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Applications of High-Resolution 3D Imaging to the Recording and Conservation of Ancient Crypt and Grotto Sites

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Abstract:
The National Research Council of Canada (NRC) has collaborated with numerous Canadian and international heritage institutions on the development of a complete suite of 3D imaging technologies for archival quality imaging, analysis and display of 3D models of museum objects and heritage sites including ancient crypt and grottos. The technology includes high-resolution laser scanner systems for recording museum objects and heritage sites, software for modeling and display of the 3D models as well as for examination, comparison and searching of 3D data. For example, we have collaborated on projects to prepare a 3D VR tour of the Tomb of Tutankhamun, for recording accurate geometric 3D models the Tomb of St. James in Jerusalem and of the Dazu (Bei Shan) Buddhist rock carvings and sculptures site in China, as well as for recording an archival quality photo-realistic 3D digital model of the Byzantine crypt of Santa Cristina in Italy. This paper presents an overview of this technology related to its applications for recording ancient crypt and grotto sites.

Keywords:
3D imaging; heritage recording; conservation documentation; shape and appearance modeling; virtual environments.

Introduction:

The accurate recording of ancient crypt and grotto sites is a challenging task. The sites have either formed naturally or been carved from the surrounding rock and typically the walls, floors, and ceilings have an irregular surface shape and the paintings follow the contours of the rock surface over large areas. These features—particularly the shape of the rock surface—are difficult to record, measure, compare and display using conventional photographic and conservation recording techniques.
Dating back to 1984, the National Research Council of Canada (NRC) has collaborated with numerous Canadian and international museums and heritage institutions as well as with industrial partners on the development of a complete suite of 3D imaging technology tools for a wide range of museum and heritage recording applications. In the process, the staff has developed a great deal of field expertise on the imaging of museum collections as well as archaeological and architectural sites.

High-resolution 3D models of museum objects and heritage sites contain a wealth of information that can be examined and analyzed for a variety of conservation, research, and display applications. For example, in the case of a site that must be closed or subjected to limited access for conservation reasons, an immersive 3D virtual reality theater can be used to enable visitors to "virtually" visit the site. Researchers can magnify or zoom in on a 3D model to examine, measure, and compare fine surface details for signs of deterioration or to examine tool mark or brush stroke features.

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Computer-based visual enhancement and analysis techniques can be applied to accomplish some "virtual restoration" techniques that cannot readily be accomplished using traditional conservation techniques. For example, sections of paintings that have been removed from a grotto to a distant museum can be scanned and digitally reintegrated into a 3D model of their original grotto. Enhancement techniques can be used to improve the legibility of faded images or inscriptions as well as to remove graffiti that has defaced the images. Structural elements that have been added at a later date can be virtually removed to enable the site to be viewed in its proper historical context. Finally, 3D models recorded before and after an actual conservation treatment, can serve as vital archival record for ongoing site monitoring and maintenance.

The objective of this paper is to present an overview of this technology with reference to its applications to the conservation and recording of ancient crypt and grotto sites.

NRC 3D Imaging Technology:
NRC's 3D technology suite includes the development of three high-resolution laser scanners for digitizing museum objects as well as archaeological and architectural sites. Software for the preparation of accurate 3D models and for analysis and comparison of 3D data for conservation and art historical examinations has been developed (Taylor et al. 2003; Godin et al. 2002). Tools have also been developed for cost effective interactive display and content based (shape searching) retrieval of virtualized 3D data (Paquet et al. 2003) and for image based 3D modeling of complex environments (El-Hakim 2002).

The three 3D imaging systems, the ***High Resolution Color Laser Scanner***, the ***Biris 3D Laser Camera*** and the ***Large Volume or "Big Scan" Laser Scanner*** (Figure 1), are designed for different imaging applications. The ***High Resolution Color Laser Scanner*** simultaneously digitizes the 3D shape and color of traditional museum objects including archaeological and ethnographic collections, paintings, small sculptures and natural history specimens and provides a maximum depth resolution of 10 microns (0.010 mm) in the z direction at sampling intervals in the x and y directions of 50 microns (0.050 mm) (Baribeau et al. 1992; Baribeau et al. 1996). On a commercial basis, NRC has licensed this technology to Arius3D (http://www.arius3d.com).

