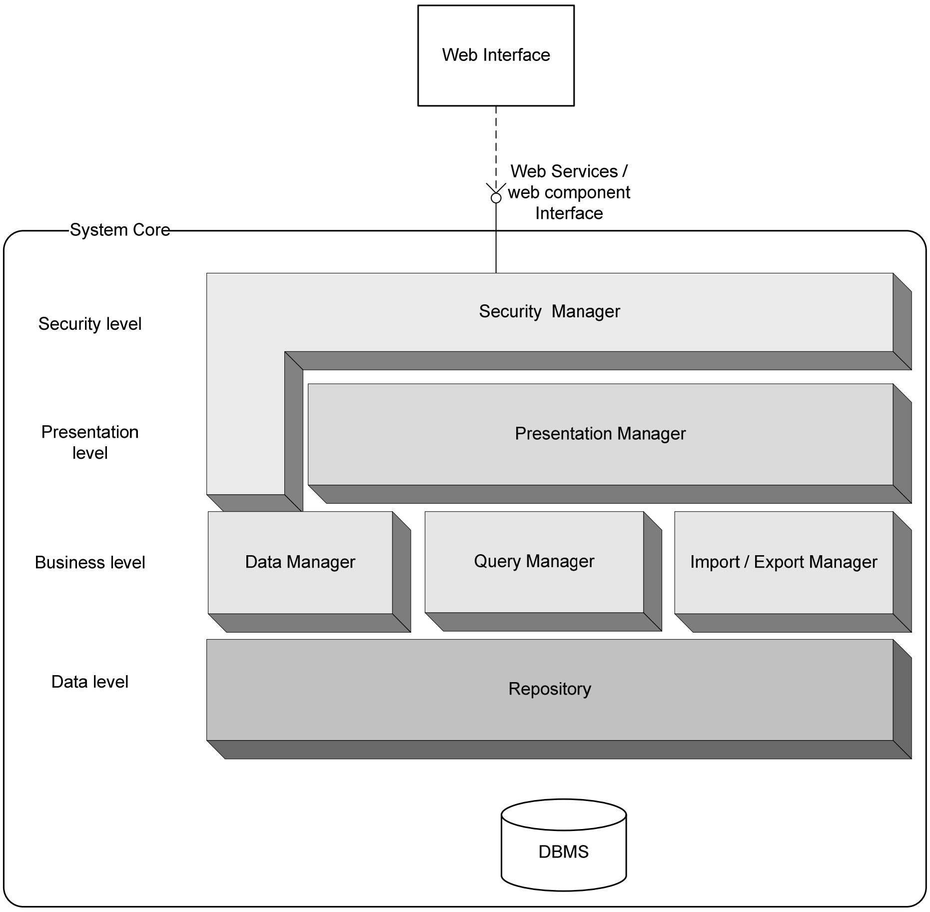

Fig. 2: *Architecture of the Pompeii Information System. Overall view.*

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.

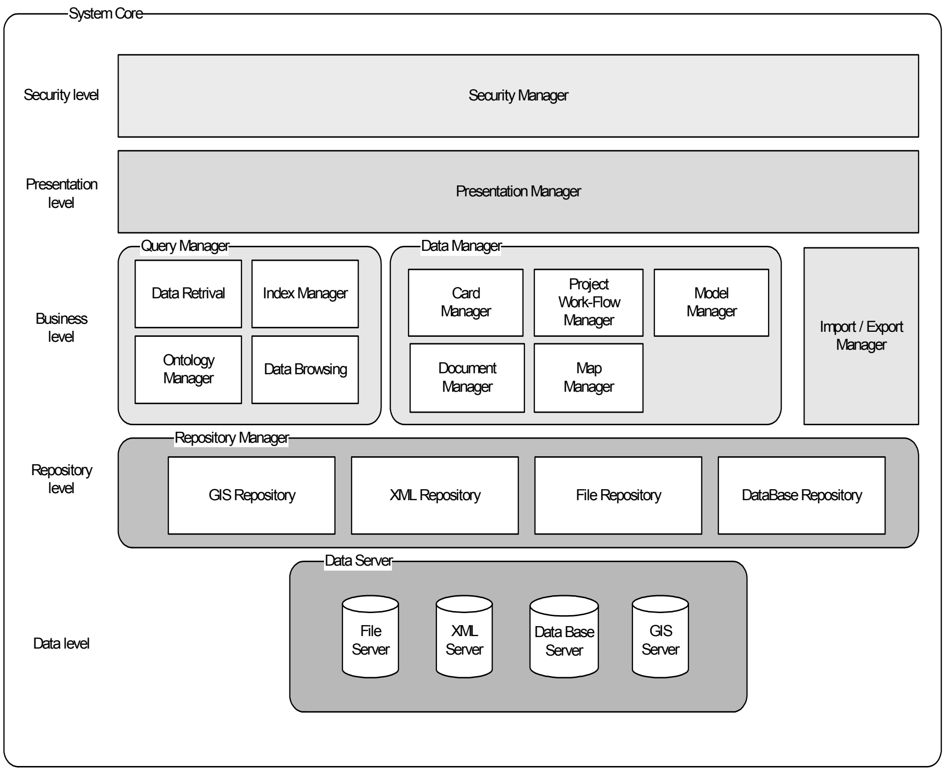

Fig. 3: *Architecture of the Pompeii Information System: detail of the integrated Modules.*

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.

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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.

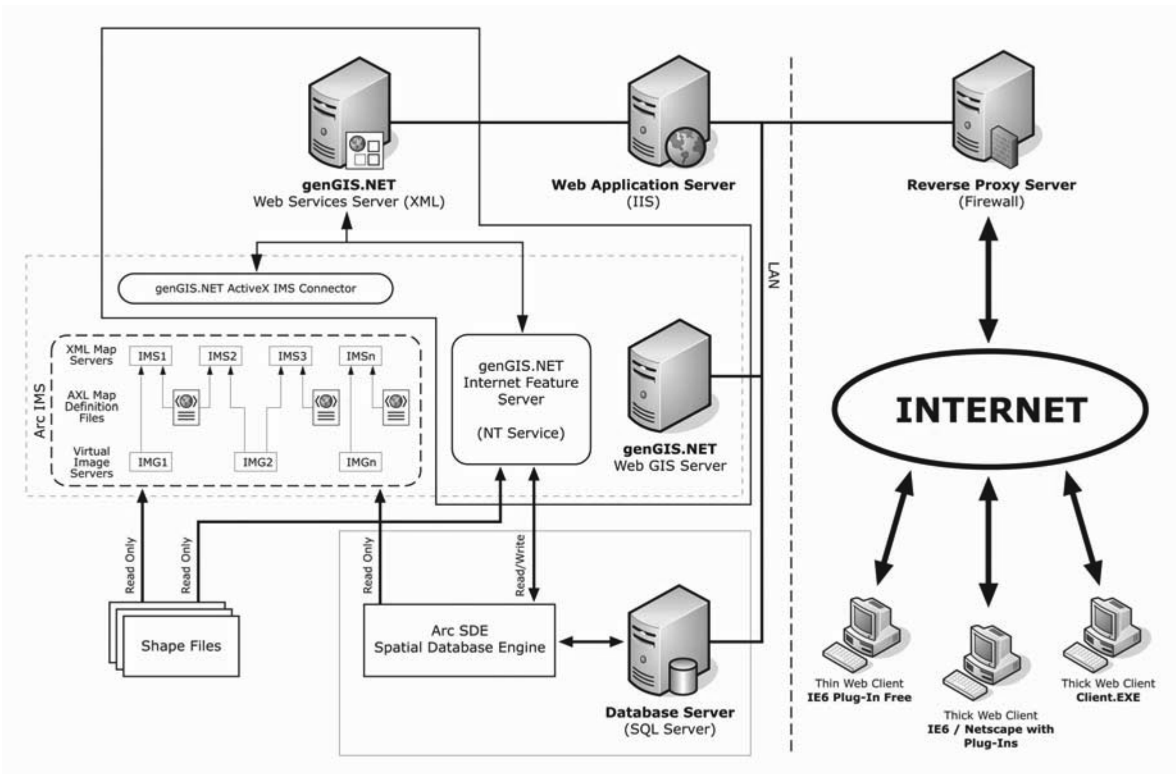

Figure 1: *Web GIS Architecture Model*

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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.*

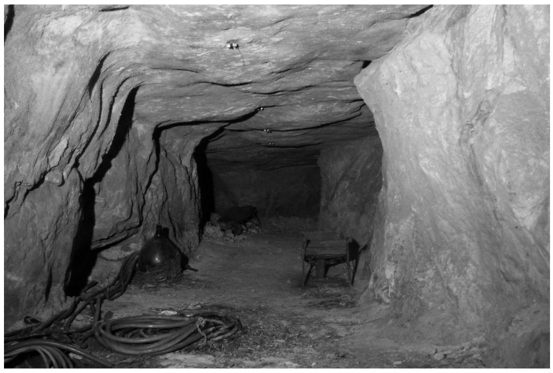

Figure 2: *Via Tirapelle mine (Valdonega, Verona): entrance. Incoherent deposit of yellow ochre.*

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.*

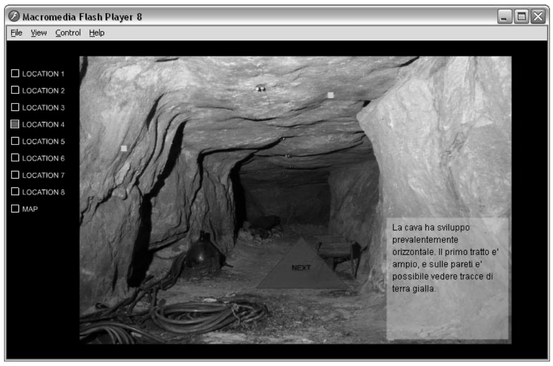

Figure 6: *Screenshot of the virtual tour of the quarry of Via Tirapelle.*

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.

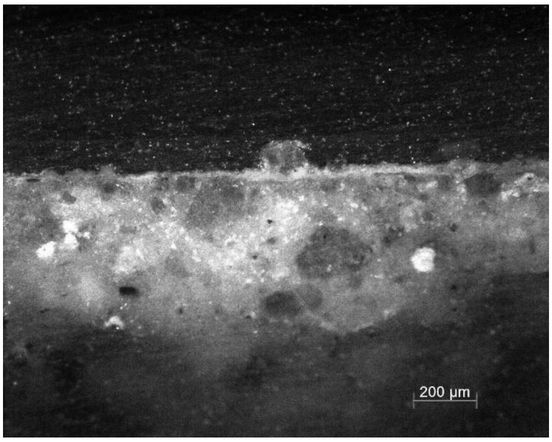

Figure 8: *Cross-section (optical microscopy in reflected light) showing a yellow layer obtained applying yellow ochre on the support.*

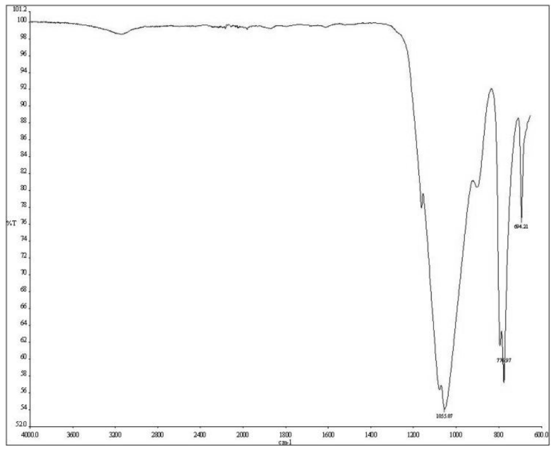

Figure 9: *FTIR of yellow ochre collected at the cave near the natural bridge of Veja.*

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).

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.

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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).

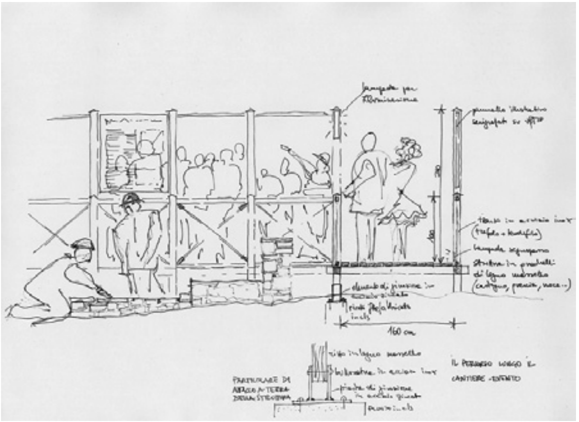

Figure 2: *The equipped trail*

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*).

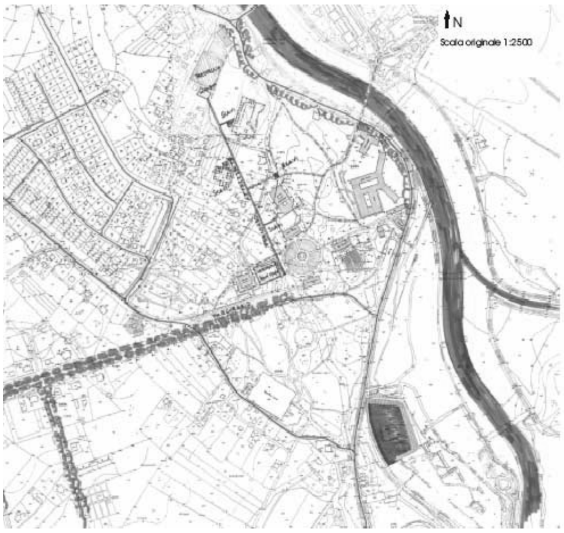

Figure 3: *The project master-plan*

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.

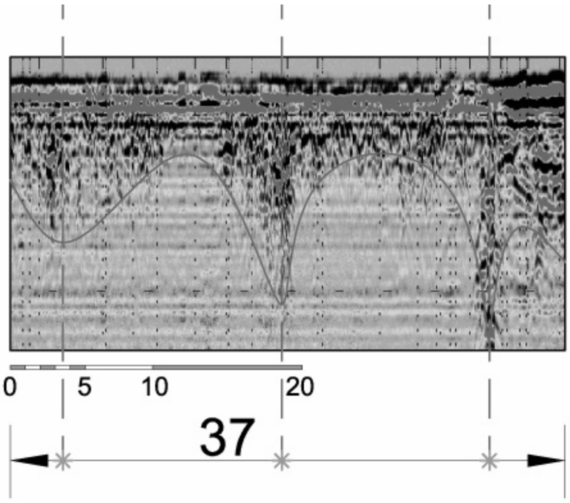

Figure 5: *Georadar stripe (the anomaly of underground has been evidenced with the red colour)*

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.

