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Laser Scan Measurement of the Niche and Virtual 3D Representation of the Small Buddha in Bamiyan

Abstract: Five years after the destruction of the Giant Buddhas in Bamiyan, the consolidation and emergency stabilization works have progressed so far that a high resolution laser scan measurement could be performed at the site of the Small Buddha in Bamiyan. The present condition of the heavily damaged Buddha niche was documented as well as the geometry and damages of the caves at the bottom back side of the niche in which the detonations took place. A 3D textured model was derived from the measurements of the niche and cliff wall and a 3D surface model of the original figure was generated from historic contour line drawings. This virtual model of the Small Buddha figure was successfully integrated into the 3D textured model obtained from the measurements on site. The result has been processed for presentation in an immersive 3D virtual environment (CAVE) at the Virtual Reality Centre at RWTH Aachen University as a communication model for ongoing activities and future actions on the site.

Introduction

The Bamiyan Valley is located within the Hindu Kush mountain range at a height of 2500 m above sea level. The previous Buddhist cave settlement extends for several kilometres on the north side of the valley facing south and leaving the fertile plane open for agriculture. The site of the Bamiyan Buddhas is composed of a set of several hundred caves which have been carved into the soft conglomerate cliff during the 4th to 8th century AD. Still very little is known of the origin of these figures and the society that created them. Since the first written records by the travelling monk Hsuan-Tsang in the early 7th century AD the ensemble of the Giant Buddha figures of Bamiyan has been known as the world's largest standing Buddha figures. The Large Buddha situated further west was 53 m high and the so called Small Buddha of 38 m was situated around 800 m towards the east. Located along the Silk Road on the crossroads of the civilizations of the East and the West, Bamiyan is regarded as an exceptional testimony to, and outstanding representation of Buddhist art in the Central Asia region. International intervention and protest could not prevent the complete destruction of the Giant Buddha figures executed by the Taliban leadership in March 2001.

Soon after the fall of the Taliban regime in 2002, a UNESCO expert fact finding mission took place in Bamiyan in which Prof. Michael Jansen of RWTH Aachen University and Prof. Michael Petzet, President of the International Council on Monuments and Sites (ICOMOS), among others examined the situation. The cultural landscape and archaeological remains of the Bamiyan valley have been inscribed on the UNESCO World Heritage List by the end of 2003. With funding from the Culture Section of the German Foreign Office, ICOMOS is actively involved in the international expert campaign of UNESCO for the safeguarding of the Bamiyan world heritage site. All works are embedded in the recommendations of the UNESCO expert working group for the preservation of the Bamiyan site, which is coordinating the efforts of the different teams from Japan, France and Italy. In autumn 2006, in cooperation with the Technical University of Vienna, a complete 3D laser image scan of the niche of the 38 m Buddha was successfully performed. The task was to obtain a photorealistic textured three-dimensional model of the actual condition of the niche that would serve as a basis for further planning on the execution of necessary consolidation work based on precise information on the existing geometry and the location and gradient of various dangerous cracks.

Fig. 1. The valley of Bamiyan and the Buddhist cave settlements – view from south-east.

Historic Documentation

First illustrations of the Bamiyan Buddhas were presented by Alexander Burns as part of his travel memoirs from India to Persia in the first half of the 19th century (Burnes 1834). His eyewitness reports and those of other travellers served as the basis for the future scientific contributions to the geography, art and religion of the Central Asia region in the 19th century such as the works of Carl Ritter (Ritter 1838). It was primarily at the beginning of the 20th century, however, when modern research methods reached Afghanistan with the Délégation Archéologique Française en Afghanistan (DAFA), that the world got to know what the figures looked like. Documentation methods of this time included an accurate topographic map of remarkable precision drawn by Jacques Meunié in 1936. Archaeological prospections as well as first conservation works on the mural painting and endangered instable caves and sections of the monuments were recorded, giving valuable photographic representations of the condition of the monument at that time and summarizing the scientific research of these first explorations (Hackin 1959). Due to the outbreak of World War II, research in Bamiyan stopped for years and continued again with research on the cave art and on the Buddhist settlement activity in the second half of the 20th century by Afghan, Japanese and American teams (Tarzi 1977; Higuchi 1983–1984; Klimburg-Salter 1989) accompanied by ongoing technical interventions by the Archaeological Survey of India (ASI).

