2d-texture builds 3d-geometry.

New approaches in documenting early-Christian mural paintings at the Domitilla-Catacomb in Rome

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Abstract: The thorough documentation of the early Christian catacombs including their mural paintings is an important step towards researching iconographic content, their allocation within the complex, the chronological development and the explanation of the building. The referenced three-dimensional models within the architectural space make the catacombs accessible to any scientist without the necessity of going there in person.

This paper aims to show the latest methods documenting early Christian murals, which where applied in the Austrian START Project “The Domitilla Catacombs in Rome. Archeology, Architecture and History of Art of a Necropolis of the Late Antiquity.”

The method presented in November 2007 was further developed and partly replaced by new applications. The data acquisition for paintings to create photo-realistic rendered three-dimensional models is now managed by a common digital SLR camera mounted on a QTVR head used under best possible light conditions.The orientation of these models to the data acquired with an Image Laser Scanner is done by calibrated tiepoints. Following a photogrammetric registration of the images single textured models are created, which in a second step are merged together. The obvious benefit of this new method is the use of the colour information to generate three-dimensional models. This technique eliminates problems in the accuracy within the registration and mapping of freely taken images. Due to the high amount of data, at present the merging of all created models of the paintings and the model of the catacomb is still a problem that needs to be solved.

The solution to this will result in the creation of a model of the entire catacomb, which will allow a registration to the Roman GIS. Subsequently the data will be available to archeologists and architectural historians for further research.

In 2005 Norbert Zimmermann, project leader of the interdisciplinary research team, submitted his request to finance a six-year project for the complete documentation and study of the “Roman Domitilla Catacomb. Archaeology, Architecture and Art History of a Late Roman Cemetery”. Content of this paper are the enhancements in the acquisition methods in the FWF START project.

From the very beginning the interaction between archaeology and high-tech methods such as terrestrial laser scanning in building research have raised high expectations. From the date of its rediscovery at the beginning of the 17th century the Domitilla Catacomb fascinated the scientist, but so far did not allow exact topographic and geometrical documentation, primarily because of its size but also due to its underground location. Although traditional surveying methods allowed to create schematic plans in certain parts of the catacomb, the entire catacomb in its three-dimensional complexity could not be recorded.

Laser scanning, a method known only recently in archeology and the other humanities and still not completely accepted, provided an appropriate method of documentation. Coming from topography, city monitoring and as-built surveying of technical infrastructures, in terms of archeology and building documentation laser scanning facilitates the description in all three dimensions which is not limited to selective ground plans and sectional views.

Criticism of laser scanning comes primarily from archaeologists but also from architects; but this criticism can be easily invalidated by a reasonable and directed use of this method (WEFERLING; HEINE, WULF 2001; RIEDEL, HEINE, HENZE 2006).

In 2006 the Domitilla START Project was set up at the Institute for Studies of Ancient Cultures which is located at the Austrian Academy of Sciences.[1] The project was financed by the Austrian Ministry of Education, Sciences and Infrastructure and is managed by the Austrian science fund FWF. The documentation work is performed by the national partner, the Institute of History of Art, Building Archaeology and Restoration of the Vienna University of Technology.[2]

The project team consists of archaeologists and architects[3] and is further supported by geodesists and mathematicians of the TU Wien, the TU Wien ILSCAN Center of Competence[4], as well as by Riegl Laser Measurement Systems in Horn (Lower Austria)[5]. In Rome, our partners are the Pontificia Comissione di Archaeologia Sacra[6], who administer all Roman Catacombs, and, with logistic support, the German Archaeological Institute and the Austrian Historical Institute.

Since about one year ago the Cultural Heritage Imaging in California[7], Adam Technology[8], Perth, Australia and the Istituto di scienza e tecnologie dell’informazione “Alessandro Faedo” of the Consiglio Nazionale della Ricerche in Pisa[9], Italy are very important partners.

