International Symposium on "Information & communication technologies in cultural heritage Ioannina, Greece from October 16th to October 18th, 2008

Applying 3D Digitisation Technologies in the Cultural Heritage Domain

C. Chamzas[2], A. Koutsoudis[2*], G. Pavlidis[1], D. Tsiafakis[1]
chamzas, akoutsou, gpavlid, tsiafaki@ipet.gr

1. Cultural and Educational Technology Institute – Research Centre 'Athena'
Tsimiksi 58, 67100, Xanthi, Greece – http://www.ipet.gr
2. Department of Electrical and Computer Engineering, Democritus University of Thrace, Xanthi, Greece – http://www.duth.gr

Corresponding author: Prof. C. Chamzas
chamzas@ipet.gr
+30-2541-078787 (112)

[*] This work was also partially supported by the research project 03ED679, a project implemented within the framework of the "Reinforcement Programme of Human Research Manpower" (PENED) and co-financed by National and Community Funds (25% from the Greek Ministry of Development-General Secretariat of Research and Technology and 75% from E.U.- European Social Fund).

Cultural Heritage 3D Digitisation and Dissemination

Abstract

Recent developments in 3-dimensional technologies and measurement instrumentation combined with multimedia databases offer today new possibilities for the integrated and complete description of Cultural Heritage Objects. The complete digital recording of Cultural Heritage is a multidimensional process. It depends highly on the nature of the subject of recording as well as the purpose of its recording. The whole process involves the three-dimensional digitization, digital data processing and storage, archival and management, representation and reproduction. In this paper we briefly review methods for three-dimensional digitization that are applicable to cultural heritage recording. We continue by presenting an application project in this domain which exploits the usage of various technologies in an archaeological site related to Karabournaki, an excavation site in Northern Greece.

Keywords : cultural heritage, 3D digitization, archiving,

Introduction

Cultural heritage (CH) is primarily promoted over the Internet using digital photographs. Over the last years, improvements that have been achieved in data transfer speeds in conjunction with the boost of multimedia technologies broadened the possibilities for an increasing amount of Internet-based 3D applications concerning nearly every sector of interest. The involvement of technology in the dissemination of cultural heritage causes a smooth transition from *subjective* promotion methodologies such as sketched and text based descriptions to more *objective* such as photographs, video and more recently 3D models/reconstructions (
Figure 1). The role of 3D digitisation is still being considered as supplemental, given the present limitations on bandwidth and real time graphics rendering.

-Insert Figure 1 here-

Even so, it is safe to allege that a 3D model provides a better perception than a typical photograph or a video sequence. The advent of these technologies has revolutionized the way information is stored, archived, retrieved and presented. Their impact on the registration, documentation, dissemination, presentation and ultimately, preservation of CH could be enormous. In addition to the visual recording (2-dimensional (2D) and 3-dimensional (3D) imaging), systematic recording of the physical and chemical characteristics, typological description and historical information of CH led to the first CH databases, mainly for research purposes.

Thus, the complete recording of artefacts and monuments is a multidimensional process. It addresses not only the digitisation problem but involves all the aspects of this new digital content management, representation and reproduction. It addresses issues affecting the whole life cycle of the digital cultural content. Five main processes have been identified in digital recording. These processes are shown graphically in Fig. 2. All there processes have their own demands for advanced algorithms, new hardware and more sophisticated software implementations.

-Insert Figure 2 here-

3D digitization of cultural heritage is considered as the first step of the overall process of the complete recording of objects and monuments. It consists of multiple processes and exhibits variations in accordance with specific application requirements. Due to the complexity of the digitization needs that emerge from the objects themselves, there is a plethora of methods and technologies. The target of every such technique is to address successfully a particular type of objects or class of objects or monuments, or to fulfil particular demands and needs of a specific digital recording project (i.e. complete recording for archiving, digitization for presentation, digitization for commercial exploitation).