Special mention has to be given to the efforts of the Japanese team under Prof. Takayasu Higuchi from the Kyoto University Archaeological Mission to Central Asia. They conducted a year-long photographic survey of all cave structures around the vicinity of the Giant Buddhas and also in the nearby Kakrak and Foladi Valley using contemporary stereographic and photogrammetric techniques during the documentation process (Higuchi 1983–1984; Barnes / Higuchi 1995). With the Soviet invasion and outbreak of an extended period of war in that region, the research on Bamiyan ceased until the worldwide outcry against their destruction in 2001. Recent documentation efforts started with the UNESCO campaign for the preservation of the Bamiyan site funded by the Japanese government. Damage assessments on the condition of the mural paintings and actual site plans were elaborated by the Japanese team of Prof. Kosaku Maeda and Kazuya Yamauchi of the National Research Institute for Cultural Properties Tokyo (NRICP 2004). Since 2004, the RWTH Aachen Centre for Documentation and Conservation has been documenting the works on the preservation of the Buddha fragments in close collaboration with restorers and stone conservators of ICOMOS. Their aim is to document the recovered rock fragments and original mud plaster surface precisely, to store them in temporary shelters and to find treatment solutions for their preservation in the long term. Due to the heavy contamination of the area with unexploded ammunition remaining from warfare in this area, all activities on the site have to be executed under the supervision of national

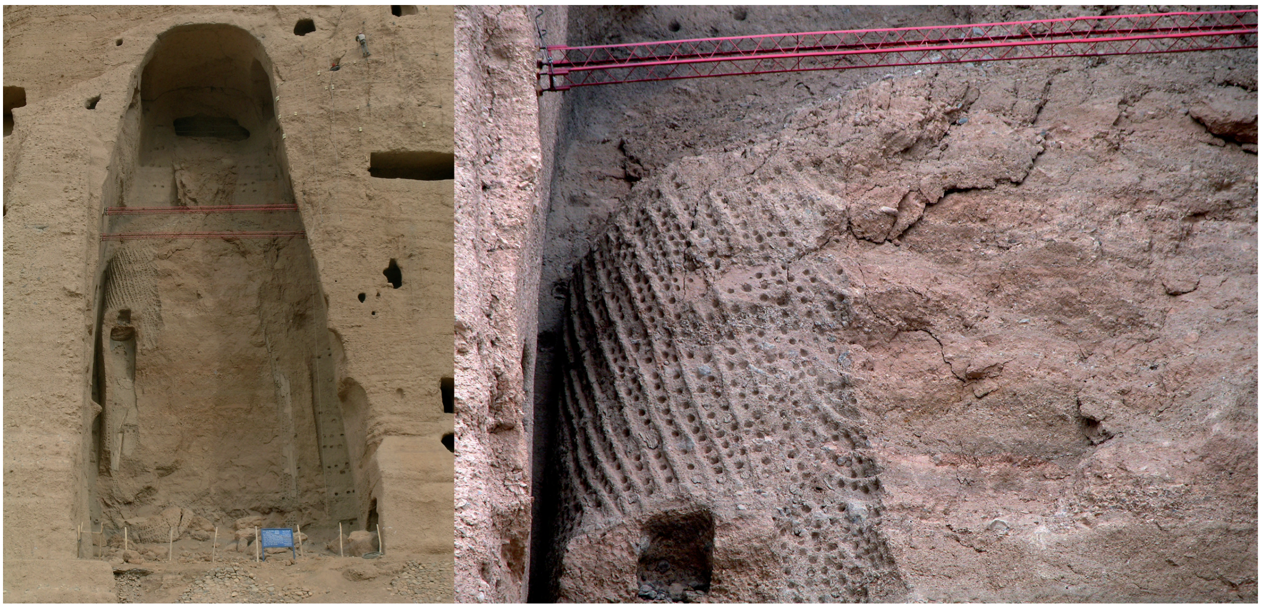

Fig. 2. Niche of the destroyed Small Buddha figure.

