3D Visual Information and GIS Technologies for Documentation of Paintings in the M Sepulcher in the Vatican Necropolis

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Abstract

Digital technologies may be very helpful in the graphic documentation of paintings, not only due to the inherently more detailed and faster method of drawing, but in particular due to the 3D representation of data (structures and materials) in real time, that is, the possibility to have many dynamic views of the same model in order to visualize and interpret features and shapes, as well as the state of conservation of structures and materials. Moreover, it is very important to highlight that paintings or mosaics are intelligible as 3D objects rather than 2D objects, since they ultimately represent solid objects. Thus, using GIS technologies for collecting data, it is possible to process the relative information in detail.

There are many situations one has to face when dealing with graphical documentation of surfaces, whether flat, bossed or curved, with or without decorations. The traditional form of graphic documentation, interpretative by definition, favours different levels of detail, depending on the scale of reduction and the different objectives under study (location of degraded areas as opposed to decorated ones, presence of discomformities and cracks, production of images and thematic maps derived from particular analyses, for example, thermal infrared surface scanning). It is certainly difficult to document a decorated vault. For this reason, we have chosen to consider the walls and the polychrome mosaic vault of the M sepulcher, also known as Cristo Sole (2.-3. cent. AD) which can be found in the Vatican Necropolis. The mosaic presents a small tessera decoration (of which only a fraction is still in place), on the walls and on the highly depressed vault; in places where the tesserae are missing, the mosaic preparatory surface still enables us to interpret the original decoration.

Furthermore, the main goal of our project is a detailed virtual 3D reconstruction of a micro-model of the above mentioned decorations through the use of digital techniques, in order to obtain a final "cognitive" representation. To obtain this, we have implemented new tools for the acquisition of detailed 3D surfaces.

The general positioning (georeferencing) was achieved using a Leica TCR 1103 total station; this instrument also enabled us to obtain vast amounts of surface data for the 3D model thanks to its reflectorless Laser EDM (Electronic Distance Measuring) range finder. Where more detail was necessary, further surface data was gathered using a Microscribe 3D Mechanical Arm Digitiser coupled to a laptop computer and driven by the Rhinoceros® 3D surface modelling software.

The project involves the following main approaches: digital acquisition of surfaces, digital documentation of mosaics and paintings, 3D virtual reconstruction of models and 3D virtual communication of the information by VRML metaphors through the Internet.

Key words: micro-GIS, 3D, M sepulcher, Cristo Sole, virtual reconstruction

1. Introduction

The graphic documentation of wall paintings and of the underlying architectural and/or archaeological structures must aim to facilitate the highest grade of knowledge and communication.

As objective and metrically correct as such documentation may be, it is, however, still subject to the interpretation of the person documenting it, whether obtained through traditional means or through the use of more advanced systems, such as, for example, photogrammetry. This does not mean that we must not search and, through experimentation, choose whichever methodology is best suited to tackle the diverse situations one may encounter.

In every documentation project, the first step is to create a spatial reference system used for proper positioning of all elements under study both in absolute terms and in relation to each other, independent of the scale and complexity. Thanks to recent technological advances, this part of the task has been greatly simplified. New options and equipment are also beginning to aid us in the successive part of the graphic documentation process: the actual "retracing" of the objects of our study, either in high detail (as favoured by historians or archaeologists) or more schematically (to create a base for the conservationist's thematic mappings) has been made much simpler.

Digital technologies may be very helpful in the graphic documentation of wall paintings not only for the greater speed it offers, without compromising any detail, but in particular for the representation of data (structures and materials) in 3D; it offers the possibility to have numerous dynamic views of the same model in

Figure 1: Total laser station for the topographic survey.

order to visualise it and thus to interpret features, shapes, as well as the state of conservation of structures and materials in real time. Moreover, it is very important to highlight that paintings or mosaics are intelligible more as 3D objects rather than 2D objects, because they represent a 3D class. As a result, using GIS technologies, it is possible to process the collected data in detail in order to interpret and analyse the digital content with multidimensional levels of overlay.

For this reason we have planned the following methodological goals:

- Testing new systems for a micro-topological survey in emergency situations (very small spaces, detailed architectonic features, preservation of materials).
- Considering digital graphic representation of mural paintings and mosaics as three-dimensional information (instead of two-dimensional).
- Using 3D GIS techniques for an interactive visualisation of architectonic models and 3D databases (figures 6-9).