Fig. 1 - A. Bosio, 1632: First Documentation of Roman Catacombs

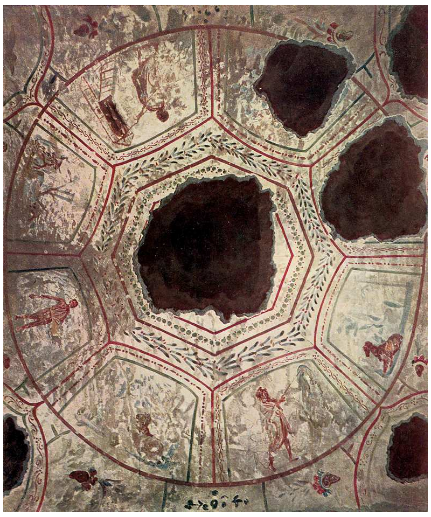

Fig. 2 – Wilpert, 1903 post colourised Photography King David, ceiling

The Object

The Roman Domitilla Catacomb is located on via Ardeatina, in the vicinities of a series of other antique graveyards outside the Roman city walls. For its enormous and until today unmeasured extension it is considered to be the largest catacomb in Rome. The galleries have been dug up to 4 stories into the Roman tuff while taking advantage of the natural stability of the different layers of tuff. Covering a life span of roughly four centuries Domitilla incorporates all stages of a typical catacomb evolution. Beginning with some isolated pagan tombs of the second century and the earliest Christian burials, the development later leads to the large Christian graveyards of the 3rd and 4th centuries, finally evolving in an important pilgrimage sanctuary, the underground basilica of Nereus and Achilleus. In 400 years about 70.000 tombs have been used for up to 100.000 or even more burials. The last written document concerning the Domitilla-Catacombe dates back into the 9th century. In 1593 the catacomb was rediscoverd by Antonio Bosio who explored some regions and prepared the first documentation not only of the Domitilla Catacomb. He believed that this catacomb was part of the nearby Callistus Catacomb which was disproved by De Rossi at the end of the 19th century. De Rossi also discovered the subterranean basilica. But Domitilla is not only famous for its underground architecture: with some ninety decorated burial environments, it also comprises one of the world’s biggest treasures of Early Christian painting. Even after 400 years of research and study, this artistically rich and historically important monument – like most other Roman catacombs – has not been studied nor published as one archaeological entity. For example the only existing plan of the catacomb is an intuitional plan of Nestori provided in 1975 (Fig. 5).
Here, laser scanning and photogrammetry are truly capable of bridging the gap. As they allow for the combined acquisition of full 3d and colour information, these techniques permit the fulfilment of an urgent desideratum in early Christian archaeology: a complete documentation serving as a database to favour all kinds of scientific debate on the monument.

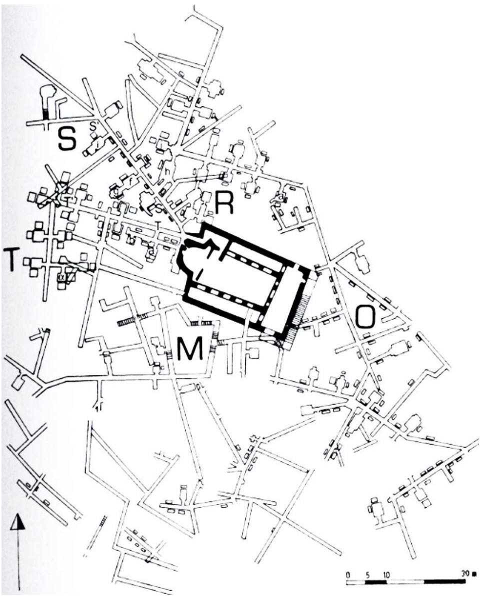

Fig. 3 – Palombi, 1904

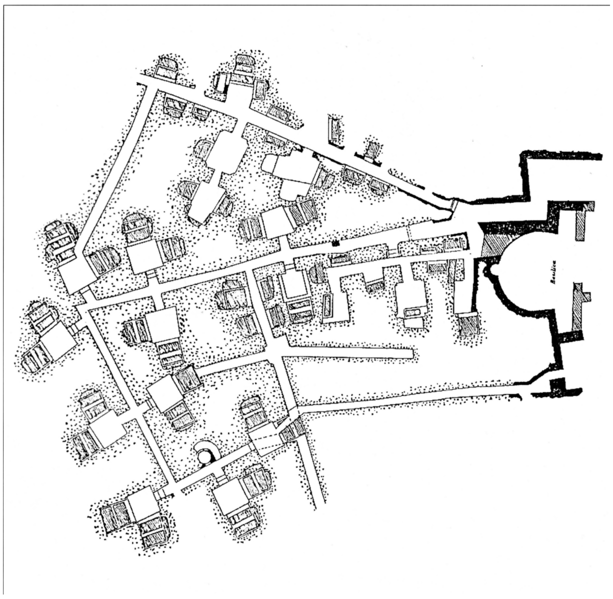

Fig. 4 – Styder, 1910-1920

Fig. 5 – Nestori, 1975

The Goals

The main goal of the project is the creation of a complete, high-quality documentation of the architecture and the paintings of the catacomb. The processing of the 3D laser scanning data for all methodological approaches of archaeological debate is carried out in two different ways of different qualities.