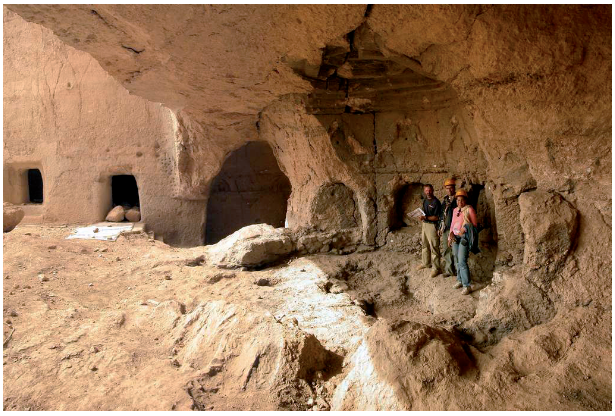

Fig. 3. Destroyed caves at the bottom of the backside of the niche.

de-mining experts together with the Afghan Ministry for Culture (ICOMOS 2005).

Laser Scanning

The Institute of History of Art, Building Archaeology and Restoration (Prof. Marina Döring-Williams) of the Architectural Faculty in cooperation with the TUWIL-Competence-Centre of the Vienna Technical University (TU Wien) executed the 3D laser scan of the eastern Giant Buddha in Bamiyan within the documentation campaign of RWTH Aachen University.

A Riegl Laser Measurement System Z420i in combination with a Canon EOS 1Ds (f=20 mm, 10 Megapixel) digital camera mounted on top of the scanner was used. The scanner works on a contactless and non-destructive principle with a range of 1.2 m to 800–1000 m distance to the measured object.

The scanner allows a very flexible alignment of the resolution according to the scan size and the scan distance by adjusting the angle of the moving laser light (0.12–0.02°). The standard noise of the Riegl LMS Z420i is ±8 mm. To obtain a full model of an object it is necessary to make several scans from different positions. The system is designed for direct communication with a separate digital camera and ensures the automatic adjustment of the pictures to the measurements of the individual scans. Every time the digital camera is mounted again on the scanner body a manual calibration (mounting calibration) has to be performed by manually assigning features visible in the scan to the digital pictures.

A LEICA Total Station TCR 1105 was used for measuring all scan positions exactly and for linking the newly obtained measurements with the UTM reference system and the site control points established by the Japanese survey team of NRICP Tokyo. In close range to the eastern-most ground control point B3 and complementary to other existing fix points of the site reference system, a new fix point directly in front of the eastern Buddha niche was measured and fixed into the ground (BP01).

In order to cover the niche of the Small Buddha completely, 23 separate scan positions were required. The scan positions could not been chosen freely, unfortunately, but instead were determined by accessibility and safety concerns which left some parts of the niche unreachable by laser. To calculate the single scans into the overall reference system, approximately 40 reflectors were set up within the niche. Flat circular retro reflectors of 5 cm and 10 cm diameter were distributed equally to cover the scanned area. Biaxial bireflex flat circular retro reflectors (5 cm) were used on the adjunct sides and back wall of the niche in order to create the necessary tie points for the calculation and automatic processing of the different scan positions. The result of each scan is a point cloud of single surface measurements. To obtain sufficient precision for the final model, the resolution was set to ensure a point

Fig. 4. Laser Scanner LMS 420i.