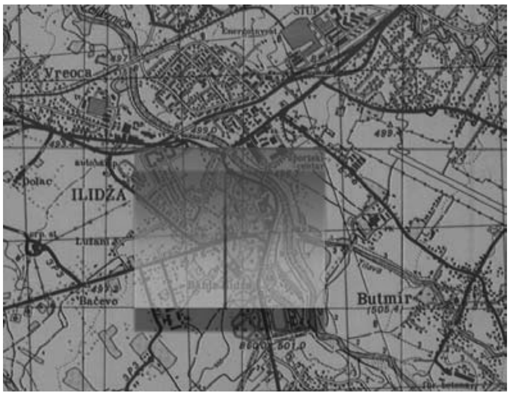

Figure 6: *Low quote flight*

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].

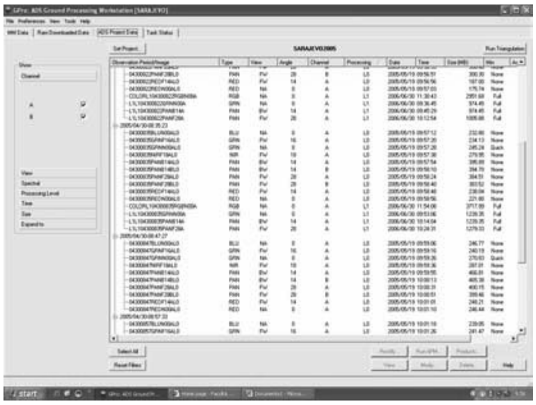

Figure 7: *GPro displayed L0 and L1 images*

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.

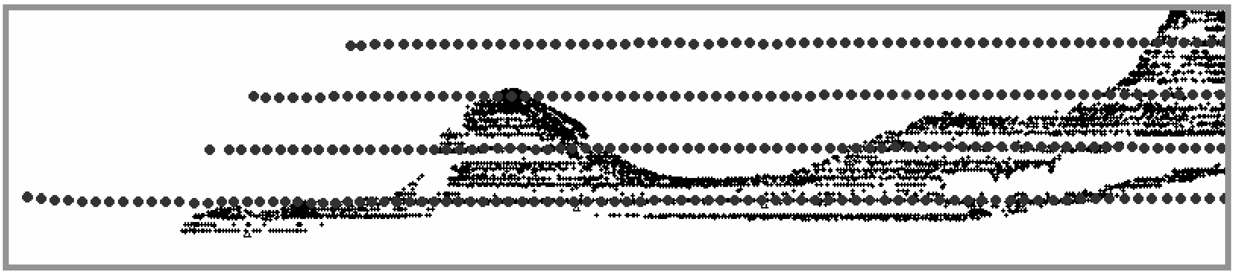

Figure 8: *In blue are showed the orientation fixes and in black the Automatic Point Matching*

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.

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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

† Head of the 3D Computer Graphics and Animation Sector

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.

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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.

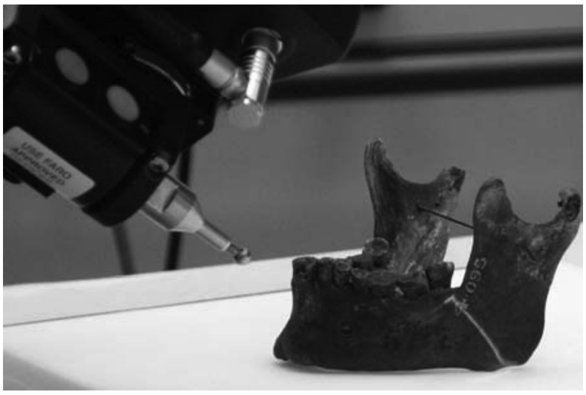

Figure 6: *Laser scanning the mandible of 'Leasowe Man'.*

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.

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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.*

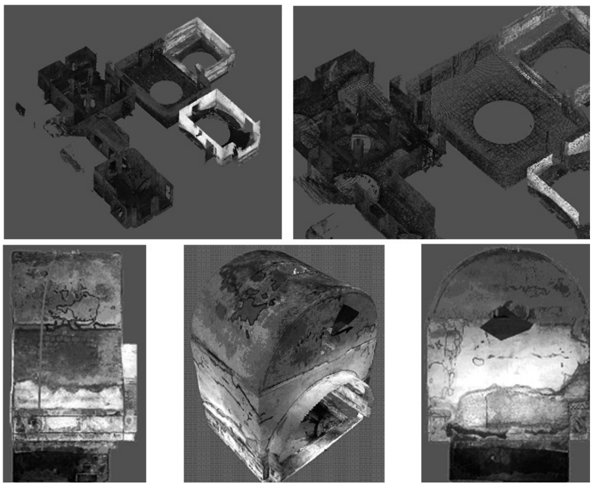

Fig. 7: *Above: views of the 3D model under construction; below centre: prospective view of a room, below left and right: two orthographic views.*

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.

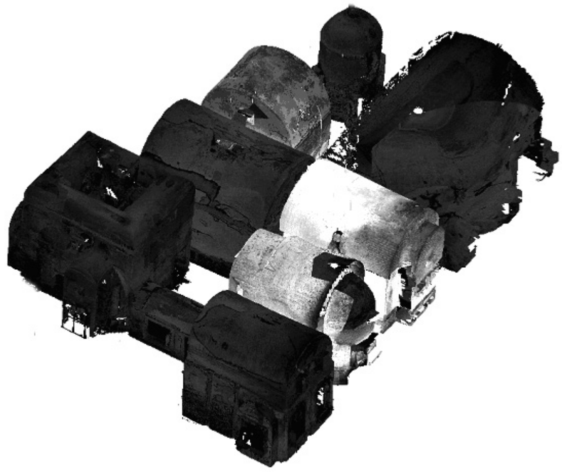

Fig. 8: *Prospective view of the model with various of rooms joined together.*

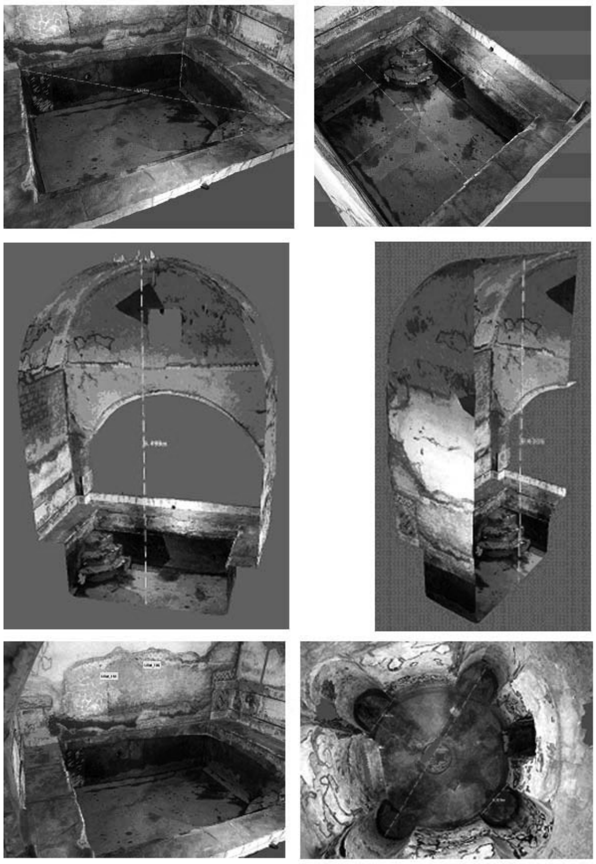

Fig. 9: *Examples of measurements and analysis of parts of the model within the management software.*

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.

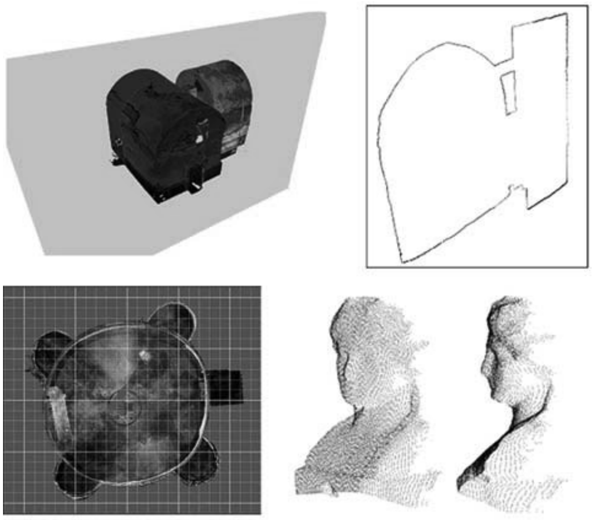

Fig. 10: *Examples of sections or plans drawn from the model.*

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.

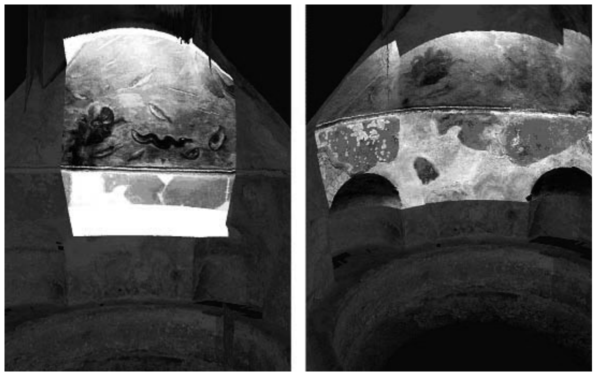

Fig. 11: *Example of the model using a photograph taken during the scan (right), compared to an archive photo (left).*

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.

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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.*

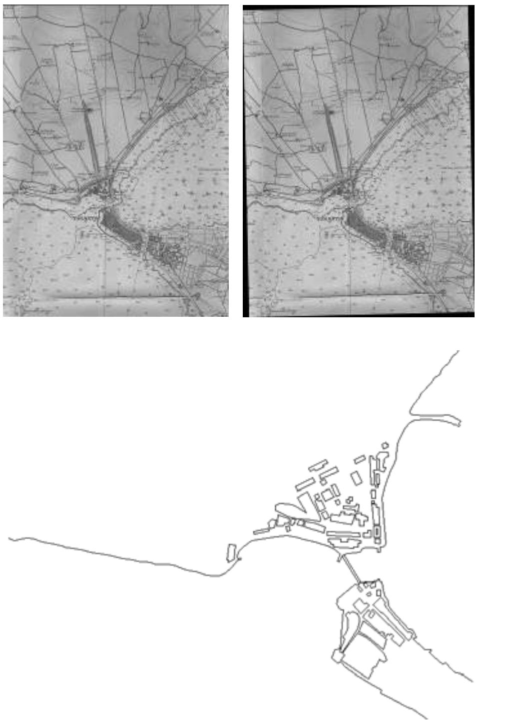

Figure 5: *Georeferentation and vectorialization map of Mar Grande e Mar Piccolo (1890).*

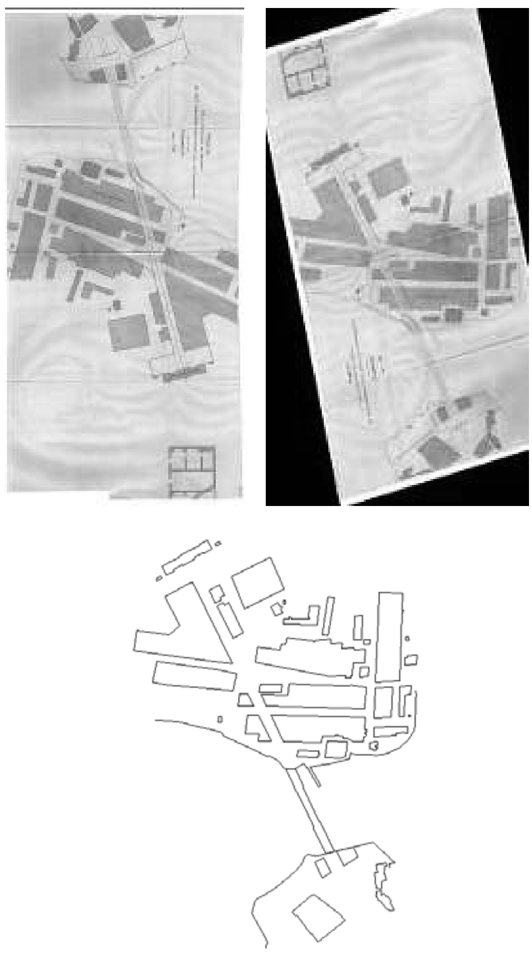

Figure 6: *Georeferentation and vectorialization map (1926).*

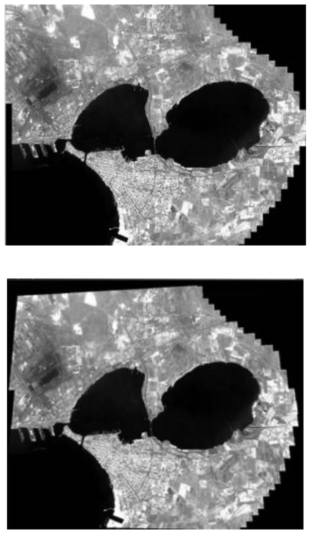

Figure 7: *Georeferentation and vectorialization IKONOS.*

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.

