Three-Dimensional Scanning Techniques Applied to 3D Modelling of Pottery Finds

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1 – Introduction: Choosing the right Products

The project *Archeologia dei Paesaggi Medievali* (http://paesaggimedievali.it), derives from a collaboration between the Medieval Archaeology Area of the Department of Archaeology and Art History of Siena University (http://archeologiamedievale.unisi.it) and the Foundation Monte dei Paschi di Siena (http://www.fondazionemps.it/); it aims at intensive application of innovative technology in the field of Tuscan archaeological and historical heritage evaluation and preservation.

In the process of experimenting new approaches to computer applications in archaeology, we decided to equip the LIAAM (Laboratory of Computer Science Applied to Medieval Archaeology – Department of Archaeology and Art History, University of Siena, http://archeologiamedievale.unisi.it/NewPages/LABORATORIO/home.html) with a 3D scanning system. Our choice has moved from the need of developing new methods of archaeological recording, pointing heavily on three-dimensional aspects of finds.

An overview of the products available on the laserscanning market has drawn our attention towards the peripheral Minolta VI-900; its technical specifications appeared to fit our needs of experimenting small artefacts 3D scanning.

During the winter of 2001, on an emergency excavation at the S. Maria del Carmine monastery in Siena, we came upon round 360 perfectly preserved pottery pieces placed over a 14th century vault; the opportunity of organizing an exhibition based on these finds (Francovich, Valenti 2002, http://www.paesaggimedievali.it/volta/index.html, held during the summer 2002 at the Siennese museum Ospedale Santa Maria della Scala), has been a good occasion to immediately start testing the newly acquired peripheral.

3D scanners from Minolta have already been used in several disciplines, ranging from archaeology to architecture, from computer graphics to industrial design, and also in the field of medical research (http://www.minolta-3d.com/applications/index-en.html).

Regarding archaeology, for example, an application has been focused on the wall paintings of the prehistorical cave in Altamira (close to Santillana del Mar, in the region of Cantabria), where highly interesting results have been achieved. The local heritage administrations had an urgent need of preserving the Magdalenian age paintings from the serious damage caused by a large amount of daily visitors; the issue was to heavily limit the number of people entering the cave, without reducing financial incomes and the attractions of the site (http://www.minolta-3d.com/applications/eng/altamira.html). The project, led by the English company Ingenia & Empty in collaboration with Madrilenian company Tragacanto, has seen, in its first stage, an integral 3D scanning of the painted walls. Single scanning documents have then been processed

using the software package Rapid Form; CNC milling based on 3D data allowed the creation of foam models employed to obtain silicon moulds which were finally used to exactly reproduce the original environment.
This replication, placed at the local museum, has ensured a high affluence of people, allowing better preservation of the real cave where visitors are now admitted in very small groups.

Different purposes have determined an application of the same technology to another archaeological monument; during the recent restorations conducted on the Coliseum by the Dipartimento di Rappresentazione e Rilievo of the University "La Sapienza" of Rome, the NubLab (Centre for Survey and 3D Modelling) of the Architecture Faculty of the University of Ferrara in cooperation with the Politecnico of Milan have used a 3D scanner to obtain a spectrophotometric and telephotometric survey and three-dimensional texturized models (http://www.minolta-3d.com/applications/eng/colosseum.html) of some architectural elements.
The project has seen integration of three-dimensional aspects with traditional planimetric survey, in order to provide a helpful tool in monitoring the phases of restoration. A 3D scanner has been used to acquire a ionic capital base of the northwestern facade and a decorative frieze located in the hypogeum; the objects have then been processed using the software Alias Wavefront and finally exported in VRML format and rendered as photorealistic images. The last step has concerned publication of the results on a web-based hyper textual 3D database (http://www2.unife.it/architettura/labs/NubLab/colosseo/index.html).

The restoration project of the Notre Dame facade in Paris, conducted in 2000 and aimed at an exterior facade cleaning, represents a further example of Minolta's 3D laserscanning technology applied to relevant historical architecture (http://www.minolta-3d.com/applications/eng/notredame.html). Techniques applied to this case resemble those of Altamira; a part of the project regarded the reproduction at different scales of some statues located in the arcs of the portal. A prophetical figure of the central archway has been captured, processed as a 3D surface model and milled through a CNC machine; several copies of the statue have finally been obtained through moulding.

This brief excursus on significant projects, shows clearly how 3D scanning applied to archaeological finds might represent an innovative and stimulating opportunity of testing this technology; our main purpose, in buying and using the scanner, has been to produce 3D recording of artefacts coming from excavations.

2 – 3D Scanning of Artefacts

2.a *The peripheral and the reverse engineering software*

The 3D scanner VI-900 is a peripheral, which captures three-dimensional geometry and a colour image of a surface. The scanning system is based on acquiring single points through optical triangulation; the main component is a cylindrical lens crossed by a horizontal slit-shaped laser beam directly projected on the object to capture, while a CCD system reads the beam returning an exact measure of the distance. This operations are replicated by a galvano mirror, which acquires a cloud of points by projecting a light beam from the top to the bottom of the surface to scan. Besides the surface, the scanner records a bitmap image at a 640x480 pixel resolution.
Converting the cloud of points into a surface can be done using Minolta's software called *Polygon Editing Tool* 1.03 (from now on called PET), or other applications such as Rapid Form

or 3D StudioMax, which have a plug-in allowing direct control of the scanning peripherals and support of Minolta's native format *(.vvd*).