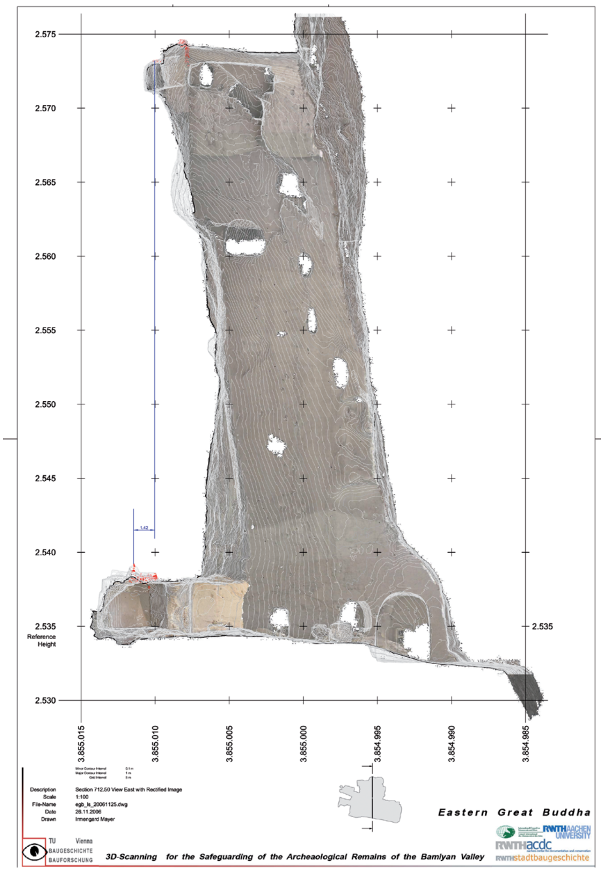

Fig. 5. Orthophoto generated from the laser scan.

distance of 8 mm on the surface of the cliff stone. In addition to the measured point cloud of the Riegl LMS Z420i, a set of pictures is taken automatically after each scan by the top mounted digital camera Canon EOS 1Ds. Due to the internal calibration values of the system, the colour information of each pixel from the digital image is automatically assigned to the measured point cloud. This process allows the automatic mapping of the taken pictures on the final mesh at a later stage. The software RiScan Pro 1.2 used during the scan process is provided by the laser scanner manufacturer Riegl.

Post-Processing

The software QTSculptor v2.85 by Polygon Technology was used to mesh or triangulate the measurement points in the post-processing phase. The calculation of the 4 GB of raw data would have required more computational resources than provided by the computer system used (Pentium D CPU 3.2 GHz, 4 GB Ram, NVIDIA GeForce 7900 GT). In order to overcome this difficulty, the model was divided into three parts, which were calculated separately and

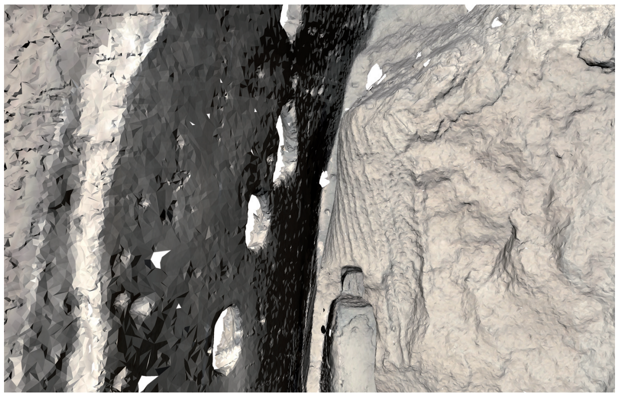

Fig. 6. Mesh generated from laser scan.

merged at the end. The number of triangles should be as low as possible to limit the file size, but as high as necessary to be able to recognize important details. When dividing the point-cloud it is important that sufficiently large overlapping areas remain. In this case, 1.2 million triangles were created by QT-Sculptor v2.85 out of the 77 million measurement points. The last step is the assignment of the digital images on the mesh. The images can be applied automatically using the mounting calibration which has been assigned on site. From the final 3D model,