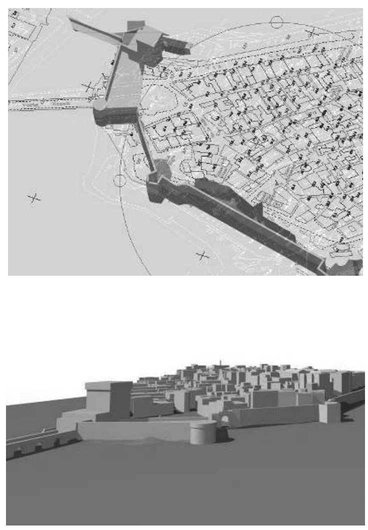

Figure 8: *Construction of urban transformation 1800.*

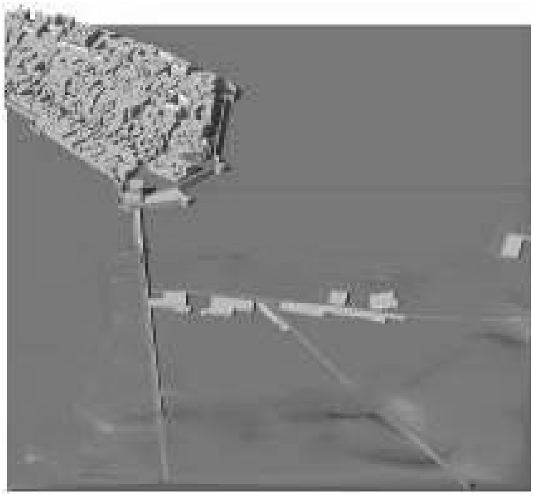

Figure 9: *Urban transformation 1800.*

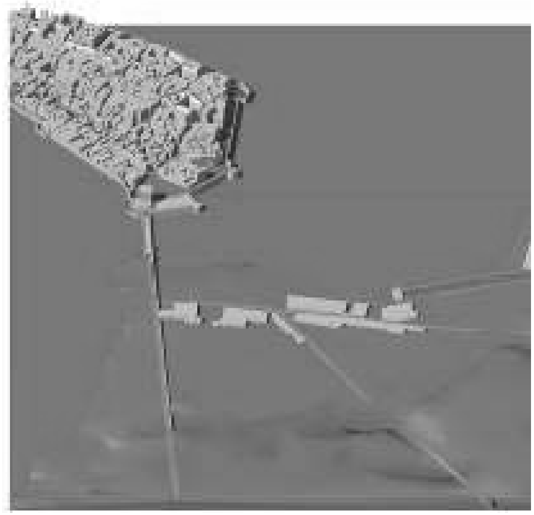

Figure10:– *Urban transformation 1860.*

Figure 11: *Urban transformation 1885.*

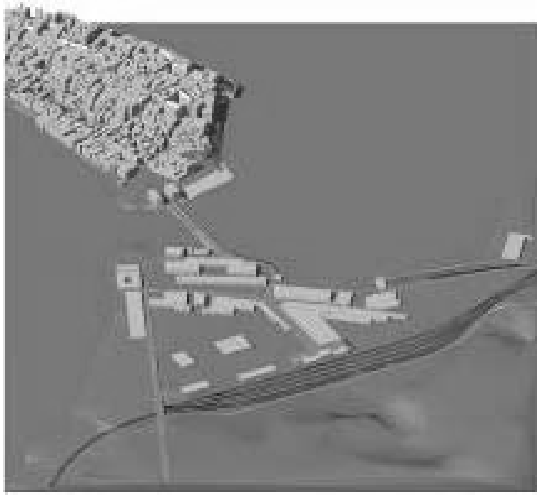

Figure 12: *Urban transformation 1900.*

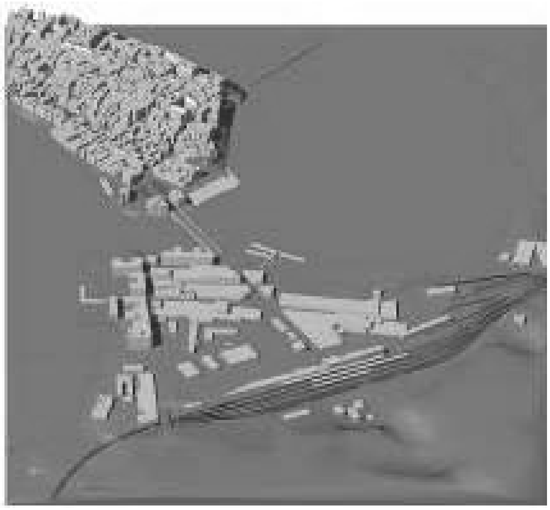

Figure 13: *Urban transformation 1930/40.*

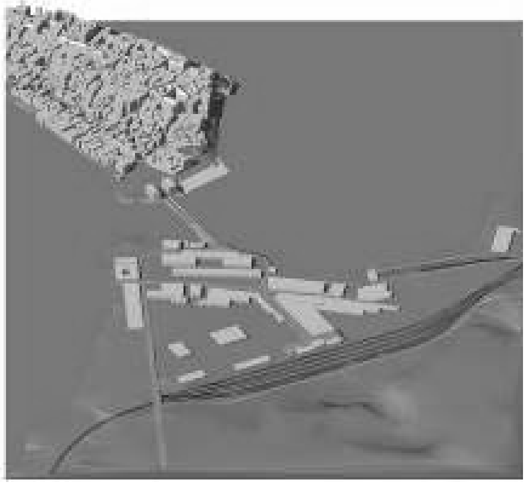

Figure 14: *Urban transformation 1960.*

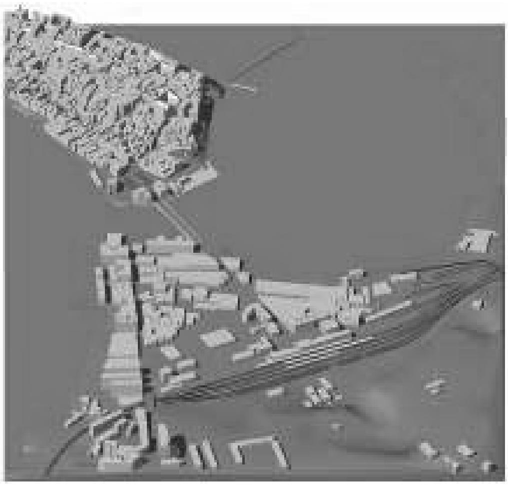

Figure 15: *Today.*

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).

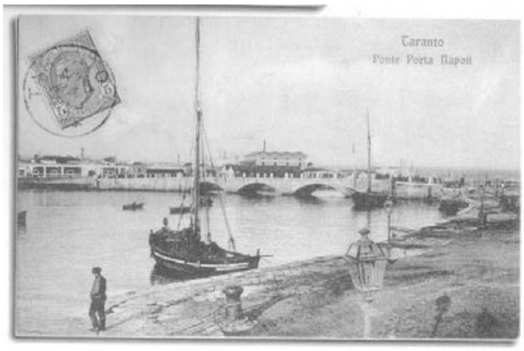

Figure 16: *Porta Napoli bridge (1890).*

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.

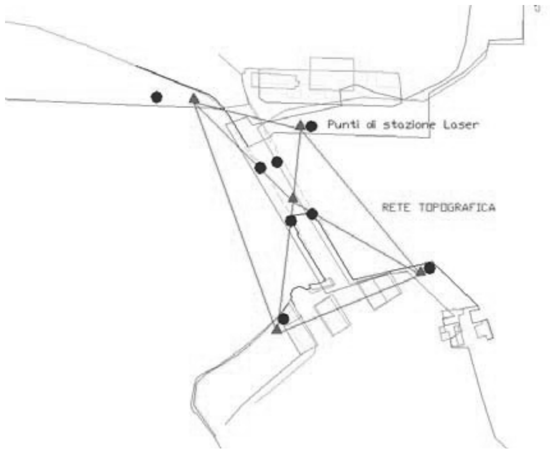

Figure 19: *Survey project.*

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.*

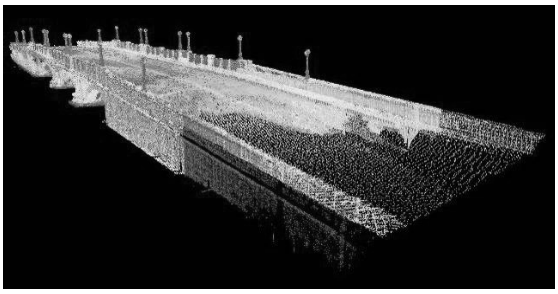

Figure 21: *Representation 3D of point clouds.*

Meaningful elements of the constructive and decorative apparatus are chosen for later elaborations (figure 22-23-24).

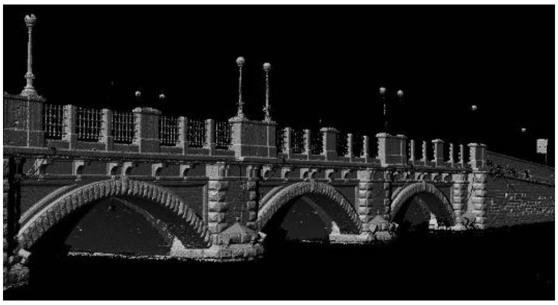

Figure 22: *Representation 3D for complex mesh.*

Figure 23: *A particolar of model.*

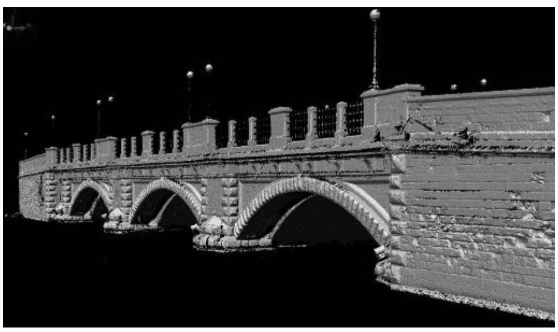

Figure 24: *A particular of model.*

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.*

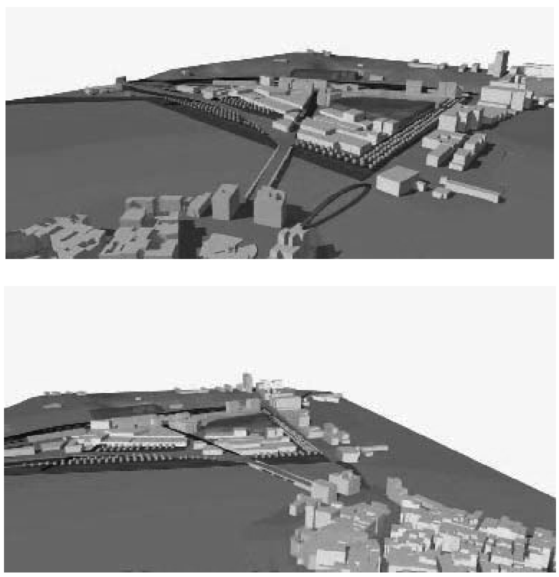

Figure 26: *Parco Urbano Portuale - 3D Simulation.*

Figure 27: *Parco Urbano Portuale – Simulation.*

Figure 28: *Parco Urbano Portuale – Simulation.*

Figure 29: *Parco Urbano Portuale – Simulation.*

Figure 30: *Parco Urbano Portuale – Simulation.*

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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

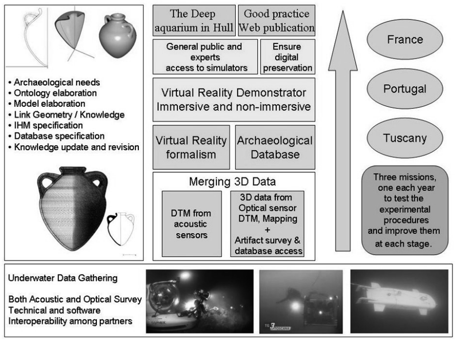

Figure 1: *VENUS project architecture diagram.*

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

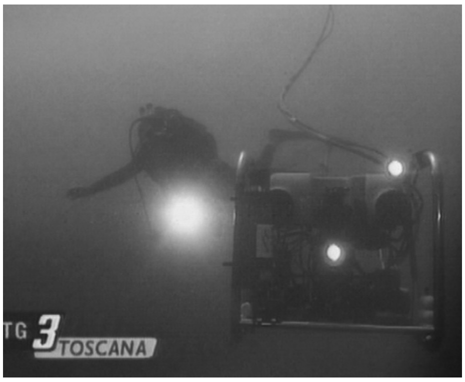

Figure 2: *ROV and Diver, ISME.*

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].

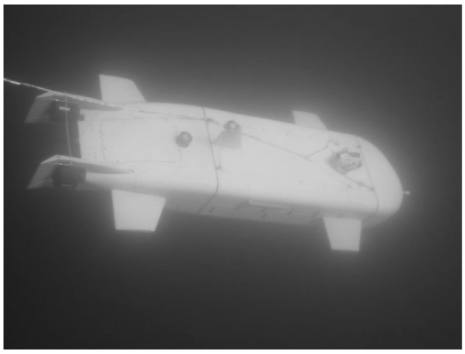

Figure 3: *Autonomous Underwater Vehicle (AUV) of IST.*

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.

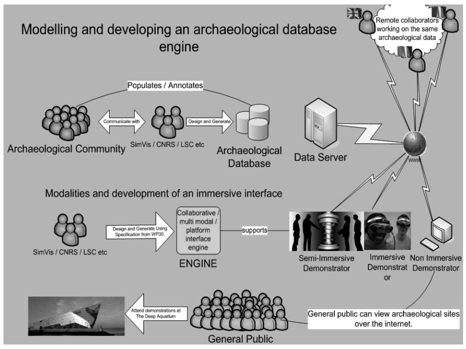

Figure 4: *Synoptic schema of integrated Virtual Reality in VENUS.*

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 Galia, 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.

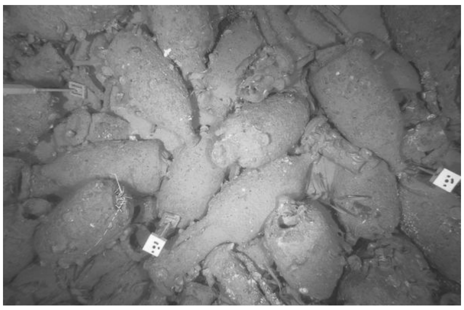

Figure 6: *The "Calanque de Port Miou" photograph from ROV of COMEX.*

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.

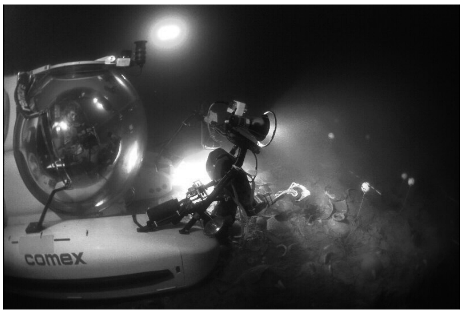

Figure 7: *The submarine REMORA 2000 of COMEX during rhe Grand Ribaud F excavation, 2000. Photo Frederic Bassemayousse.*

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.

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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.

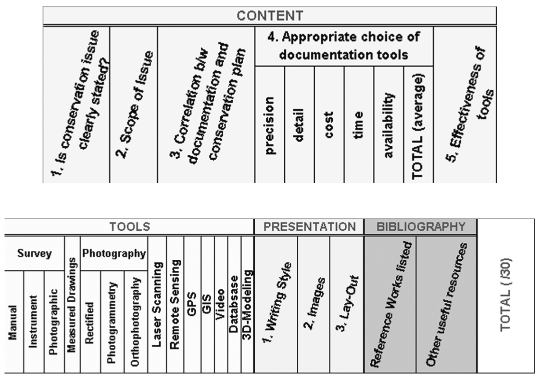

Figure 1: *Example of the rating matrix.*

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.

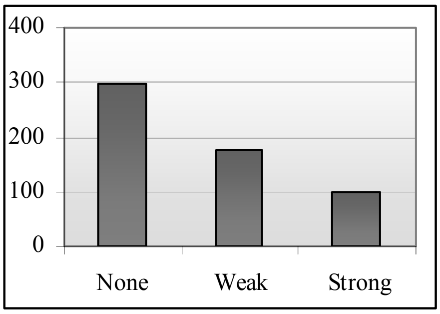

Figure 2: *Conservation relevance.*

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.