The ***Biris 3D Laser Camera*** is a portable monochrome 3D imaging system developed to work in difficult environments where reliability, robustness, and ease of maintenance are important. As such, it is ideally suited for archaeological and architectural field recording applications, where a record of the three-dimensional shape of an object or a specific site feature is required (Beraldin et al. 1998; Farouk et al. 2003). The Biris system has a maximum range accuracy of 0.03 mm (30 microns) and is available commercially as the from the ShapeGrabber Corporation (http://www.shapegrabber.com/). MCG3D (formerly Innovision 3D) provides a commercial heritage scanning service using this scanner (http://www.MCG3D.com).

The ***Large Volume or "Big Scan" Laser Scanner*** is a research prototype system currently under development for high-resolution 3D digitization of large structures, which generally are larger in size than those recorded using the Biris System (Rioux et al. 1997). The system allows 3D recordings at a camera to object distance (camera standoff) which ranges from 50 cm to 10 m. At a standoff of 75 cm, it provides a resolution of 0.07 mm (70 microns).

For ***Modeling, Examination and Display*** of the 3D image data recorded using NRC 3D imaging systems we have collaborated with InnovMetric Software Inc. (http://www.innovmetric.com) on the development of the suite of PolyWorks™ software tools. Using PolyWorks on a Unix or Windows platform, the multiple view data sets recorded by the scanner are merged into a seamless archival quality high-resolution 3D digital model of the object (Soucy et al. 1996). Once the 3D model is prepared, for conservation applications, the PolyWorks IMInspect module can be used to examine and measure features on the models as well as compare the shape of different models scanned at different time periods. PolyWorks also contains editing and data compression tools which enable the creation of texture maps for reduced models for web applications. The models can also be transferred into different formats and used for a variety of other heritage applications such as interactive 3D display and the preparation of replicas.

To prepare quality ***photo-realistic 3D digital models*** of Crypts and Grottos which contain both color and shape data, a technique has been developed which is based on mapping geometrically correct high-resolution texture maps recorded using a digital camera to the 3D shape data recorded using a laser scanner (Beraldin et al. 2002).

Applications of 3D Imaging for Recording Crypt and Grotto Sites:

As noted in the Abstract, we have collaborated with various partners on projects to prepare a 3D VR tour of the Tomb of Tutankhamun, for recording accurate geometric 3D models of the Tomb of St. James in Israel and a niche at the Dazu (Bei Shan) Buddhist rock carving site in China and for recording an archival quality photo-realistic 3D digital model of the Byzantine crypt of Santa Cristina in Italy. The following is an overview of these projects.

3D VR Tour of the Tomb Tutankhamun

Interactive 3D Virtualized Reality Systems are increasingly being used for museum display and heritage site interpretation applications. In a 3D VR display, the simulation models are created from 3D imaging data recorded directly from the site or object (Boulanger et al. 1998). The 3D display provides a real-time interaction that gives the user 3D immersion in the model world and direct manipulation of objects. These systems offer the potential of accurate "digital reconstruction" of archaeological and historic sites as well as "digital repatriation" of models of artifacts, which have been removed to distant museums, back into the virtualized model of the original site.

In May 1998, the exhibition, Mysteries of Egypt opened at the Canadian Museum of Civilization (CMC) in conjunction with the world première of the IMAX movie *Mysteries of Egypt*. As a new feature, the Museum collaborated with NRC and several partners, on the construction of a Virtual Reality 3D Theatre (Figure 2a) and on the production of a 3D VR Tour of the Tomb Tutankhamun (MacDonald et al. 1999). The Tutankhamun tour featured a virtual visit into the burial chamber. Visitors to the actual tomb can enter only the first undecorated antechamber; a railing prevents entry into the burial chamber. One of the theme messages conveyed to visitors during the tour was that unlike visits to the actual tomb – which can result in environmental and physical damage to the tomb – VR visits enable detailed visits without the prospect of actual damage to the tomb.