Our scanning station is composed by the scanner VI-900 connected via SCSI bus to a PC (Pentium 4-1.6 GHz with 1 GB of RAM and a GeoForce 2 graphical card) running Windows NT, a rotating table (model isel RF-1) connected to the serial bus of the PC, two calibration tables used to calculate the position in space of the single scanning on the basis of the rotation angle of the table.

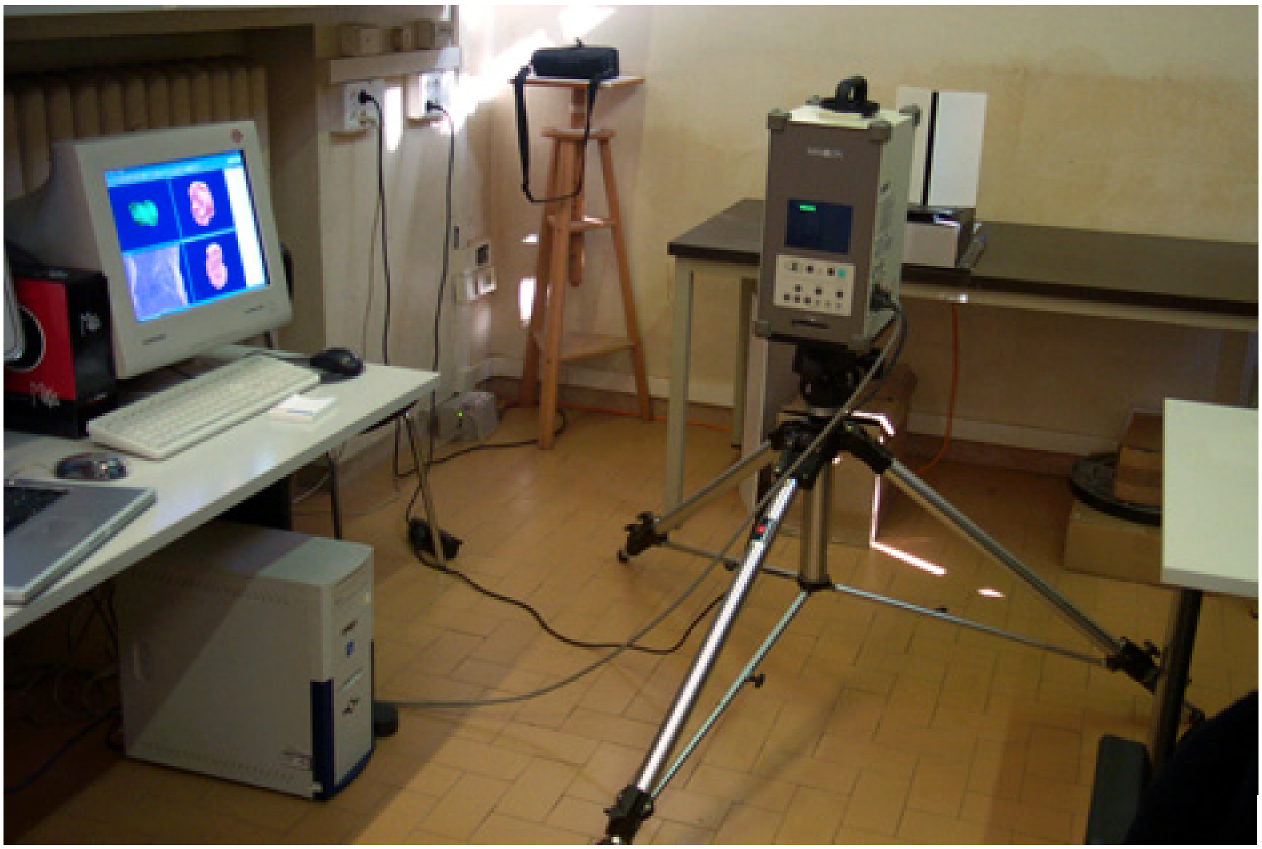

Figure1. The scanning station

PET (or the plug-ins we mentioned above) allows direct control from the computer over the scanner and the rotating table; parameters of the table (rotation angle) and of the scanner (manual setting of object distance, power of laser beam, etc.) can be entered from the software's user interface.

Our pottery pieces have been scanned using PET, with a 40° rotation angle of the table; laser beam power has been set manually, especially in the case of artefacts with dark or translucent surfaces.