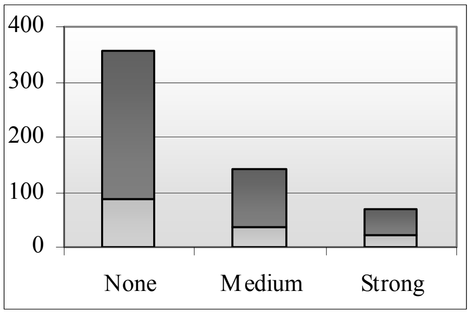

Figure 3: *Correlation between conservation and documentation. The lighter area represents the articles featuring hi-tech tools.*

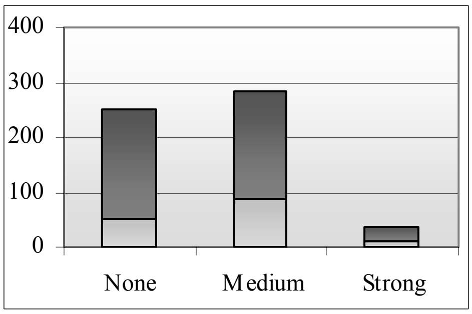

Figure 4: *Appropriate tool selection. The lighter area represents the articles featuring hi-tech tools.*

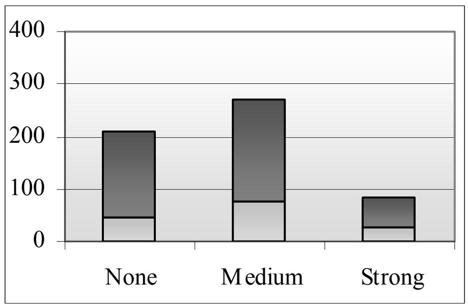

Figure 5: *Effectiveness of documentation results in planning intervention implementation. The lighter area represents the articles featuring hi-tech tools.*

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

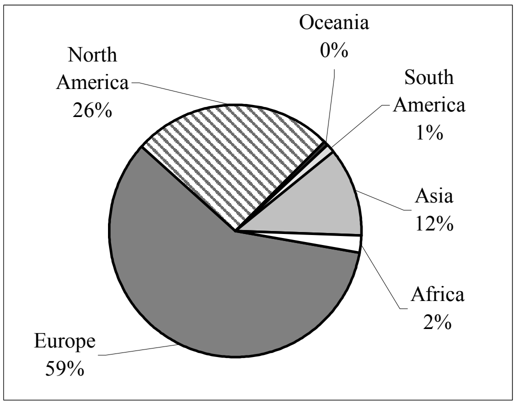

Figure 6: *Geographic distribution of country of publication.*

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]).

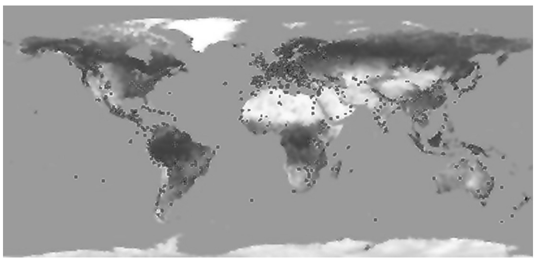

Figure 7: *A map of sites on the World Heritage List correlates with this result.*[5]

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.

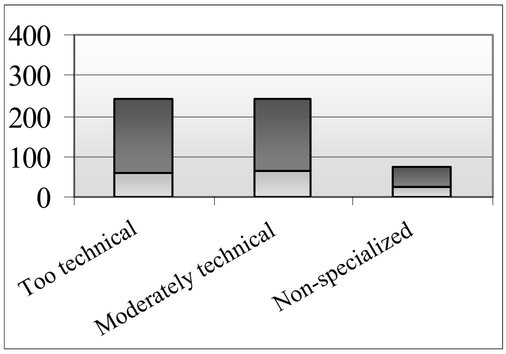

Figure 8: *Writing style (The hatched area represents articles featuring hi-tech tools).*

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.

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

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.

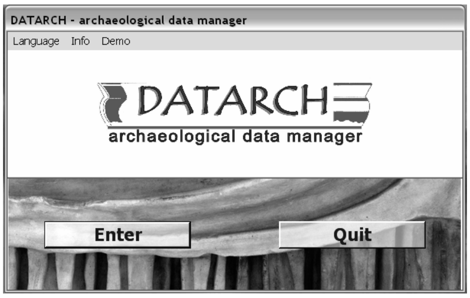

Figure 1: *DATARCH Starting Panel*

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 syncrodiachronic 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 syncrodiachronic 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.

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

Project Presentations

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.

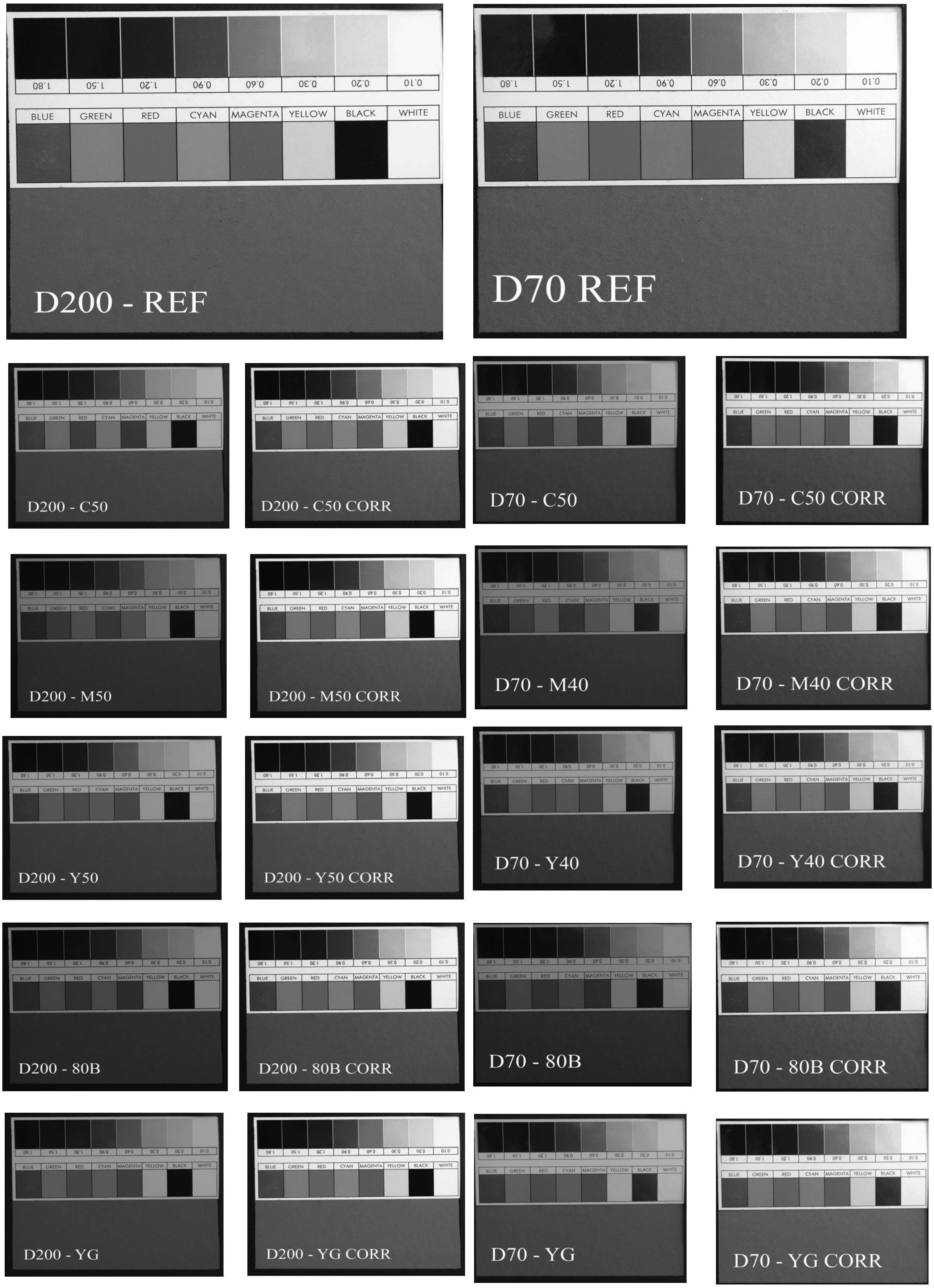
Including (always) a chromatic and grey scale in your real images offers a simple and easy comparison with a reference shot to confirm immediately the reliability of the final image, obtained e.g. after a processing (both optical and via software).

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
D70 - 80B CORR
D200 - YG
D200 - YG CORR
D70 - YG
D70 - YG CORR

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Project Presentations

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.

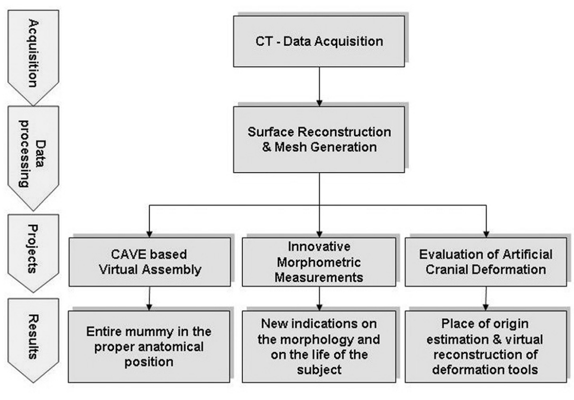


Figure 2: *Project work-flow.*

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).

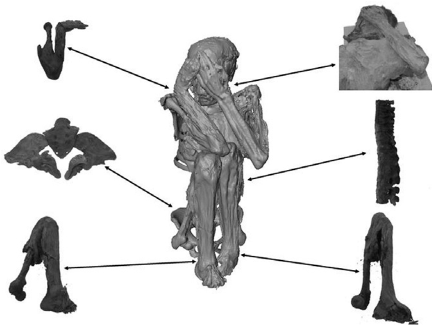


Figure 3: *The Virtual Model of he entire mummy.*

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).

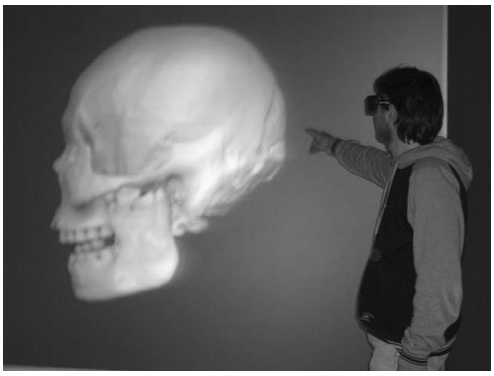


Figure 4: *Exploring the Virtual Model in the CAVE.*

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).

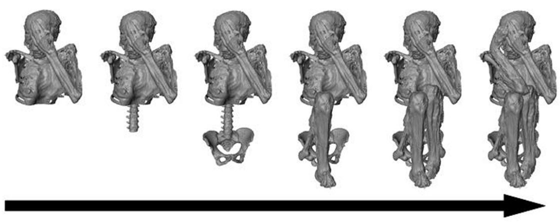


Figure 5: *The Virtual Assembly Process.*

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.

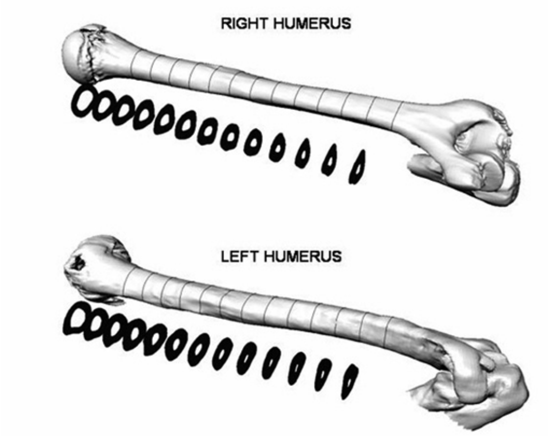
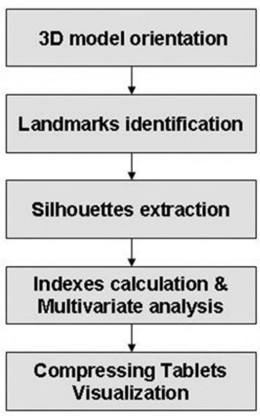


Figure 6: *Virtual sections of the right and left humerus.*

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.

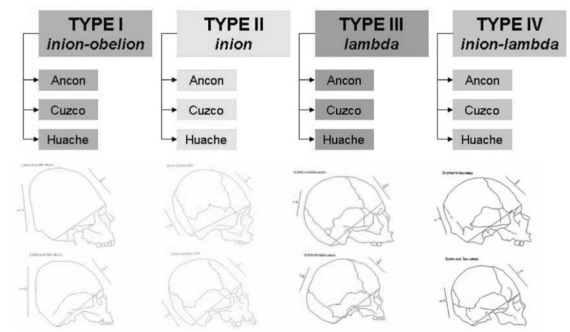


Figure 7: *Artificial Cranial Deformations according to Pardini.*

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).

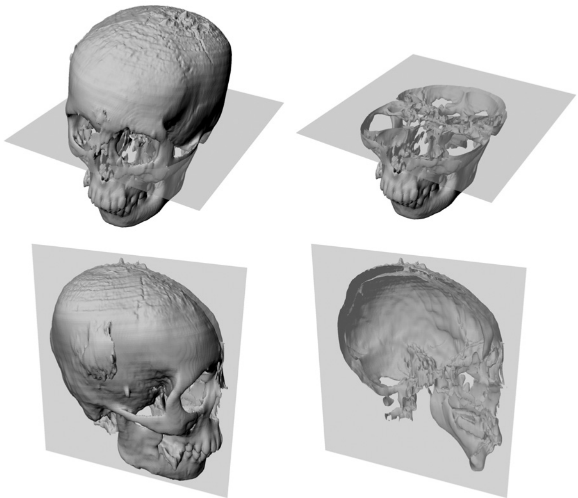


Figure 8: *Frankfort Plane on the top and Mid-Sagittal Plane on the bottom.*

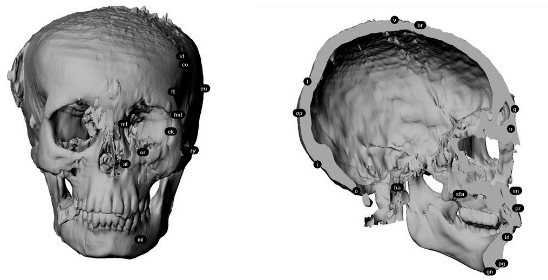


Figure 9: *Landmarks.*

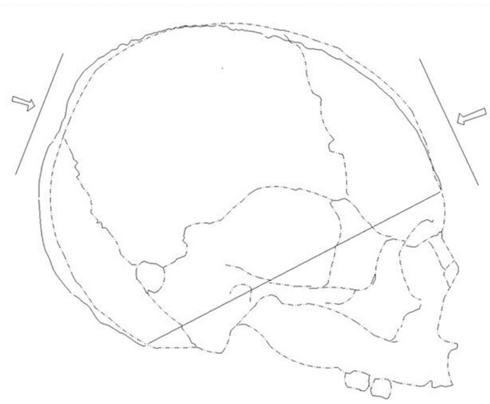


Figure 10: *Silhouette comparison.*

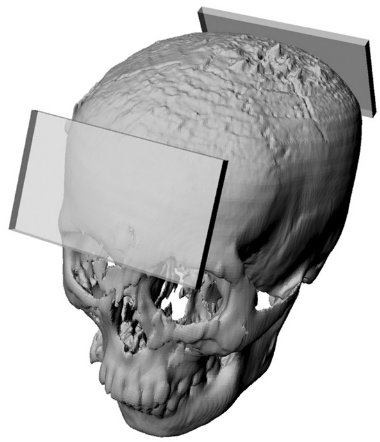


Figure 11: *Visualization of compressing tablets.*

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.