In the first place there is the complete geometric presentation of the catacomb based on image laser scanner data. (Fig. 6) The acquisition of these data consumes a vast amount of time due to the size of the catacomb. The subsequent creation of a closed surface model requires a lot of time as well but also needs sufficient computing capacities to be able to process a huge amount of data. After the completion of the recording on the site, presumably in January 2009, processing will start.

Another task on which we have primarily focused in recent years, consists in compiling a repertory of all Domitilly paintings (Fig. 7). Its aim is to deliver 3D models of all paintings in their architectural context, to be made available to scientists for further archaeological, historical and building historical research.

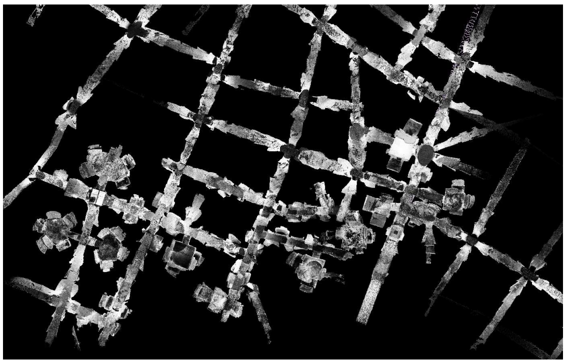

Fig. 6 – Domitilla, point cloud, 2007

Fig. 7 – Cubiculum of Orpheus in photography

Surveying methods

With its dimensions of about 300 per 300 meters and up to four levels deep, the Domitilla catacomb is one of the larger and more complex monuments. Antique staircases connect the four stories which are dug irregularly into the roman tuff and have grown together from different directions. Antique light wells, in most cases closed today for safety reasons, are located in front of important cubiculae and at large crossings, and connect the different stories vertically. The coalescence of the catacomb from locally separated hypogea led to an irregular structure which follows a grid only in very rare cases. Nevertheless there are recurring structures within the catacomb, primarily including the long galleries for community burials and the cubiculae of richer people and professions some of which are provided with stucco and paintings.

In order to meet the complexity of the structure in surveying, the acquisition on site was divided into three different methods. First of all a tacheometric basic grid was laid through the entire catacomb, using a Leica TCRM 1103i total station. The traverses were erected along the main corridors and the staircases to create a basic grid with long base-lines.

In order to be able to document the amorphous structure and surface of the entire catacomb, we used an Image-Laser-Scanner LMS Z420i of the Austrian company Riegl Laser Measurement Systems in Horn (Fig. 8). With a field of view of 80 x 360° and a range of 1 to 800 meters the scanner has a standard deviation of ±8mm. In addition a calibrated digital camera can be added to achieve color information to the 3D scans. In our case it was a Nikon D100 with a 14mm objective (JANSE, STUDNISCKA, FORKERT, HARING, KAGER 2004).

For the documentation of a good 90 paintings a high resolution texture is of prime importance. Therefore photographs were taken with a Canon EOS 1Ds digital camera with a 14 mm objective. In addition to this, the challenging light conditions underground required the use of a professional lighting system which we found in the very flexible light panels made by KINO FLO [10], which are well known in professional photography and film production (Fig. 9).

Fig. 8 – Laser scanner Riegl LMS Z420i on site Mensores

Fig. 9 – Photography of early Christian wall paintings at Cubiculum of

Post processing

The following chapter presents the new method to create accurate high-resolution texture 3D models of the paintings of the catacomb. The major problem of the method used until last year was the texturing of the meshed models.

Freely taken photographs had to be registered manually by setting tie points on the meshed model. Since the surface structure of a plastered wall shows hardly any distinctive characteristics it was a time consuming work and in some cases led only to unsatisfying results.

The present method allows to create the model itself from its later texture. Paying attention to certain rules pictures were taken, registered to one another and meshed.

For the generation of a meshed, textured 3D model different software packages are used; the four most important are 3DM CalibCam and 3DM Analyst from Adam Technology and MeshLab [11] and Octree Merge from ISTI. In addition RapidForm[12] and Photoshop[13] are used.