Fig. 7. Virtual reconstruction of the Small Buddha.

further plans such as sections, views and orthophotos were created from all viewpoints. The main purpose of these maps will be the precise orientation and localisation of further results that will be obtained from the ongoing geological analysis of the preserved fragments and especially the geological profile of the backside of the niche. Initial tests on site revealed that the geological features of each fragment allow a precise identification of the composition of the conglomerate suitable to identify its place of origin based on geological profile matching (Urbat / Krumsiek 2004). The maps obtained from the high-precision measurements are the basis for the documentation of the geological profile of this portion of the cliff.

Reconstruction of Destroyed Structures

Although the explosions destroyed large portions of the Buddha figure and all separation walls between the caves at the backside of the niche, several distinctive edges endured the detonation and are clearly visible both at the site and within the 3D textured niche model obtained from the new measurements. The processed plans from the niche model revealed significant distinctions in the geometry of the niche in comparison to previous publications. In addition, the shapes of the caves slightly differ from the ideal form of hexagonal and octagonal cave typologies known from previous maps (Ball 1982; Klimburg-Salter 1989). While the extension and complexity of an object and the necessity for precise plan information justify the usage of high-precision techniques for the documentation process, the questions and purposes dealing with reconstruction have to be addressed carefully. The methodological approach has to reflect both technological and epistemological questions and has to be aware of its potentials and even more important of its limitations (Petzet 2002; 2004; Petzet / Melzl 2007). In the case of the Giant Buddha figures of Bamiyan, ethical components also have to be considered since the general discussion on physical reconstruction currently underway (UNESCO 2005–2006) is still far from being resolved decisively.

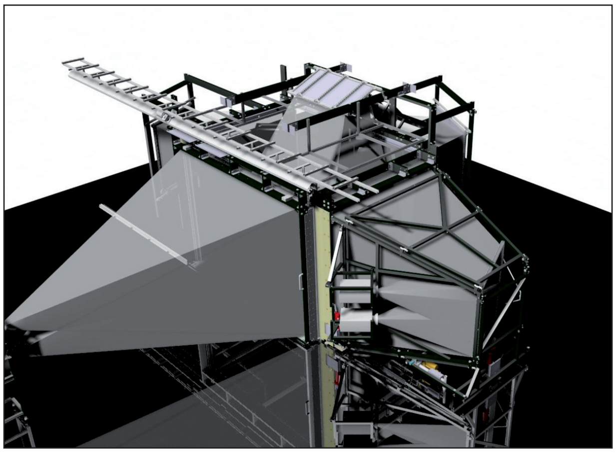

Fig. 8. CAVE concept.

The potential of photogrammetric methods has been explored by ETH Zurich on the Big Buddha of Bamiyan (53 m) for which a set of stereometric images from 1974 was available and used for a virtual reconstruction. Automated and manual procedures were also applied on further distinct image sets of different origin and time in order to create a detailed reconstruction of this figure. Due to the origin of the individual image sets, differences in illumination, viewpoint and image size obscure the delicate details of the destroyed figures which could be overcome by individually assigning values from manual measurements within the different image sets in a labour intensive process (Gruen / Remondino / Zhang 2002; 2004).