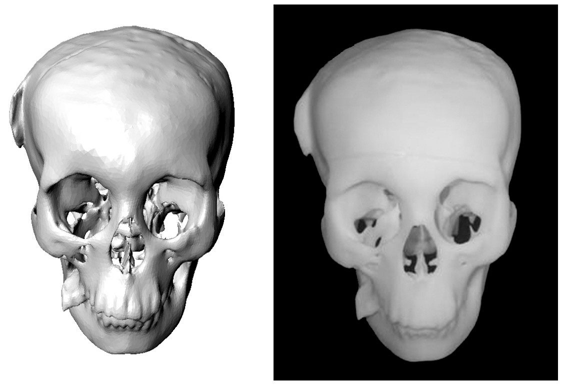


Figure 12: *The Virtual Model on the left and the Physical Model on the right.*

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.

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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

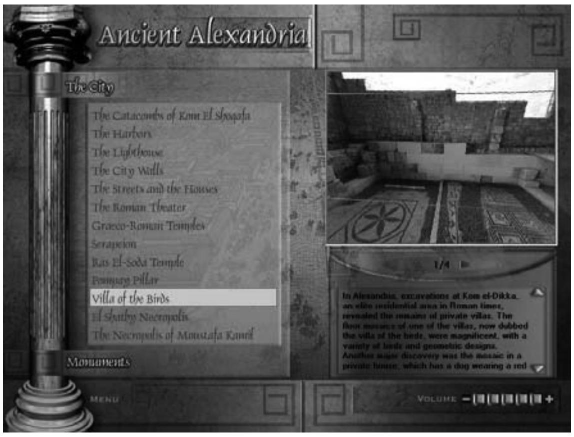
The name of Alexandria recalls the legends of Alexander the Great, Anthony and Cleopatra, and a hall of fame list of Roman Emperors that includes no less than Julius Caesar, Hadrian, and Marcus Aurlieus. The beauty of the city was unrivalled. Planned following a rectangular grid, the city consisted of 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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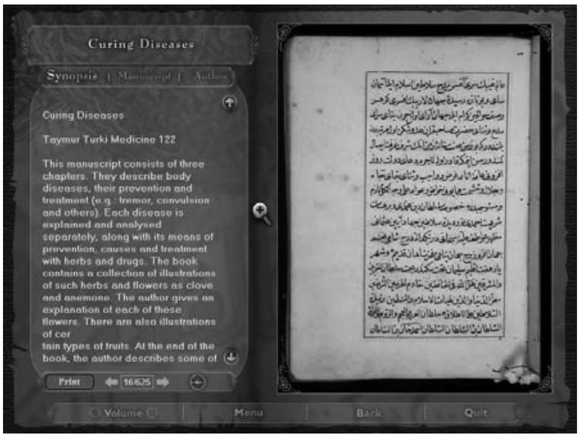
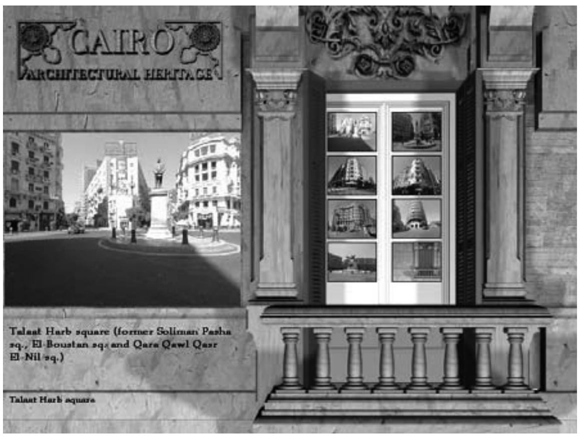


3. The Architectural Heritage of Down Town Cairo

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.

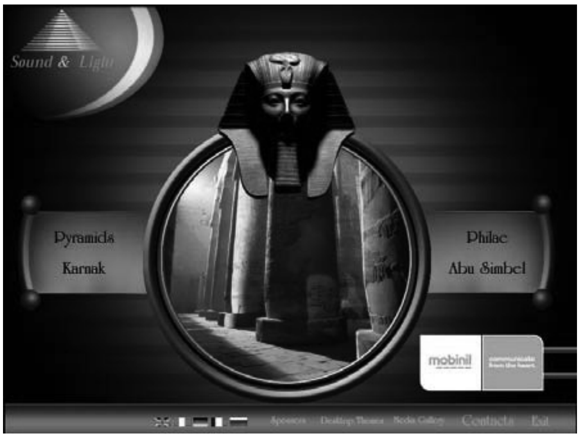
The campaign incorporates breath-taking imagery and a wealth of cultural heritage; a multilingual (5 languages) CD-ROM, Web Portal, Magazine Campaign and a multitude of Touch Screen Information Kiosks.

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.



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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.

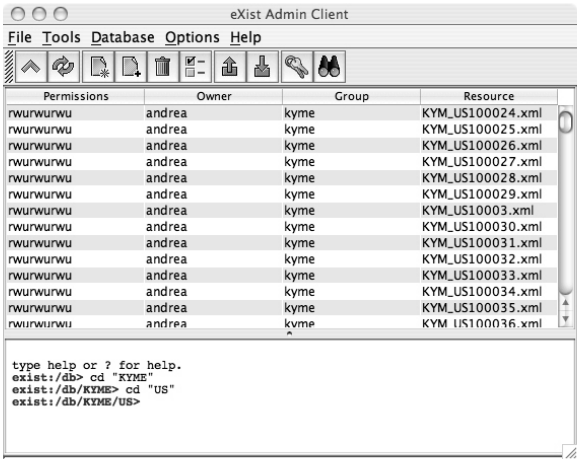

Figure 1: *The eXist Graphical User Interface.*

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).

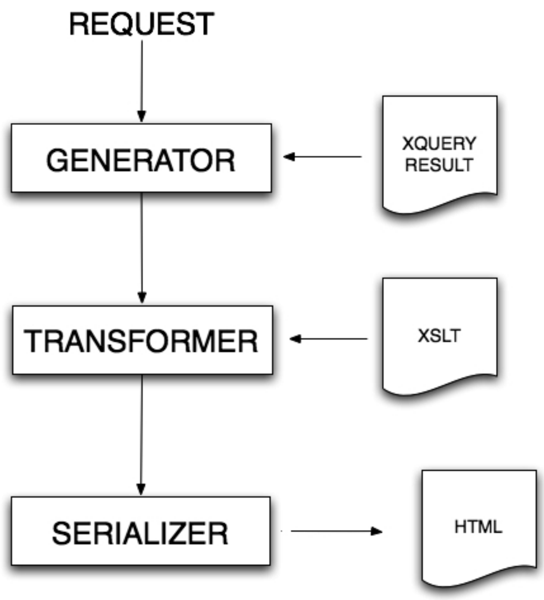

Figure 2: *The Cocoon Pipeline Mechanism.*

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 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).

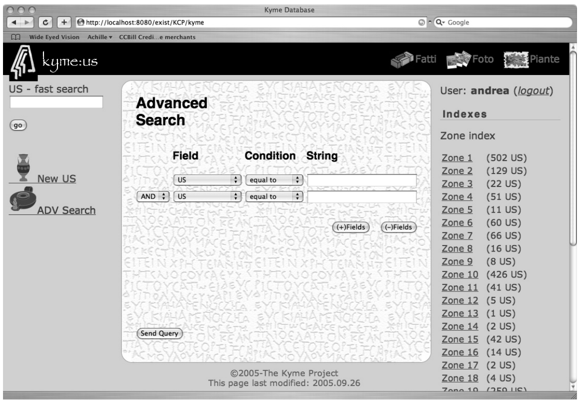

Figure 3: *Indexes and Query Interfaces.*

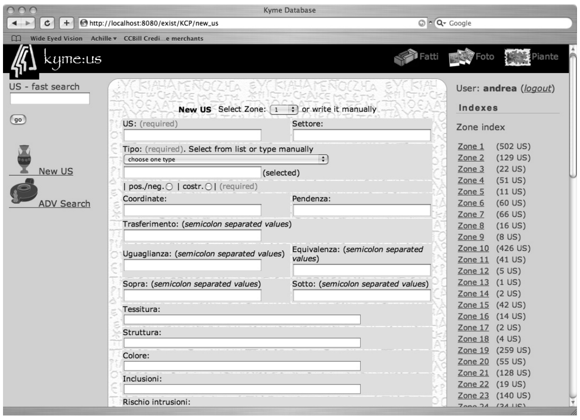

Figure 4: *New Record Creation and Record Update Form.*

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.

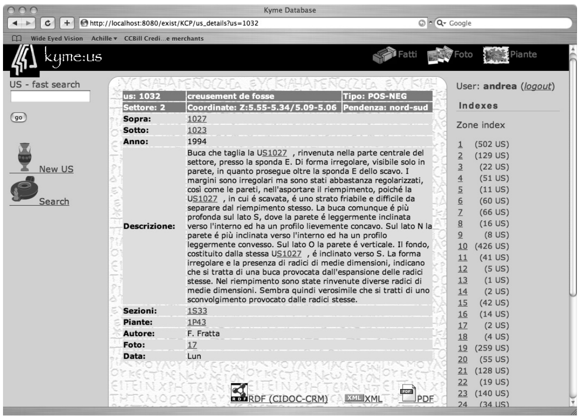

Figure 5: *Record Details and Export Options.*

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.

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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 the-

ory, 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.

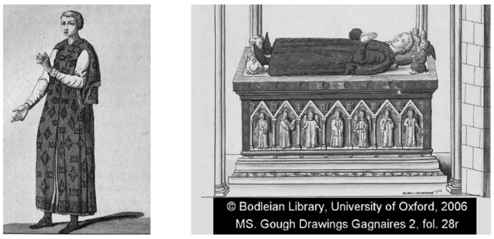

Figure 2: *Philippe Dagobert - (left) Stained glass window drawing, (right) Drawing of the tomb with its recess.*

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

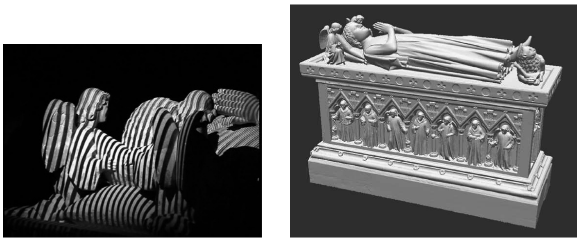

Figure 3: *(left) 3D digitization using structured natural white light. (right) 3D colorless model displayed with Catia (Dassault System software).*

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).

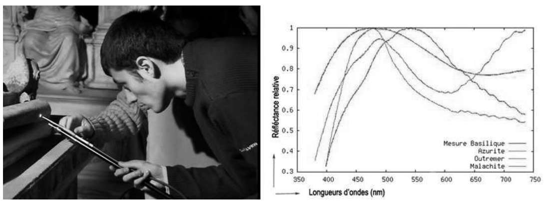

Figure 4: *Spectral data acquisition and analysis.*

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

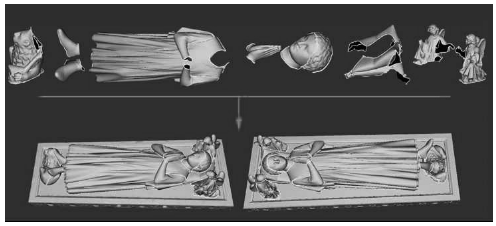

Figure 5: *3D model cut up not completely decomposed in color parts.*

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

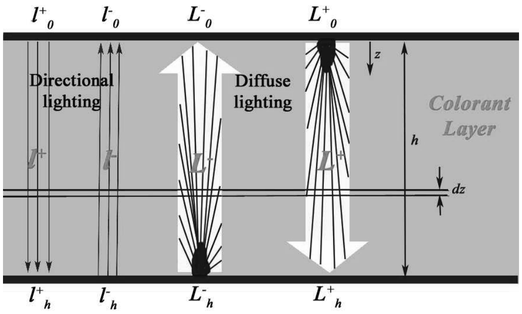

Figure 6: *Four-Fluxes theory: The radiances, directional (l^+,l^-) and diffuse (L^+,L^-), together with the boundary conditions.*

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.

$$dl^+ = -(k+s^+ + s^-)l^+ dz \quad (1)$$

$$-dl^- = -(k+s^+ + s^-)l^- dz \quad (2)$$

$$dL^+ = s^+ l^+ dz + s^- l^- dz - (K+S)L^+ dz + SL^- dz \quad (3)$$

$$-dL^- = s^- l^+ dz + s^+ l^- dz - (K+S)L^- dz + SL^+ dz \quad (4)$$

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:

$$R_0 = \frac{R_\infty(R_g - R)}{R_g - R_\infty(1 - R_g R_\infty + R_g R)} \quad (5)$$

S, K the scattering and absorption coefficients:

$$S = \frac{2.303}{h} \frac{R_\infty}{1 - R_\infty^2} \log \frac{R_\infty(1 - R_0 R_\infty)}{R_\infty - R_0} \quad (6)$$

$$K = \frac{2.303}{2h} \frac{1 - R_\infty}{1 + R_\infty} \log \frac{R_\infty(1 - R_0 R_\infty)}{R_\infty - R_0} \quad (7)$$

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.

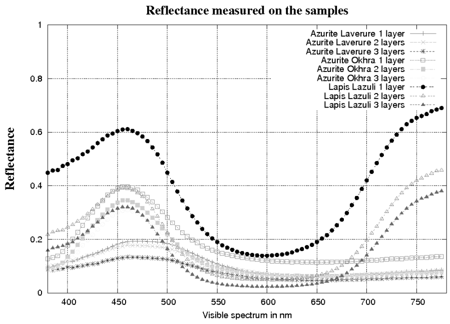

Figure 7: *Reflectance spectra of the blue pigments, azurite and lapis-lazuli.*

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.