On the basis of the above mentioned approaches, we have implemented the following main stages:

- Digital acquisition of all architectonic surfaces with a 3D pantograph (Microscribe, http://www.immerse.com/microscribe/digitizers.html) for a total of 11.000 points (figure 4).
- Rectification and digital photo-mosaic of all walls (3 walls and 1 vault, figures 5-8)).
- Infrared thermal survey (thanks to ENEA's contribution, Ente per Nuove Tecnologie, l'Energia e l'Ambiente).
- 3D interpolation of the micro-relief data (figure 9).
- Digital data-entry in a 3D GIS.
- Texture mapping and draping of all graphic surfaces of the walls on the micro-DEM (figures 6-8).
- Virtual reconstruction of the tomb in VRML (figure 10).

2. The Vatican Necropolis

The work presented here was carried out during the restoration works in the Vatican Necropolis (figure 3). This previously open-air burial ground is now placed under the nave of St. Peter's Basilica. In fact, the Necropolis was covered when the Constantinian Basilica was erected. Furthermore, successive burials have altered the stratigraphy of the site which was also influenced by the structural works for the construction of Bernini's *Baldacchino* and the sequence of constructed altars, the construction of which took place during the centuries gone by. All of this took place on top of the sacred spot considered to be St. Peter's burial place. Today the Necropolis presents itself with walls of considerable size which can be found in a good state of conservation, although the view is at times obstructed by modern pillars needed to sustain the above structures. These proved necessary after the soil removal following the excavations carried out in the early 1940s. The explored area of the Necropolis covers an extension of about 69 x 18 meters and presents itself as a double row of burial edifices separated by a narrow passageway. In particular, the M sepulcher is inserted between two other structures of which it uses the outer walls; this makes it one of the last, chronologically speaking, constructions of the Necropolis (Apolloni Ghetti et al. 1951).

3. The M sepulcher, known as *Cristo Sole* (Christ the "Sun God")

The M sepulcher (figure 2) was discovered in 1574 during an excavation carried out under the pavement of St. Peter's Basilica (Guarducci 1997). Thanks to the discovery of an epigraph (of which only a transcription of its text has reached us) and through the study of the wall typology, it was possible to suppose an originally pagan structure, dated from the mid second century AD, and its successive transformation into a Christian mausoleum at the beginning of the third century. A very rich mosaic decoration originally covered the upper portions of the walls and the whole vault, while the lower portions of the walls were decorated with geometric patterned frescoes. Today the mosaic decoration is partially missing, however, it is possible to recognize the original designs thanks to the traces left by the lost tesserae which indicate M sepulcher as the only entirely Christian burial in the Necropolis. On the preparation layer of the mosaic on the west side we can catch a glimpse of the Good Shepherd; on the frontal (north) scene we can see the Fisherman (Christ or Peter) with a fishing rod; on the eastern most hand side lies the depiction of Jonah being swallowed by the Whale and finally, on the vault lies the image of Christ as the "Sun God" ascending to the sky on a chariot drawn by four horses; the later image is surrounded by an interlacement of vine branches and leaves (Guarducci 1997, Apolloni Gheti et al. 1951). The complexity of the structure, the decorations and the indubitable importance of this sepulcher were decisive factors in

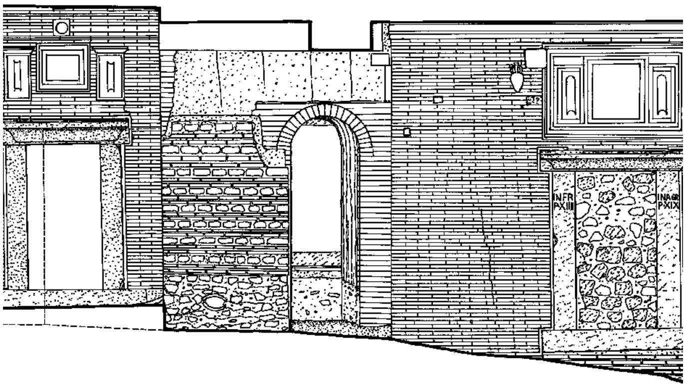

Figure 2: Entrance to the "M" Mausoleum, known as the "Cristo Sole" (Christ the Sun God).

selecting it as an example for testing the integration of different documentation and analysis methodologies.

4. The Micro-topographic survey

The survey and graphic documentation of the Necropolis plan was carried out (thanks to a Sokkia SET 4C total station, figure 1) by creating an accurate surveying base through the establishment of a closed traverse with branches entering into each and every mausoleum; this involved the placement of around 70 instrumental stations. All mausoleums were documented in detail with all documentation referable to this topographical base (figures 2-3).