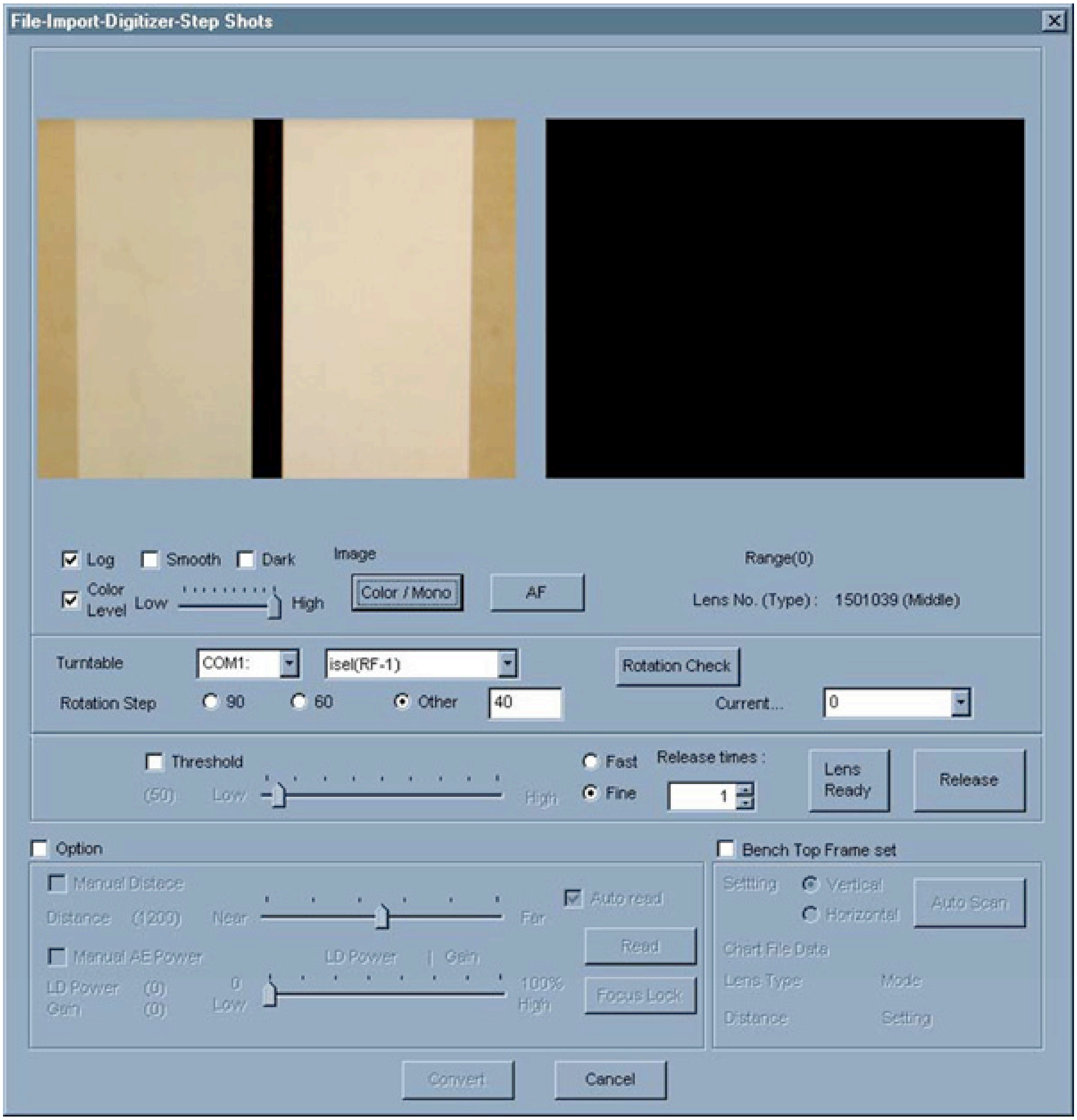

Figure2. PET application's user interface

The second reverse engineering operation consists in importing the cloud of points within the PET working environment, where a first automatic noise removal is applied; this reduces of 1/4th the scanned points. Objects obtained after surface merging are made up of a number of points ranging from 42.000 to 82.000 points, varying on the basis of dimensions and complexity of the acquired shape.

The PET working environment is used for cleaning of redundant points and merging of the single scanned surfaces. These may, in some cases, present capturing holes which the software completes automatically (the user can choose between two different mesh algorithms and a point-to-point triangulation process); the same job can also be performed manually, only on simple (one-faced) surfaces, by selecting three points in clockwise or counter-clockwise order depending on the turning (towards or against the operator) of the polygon's normal.

Each pottery piece is recorded in two files, one at a high resolution of points and another with less accuracy. The software allows to reduce at any time the density of points by manually defining a surface, or by applying a smoothing filter.

Merging every single scanning into one object produces also a bitmap document (a sort of orthorectified image of the complete object's surface), automatically applied on the 3D object and managed within the working environment.