From the documentation of the site prepared by the Archaeological Mission to Central Asia at Kyoto University in the years 1972–1978 the team at RWTH Aachen obtained a high resolution scan (6800 x 10400 pixel) of the original 1/50 scale ink drawing of the contour line interpretation from the Small Buddha (38 m) sculpture. Unfortunately the original stereo pictures could not be found at that time. From this drawing, 10 cm isohypse contour lines were digitized in Autodesk AUTOCAD 2004 software and a 3D surface of the Small Buddha figure was generated. In order to combine the results from the Riegl Laser Scan measurements with this 3D surface of the Buddha figure reconstructed from the contour line drawings, both datasets were transferred to McNeal RHINOceros 3D application for further processing. Based on characteristic features that were heavily damaged but still traceable at the site and also visible in the contour line drawing, the generated surface was orientated by eye within the 3D textured model of the niche generated from the laser scans by manual alignments *(Figs. 6 and 7)*. The results reveal the amount of material that has been lost due to the detonation of the figures. It also becomes clear that the Small Buddha was more a relief structure, carved out of the soft conglomerate stone. The depth of the destruction can be measured from the actual rock surface to the surface of the reconstructed figure and ranges from 10 cm to 170 cm.

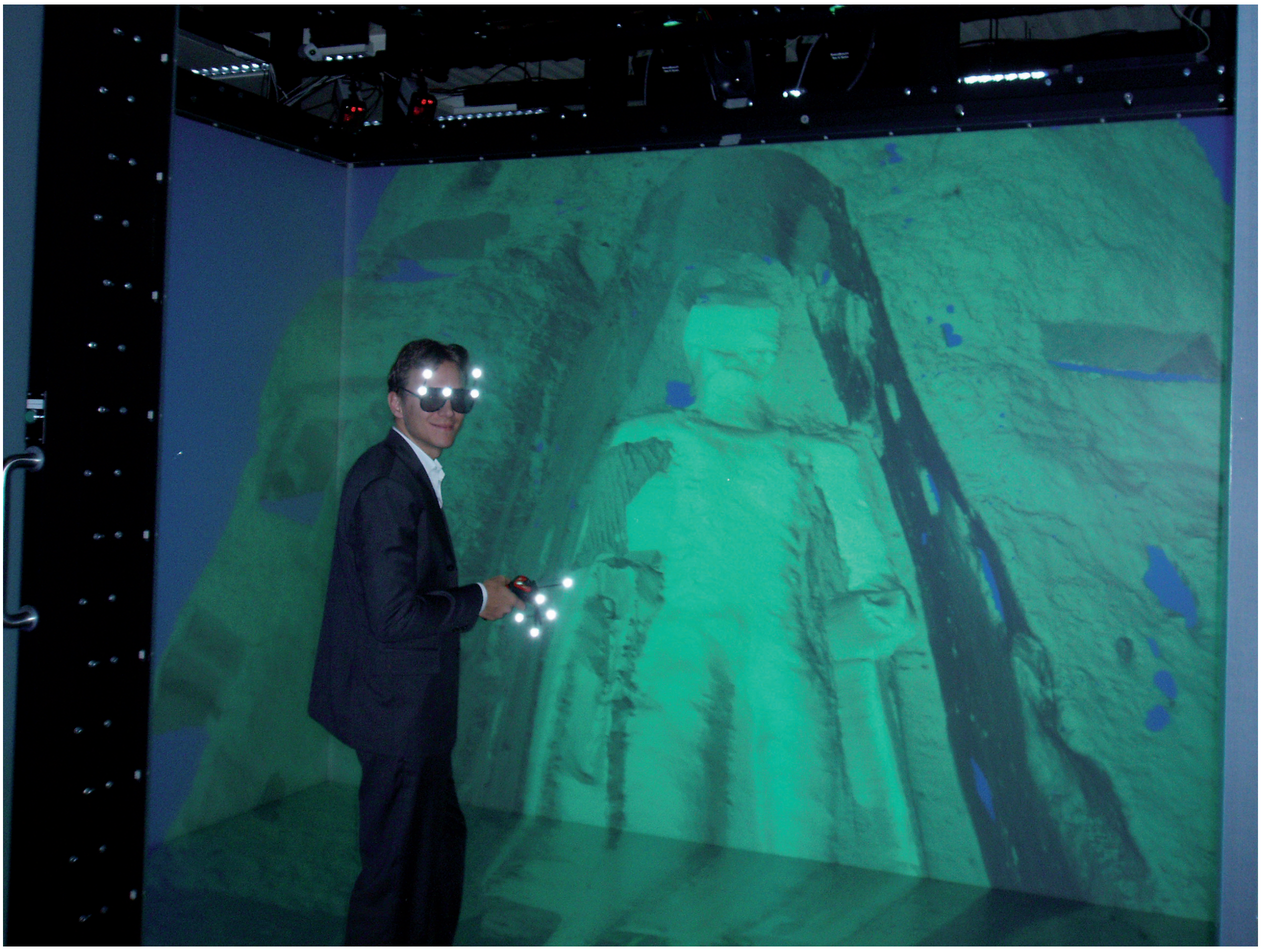

Fig. 9. Real time infrared Tracking System.

The results were first presented during the 5th UNESCO expert working group meeting for the preservation of the Bamiyan site in December 2006 at RWTH Aachen University. The immersive virtual environment BARCO CAVE™ (Cave Automatic Virtual Environment) at the Virtual Reality Centre of RWTH Aachen University represents an advanced version of the system (Cruz-Neira / Sandin / DeFanti 1993) and is used for research of multimodal and interactive 3D interactions and visualization of complex numerical and technical simulations in real time. The CAVE system is a cube of 3 x 3 m that allows a five sided projection of stereo images onto the walls and ceiling *(Figs. 8 and 9)*. The resolution of images or videos projected is 1600 x 1200 pixels per plane using ten BARCO Sim6 Ultra projectors that project the stereo images. The user of the CAVE wears a pair of polarized glasses with attached reflectors so that his position in space is constantly measured by an optical tracking system based on six ARTtrack1 cameras. The viewpoint of the spectator is processed in real time and the stereo images are rendered accordingly by a PC cluster of a total of ten render clients (Pentium IV, 4 GB RAM Memory) connected