The surveying instrument also proved very useful at recording the salient points necessary to carry out a metrically correct documentation of wall paintings and architectural decorations even through the subsequent use of traditional means (measuring tape, plumb bob, level etc). When faced with the particular conditions posed by the "M" Mausoleum it was decided that a more unconventional approach might not only simplify the task but also provide the capability of representing the object of study in a radically new way: by virtually recreating the actual surfaces of the walls and vault, in full detail, with the obvious superimposition of the decorations (mosaic or painting) they were adorned with.

Although the concept of a computer generated 3D model was not new, it had always been applied to generate, at the most, schematic exemplifications of structures on which to project the images of any surface texture, obtaining a great general effect, but still hardly useful for the purpose of study. We were encouraged in this by the availability of two new instruments: a total station (Leica TC1103) equipped with a coaxially (along the line of sight) mounted reflectorless EDM laser (this laser does not need reflecting prisms to measure distance) and a 3D digitising arm, that is a sort of 3D pantograph (Microscribe 3DLX).

A few words should be said on this last item: the Microscribe is a 3D digitising (figure 4) precision mechanical arm in which high performance sensors embedded in its articulated joints track the position and orientation of the stylus tip as it is moved in space by the operator. By pressing a button or a foot pedal (depending on the accessory in use), it is possible to record the relative spatial position of the tip in any given moment and, through a serial connection, send such data to a computer. There are many CAD and/or 3D oriented software packages capable of making use of such inputs just as if it were coming from a mouse or digitising tablet (with the fundamental difference of the 3D nature of such data).

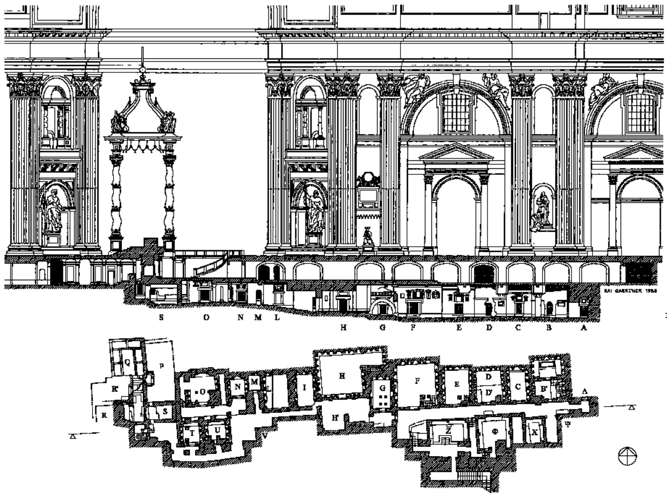

Figure 3: Plan of the Vatican necropolis.

Moreover, the system is highly portable: whether it is set on a table simply sitting on its base or on a tripod it can be placed just about anywhere provided there is a power source and a connection to a computer (a notebook for example). Not only is it possible to record single points but also streams of points by keeping the input button or pedal continuously pressed while the stylus tip is passed over the object we want to digitise; this method is particularly useful in association with software that makes use of "point clouds". Since the first three points recorded during a digitising session are used to establish the reference plane to which all successive points are referenced, it is also possible to fix in a different area, another set of three points during the same session to be used as reference points for a subsequent session. This enables much wider areas to be covered, far beyond the actual reach of the digitiser. As a last consideration we must not underestimate the intuitive and easy operation of this device, with which the operator is always in total control of all activities.

With these instruments, we were able to accurately reproduce a virtual representation of the actual surfaces in extreme detail and accuracy and not only plot points or lines. The "M" Mausoleum presented varying characteristics such as "frescoed" and "once mosaic covered" (though still readable thanks to the traces left by the lost tesserae on the preparation layer) wall surfaces and a vault with a rather undefined shape (a very low cross vault) only partly covered with the polychrome mosaic that once characterised the whole upper portion of the mausoleum.

The first step was to place the laser EDM total station inside the mausoleum onto a predetermined station tied to the main traverse used in the survey of the Necropolis plan. Through the use of this instrument we were able to scan the different wall and ceiling surfaces, carefully distinguishing the brick and plastered surfaces of the left wall, the mosaic preparatory layer, the corbel and frescoed lower portion of the front wall, and the preparatory layer and fresco of the right wall. Furthermore, the total station was used to record points for spatial referencing and geometric rectification of the photographs of various surfaces. Finally, we recorded the points to be used later on in order to reference the 3D digitiser survey sessions (3 points for every session).