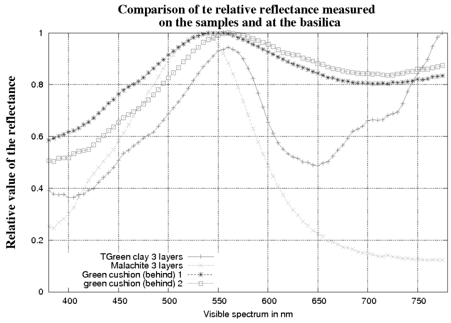

Figure 8: *Comparison of the in situ measured diffuse reflectance spectra with the corresponding spectra of the handcrafted samples.*

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

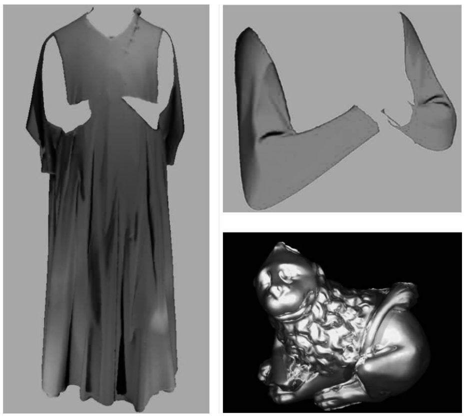

Figure 9: *(left) Philippe-Dagobert's surcoat rendered in lapis-lazuli blue pigment by the radiosity software Candelux. (right) Philippe-Dagobert's sleeves - vermilion pigment rendered with Candelux, gilded lion (spectral ray-tracing).*

incidence on a smooth surface. We use throughout the calculations the Max Born's notation for the complex index of refraction, ie:

$$\eta(\lambda) = \eta(\lambda)\,[1 + i\kappa(\lambda)] \quad (8)$$

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.

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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.

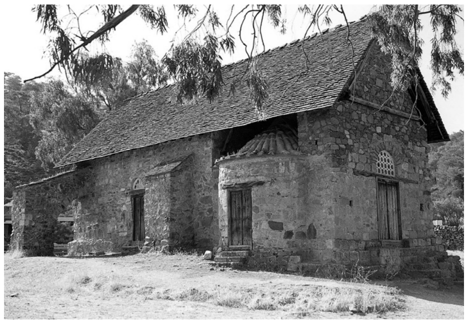

Figure 2: *North-western view of the Church.*

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 ±3mm ±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.

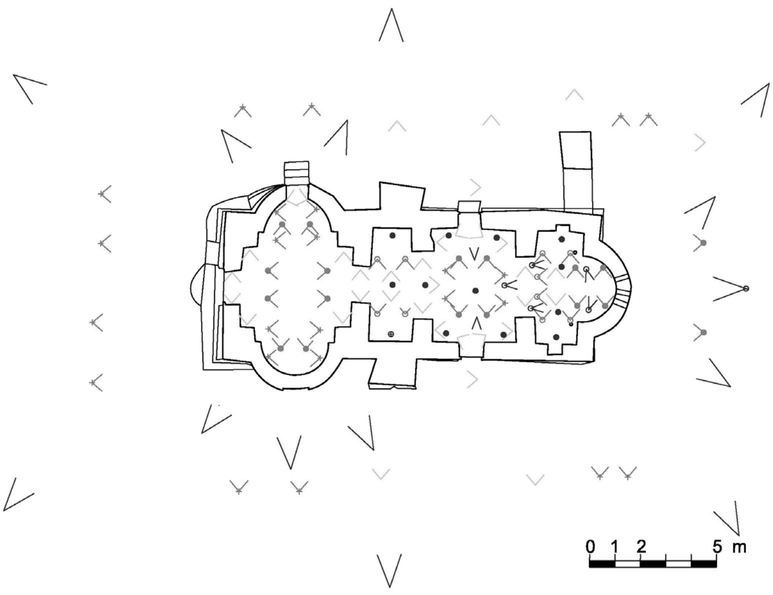

Figure 4: *Plan view of the church, showing scanner set ups (in blue) and camera locations for stereopairs (in red) or monoscopic images (in green).*

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.

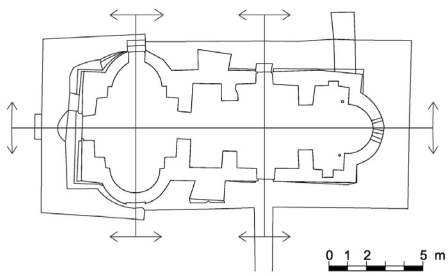

Figure 5: *Horizontal plan of the church showing the positions of the vertical cross sections.*

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.

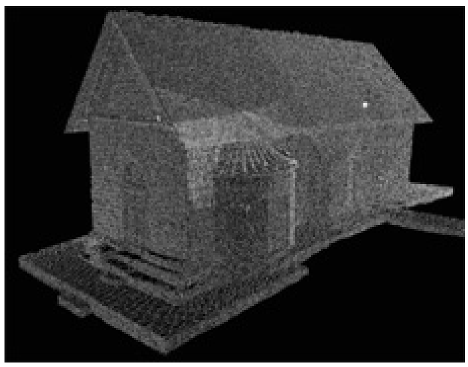

Figure 6: *Registered point clouds.*

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)

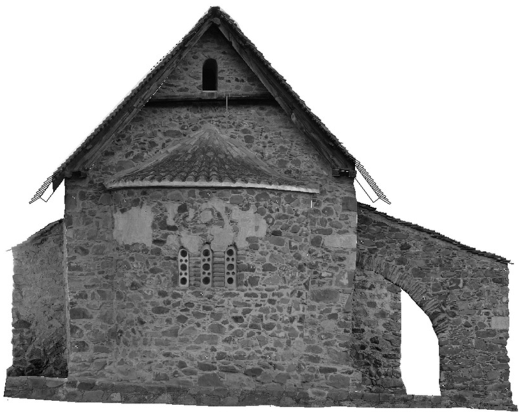

Figure 7: *Ortho-mosaic of the eastern facade.*

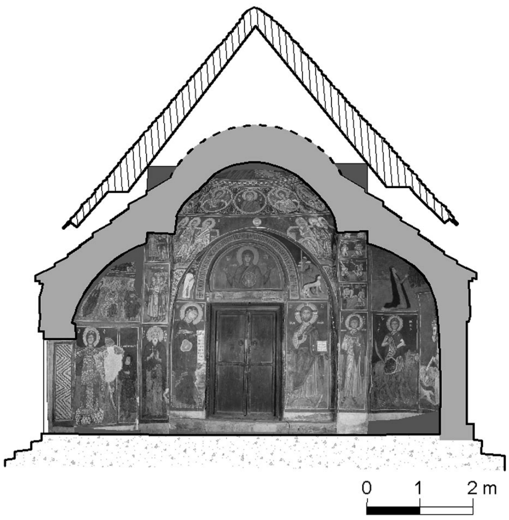

Figure 8: *The N-S cross section "looking" to the west.*

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).

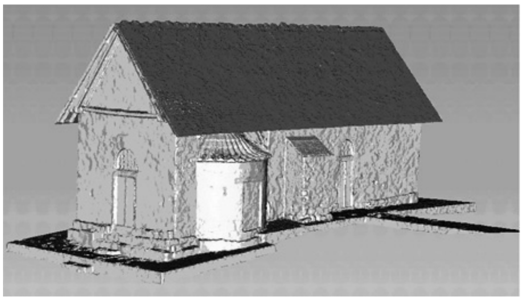

Figure 9: *South-western view of the Church's 3D model produced by the Geomagic software.*

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.*

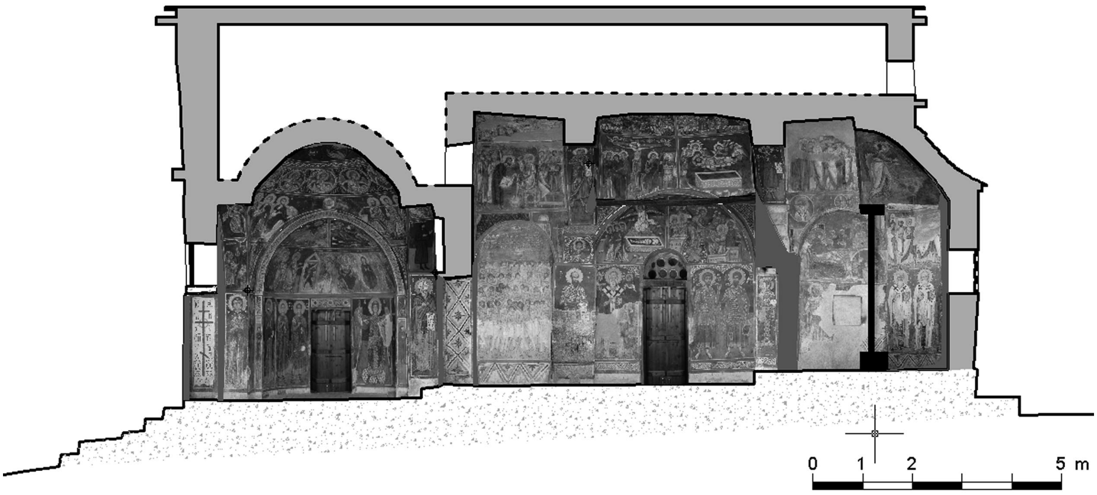

Figure 12: *The longitudinal vertical cross section "looking" to the north.*

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.

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

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).

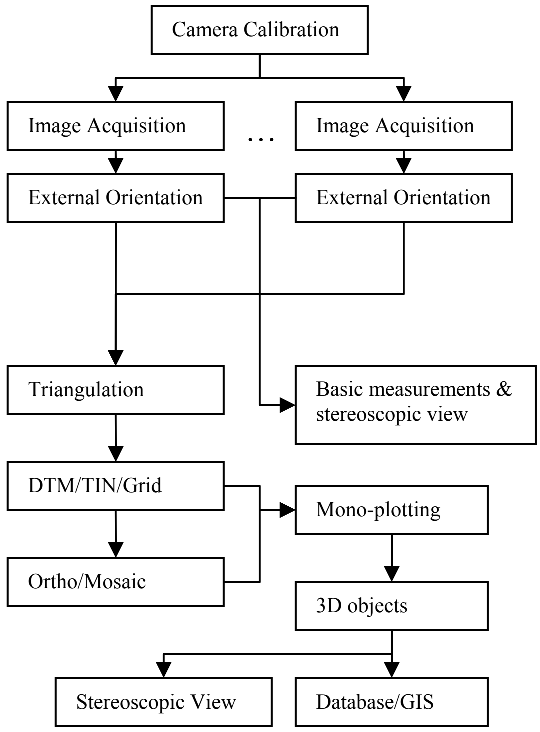

Figure 1: *Basic flow chart of recording procedure*

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.

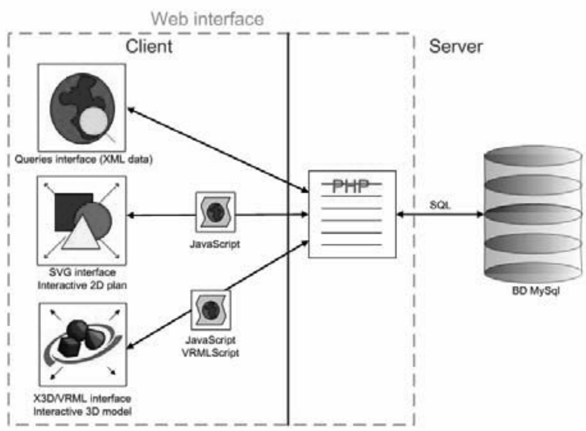

Figure 2: *Schema of the computer behavior of the coming web Information System*

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.

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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.

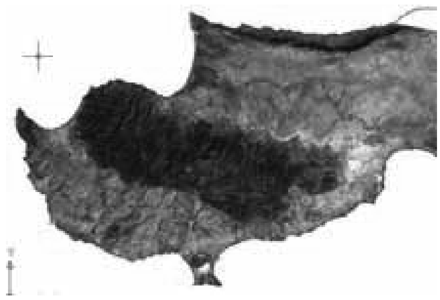

Figure 1: *Landsat-5 TM satellite image of Cyprus acquired on 3/6/1985 (partial scene). Distribution of some cultural sites is shown for Paphos and Limassol District areas.*

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.*

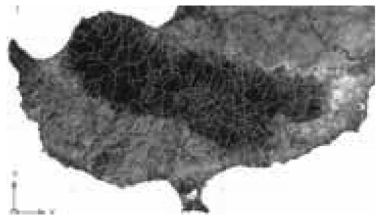

Figure 3: *Overlay of GIS location-information on a Landsat-5 TM satellite image of Cyprus acquired on 3-6-1985: Registration of the selected cultural sites based on the information provided by the developed database*

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).

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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.

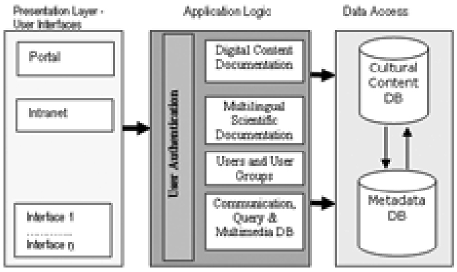

Figure 1: SCCM System Architecture

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.

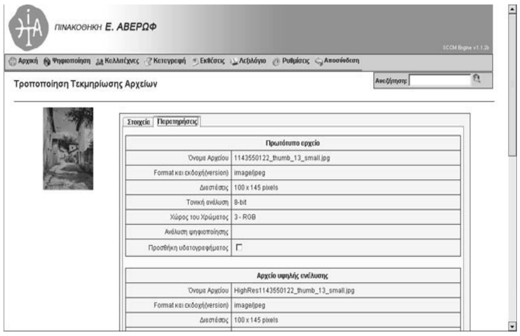

Figure 2: SCCM installation for Averoff Museum Screenshot 1

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.

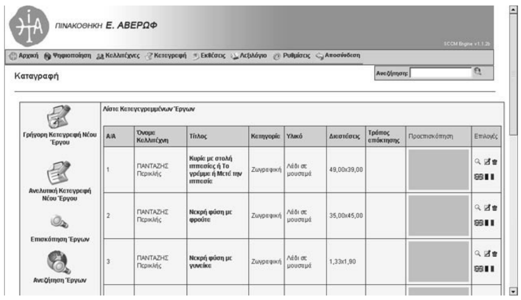

Figure 3: SCCM installation for Averoff Museum Screenshot 2

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.

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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, multi-resolution 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.