The plethora of available 3D digitization systems is the result of three main factors that influence the suitability and the applicability of a method. These are the *complexity in size and shape*, the *morphological complexity (level of detail)* and the *diversity of raw materials*. On the other hand, there are techniques with satisfying results for microscopic objects, others for small, medium and large objects and others for monuments. There are different techniques for ceramic or metallic or glass objects. We propose a Nine-Criteria Table (Table 1), which summarizes the possible parameters for choosing a 3D digitization system for cultural heritage applications.

-Insert Table 1 here-

The three dimensional digitization is a complex process that can be divided into three main phases. These are the following:

1. *Preparation*, during which certain preliminary activities take place that involve the decision about the technique and methodology to be adopted as well as the place of digitization, security planning issues, etc.
2. *Digital recording*, which is the main digitization process according to the plan from phase 1.
3. *Data processing*, which involves the modelling of the digitized object through the unification of partial scans, geometric data processing, texture data processing, texture mapping, etc.

Three Dimensional Digitisation of Artefacts

The 3D digitization approach can be categorized by the size of objects it is applied to. Due to technical limitations and application requirements, there must be a distinction between the digitization of objects and the digitization of monuments. Digitization of monuments is, in many cases, based on methods that involve traditional topographic techniques (due to the scale in this problem). On the other hand digitization of objects is a field of continuous research and development that can offer with many possibilities, again under the scope of a specific digitization plan. In the following paragraphs we briefly review some of most applicable methods.

Laser Scanning

Laser scanning techniques are based on a system with a laser source and an optical detector. The laser source emits light in the form of a line or a pattern on the surface of the objects and the optical detector (usually a digital camera) detects this line or pattern on the objects (Fig. 3). By applying the well known triangulation principle the system is able to extract the geometry of the objects. The advantage of using laser sources is that laser light is very bright and highly focused for long distances. As a result the emitted pattern can be always focused on the surface of the objects. One of the most significant advantages of laser scanners is their high accuracy in geometry measurements. On the other hand, it should be noted that in many such systems, geometry can be extracted without any texture information. Additionally, special attention should be paid for surfaces with specific properties, such as reflectance and transparency. One other important aspect is the high cost of such devices, which renders this method useful to specific applications. Finally, the productivity of the method, as well as the portability, depends upon the used system and can vary significantly (Curless & Levoy,1995)(Rioux,1994)(Beraldin et al.,2000).

-Insert Figure 3 here-

Shape from structured light

This method is based on projecting a specific pattern on the surface of the objects and trying to extract geometry information from the deformations of this pattern (Fig. 4). This method is also based on triangulation but does not need to use specific laser sources. In many cases this method is confused with the laser scanning methods and there are commercial systems that can not be absolutely categorized to the one or the other method. The method works by projecting a specific predefined light pattern that covers the whole (or part of the) surface of the objects. This scene is then captured by a typical digital image detector and processed in order to deduce the geometry from the deformations of the pattern in the digital image. These patterns can be simple multiple fringes of different colours or complex patterns with curves, either time or space coded. This method is accompanied by texture acquisition and can lead to very impressive results in terms of accuracy and productivity. The systems are usually portable and easy to use. A lot of work is still being done to develop even more the resolution of the method, which is one of the main fields of research in 3D scanning today (Salvi et al. 2004)(Rocchini et al.,2001)(Caspi et al.,1998)(Guhring ,2001)(Hall-Holt & Rusinkeiwicz,2001)(Durdle et al.,1998)(Salvi et al. 1998)(Petriu et al.,2000), (Zhang et al., 2002)(Morano et al.,1998)(Wust & Capson,1991) (Horn & Kiryati,1999).