Rather than imaging the Tomb directly at the site, the 3D model (Figure 2b) was prepared from survey data provided by the Theban Mapping Project using a CAD program. Texture maps of the paintings in the burial chamber were mapped on the 3D model using detailed color slides provided by the Getty Conservation Institute. Permission to use the survey data and slides was granted by the Supreme Council of Antiquities in Egypt.

To illustrate the concept of "digital repatriation", a 3D model of a replica of Tutankhamun's funeral mask was integrated into the 3D model of the tomb. The replica was scanned at the Museum using a commercial 3D scanner, which was based on NRC's High Resolution Color Laser Scanner (Figure 3a). The mask model was placed inside the sarcophagus where it was found and was introduced into the display at the conclusion of the Tour to demonstrate how models of objects, which are originally associated with a site, can be reintegrated into a digital reconstruction (Figure 3b).

The 3D VR tour received very positive responses from the media and the general public. A review in the Globe and Mail – one of Canada's major newspapers – noted "*the major innovation in the exhibition is the 3D virtual-reality tour of the tomb*". A visitor survey undertaken by the Museum during the Exhibition found that 86% of the respondents got the message *"virtual reality offers a way of seeing World Heritage Sites without causing further damage to these sites"*. Two of the more interesting professional level comments came from a representative from the Supreme Council of Antiquities during a visit to the Exhibition. First, it was suggested that it would be useful to have a 3D VR theatre at the Tomb itself. It would enable visitors to virtually visit the burial chamber – which is closed in the Tomb itself. The second, and most poignant observation was that the most obvious visual limitation was that since the in 3D model of the Tomb had been constructed from survey data using a CAD program, the walls were flat – similar to a normal office building. He noted that the walls in the Tomb have an irregular surface and that it would have been a much more realistic display if the tomb had been scanned to record and display the actual irregular shape details of the Tomb.

Conservation Documentation: St. James' Tomb, Israel and Buddhist rock carvings, China.
Accurate and geometrically correct 3D models of crypts and grottos provide archival quality conservation records which can be used to document the physical condition of the rock surface at the time it was scanned as well as to monitor ongoing change.

In 1996, in collaboration with the Israel Antiquities Authority, we undertook a project to demonstrate the application of the ***Large Volume or "Big Scan" Laser Scanner*** for conservation documentation of the Arcosolia Room of the Tomb of St. James in Israel (Figure 4a). Subsequently, in 1999, in collaboration with the Canadian Foundation for the Preservation of Chinese Cultural and Historical Treasures, MCG3D – one of NRC's industrial partners – and the State Administration of Cultural Heritage (SACH), we undertook a similar pilot project to demonstrate the application of the ***Biris 3D Laser Scanner*** technology for recording Buddhist rock carvings at the Dazu (Big Foot) cliffside site in Sichuan Province, China (Figure 4b).

The Arcosolia Room of St. James Tomb, which measures approximately 2 m x 2 m x 1.8 m in height, has been carved in the rock, and its interior surfaces are rough and irregular (Figure 5a). The Buddhist rock carving in Niche #147 at the Dazu (Big Foot) cliffside site is smaller - 97 cm x 67 cm – however, since it has also been sculpted from the rock and subsequently exposed to the elements, it has a rough and weathered surface (Figure 5b). Crypts, grottos and rock carvings, which have surfaces of this nature, are often difficult to accurately record at a high level of detail using conventional techniques. For conservation applications, once a 3D digital model is prepared, all the resources of computer graphics and computer vision can be used to display and analyze the results. In contrast to photographs, the actual geometric 3D position of each point on the surface of the model is available, thus allowing detailed examination and comparison of surface features as well as accurate dimensional measurements between points of interest. For example, one can zoom in and examine and measure an area such as a crack or a loss to monitor ongoing changes.