3DM CalibCam permits the registration of the taken images, 3DM Analyst the generation of meshed models and MeshLab and Octree Merge the creation of a complete high-quality textured model.

Prior to taking photographs, an acquisition concept should be developed, especially for complex objects. Essential conditions for the optimal registration and meshing are the sufficient overlapping of the individual images and positions (Fig. 10), and the optimum ratio between basis and distance to the object. In the catacomb we find two different recurring situations asking for different concepts which can be slightly modified if required.

Many of paintings to be registered are located in cubiculae or galleries. For the meshing it is important that every single point to be meshed is visible on at least two different pictures, which were taken in a distance-basis ratio of 1:8 to 1:2. The “strip photography” was used for the often very narrow galleries. In the mostly nearly quadratic cubiculae with a side length of about 2.5 meters a different concept was applied. A camera was positioned in all four corners, taking photographs of their opposite walls (Fig. 11). For bigger or rectangular cubiculae an additional camera was positioned at the longer side to ensure the distance-basis ratio of 1:8 to 1:2.

Depending on their depth photographs of the arcosols were taken either by single pictures or using the strip photography method. The narrow entrances to the cubiculae were also taken by strip photography, as were the ceilings and floors of the cubiculae and the galleries. Some more complex

rooms ask for a variation or a reasonable combination of these two concepts to ensure that all relevant surfaces have been sufficiently documented.
In order to take photographs of a complete cubiculum of average size, with two arcosols and the entrance, some 120 to 150 images are necessary. For long gallery sections with paintings on both sides and on the ceiling more than 500 may be needed.

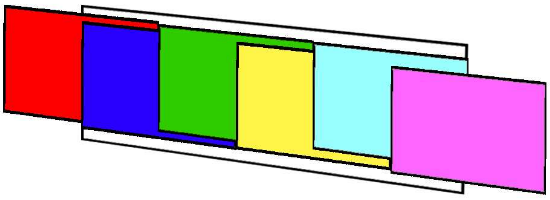

Fig. 10 – Strip Photography, overlap between pictures

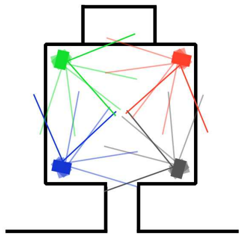

Fig. 11 – Camera positions in a rectangular cubiculum

At the first acquisition campaign last autumn sequences of exposures were taken to achieve photos as perfect as possible for the later texture. However, during the post processing process we discovered that sequences of exposures are not necessary as in any case the differences in lighting must be corrected in Photoshop.

After the acquisition the images are loaded into the 3DM CalibCam software. During the last year this software was improved by the developers so that currently more than 500 images can be registered in less than 15 minutes, without setting tie points. That was not possible in the beginning. The images had to be divided into several projects and the registration process for about 200 images took as long as 2 hours, if it worked at all and if the lack of computing capacities did not prevent results.

In order to achieve better results in meshing the models, a panoramic tripod head may be used to take the images. This panoramic tripod head allows to rotate the camera around the focus of the lens which makes it possible to create stitched photos taken from the very same camera position. Images taken from one position with the panoramic tripod head can be handled as “station” in CalibCam, which helps to accelerate the registration process.
In order to register the images, in the first place as many stations as needed are created and the corresponding images are loaded, and in the second place the images – even within one station – must be connected by tie points. CalibCam offers a tool for the automatic generation of “Relative-Only-Points”, but this tool delivers satisfying results only for a very small amount of images. Hence “Relative-Only-Points” have to be generated for every pair of images (Fig. 12).

3DM CalibCam calculates both the inner calibration of the camera and the external calibration of the single images. Naturally the calculation of the inner calibration takes longer, the calculation of the external calibration can be used to check very quickly the correct position of the “Relative-Only-Points” and accurate registration of the images. The rendered result is the orientation of the individual camera positions and the “Relative-Only-Points” in the three-dimensional space (Fig. 13).

Until now no scale has been implemented and without a scale the object floats in an undefined position in virtual space. CalibCam offers also the possibility to take over coordinates from superior systems. With the total station at least three, for larger areas even more – tie points are surveyed into the existing coordinate system of the Domitilla catacomb. In our case we use reflecting targets from the scanning due to better visibility. The use of natural points is also possible. After recalculating the orientation the object was moved and rotated to the right place and scaled into the right size.