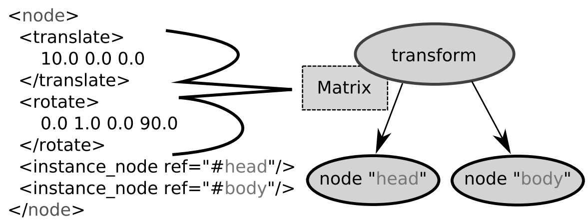

Figure 3: *Collada* <node> *mapped to OpenSG sub-scene.*

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.

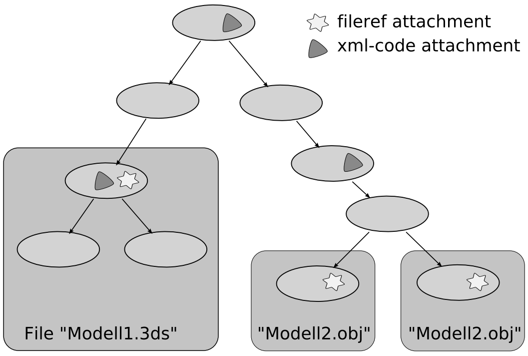

Figure 4: *The use of xml-code and fileref attachments.*

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 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.

```
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++.*

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.

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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.

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.

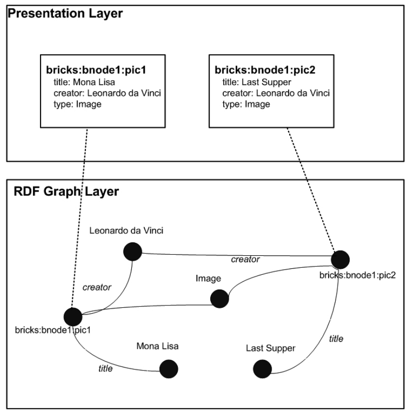

Figure 1: *Two-layered metadata model*

Fig. 2 shows the relation between Physical and Logical Collections.

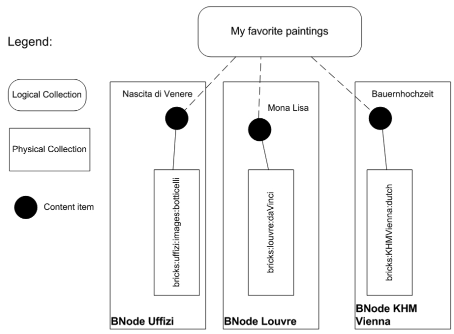

Figure 2: *Physical and Logical Collections*

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.

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[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)
Project Presentations

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].

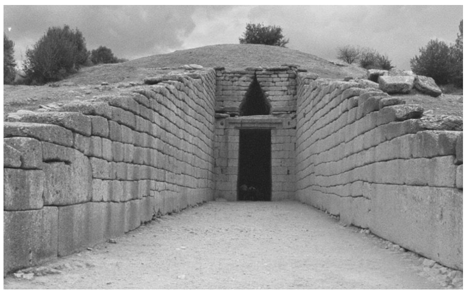

Figure 2: *Photo of the dromos and of the facade of the tomb as they are today.*

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.

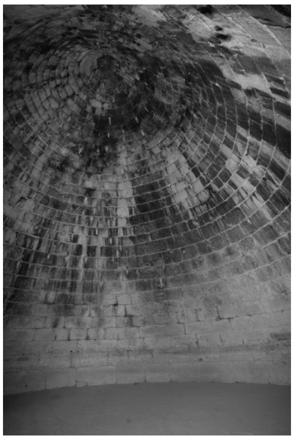

Figure 3: *View of the inner side of the tomb.*

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].

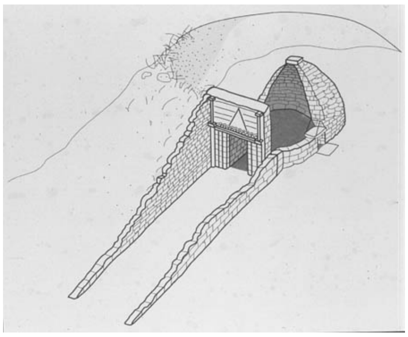

Figure 4: *Schematic representation of the shape of the Grave of Atreus in the antiquity [Wac49].*

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°x40°. 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 $3\div5$ 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

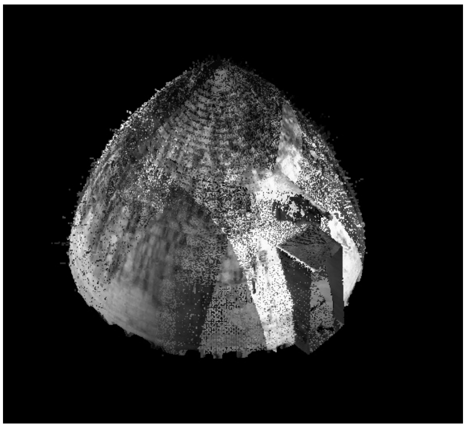

Figure 5: *Registered point clouds of the doorway and the main chamber.*

- 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 inhouse 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.

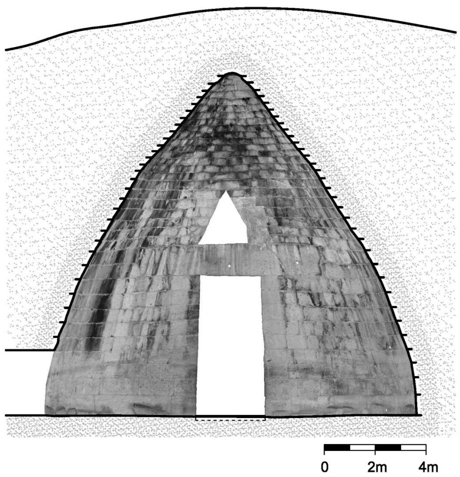

Figure 6: *Eastern facade of the internal of the chamber.*

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

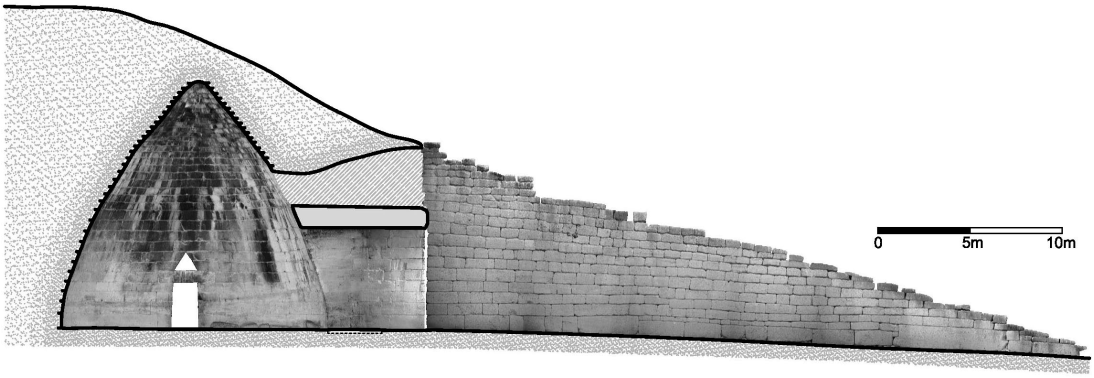

Figure 7: *Section along the axis of dromos, in raster format.*

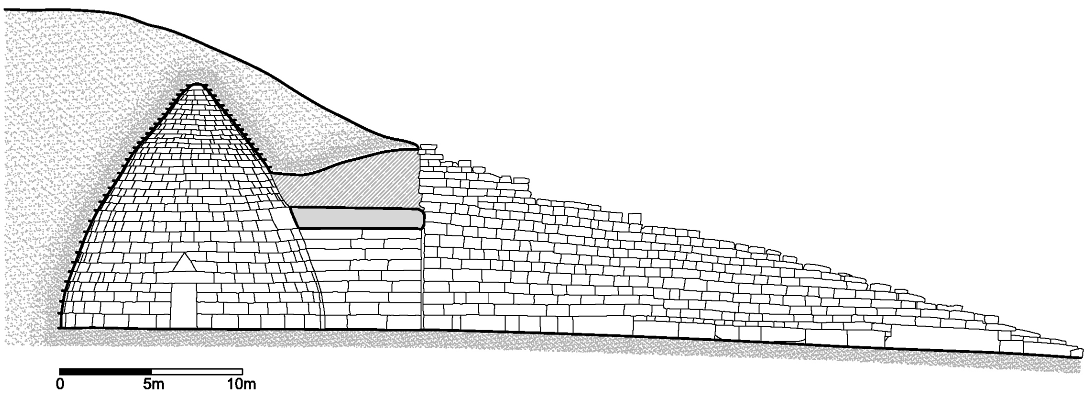

Figure 8: *Section along the axis of dromos, in vector format.*

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

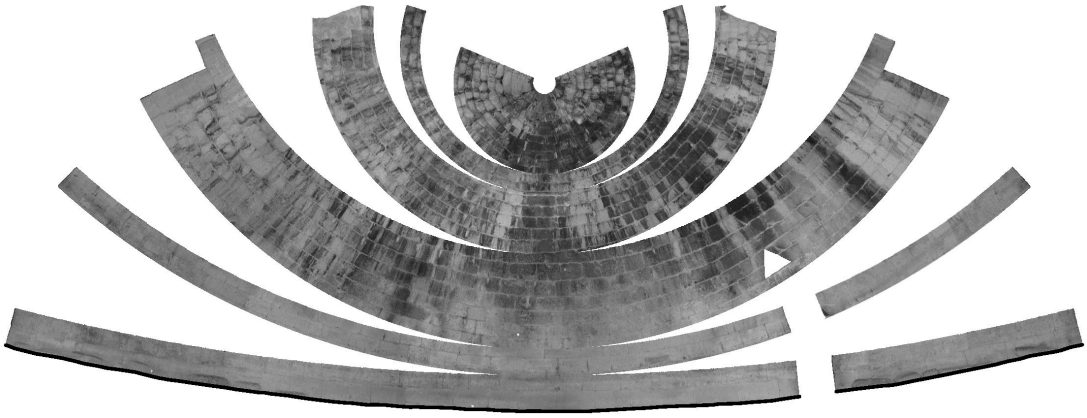

Figure 9: *Developments of conical surfaces of the inside of the chamber.*

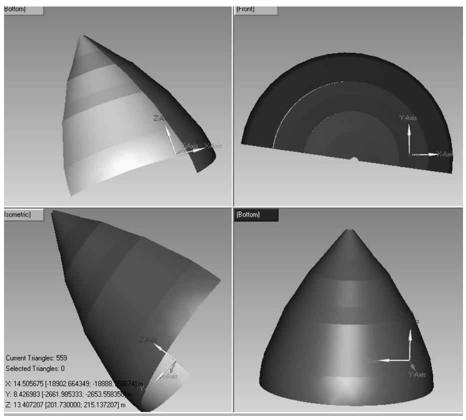

Figure 10: *3D model of the chamber using conical surface.*

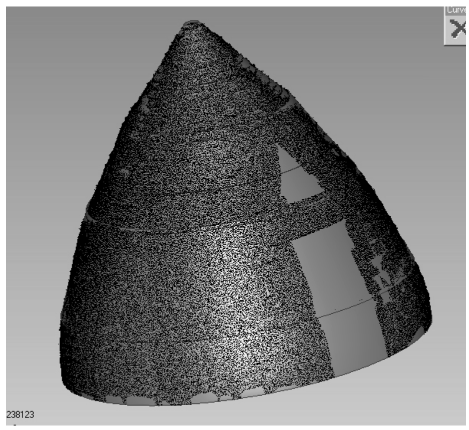

Figure 11: *Simultaneous representation of the point cloud and of the 3D model of the conical surfaces.*

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.

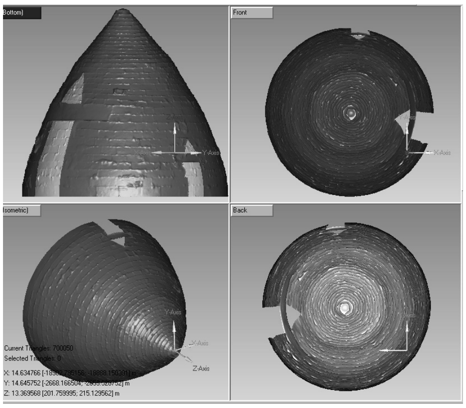

Figure 12: *3D views of the chambers' model, produced using Geomagic software.*

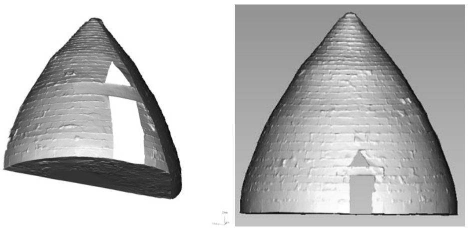