The 3D digitiser was used to retrace the outer contour of the only remaining portion of the mosaic placed on the vault, point by point. A series of parallel lines running over the vault's surfaces were

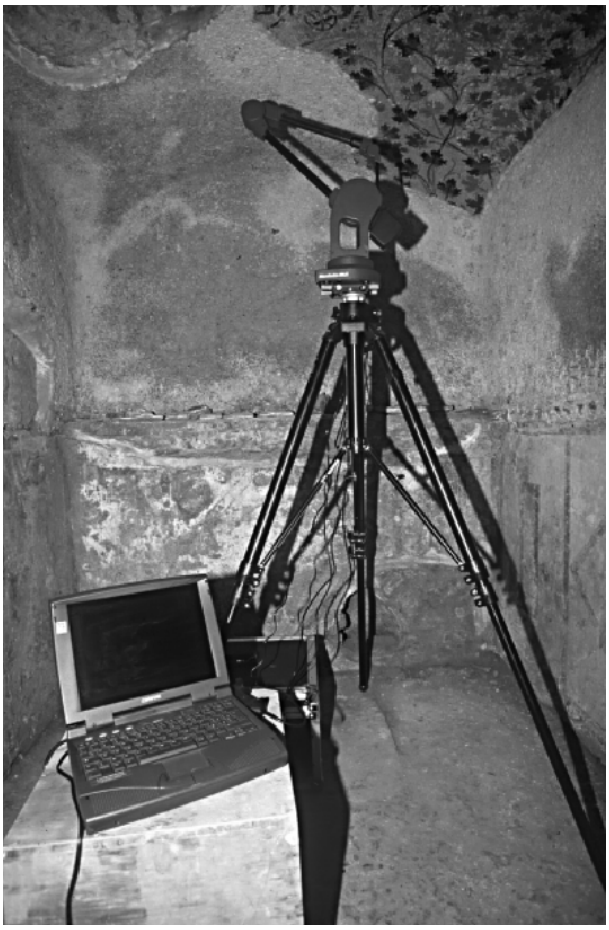

Figure 4: The Microscribe 3D arm.

also digitised to be used as a basis for their reconstruction. This procedure was chosen given the insufficient clearance between the vault and the total station for the laser rangefinder to work properly. All the frescoed designs and the traces of figures left on the lost portions of the mosaics were digitised with the Microscribe Arm and, as a further test, a detail of the face of Christ was digitised tessera by tessera prior to the restoration operations.

At this point we had a clear indication of how helpful these techniques were in obtaining metrically correct graphic documentation directly on site, through the detailed examination of all elements necessary for the interpretation and comprehension of the structures and of the decorative apparatus.

The software used in connection with the digitising arm (Rhinoceros 3D, figures 4-5) not only gave an interface between the instrument and the user, but it also permitted us to digitally recreate shapes, lines, curves and surfaces in their exact spatial position and, most of all, in real time.

This data (through further processing) was instrumental in the construction of our 3D model, to be used either for the extraction of two dimensional representations by projecting it onto whichever plane we desired to observe it on or, by retaining its 3D characteristics, to use it in one of the many applications that made use of spatially defined entities. The model thus created was, for example, used to map the information gathered during a thermal infrared scanning analysis carried out on the frontal (North) wall of the Mausoleum.

To insert the infrared imagery and the result of its processing into our metrically correct representation of the wall, a series of marks,

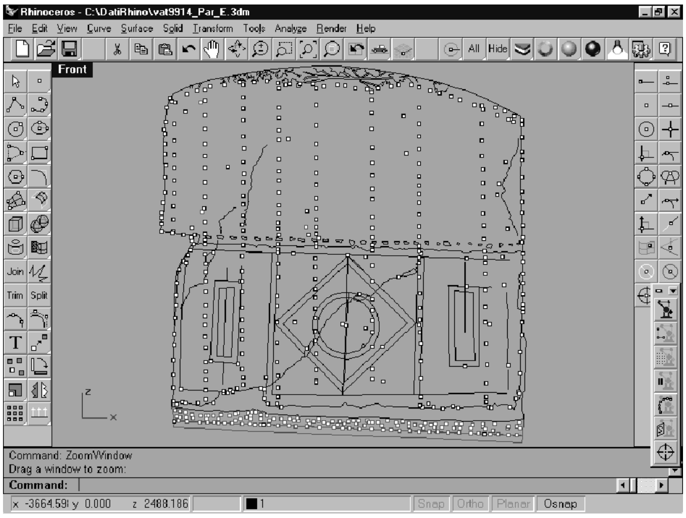

Figure 5: Rhinoceros software interface.

visible both in visible and thermal infrared bands, were placed on the surface and surveyed.