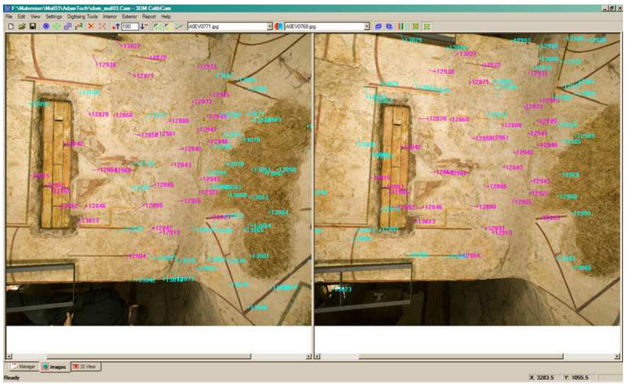

Fig. 12 – 3DM CalibCam, Tiepoints in two different images

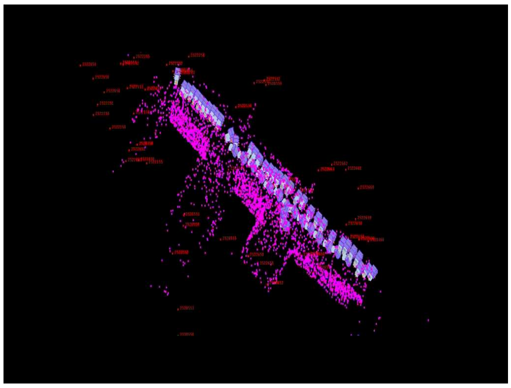

Fig. 13 – 3DM CalibCam, camera positions, Relative-Only-Points

The software also allows the use of images taken by different cameras, or by the same camera but with different objectives in the one project.

After the successful registration the meshing can be started. The principle of the photogrammetric spatial intersection allows the meshing of only two pictures to one part mesh. Hence it is essential to follow a strict plan during the acquisition and the meshing.

As mentioned above its possible for images made with the panoramic tripod head from one position to be computed into one big or at least bigger image. This is possible only within the natural limits of an objective. Images with a 360° angle can’t be generated. Furthermore attention should be paid during the meshing process that the individual models overlap.

After loading two images some parameters can be adjusted which more or less influence the result, or which will lead to a result in the first place. The value “match similarity” indicates the similarity of pixels in the two images with which a three-dimensional point should be created, which in turn will influence the accuracy and the resolution of the model. In some cases the changing of the “Image Projection” even allows the meshing of non-meshable images.

The outcome is now a high-resolution meshed and already textured three-dimensional model (Fig. 14 and 15). In order to display an entire painting it will be necessary to mesh all areas in part meshes with 3DM Analyst. A standard cubiculum can be covered by about 25 to 30 part meshes whereas a painted gallery will need as many as 100 or even more.

Although the meshing works quite good in 3DM Analyst it is necessary to clean the part models which can be done either with RapidForm, Geomagic[14] or any other commercial 3D software or with the OpenSource Software of the Istituto di scienza e tecnologie dell'informazione called MeshLab.

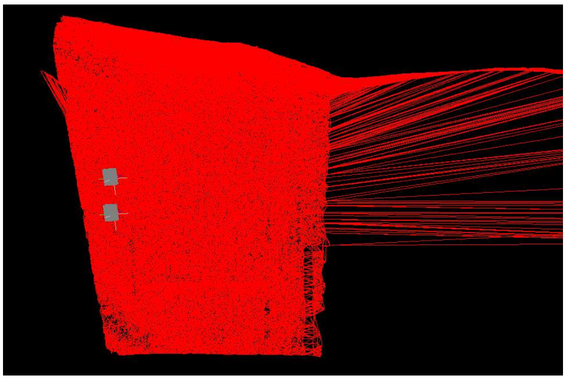

Fig. 14 – 3DM Analyst, created 3D model wireframe

Fig. 15 – 3DM Analyst, created 3D model textured

After generating all these part models they must be merged to one textured model with a consistent geometry.

There are two possibilities of describing the texture of a meshed model. One is texture mapping by giving texture information to each single triangle of a mesh. This leads to a very big data volume. The second possibility is to give every vertex the color by a projection ray through the oriented picture onto the surface of the mesh. So it is obvious that the higher the resolution of the model, the higher the resolution of the texture.

The cleaned models created by 3DM Analyst are now in the format .obj[15] for further processing; it is essential to convert all part models into .ply-files[16] which can be done automatically. During this process every vertex obtains the color. The color of a polygon is mixed out of the color of the adjacent vertices.