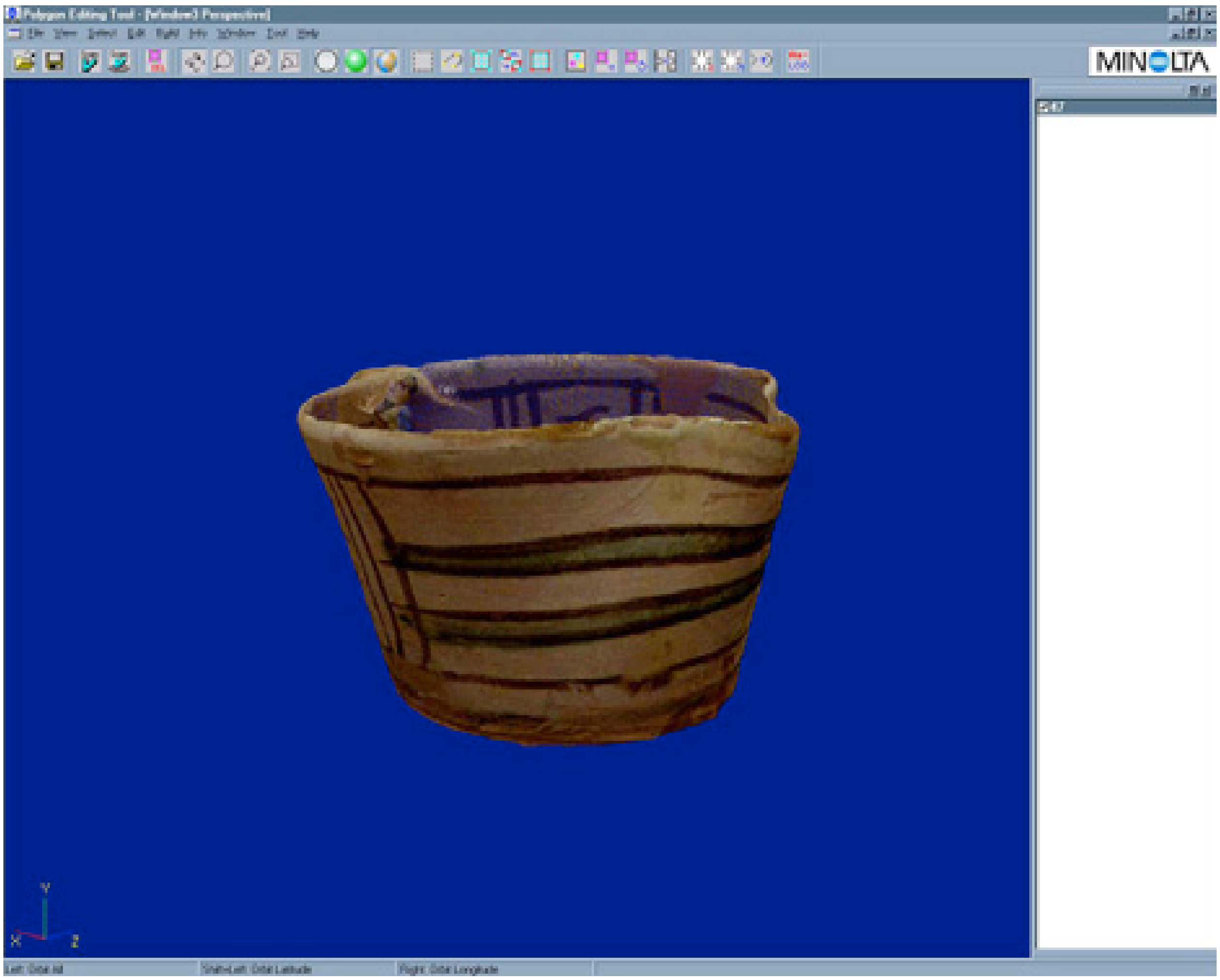

Figure3. Visualization of a pottery model with the texture image applied within the PET environment

In the specific case of the potteries found at the medieval monastery of S. Maria del Carmine in Siena, we have scanned and processed 36 pieces, comprehending all the "maiolica arcaica" finds and a typological sample of the other ceramic classes (coarse ware and fine uncoated ware).

Surprising results have been obtained in the scanning precision (with the peripheral configured to acquire a cloud of points at the highest possible resolution: 0.17 mm on the X and Y axes, 0.047 mm on the Z axis); some 3D models of the "maiolica arcaica" potteries show, for example, details on the thickness of each single decorative brushstroke.