The thermal infrared scanning was carried out with the Marconi TICM II, a high resolution system, operating in the 8-13 micron wavelength range. The images were processed through dedicated software by MEDIA CYBERNETIC, applying the appropriate filters to enhance the readability.

In the example image, captured during the cooling phase, we saw a presence of warmer areas (yellow-red) which correspond to possible slight detachments of the plaster layer from the brick surface. The cooler (blue) areas indicate the presence of a humidity front. By processing the infrared image, we can produce thematic maps and in this particular case we have recorded and outlined the above mentioned areas.

The software used throughout our documentation campaign comprised of AUTOCAD for the acquisition and projection of topographical data, CAD OVERLAY for the processing of orthographic photographs and RHINOCEROS for 3D digitiser data acquisition and subsequent modelling of various surfaces.

RHINOCEROS, in particular, is a tool that enables us to produce mathematically defined (NURBS) surfaces (as opposed to TINs or grid meshes) by combining a series of parallel or criss-crossing curves.

The most complex surface to process was certainly the vault: both because it consisted of two separate surfaces (mosaic and preparatory layer) and also due to its non-regular geometric shape.

Through the use of curves obtained by 3D digitising, the software enabled us to digitally reproduce nearly exact replicas of the surfaces and eventually project images or drawings onto them.

In short, we started with a decorated surface, we surveyed it obtaining a 3D model, and we then digitised its decorative elements in order to obtain a metrically correct base for their successive manual graphic documentation. At this point we were able to reintegrate the surfaces with their now spatially referenced pictorial images in order to be able to visualise the complete model from different points of view.

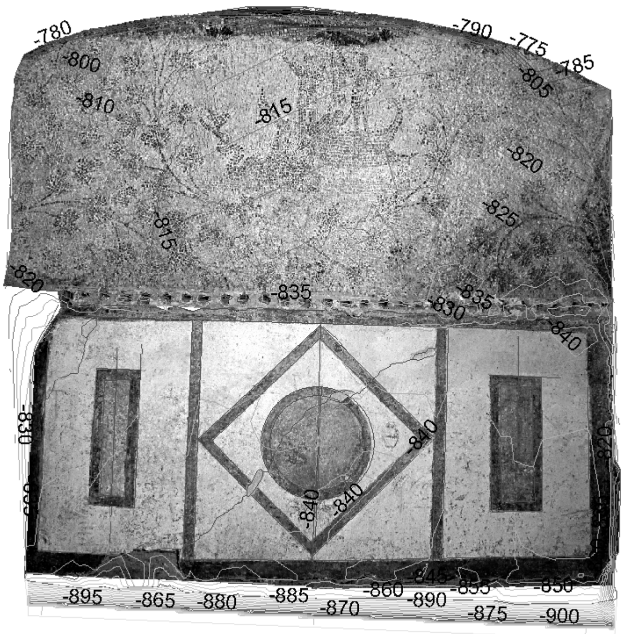

Figure 6: N wall: GIS overlay of contour levels.

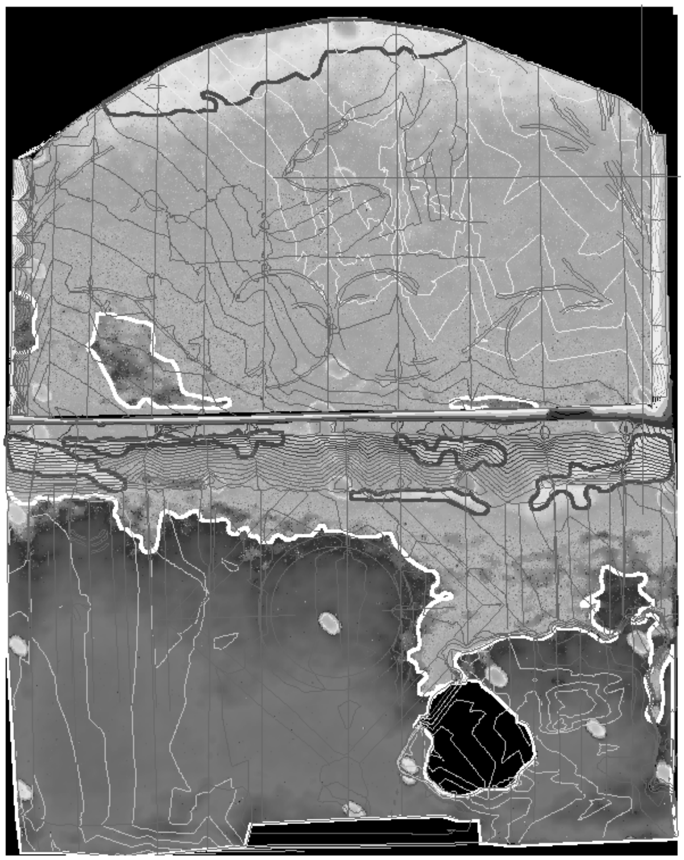

Figure 7: N wall: GIS 3D overlay of different layers (infrared processing, contour levels, drawings, outlines).