to the projectors. One master station (Dual Xeon system, 4 GB RAM memory, NVIDIA GeForce 6800 GT) controls the synchronisation of all calculations with a specially designed application programmed in VISTA, a cross platform VR toolkit under development at RWTH Aachen. The projected stereo images personalized to the eye distance of the user and the processing of the images according to every movement of the spectator in real time create a complete immersive 3D for the user of the CAVE.

Conclusion

The abundance of generated detail information by means of high precision measurement technologies poses the questions on how to incorporate all this information in sets of plans that have to describe the monument as a whole (Weferling 2006). Since our work is intended to support the practical preservation and restoration works on site, the primary aim was to generate a model serving as a means of communication that provides a general outline with enough precision so that more specific observations and findings can be incorporated easily at a later stage.

The precision and high density of the laser scan measurements capture delicate details (original clay plaster and carved cliff surface) and facilitate the production of detailed 2D plans of the geometry of the niche (section, views) in almost all directions. This allows the study of otherwise inaccessible head and shoulder portions of the remains of the destroyed figure. Though the creation of the initial contour line drawing of the Japanese researchers consequently entailed detail information losses that could not be retained in the reconstructed 3D surface of the figure, the results are adequate to serve as a sound communication model that is able to integrate all ongoing research results from restorers and geologists and to serve as planning basis for future interventions on the site. Additionally, it is precise enough to contribute to the discussion process on the future of the site in the sense of "work in progress" without pre-assuming a final state that has to be achieved. Based on this virtual model it is possible to study and to compare concepts for technical measures in the future in detail prior to their execution.

Due to the enormous object size and the complexity of the niche, it became clear that the original shape information of the destroyed Buddha figure is essential in order to make the spatial configuration readable and understandable again. How far this shape has to be reconstructed in future interventions such as a full or partial anastylosis can now be evaluated comprehensively by making use of the CAVE at the Virtual Reality Centre Laboratory situated at RWTH Aachen University.

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