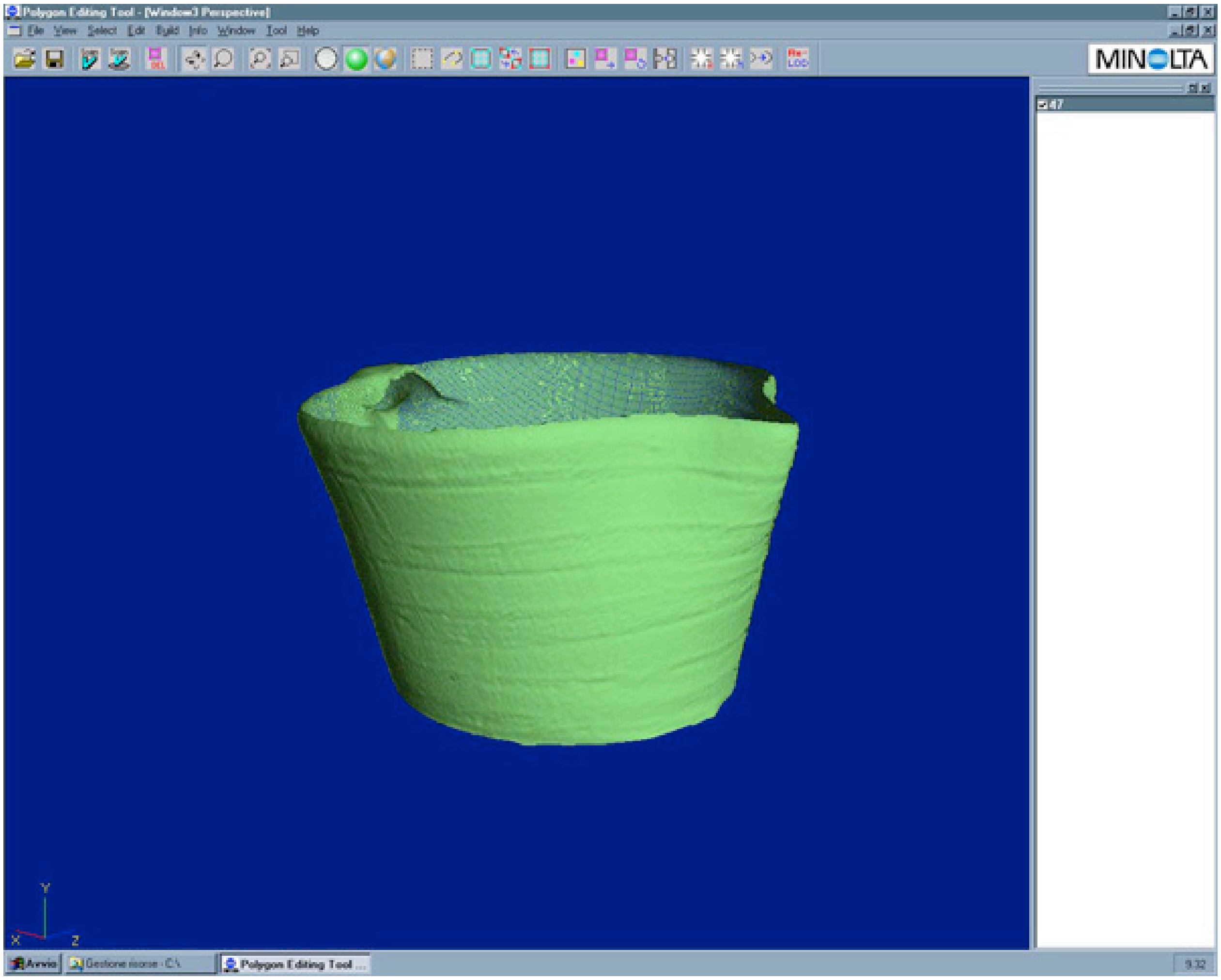

Figure4. 3D model of decorative brushstrokes on a small cup of "maiolica arcaica" pottery (Monastery of S. Maria del Carmine, Siena)

Such outcomes suggest new and interesting potentialities about application of laserscanning technology in archaeological, architectural and iconographic recording and representation.

2.b *Issues regarding laserscanning techniques applied to pottery artefacts*

Testing the peripheral and its software package on finds characterised by complex (double-faced) surfaces, has shown some limits in the scanning stage as well as during onscreen visualization and processing of the virtual model.

In the case of wholly preserved closed shapes (such as jugs, pitchers, etc) it is impossible to obtain an integral scanning of the object, since the laser beam cannot reach the entire extension of internal surfaces. Regarding open shapes (such as cups, bowls, etc.) the problems are related to correct visualization of the object: in fact the bitmap image associated to the 3D model has been often subject to imprecise merging; the error becomes even more evident when the object is exported into a universal format such as VRML: the internal portion appears in some cases completely deprived of its texture image.

The PET software supports seven export formats; only two maintain the texture image (VRML and HRC), while the others allow only exporting of the 3D model (OBJ, DXF, ASCII text, STL binary, STL ASCII). Saving of the image derived from surface merging in any standard

bitmap format is not supported, but it is possible to export the single captured images; this function should be easily implemented in future releases, since the package already allows to show in a preview window, while exporting in VRML or HRC format, the image which will be mapped on the object. Having such a feature would avoid the use of external software to read and save the mapping image as a separate file, or the workaround of taking screenshots of the mentioned preview window in order to save the image (like we did in the case of the Carmine monastery potteries).
Direct exporting of the image should also allow users to save documents at different resolutions; at the same time it would avoid colour calibration errors derived, from different profiles of the monitor where screenshot is taken and the software used with the peripheral. This last issue can become of crucial importance if the information related to the colour of the object represents a relevant information class of scanned objects.

Another "courtesy" feature missing in the current release, is the possibility of binding an alpha channel to the image in order to save a single scanning as well as a model derived from merging operations (anyway this is easily accomplished through the use of bitmap graphic applications such as Adobe Photoshop).
In the case of a single scanning the possibility of associating an alpha channel path representing the imported surface's contour, to be used in the rendering process, would be quite useful. On merged images the alpha channel could help to track paths of the parts in which the object's surface is missing (as it happens, for example, in the case of not wholly preserved ceramics); this would facilitate the rendering since dedicated applications usually have features allowing to associate a homogeneous colour to a particular mapping image.

3 – Conversion of a scanned artefact into a QuickTime VR Object

The second phase of our work has been to produce QTVR movies of the scanned finds; it can be divided into three steps, applying the following techniques:

1. 3D modelling;
2. image processing of the bitmap mappings;
3. final rendering project.

The choice of producing movies based on QuickTime technology instead of VRML format depends mainly on two considerations: universality of the QT standard, which is correctly supported by all the most widespread operating systems (in opposition to VRML which is badly supported on some platforms) and visualization quality and precision of the final product, intended as a result which reflects most closely the original find.

The overlapping of mapping images and 3D model presents usually no particular issues in the case of objects with simple surfaces (one, usually external, surface), such as architectural elements; objects with complex surfaces (internal and external), like the ones treated in this paper, may cause complications in photorealistic rendering and visualization, especially if the surfaces have different attributes.
In this sense, the pottery finds of the Carmine monastery have been a good case study. Some of the classes attested on the site, such as the "maiolica arcaica" or the glazed pottery, present clothed surfaces characterised by different colours and decorations.
This has been, besides obvious aesthetic grounds, the practical reason which forced us to engage in complex processing, which may be resumed in converting the scanned finds from the native VVD format to QuickTime VR movies.

3.a *Exporting and redefining the objects*

Aiming at a final product which had to resemble faithfully the original find, the surfaces have been “redefined”, or better they have been divided into more objects following different methods for open and closed ceramic shapes.

We have already mentioned the difficulties in capturing the internal portions of closed shapes, noticing how an exclusive use of the peripheral and the software package that comes with it will not solve the problem. In our experience the scanning concerned directly only the external surface, while the internal has been derived aprioristically in a 3D modelling environment (*formZ* produced by Autodesys). In fact the scanned surface has been exported as an OBJ document and then imported within the 3D modelling software, where we produced horizontal sections of the scanning; the internal surface has been obtained by resizing of the sections, which were then used as source objects in the creation of a mesh surface reproducing, with smaller dimensions, the external profile.