-Insert Figure 4 here-

Shape from silhouette

This technique is based on multiple photographic capturing of the object from different viewing angles, and deducing the geometry from the object's silhouettes (Fig. 5). This is, actually, an old idea originating back to 1960 when Francois Villeme discovered a method called photo-sculpturing: 24 photographs covering the surface of the object are taken and are projected onto clay. This method regained interest about 100 years later with the advent of computers. Recent improvements of this method use texture information to correct or enhance geometry with very interesting results in terms of the final recorded geometry. Shape from silhouette is an automated process with high productivity and relatively low cost. As of this moment it is very popular. It can capture both geometry and texture. It is portable and easy to use. The main disadvantage is the medium-to-low resolution in geometry measurements (Tosovic et al., 2002)(Laurentini, 1994)(Baumberg et al. 2003)(Potmesil,1987)(Noborio et al.,1988)(Ahuja & Veenstra,1989)(Lensch et al., 2001).

-Insert Figure 5 here-

Shape from stereo

The main goal of this method is the extrapolation of as much geometry information as possible from only a pair of photographs taken from known angles and relative positions, simulating the human visual system. Stereo-photography has a significant application in robotic and computer vision. It is based on taking pairs of photographs from slightly different angles. When certain parts of the object in the scene are visible to both photographs, specific algorithms from vision can be applied to extract the geometry of the object. The external as well as the internal parameters of the optical system are used for calibration. Calibration is critical in terms of achieving accurate measurements. The method can either be fully automated or manually operated. The final result is a depth map of the object in the scene, reflecting the distance of each recognized point on the surface of the object from the photographic sensor. Advantages of this method are the ability to capture both geometry and texture, the low cost and portability. A disadvantage of the method is its low resolution (Scharstein & Szeliski, 2002)(Bertozzi et al., 2002).

Three Dimensional Digitisation of Monuments

For the digitisation of larger scale objects such as monuments other approaches has to be followed. Some of them are characterised as reconstruction approaches (e.g. photogrammetry) and others are digitisation techniques (e.g. range scanning)

Empirical techniques

During an empirical recording of monuments, measurements are taken (by hand) of distances between characteristic points on the surface of the monument. The definition of the coordinates is done on an arbitrary coordinate system on a planar surface of the monument. The method is simple and productive, portable and of low cost. On the other hand it is of low accuracy and demanding in terms of time of physical presence near the monument. It can be successfully applied when a monument has simple shape, or there is a need for recording a sectional plan or sections of interiors (Livieratos,1992).

Topographic techniques

The topographic method implements a 3D orthogonal coordinate system by using complicated and high-accuracy measuring devices. Mainly, this method uses a Geodesic Station, a system for measuring angles and distances of characteristic points on the surface of the monument, which are further transformed to coordinates in reference to the initial orthogonal coordinate system. The main advantage of the method is its high accuracy and objectivity of the measurements. It is reliable and it is easy to process its results. A disadvantage is the need for long physical presence near the monument, but it is one of the only methods to be used under difficult conditions, such as complex shape and difficult access. It is referred to as ideal for producing high-accuracy models of scale 1:50 or smaller (Livieratos,1992).

Laser scanning techniques

Laser scanners can actually be considered as advanced geodesic stations and can be used to measure topographic quantities. They can measure the direction of a fictional optical line joining the characteristic points on the surface of the monument to a reference point on the measuring device (Fig. 5). Additionally these scanners can estimate their distance from these points. By applying the known triangulation principle they produce Cartesian coordinates automatically. The main advantage is the high accuracy and productivity, as well as the large volume of measurement data produced. It is reliable and objective. On the other hand it is a method of high cost and difficulties in portability and autonomy. It can be applied on almost every monument digitization, but can experience interference from very bright light (Boehler & Marbs, 2002).

Photogrammetry

Common digital photos can be used, under suitable conditions, for measurements that can be of the accuracy obtained by the topographic methods. By applying orientation processes and transformations of digital photogrammetry it is possible to deduce 2D or 3D coordinates from one or two photos. The method is objective and reliable and can be aided by CAD software. It is relatively simple and has low cost. On the other hand it has to be combined with topographical or empirical measurements, and the final outcome is a function of the time spent. It can be used for complex objects with high surface detail, but since it is based on photos, there is a need for adequate space. It is also useful when direct access or contact to the monument is prohibited. It can be used to record stages of the monument in time. When combined with accurate measurements it can produce models of high accuracy for scales of 1:100 and even higher (Livieratos,1992)(Hanke & Grusenmeyer, 2002)(Tsioukas & Patias, 2002).