5. GIS and visual information

The main goal of our project was a detailed virtual 3D reconstruction of micro-models of paintings documentation by digital techniques and through different information layers, in order to obtain a final "cognitive" representation (Forte 2000). In the case of a monument such as a tomb, the best cognitive micro-representation is increasing the level of knowledge and of interpretation, practically de-constructing in the first phase the pictorial and architectonic information, finally, recombining every component of the structure into a unique, whole virtual model. The process of de-construction and re-construction is a cognitive dynamic process of knowledge that we think is fundamental for a new approach to digital graphic representation: we disassemble and then reassemble information. Thus a model becomes an articulated set of multi-layered information, where the whole increased model is more significant than each single component.

In this context, 3D GIS (Geographic Information System) and virtual reality technologies have been fundamental in obtaining good results. In fact, even though GIS software is typically used in territorial studies and analyses, it can give very interesting results also in other non-traditional contexts. Furthermore we have to consider GIS as an open planning platform, where the scientific user chooses the directions of research, combining several layers of documentation.

All the work phases have been carried out exchanging all data online (by Internet tools) and creating a network of persons with different roles and functions: topographic survey and acquisition (A. Bizzarro, S. Tilia), data processing (S. Tilia), rectification and topological referencing of images (A. Tilia), GIS implementation and 3D processing (M. Forte), VRML reconstructions and virtual reality applications (A. Tilia, S. Tilia, M. Forte).

In order to process the digital data the following software was used:

- ER Mapper 6.1 (3D visualisation and draping, infrared spectral analysis);
- Arcview 3.1 (GIS data-entry and overlay);
- VRML Cosmo Player (3D visualisation of the reconstructed model).

In our case the most important work phase was the superimposition of data, that is the representation of data in a unique referenced co-ordinate system, through the exact use of a GIS implementation.

Starting from the importation of data within the GIS, the main steps of the working project have been the following:

- Data entry of vector (drawings) and raster (images) files.
- Topological referencing of raster (photomosaics and graphics) and vector (decorations, drawings) layers in Arcview (figures 6-9).
- 3D interpolation of data by CAD and GIS software (Arcview 3D Analyst) for the creation of 3D surfaces (interpolation by GRID and by TIN, figure 8).
- 3D Superimposition of all the geometric and graphic layers (figures 6-9).
- 3D Texture mapping of the graphic documentation over the model and draping of all the referenced data over the microDEM of the walls and of the vault (figure 9).
- Real time visualisation of the virtual models (in our case 4 models for the documentation of the tomb) using Er Mapper and the 3D Analyst module of Arcview.
- Merging all types of data systems in order to analyse and to compare the different information layers (raster and vec-

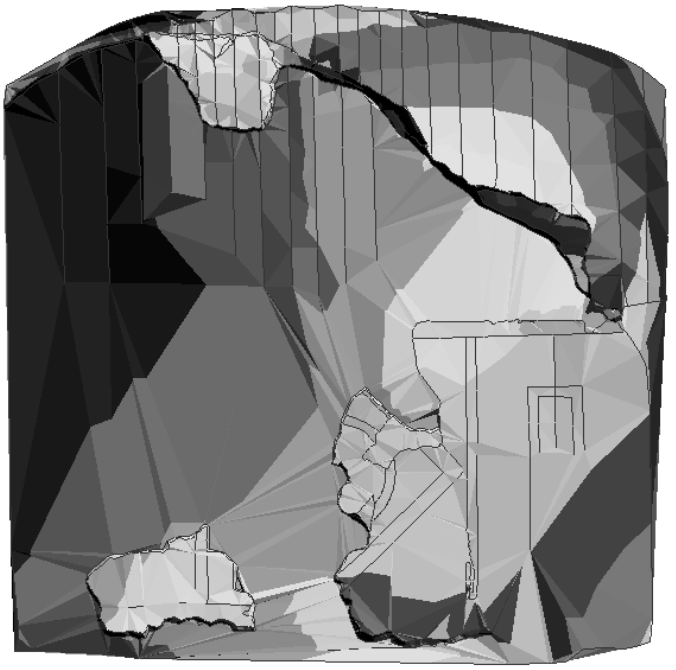

Figure 8: E wall: grid interpolation and vector overlay.

tor, such as images, contour lines, polylines, graphic edges, interpretations and so on).