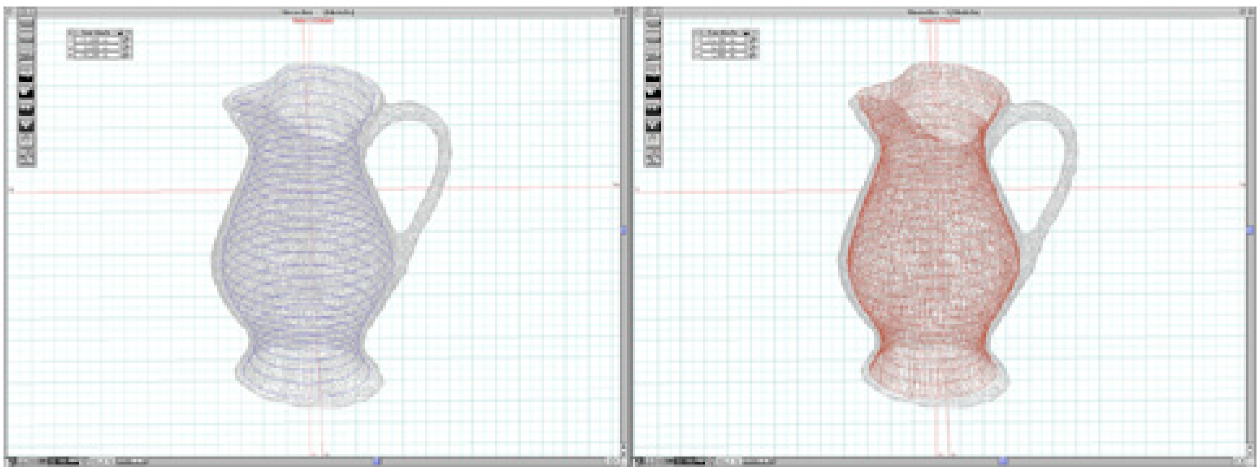

Figure5. Phases of an internal surface creation process (1. profile design, 2. the derived mesh surface)

The two surfaces have then been merged on a point-to-point basis; the internal bottom of the find has been represented as a third object generated from the first inferior section.

Pottery finds having open shapes have been treated differently; correct visualization of the internal portion has been obtained by dividing the whole model in two different and adjacent internal and external surfaces.

This operation has been carried out directly within the PET environment, by selecting the points related to each portion of the object in order to define the new surfaces. *Toggle point* (inverse selection) has been the most used tool in this processing stage; it turned out to be quite efficient, even though some improvement could make the use of the tool more practical. A particularly useful option could be represented by the possibility of deciding whether to associate or not the previous selection boundaries to a newly defined selection.

Such a feature would certainly have allowed much time-saving in the selection of single contour points, needed in order to ensure the presence of connection polygons between the two derived models. The objects obtained through this time-consuming process have been exported in OBJ format and imported within the mentioned 3D modelling environment.

In both cases (closed and open shape of pottery finds), passing through *formZ* has also been necessary to implement exporting of the definitive models as FACT objects, the native format of the rendering package we have used (ElectricImage, produced by ElectricImage Inc.).

3b. *Image processing of the bitmap mappings*

Adobe Photoshop has been applied to processing of the bitmap images used for surface mappings. Images of the internal and external sides have been exported from the scanner's capturing software (directly or through a screenshot of the preview window, as mentioned above); both sides of the bottom have been acquired through a digital camera.

Image processing of the bitmaps has aimed mainly at fixing the mappings generated by PET merging, balancing of colours and brightness, creation of new documents in order to represent decorations and integrations of the single potteries. It has probably been the most time-consuming phase, especially for the pieces of "maiolica arcaica" pottery. All the imperfections derived from the PET's surface merging, especially in areas of single image overlapping, have been corrected; decorative motifs have been made more readable through the use of tools such as the clone stamp and the airbrush applied with different opacities and fusion methods.

Figure6. External mapping of a "maiolica arcaica" piece, before and after image processing

The image processing operations aimed at two different purposes: achieving a high quality mapping to apply on the 3D models and obtaining an explicative record of pottery production techniques.

The final images are, in fact, a really innovative archaeological record, representing an orthorectified high-resolution image of external pottery surfaces. We have used this documents to build a decorative thesaurus of the Siennese “maiolica arcaica”, since the finds of the Carmine monastery allowed us to heavily integrate the typological frame known before.

Planimetric images of pottery decorations represent an interesting archaeological record, allowing in-depth studies of geometric, vegetal, zoomorphological and heraldic motifs.

Figure7. Orthorectified images of decorative motifs on Siennese “maiolica arcaica”
a. geometric b. vegetal c. zoomorphological d. heraldic

3.c *Texture mapping and rendering*

The last step has focused on mapping of the texture images, creation of the object’s visualization environment and definition of the rendering attributes.

In the texture mapping process we have adopted standard rules. Cylindrical projections have been applied to external and internal sides; for the two bottom images we have adopted a planar method of projection.

ElectricImage supports overlapping of textures on the same object; the feature has been used to reproduce particular decorations, located on specific parts of the pottery pieces (especially on the handles), and restoration integrations.

Setting the visualization environment has concerned mainly the evaluation of an appropriate illumination set and the definition of the background colour. The illumination set has been implemented through four radial lights, coupled by intensity and placed to form a rectangle from any prospective view. This solution allowed a sufficiently uniform light exposure and, at the same time, helped to exalt morphology through contrast generated between different light intensities; white has been chosen for the background colour.

In the final rendering of each single find we produced two QuickTime movies, having different size and video compression, directly connected to different output requirements. In fact, at the exhibition of the finds, we have set up three different products using the final renderings: a multimedia database management system (using the application Canto Cumulus Desktop Pro) allowing visitors to easily retrieve the movies through a system of keywords, a hypermedia presentation (published on CD-ROM and running at the exhibition) and a web site of the event (http://www.paesaggimedievali.it/volta/index.html).