Recording the past in new ways

The previously described methods offer today the ability to completely record and disseminate an archaeological site and its findings. In the following paragraphs, we show our approach to solving the problems involved in an attempt to integrate novel methodologies and data into a complete digital archaeological site named *Karabournaki – Recording the Past*. Karabournaki is an excavation site in Northern Greece.

Digital recording

The first step in every digital representation application is the digitization that leads to a "sampled" and "discretized" version (or representation) of the real world. Digitization is targeted upon every data form, but since visual data are playing the most significant role in comprehension, digital representation of visual data is a field of continuous research and development. Digitization of an archaeological site involves many aspects. The "Karabournaki-Recording the Past" system, as a collaborative project of experts in various fields, had to take under consideration all these aspects.

The product involves three major categories of digitization that correspond to the total amount of data coming out of the excavation:

- *Landscape (site) and structures digitization*: complete digitization of the archaeological site using contemporary 3D scanning methods applicable to landscapes, structures and buildings. These methods involve the usage of either laser devices, either photographic/photogrametric methods and remote sensing, either hybrid-combined methods. Traditional methods were also employed: usage of (digitized) standard 2D topographical maps and 3D digital reconstruction through specifically designed software tools. Furthermore, since the site is described both in drawings and documents, 2D visual data were also included in the digitization process.

- *Objects (findings) digitization*: complete digitization of all objects in 2D and 3D. The present practice guides that objects are recorded through multiple photographs and entries in the excavation notebooks, as well as other referencing documents. Our first approach was to digitize all 2D visual material concerning the findings of the excavation. The next step was to record the objects in 3D. As will be explained in a following section, 3D technologies offer the ability to completely reconstruct objects with missing parts using scans of the findings and archaeological data. Fig. 1 shows two methods of 3D object scanning (laser and photographic) and a method of surface physicochemical properties extraction.

- *Documents (notebooks and forms) digitization*: complete digitization of the documentary material in the form of 2D images. This process could also include the digital reproduction of all texts, so that full text search capabilities can be integrated. In its present form the system processes all documentary material as 2D digital images.

To produce and maintain a completely digital archaeological site, it is imperative that after the digitization of the existing material, digital recording of new facts and findings is continued through the usage of specifically designed software tools that permit the archaeologists to go on with the digitization without any help from technical staff. To this very end, special purpose, user-friendly software tools are provided, with the additional ability to record data on-site: the archaeologists can record current findings using a PC or a laptop on-site, and have the ability to easily integrate the new data into the overall data management system.

Summarizing, for the needs of Karabournaki, a 2D and 3D digitization strategy have been adopted, accompanied by 3D digital reconstruction (where possible) and GIS functionality. According to this strategy, all visual material is being digitized using high resolution 2D scanners and 3D laser and photographic techniques (Tsirliganis et al. 2002a). Archaeometry data are being produced by using contemporary analysis tools, like XRF scanners (Tsirliganis et al. 2002b), and object surface data are being acquired and recorded. These data involve physical or chemical properties measured in a point-wise manner, on significant areas of the objects' surface.

Digital data management

All digitization processes produce a large amount of digital data in many digital file forms. This amount of information no matter how precise and complete is, can be rendered virtually useless if one is not able to manage it efficiently. Traditional methods of data management involve the design and usage of relational models to represent and combine the data, by imposing relations on each other imitating human cognitive processes (Capsi et al., 1998). For the purposes of Karabournaki, we have adopted a relational data model to represent the data. In this model, information unit-entity is the finding, object. Side information is provided by bibliographic entities, data from conservation and archaeometry, as well as other complementary data entities. An important aspect of our implementation is that it is based on open-source *MySQL* database that significantly cuts the costs of the integrated system. *MySQL* is a database engine that uses the standard relational model to represent data. Access to the content is achieved by using *SQL* queries. Data management as well as data retrieval is web based, portable and straightforward. Data input in Karabournaki database is done in a twofold way: either explicitly, by accessing the central database through an account with administration privileges, or implicitly, by using specifically designed software data input forms that provide with the flexibility to collect data even during on-site works (using a laptop). Data input forms include versions to handle data produced from archaeological, archaeometrical and conservational research and works.