- Z exaggeration of the interpolated models in order to stress the surfaces for testing the state of conservation of the mural paintings, and the relationships between mosaics, graphic decorations, architectonic elements, lack of materials, etc.
- Model reconstruction in VRML (Virtual Reality Modelling Language, see below) in order to visualise and to interact the data online using the Internet or offline on any PC (figure 10).

One of the most important final steps of GIS applications should be the communication of available data online. The chance to put information (raster, vector, 3D, etc.) on the Internet gives scholars and other interested people the possibility to access remote systems, thus enabling them the comparison and analysis of data and finds. The development of multimedia applications within a GIS environment is now in progress but it will represent one of the most interesting possibilities for communicating information in the future. In particular the Internet or a net of georeferenced 3D databases and graphic libraries could constitute the final goal of GIS, giving the users the possibility to obtain and add information in real time. In our case, using the 3D analyst module of ArcView, the 3D GIS models were reassembled in VRML 2.0, so as to explore them interactively through Internet browsers.

5.1. 3D Interpolation

Interpolation methods allow the creation of 3D surfaces starting from scattered elevation points (or Z values); the choice of the method of interpolation influences the interpretation of the model, thus it is important to know the main techniques in order to obtain good results. In fact topographic, topological or digital terrain data, once “gridded”, can be processed and displayed to highlight important physiographic and/or geometric features in territorial or architectural contexts. The 3.0a release of 3D Analyst involves

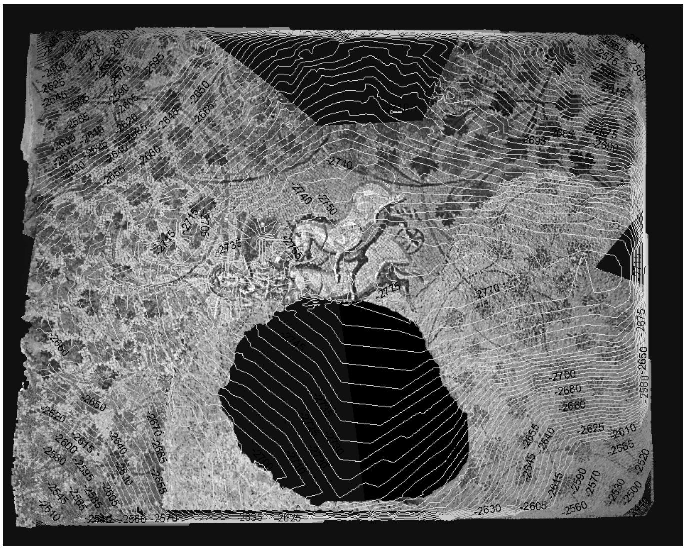

Figure 9: 3D visualization of the vault with contour levels.

two methods of interpolation, Grid and TIN (Triangulated Irregular Networks).

- Grid interpolation is a representation of surfaces using a mesh of regularly spaced points. The grid model is simple and processes on them tend to be more efficient than those on other models. Elevation data in the grid format is relatively abundant and inexpensive. However, the mesh structure prevents linear features from being represented sufficiently for large-scale applications.
- On the other hand, Triangulated irregular networks (TIN) represent surfaces using contiguous, non-overlapping triangle facets. One can estimate a surface value anywhere in the triangulation by averaging node values of nearby triangles, giving more weight and influence to those that are closer. The resolution of TINs can vary, because they can be more detailed in areas where the surface is more complex and less detailed in areas where the surface is simpler. The coordinates of the source data are maintained as part of the triangulation, so subsequent analysis, like interpolation, will produce the source data precisely; no information is lost. Unfortunately TINs tend to be expensive to build and process. The cost for having good source data can be high and processing them tends to be less efficient than grids. We can consider this step a detailed “microrelief” of the structures.

6. VRML reconstruction

The Virtual Reality Modelling Language (VRML), is a 3D modelling language for virtual reality applications using 3D scenes. On the basis of the definition of the VRML consortium, VRML is an open standard for 3D virtual and multimedia worlds, connected and linked by the Internet. In December 1997, VRML has been classified as an international standard (ISO/IEC-14772-1: 1997) from ISO (International Standard Organisation) and from the International Electro-technical Commission.