In addition, the 3D model data can be used to generate new displays of profiles and features, which cannot be done using conventional techniques. For example,
Figure 6 shows the entire outer shape of the Arcosolia Room as seen from an artificial point of view embedded in the rock (Godin et al. 2000).

Photo-Realistic 3D Model of the Byzantine Crypt of Santa Cristina in Italy
In 2002, NRC collaborated with the SIBA Coordination at the University of Lecce in Italy to apply a technique, which combines photogrammetry, 2D digital photography and 3D scanning to prepare a photo-realistic 3D model of the Byzantine Crypt of Santa Cristina in Carpignano, Italy. The

Crypt, excavated around the 9th century c.e., measures about 16.5 m x 10 m x 2.5 m and has a number of well-preserved frescoes on the walls.

To model the Crypt, a photogrammetric technique was used for the outside (i.e. main and secondary entrances located above the Crypt) and a commercial laser range scanner was used to provide plain clouds of 3D points for the interior of the Crypt itself (located underground). Texture was acquired with a high-resolution 6 mega-pixel digital camera. The 2D digital photographs were not only used to produce 3D textured models but also to perform geometric measurements. Proper camera calibration and bundle adjustment algorithms combine in digital photogrammetry to give accurate feature coordinates and reliable pose estimations (Beraldin et al. 2002).

The 3D modeling of environments or heritage sites like the Byzantine Crypt is more difficult than object modeling because of the size and complexity involved. Yet, techniques for the creation of accurate and photo-realistic 3D models of sites are important. The 2D photographs that are conventionally used to document and illustrate the site don't show the important aspect of the three-dimensionality of the site. When combined with immersive technologies, a photo-realistic 3D model can be used to prepare a virtual site visit, which is a new and appealing way to study, promote - or even protect - a cultural site (Figure 7). To compliment or help plan physical restoration of the site, "virtual restoration" can be applied directly to the digital copy. For example, faded images can be enhanced (Figure 8) and architectural elements that have been added over the years can be removed. To do, so however, it is important to create a geometrically correct visually realistic and highly detailed 3D model (Beraldin et al. 2002).

Conclusions:

Three-dimensional models of ancient crypts and grottos provide an important new level of documentation, which can be used for a variety of conservation, research and display applications. Perhaps the most important is that 3D VR theatre displays of accurate virtualized models of the sites can be used to enable very realistic virtual visits to the sites in lieu of actual site visits, which endanger the site itself. A second very important application is the use of the data to reliably monitor the condition and stability of the site.

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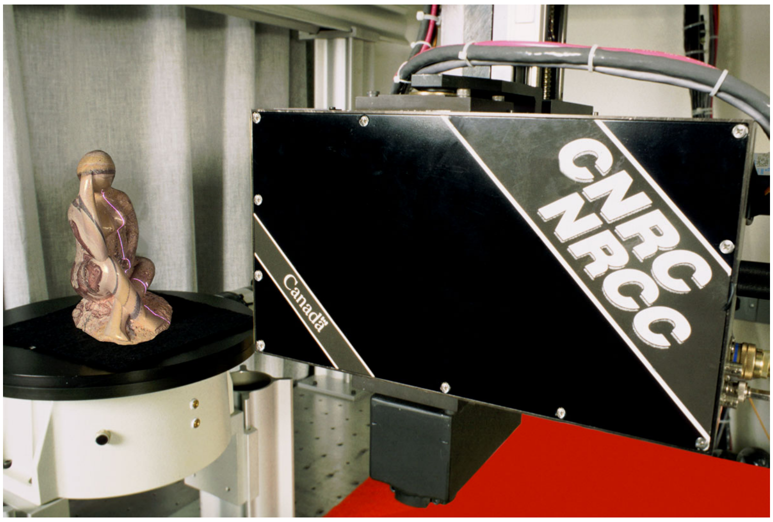
Figures