Digital data visualization

Since the eighties of past century Computer Aided Design (CAD) systems have been systematically used in archaeology (Daniels)(Bateman)(CSA) not only as a sophisticated means of digitization, but also as a tool for reconstructing archaeological context. CAD and 3D modelling allows archaeologists for the first time to record, integrate, organize and handle the visual parts of archaeological information (plans, drawings, maps etc). CAD has a number of advantages over traditional architectural and topographic design methods like the unique ability to work on different layers in the same drawing, but its true power lies in its ability to integrate and display multivariate data on a single canvas. The integration of data in a 2D or 3D model enables the researcher to gain a stronger understanding of the archaeological context and to seek spatial relationships between the different elements. Moreover, 2D and 3D mapping have evolved to a necessary preparatory stage in order to advance to the application of Geographical Information Systems (GIS) technology or the use of Virtual reality (Gillings & Goodrick, 2000) as a means to approach ancient landscapes. In other words GIS promises the archaeological community the ability to record, analyze, seek, retrieve and represent vast amounts of complex spatial data in a homogeneous manner. The adoption (Wheatley, 1996) of such a powerful spatial tool in intra site analysis can revolutionize the manner we reconstruct archaeological context.

In this case study a 3D visualization approach was employed; an approach that is twofold:

- *Visualization of the site* itself (Fig. 6), using standard CAD design and GIS techniques, fed by digitization data either from 2D scanning or 3D scanning methods, and

- *Visualization of the objects (*Fig. 6), using an extension of a standard GIS system, that has been specifically implemented. This system is targeted upon the construction of a virtual "3D-GIS" environment for cultural objects, where the object itself is treated as a geographical entity. In its present form, it is a browser client plug-in, that gives the user all the known 3D viewing capabilities, while extending the interactivity by providing with the option of selecting surface areas and reading archaeometry or complementary data stored in the database that concern the selected area. This way, the system is promoted to a GIS-like environment for objects.

-Insert Figure 6 here-

Digital data dissemination

In order to integrate the overall database management system into a web-enabled information dissemination system, one has to design an Internet front-end with extended search capabilities to be able to exploit the reach information content to the maximum. The scheme adopted for the purposes of Karabournaki was based on *MySQL* database using *PHP* as the main programming language for constructing the dynamic web content and accessing the database. The whole system is dynamic, displaying data straight from the database, using only minimal static information needed mainly for customizations. It is based upon well known and tested technologies that are successfully combined into a single and meaningful integrated interface, which is able to provide with extended search and visualization capabilities. The structure of the final web application as well as all involved technologies is shown in Fig. 7.

-Insert Figure 7 here-

Conclusions

The complete digital recording of cultural heritage is a multidimensional process and a multivariate problem. It depends highly on the nature of the subject of recording as well as the purpose of its recording. In this work we made an attempt to summarize some of the methods available today for three-dimensional digitization that have already been applied to digital cultural heritage recording with success and give a case study example of applying these new technologies in an archaeological site. It has proven to be a complex and multivariate problem. Thus, several existing technologies have to be combined and some new had to be developed.

In this case study, a first attempt is being made to overcome the difficulties of such a task and to provide with an integrated system with extended management and dissemination capabilities over the Internet. In order to ensure universal accessibility the system was designed as bilingual. So far, most of the system is implemented, while the whole strategy is already developed. Finally, its flexibility and capability of being expandable in data structure secures the integration of relevant future archaeological demands and needs.