Figure 13: *Representation of the inside of the 3D model: (Left) section in space and (Right) projection on a vertical plane.*

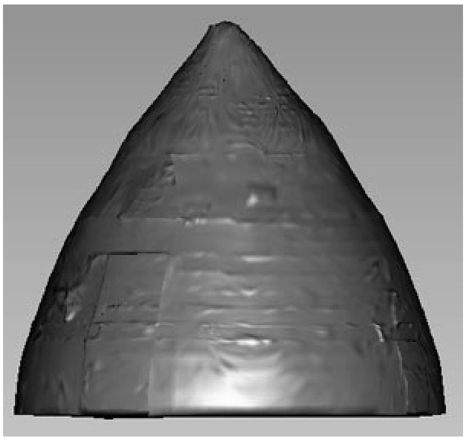

Figure 14: *NURBS model of the chamber.*

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.

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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).

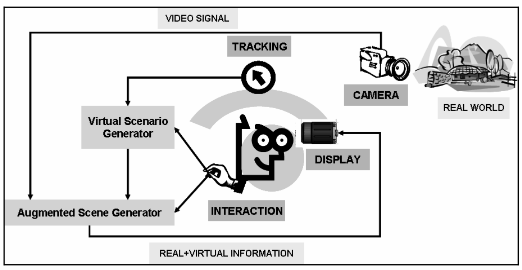

Figure 1: *Augmented Reality System*

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.

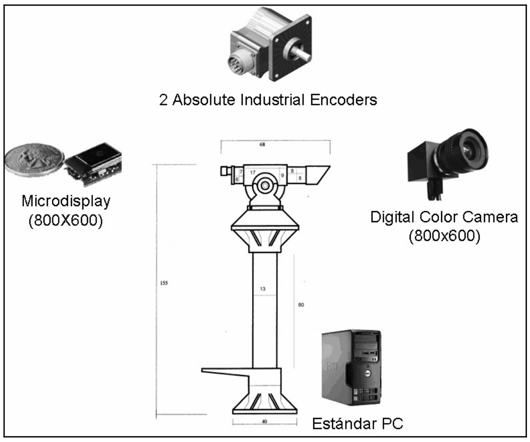

Figure 2: *Modules of the telescope.*

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.

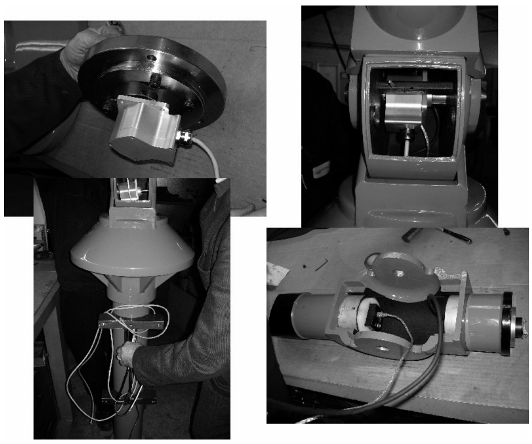

Figure 3: *Pictures from the mechanical assembly*

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.

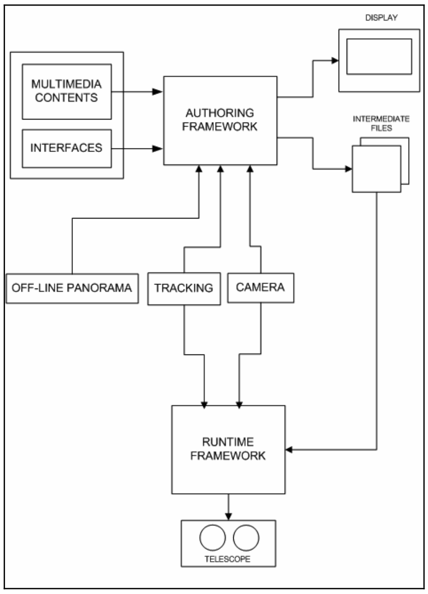

Figure 4: *Augmented Reality Platform*

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).

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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

The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage
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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.

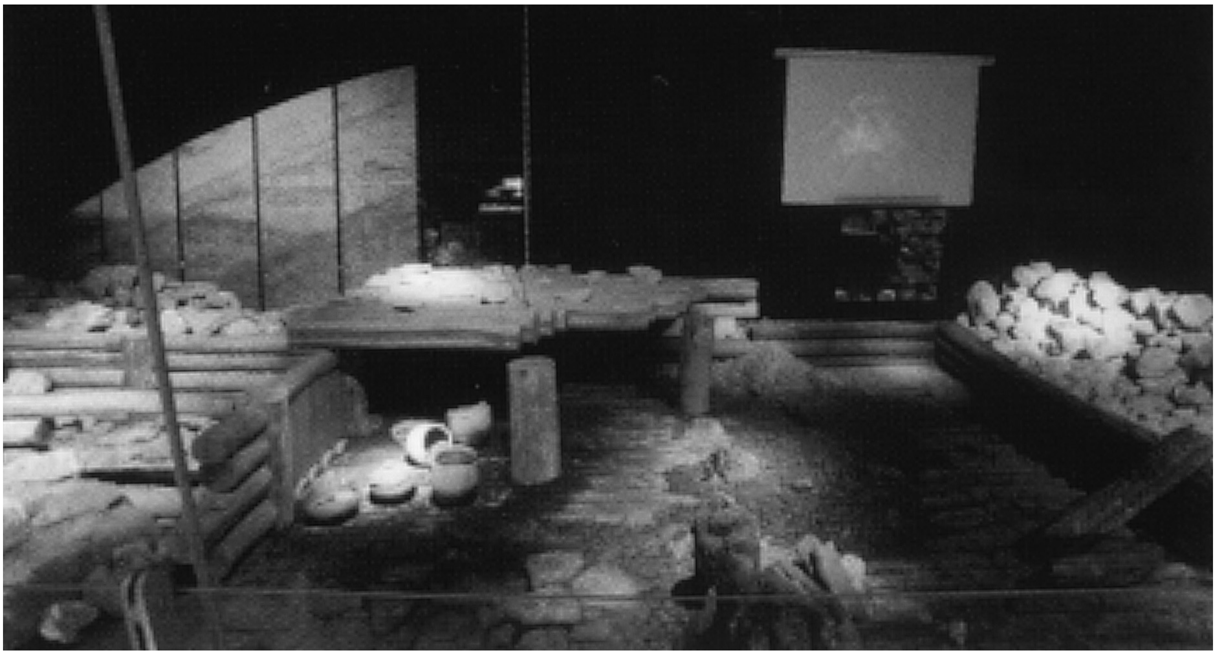

Figure 1: *Inside the Hallstatt Period burial mound including the screen, an integral part of multimedia presentation in the Százhalombatta Archaeological Park.*

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.).

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).

Figure 2: *All purpose use of multimedia equipment in the permanent exhibition of the Bakony Museum, Veszprém.*

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

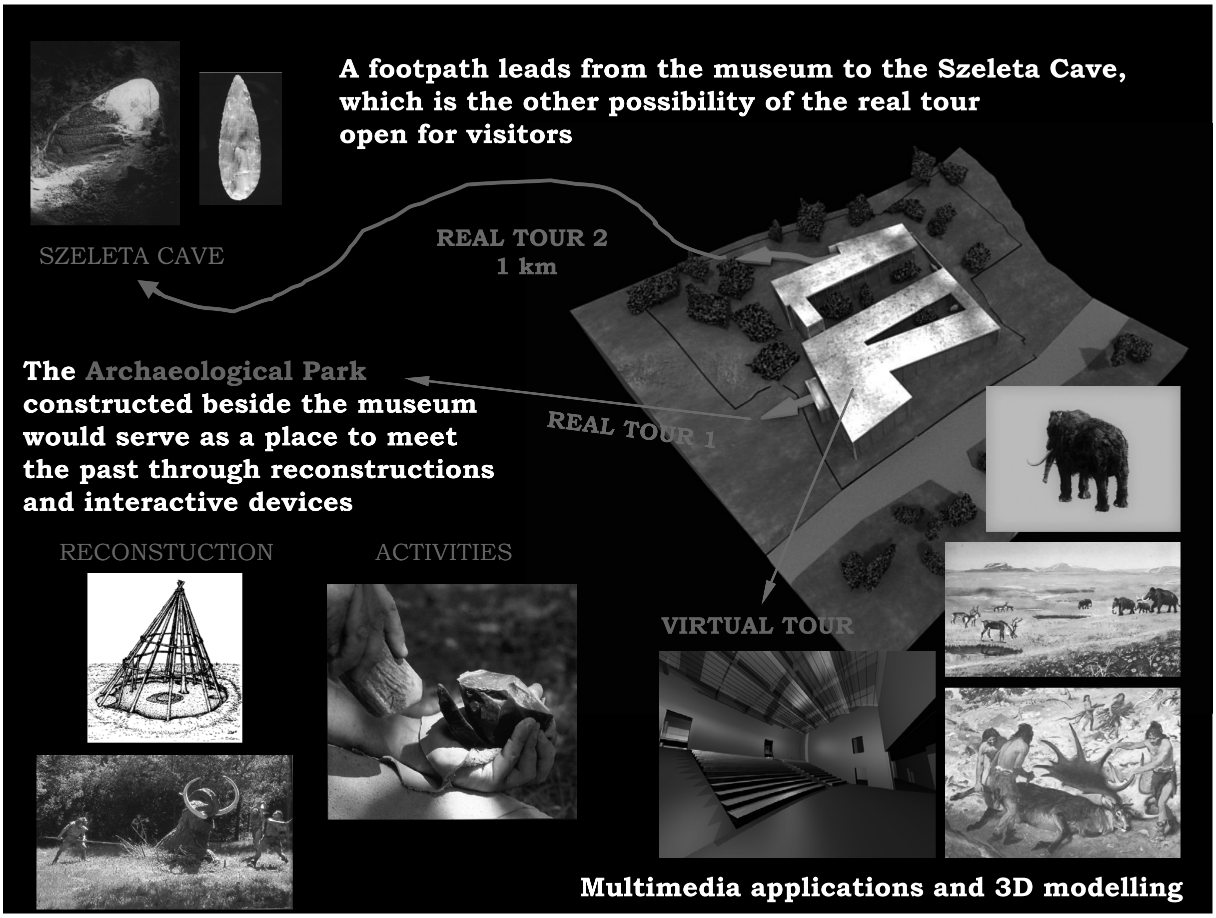

Figure 4: *IT applications (virtual tour and educational films) in the planning of the Szeleta Museum and Archaeological Park project.*

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.

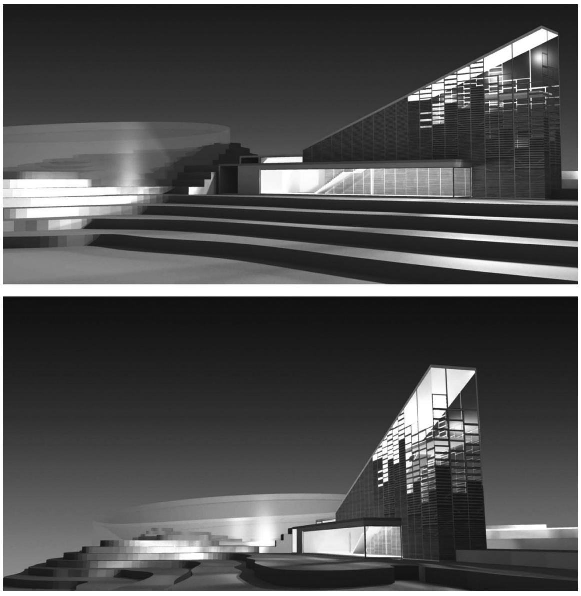

Figure 5: *Virtual design of the Sopron Visitors' Centre aimed at presenting a "time journey" from Prehistory to the present, using entirely cutting-edge virtual technology.*

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.

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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.

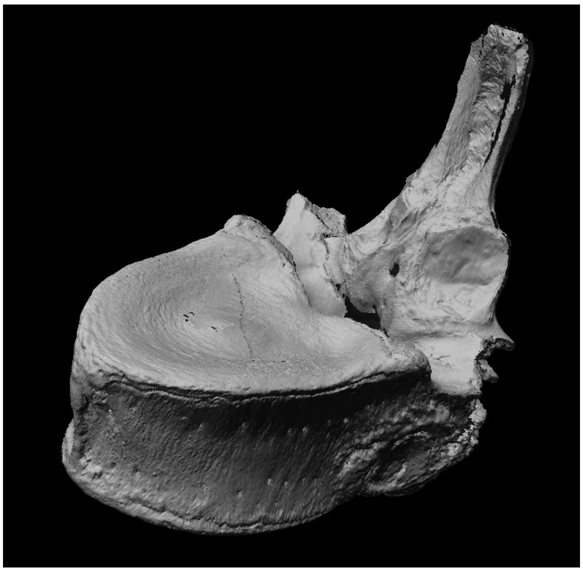

Figure 2: *Scanned vertebra bone before merging*

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.

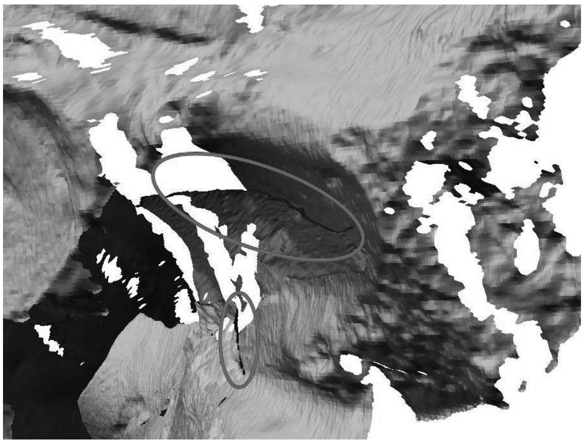

Figure 3: *“Lip-artifacts” at the ends of a sweep*

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].

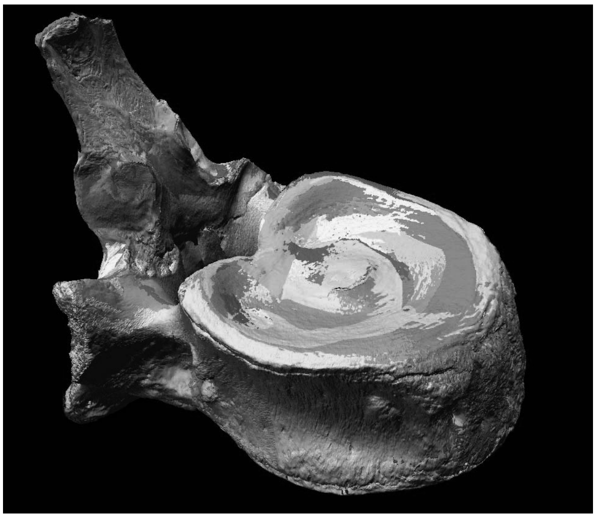

Figure 4: *Registered scan sweeps (vertebra)*

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.

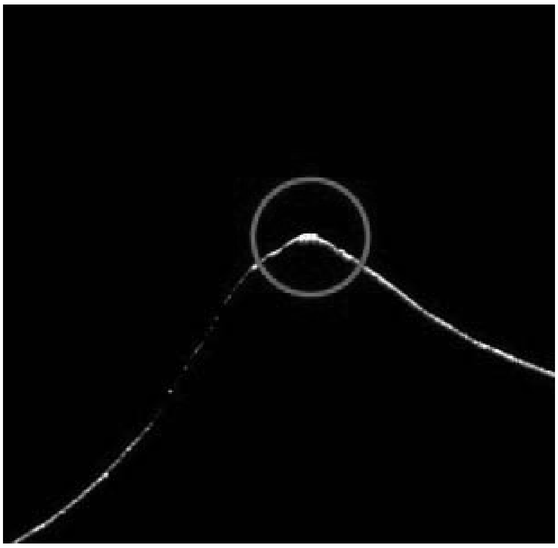

Figure 7: *Laser line glow*

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.

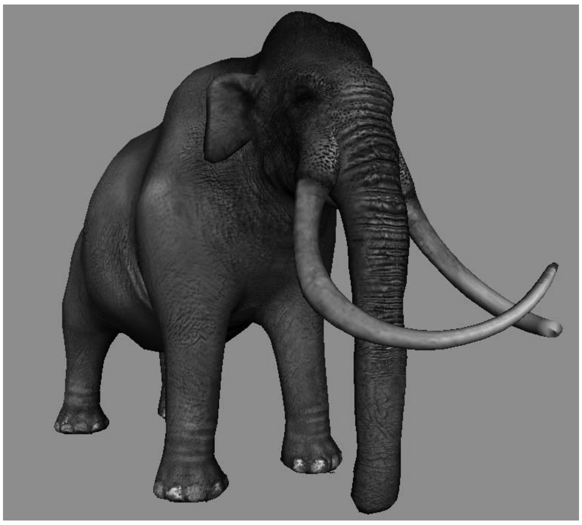

Figure 9: *Mammoth reconstructed*

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.

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