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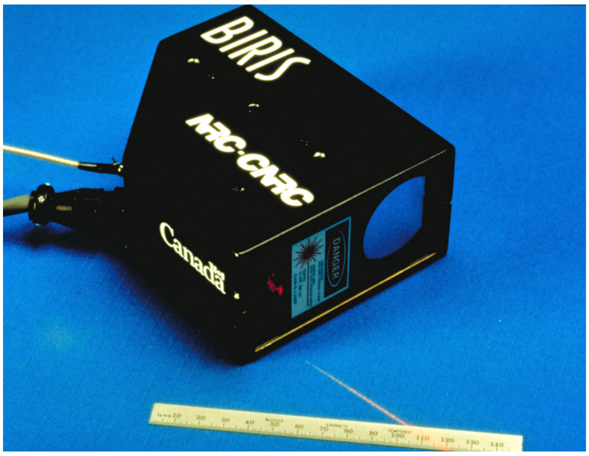

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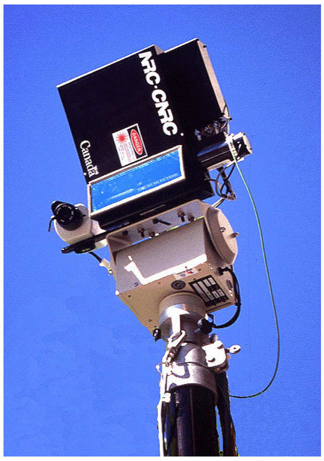
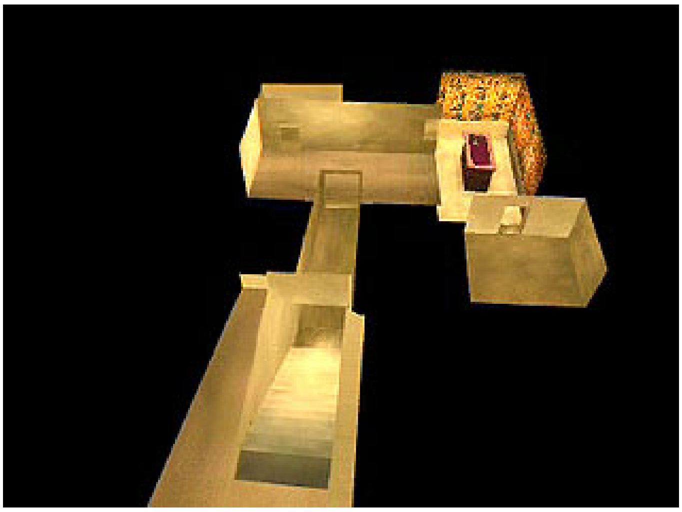


c

Figure 1. (a) The High Resolution Color Laser Scanner imaging a figurine. (b) The Biris 3D Laser Camera is a compact and robust monochrome camera for field recording applications. (c) The Large Volume "Big Scan" Laser Scanner is used for scanning large sites and structures.

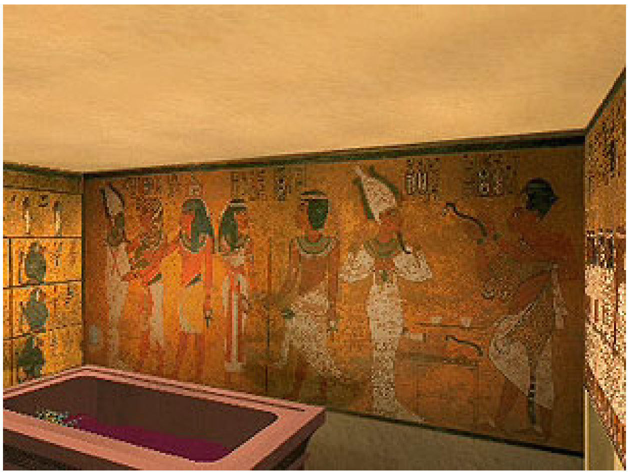
a



b

Figure 2. (a) The CMC 3D VR Theatre for the Tour of the Tomb of Tutankhamun. The tour was projected in stereo on a 3m x 4.6 m screen using overhead projection. (b) The 3D model of the tomb was prepared using ArchiCAD from survey data, by the Theban Mapping Project. Texture maps of the paintings in the burial chamber obtained from detailed color slides taken during a conservation survey in 1992 by the Getty Conservation Institute were mapped on the 3D model.