The website requirement of real-time access (or at least of acceptable loading times) to the movies forced us to produce low-resolution and small-sized documents; on the other hand, the files retrieved locally on the machines placed at the exhibition (or on CD-ROM) definitely needed a better quality.

Therefore the low-resolution movies have a size of 200x150 pixel, are compressed with Sorenson Video 3 at medium quality and millions of colours; file dimensions vary from 144 KB to 836 KB. The better quality documents are sized to 320x240 pixel, compressed with Sorenson Video 3 at high quality and millions of colours; in this case file dimensions range from 401 KB to 6.1 MB.

This working stage has required a considerable amount of time, especially if we consider the rendering schedules on the machines. Processing of one high-resolution movie on a Macintosh PowerMac G4 Dual Processor 500 MHz has taken about 6-7 hours; half the time is needed for low-resolution documents.

The rendering times can anyway be considered quite low; processing was made with 624 MB of RAM assigned to the rendering software and the *Phong* algorithm has been applied (it has proved to be extremely efficient on our hardware environment).

A new *Raytracing* algorithm has been implemented on the last release of ElectricImage; it improves drastically the quality of the movies, as we have been able to observe while working on a second project involving laserscanning techniques applied to a pottery sample coming from the excavated settlement of Castel di Pietra (Grosseto). Rendering times, even though higher if compared to the *Phong* algorithm, are still quite acceptable (in the same environment mentioned above the rendering of a movie sized 480x360 pixel, compressed with Sorenson Video 3 at high quality and millions of colours has taken little more than ten hours).

Figure8. Rendering examples of 3D pottery models (1. S. Maria del Carmine, 2. Castel di Pietra)

4. Finalities and future aims

The process described in this paper, marked by stages that demand specific competences and the use of several different software packages, has returned good results in the photorealistic and animated restitution of archaeological finds (pottery in the case of the Carmine monastery).
Producing records aimed at virtually replicating real objects fits particularly well in the communication process of archaeological data; this is mainly the reason of focusing our first test on developing products suitable for an exhibition.

The use of a 3D scanner to obtain QTVR movies surely has in hypermedia products, websites and dedicated interactive machines its main application field.
Setting up computers within exhibitions and museums puts the basis for a more confident, dynamic and in-depth approach of many visitors to archaeological subjects.

We have already mentioned how the products described in this paper have been one of the attractions at the exhibition on the exceptional pottery finds of the Carmine monastery in Siena. The same way has been followed recently in setting up a museum structure at Gavorrano (Grosseto), based on the archaeological excavations conducted by the Medieval Archaeology Area of Siena University on the site of Castel di Pietra (also in this case 3D capturing regarded pottery finds).

Continue in the traced path of communicating archaeology to the wide public, integrated by the possibility of offering helpful research tools for specialists will be our specific aims in the future use of laserscanning techniques.
Setting up a multimedia DBMS, after the model already tested at the LIAAM for pictures and movies of excavation projects, becomes therefore a primary need in order to manage the growing number of documents.