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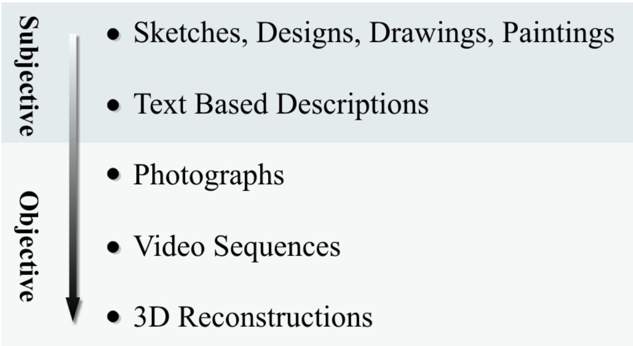


Figure 1. Means for subjective and objective cultural heritage promotion

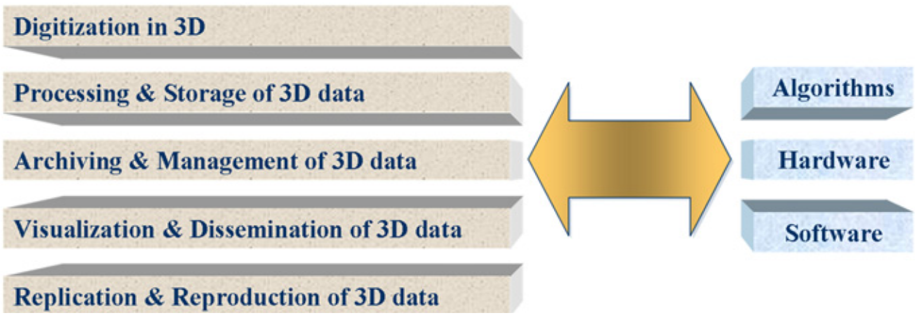


Figure 2 - Complete recording of cultural heritage.

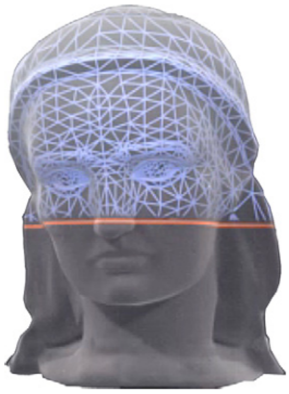
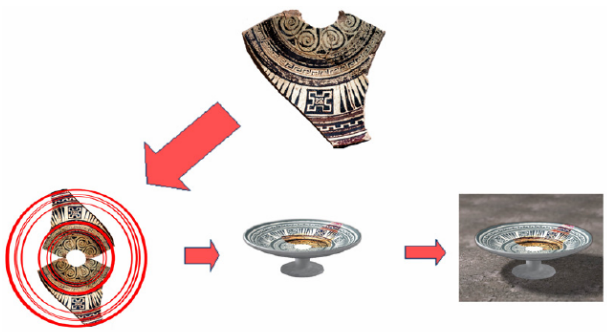


Figure 3 – 3D Laser scanning of artefacts

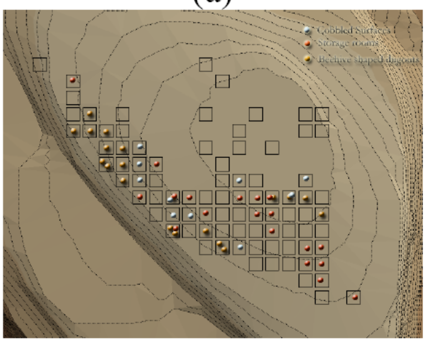
Figure 4 – Structure light projection on artefact