The VRML model was created in order to permit standard access on the web to interactive virtual environments; in fact, over a few years, it has become the most used language for the representation of 3D scenes online. Furthermore the new powerful versions of VRML (2.0 and VRML97) allow specific tools for animations and interactions with the users, very important in the field of virtual reality.

Furthermore, in our project, after the GIS applications we completed the 3D reconstruction of the tomb in VRML (figure10), so that the whole monument could be explored in real time, including textures (photo-mosaics of the walls) and geometry.

The VRML model can be visualised using freeware browsers that can be downloaded from the Internet; to view our reconstruction we use Cosmo Player (created by Silicon Graphics, http://www.cai.com/cosmo/). In this way access to VRML models is available to everybody. For instance the 3D models were created and explored using Cosmo Player 2.1 (Silicon Graphics) as a browser. Using the virtual console of the browser, and visualising the model, it is possible to move forward and back, turn left and right, tilt up and down, seeking, sliding, and so on. The interaction in real time and a user friendly interface allows us to describe the model as a cognitive model: in fact during the virtual navigation we perceive new information and new ways of visualisation, without the need to have GIS software for representing the data.

7. Conclusions

The digital project of the "Cristo Sole" tomb demonstrates that a visual information system is very important for a deep knowledge of the monument and of the pictorial content, whether for a scientific analysis, or for technological communication (*digital editing*). In fact the key point of the project was to test the possibility of using GIS systems in "monumental archaeology", mainly integrating 2D and 3D data sources. In this case we can talk of increased reality, because the digital technologies have introduced new levels of information, completely unknown before (Barceló et al. 2000). This approach opens new directions in particular for graphic representation, mainly because it encourages us to visualise multiple dynamic models, not only a simple "drawing". An open platform, such as GIS or another specific visual information system, gives the scientific community the possibility to interact, step by step, with a universe of information, always updateable and constantly increasing. In fact it is important to highlight that a virtual model is an open model, expandable with further documentation and interpretation layers (Barceló et al. 2000).

Moreover the use of a 3D tool (Microscribe arm) for creating the models has shown us another innovative system of micro-survey: at the same time it is possible to draw graphic outlines and to obtain architectonic geometry, verifying, point by point, the shape and dimension of the 3D surface.

Finally, in a few words, we can summarise the main results and the significant perspective that this project opens:

- 3D Data acquisition; new tools of 2D-3D data-acquisition through the use of a digital pantograph (Microscribe arm) have shown great potentialities for micro-topological graphic documentation, mainly in situations where it is difficult to operate with other systems.
- 3D Visual Information by a GIS application and spatial analyses. The creation of a visual information system (in our case GIS) has involved a different approach to the graphic representation of mural paintings. A dynamic visual modelling can open new perspectives in the study, analysis and the scientific communication of a painting's documentation.
- 3D Multi-layered analysis. The combination and the overlay of different sources of data increase the level of knowledge of the site on the basis of data-crossing; a more advanced interpretation depends on the superimposition of referenced data.
- Monitoring of the monument through time. For monuments such as the *Cristo Sole* tomb, it is fundamental to monitor the state of conservation, mainly analysing all the factors of alteration (chemical, physical, architectonic) in a multilayered visualisation (with the superimposition of graphic information).
- 3D Virtual reconstruction. By assembling every 3D component we have the possibility to visualise and study the model through an interactive and full visualisation, in particular excluding the difficulties existing with real views on site.
- The next stage of possible processing concerns the creation of a complete 3D database of the Vatican Necropolis with further information layers of non-destructive chemical-physical analyses.

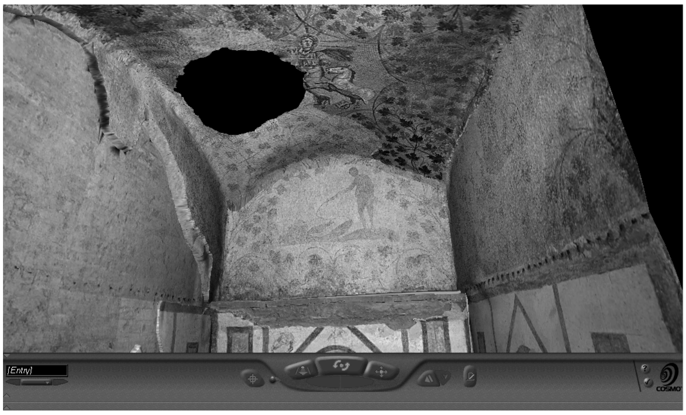

Figure 10: VRML reconstruction of the whole tomb.

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