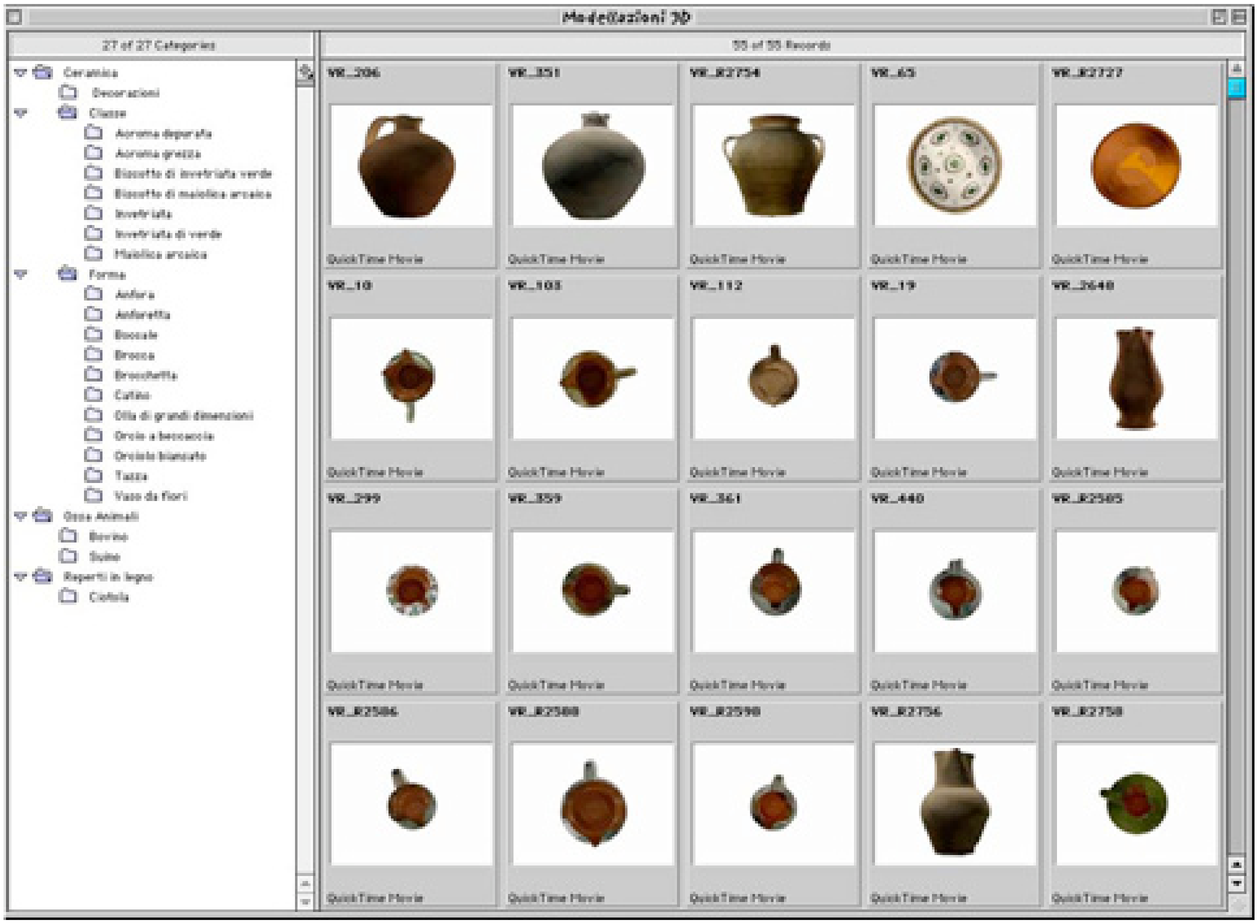

Figure9. Multimedia database of 3D scanned potteries (Monastery of S. Maria del Carmine, Siena)

Methods applied in this experience fit in perfectly with the general research tendencies in the field of computer applications in archaeology put forward at the Medieval Archaeology Area of our University (Francovich 1990); we have always aimed at the creation of an integrated system for archaeological data management (Valenti 1998). The structure of this system should be open and extendible to any kind of information (archaeological, historical, architectural, naturalistic, etc.) concurring in our interpretation and communication processes; what it really aims at is to meet the needs of an ever-growing "collective knowledge" (Francovich 1999).

It seems therefore natural that, in continuing to experiment technologies in the field of archaeology, we will try to evaluate a different way of using laserscanning techniques, aiming at the production of more specialized tools.

One of the first application we want to explore regards the scanning of finds in order to replace and enhance traditional drawings. A preliminary test has been carried out on the metal finds of the Miranduolo castle (Chiusdino, Siena; Nardini, 2001). In this case the scanned objects (spear, crossbow and arrow tips) have been imported within a 3D modelling environment, where profiles of each abject have easily been derived. Simple static renderings of this profiles (Figure 10) are exactly like the traditional drawings, used by archaeologists to set up morphologic typologies.

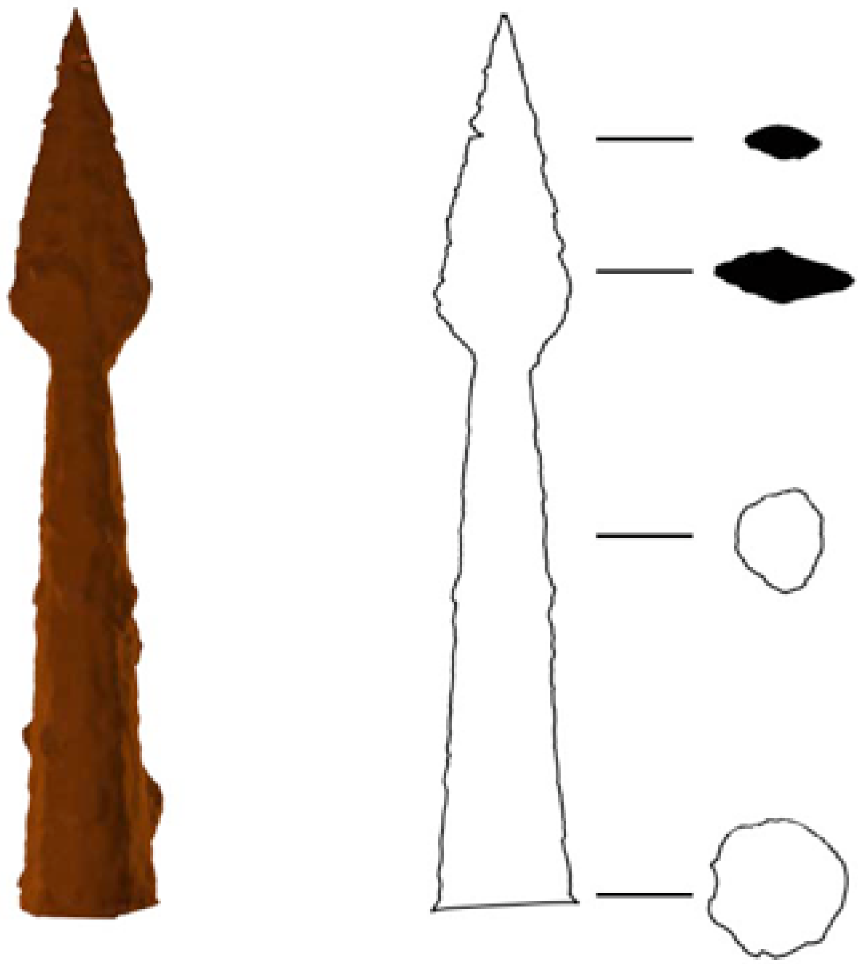

Figure10. Drawing derived from a 3D model and photorealistic rendering of a spear tip (Castle of Miranduolo, Chiusdino – Siena)

Another field of application, which we recently set up at the LIAAM, concerns the creation of a virtual collection of animal bones recovered on archaeological excavations. In this case the use of the peripheral is focused on capturing bone surfaces in order to produce osteometrical data for study and comparisons of zooarchaeological samples.

Figure11. Measurement of the first phalanx of an ox found in a 14th century context (S. Maria del Carmine monastery, Siena)

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