Now all part models are loaded in one project into MeshLab where some further cleaning can be performed. The file created here contains the name of all single part models and their position, orientation and scale in the virtual space.

Another software developed by ISTI is Octree Merge. The file created from MeshLab can be imported into Octree Merge which takes over all important information stored by MeshLab. At this stage the resolution of the final model can be influenced once again.

This software offers a tool to create a clean, non redundant surface. In a first step the octree is built. The more octree levels are generated the more detailed the final model will become. The resolution should orient itself to the resolution coming from the mesh generation in 3DM Analyst. A higher resolution than this will only produce more data without improving the quality of the texture.

The following step allows to merge the part meshes in subblocks to be sure that the available computing power can handle the data. The generated subblocks can be now merged in MeshLab to one single mesh where final cleaning can be performed.

So far the resolution of meshes generated with 3DM Analyst is not high enough to achieve an appropriate texture quality in the final mesh. Our partner in Pisa, the Istituto di scienza e tecnologie dell'informazione, is working on a tool to first densify the mesh and in a second step, to recalculate the texture onto the mesh. With the higher resolution of the basic model the quality of the texture will automatically improve.
With the implementation of this two new processes the quality of the models of the paintings should have improved that much that models with high resolution texture with a proportional small amount of data are available. Furthermore, a viewer working with different levels of details offers the possibility to watch the model in real time, even with a standard computer.

Fig. 16 – Texture mapping

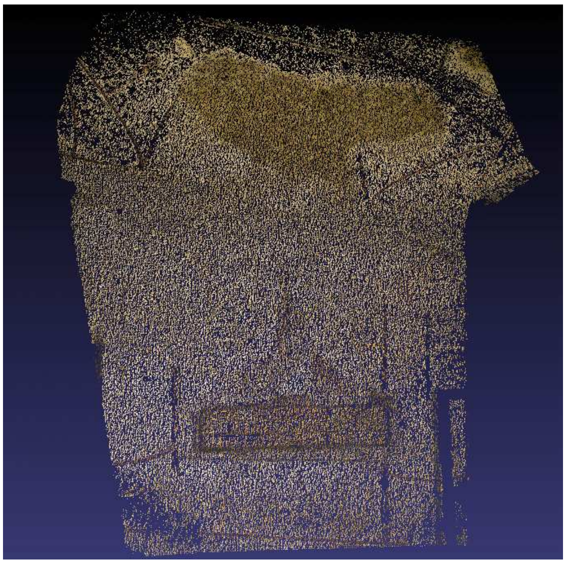

Fig. 17 – Color per Vertex

Conclusio

The method of working with texture mapping which was presented last year required, without on-site data acquisition, two or even more weeks of work to achieve a high-resolution texture model of a standard cubiculum.

With this new working process the most time consuming work step is the setting of the tie points on the images and the subsequent calculating of the orientation which takes one, or maybe one and a half day. The following steps should be completed in half a day, maybe in one day should there be any problems. With this new developed workflow we were able to reduce the post-processing time by 20 percent in comparison with the old method.
This method could finally offer a tool to mesh and texture limited but quite complex archaeological objects, without major investments in software packages, in a clear time frame.

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[4] Homepage TU-WIL Scan Center of Competence: http://tuwilscan.cg.tuwien.ac.at/

[5] Homepage of Riegl Laser Measurement Systems: http://www.riegl.com

[6] We warmly thank the secretary of the PCAS, Prof. F. Bisconti, and the inspector of the Roman catacombs, Dr. R. Giuliani, for the commission and all kind support and help.

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[8] Homepage of Adam Technology http://www.adamtech.com.au/

[9] Homepage of ISTI http://www.isti.cnr.it/index.html *Not available anymore.*

[10] Homepage of Kino Flo Inc., Homepage: http://www.kinoflo.com

[11] Meshlab was developed by Paolo Cignoni, Istituto di scienza e tecnologie dell'informazione "Alessandro Faedo" of the Consiglio Nazionale della Ricerche in Pisa

[12] Rapidform is a brand of INUS Technology Inc., Homepage: www.rapidform.com

[13] Homepage of Adobe: www.adobe.com/products/photoshop

[14] Homepage of Geomagic, Inc.: www.geomagic.com

[15] Wavefront is a useful standard for representing polygonal data in ASCII form

[16] Polygon File Format, this format was designed to store three-dimensional data from 3D scanners