a



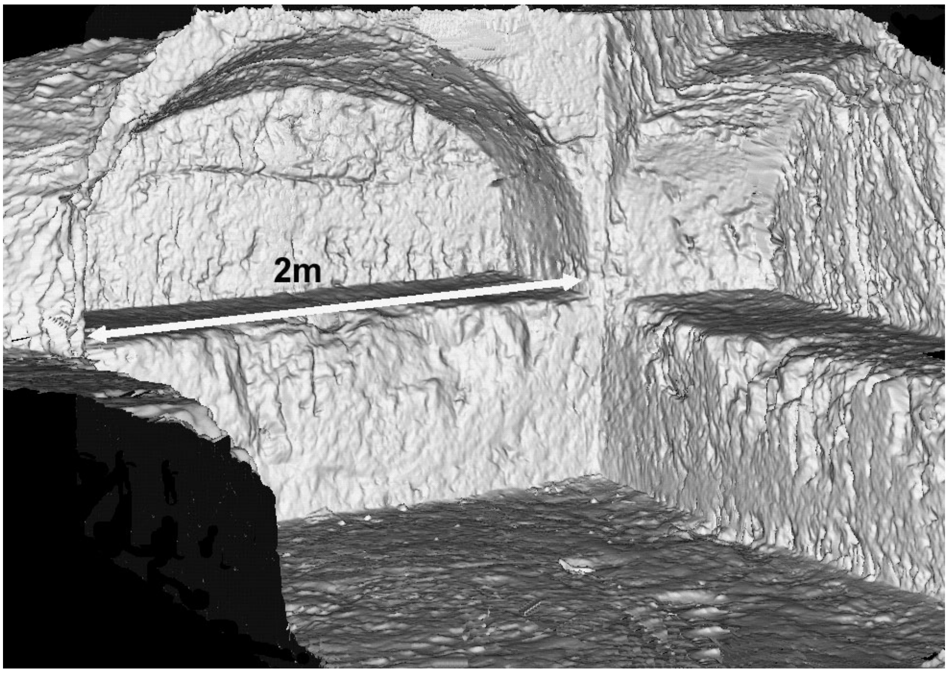
b

Figure 3. (a) A 3D laser scanner at the Canadian Museum of Civilization was used to scan a replica of Tutankhamun's funeral mask and to prepare a 3D digital model of the mask which was "digitally repatriated" into the model of the tomb. (b) View of the 3D tomb model looking into the burial chamber from the antechamber. The digital model of Tutankhamun's funeral mask is just visible in the sarcophagus. In the actual tomb, a railing at this point prevents visitors from entering the burial chamber.

a

b

Figure 4: (a) The Large Volume or Big Scan Scanner set up to scan the entrance to the the Arcosolia Room of the Tomb of St. James in Israel. The camera is shown mounted on a tripod with the computer controller on the right. (b) The Biris camera set up on a linear translation stage to scan Niche #147 at the Buddhist rock carving site at Dazu in China.