Fig. 5. An example of a *Shape from silhouette* set up

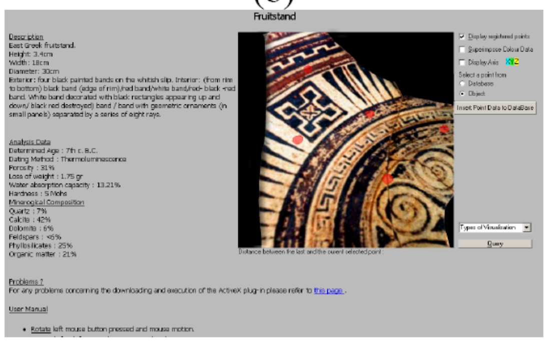


(a)

(b)

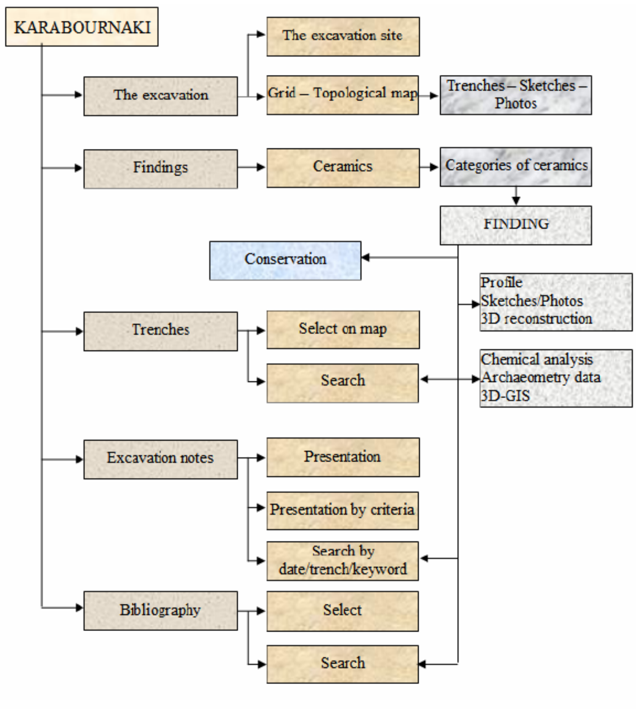


(c)

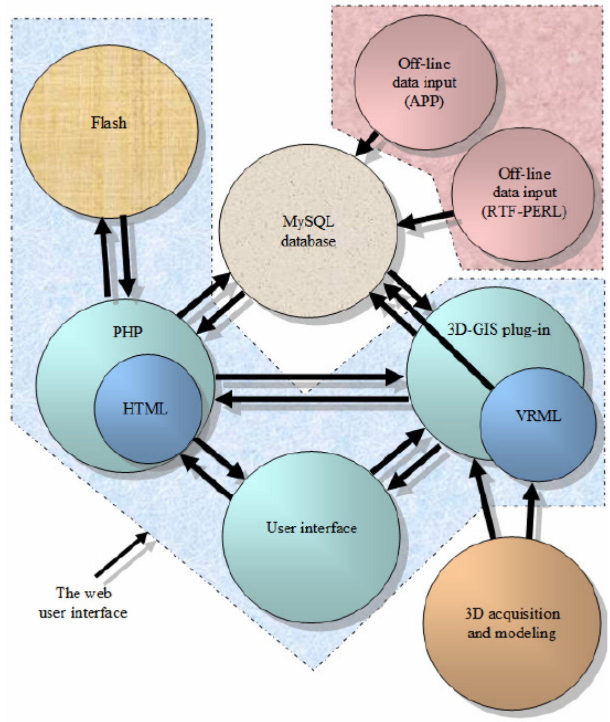


(d)

Figure 6 - (a-b) 3D virtual reconstructions, (c) GIS and (d) 3D-GIS of objects



(a)



(b)

Figure 7 -Overview of (a) the Internet application scenario schematic and (b) the underlying system technologies

No.	Criterion
1	Cost
2	Material of digitization subject
3	Size of digitization subject
4	Portability of equipment
5	Accuracy of the system
6	Texture acquisition
7	Productivity of the technique
8	Skill requirements
9	Compliance of produced data with standards

Table 1 - The Nine-Criteria-Table for choosing an appropriate digitization system