a

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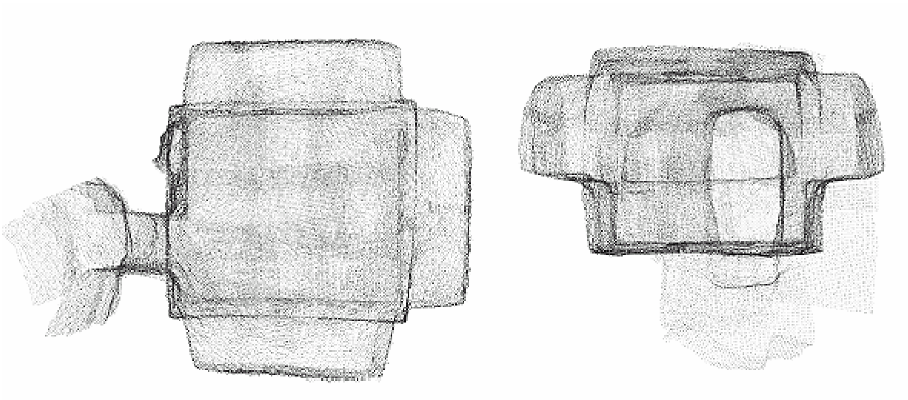
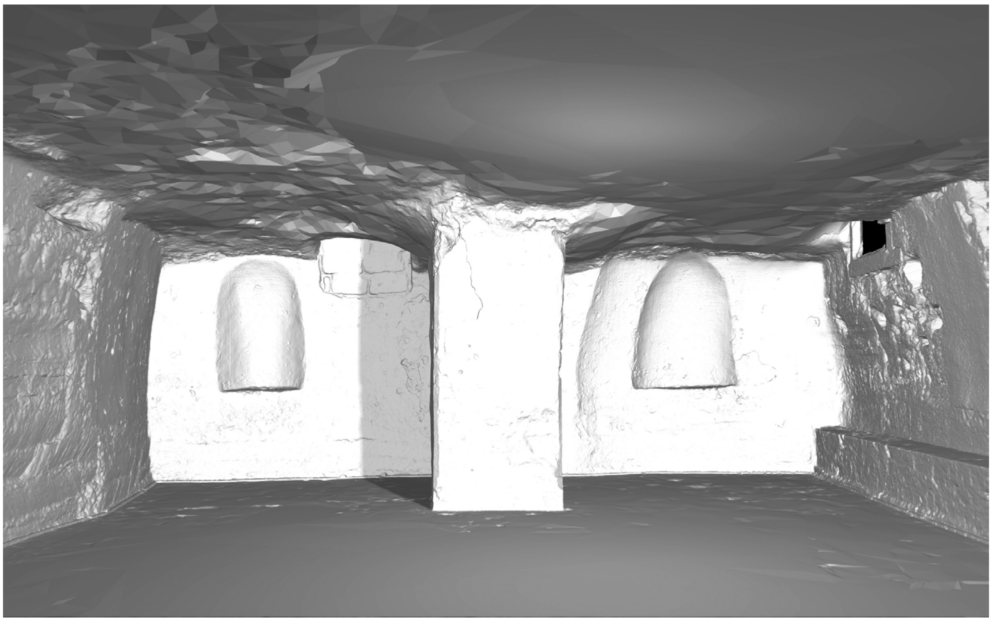
Figure 5: (a) The 3D model of the Arcosolia Room (approx. 2m x 2m x 1.8m) of the Tomb of St. James was recorded with a lateral resolution of 2 mm in x and y and a depth resolution (z) of about 0.3 mm. (b) The 3D model of the central figures (97 cm x 67 cm) in Niche #147 at Dazu were recorded with a depth resolution of approximately 0.08 mm. 3D models, which accurately record the irregular shape of the rock surface of sites such as these, provide an archival conservation record that can be used to document the condition of the site and to monitor ongoing erosion.



a b

Figure 6: The complete envelope of the Arcosolia Room including the entrance tunnel as seen from an artificial point of view embedded in the rock. Views from top (a) and from entrance (b) displayed as a cloud of points.



a

b

Figure 7: Photographs created from the solid 3D model of the Crypt of Santa Cristina. (a) Artificial shading applied to the model and (b) and the texture mapped. Accurate photo-realistic 3D models of heritage sites such as this offer high level of realism and important new ways to study, promote and protect sites.

a

b

Figure 8: Example of a simple virtual restoration, (a) current state of some of the writings, (b) enhanced version which renders the writing more legible.