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# 3D Laser Scanning and Post-Processing of the Niche of the Eastern Buddha, 2006

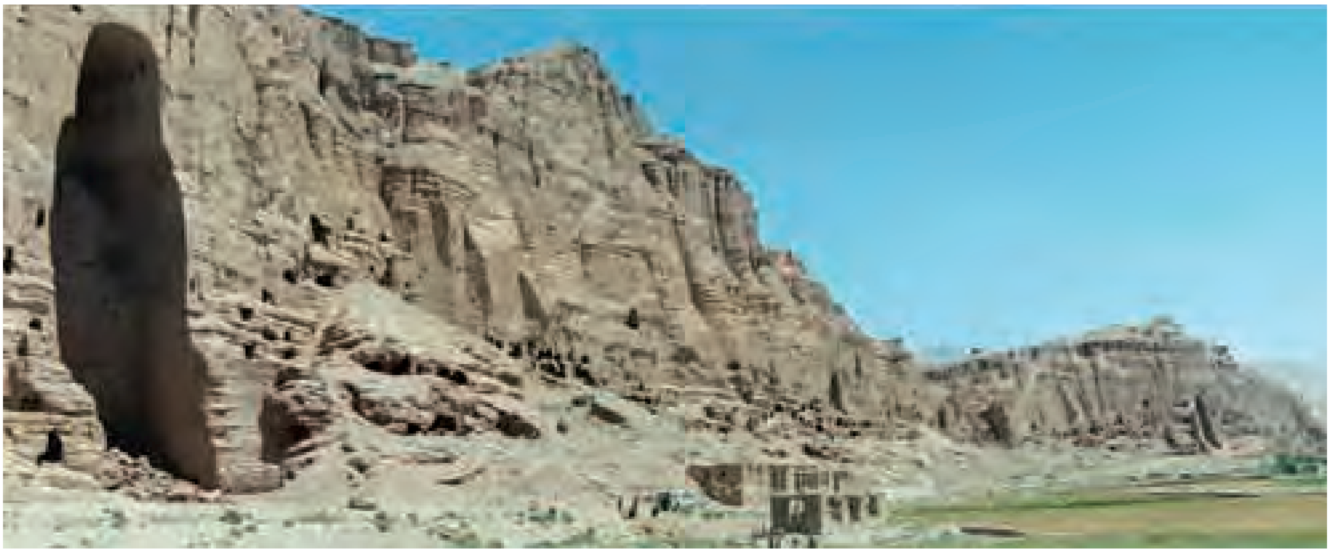
and Restoration (Prof. Marina Döring-Williams) of the Architectural Faculty in cooperation with the TUWIL-Competence-Centre of the Vienna Technical University (TU Wien) executed the 3D laser scan of the Eastern Buddha in Bamiyan within the documentation campaign of RWTH Aachen University.

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 800–1000m 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 degree). 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 most eastern 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 Eastern Buddha completely 23 separate scan-positions were required. The scan-positions unfortunately could not been chosen freely but were determined by accessibility and safety concerns which left some parts of the niche unreachable for the laser beams. 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 reach a sufficient precision of the final model the resolution was set to ensure a point distance equal 8 mm on the surface of the cliff stone. Additionally to the measured point cloud of the Riegl LMS Z420i a set of pictures is taken automatically after each scan by the on top

The site of the Bamiyan Buddhas (view towards east)



Rielg Laser Scan Z420i in various scan positions

mounted digital camera Canon EOS 1Ds. Due to the internal calibration values of the system the color 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. For the meshing or triangulation of the measurement points in the post processing phase the Software QTSculptor v2.85 of Polygon Technology was used. The calculation of the 4 GB of Raw Data would have required more computational resources than provided by the used computer system (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 merged at the end. The number of triangles should be chosen 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 QTSculptor 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 further plans such as sections, views and orthophotos have been created from all viewpoints. 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. First 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 et. al. 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.

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. Also 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].

*Reconstruction of destroyed structures*

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 or Giant Eastern) sculpture. Unfortunately the original stereo pictures have not been found. In this drawing each of the 10 cm isohypse contour lines is clearly readable and was manually digitized. The 3D surface of the Eastern Buddha was generated with *Geomagic Studio v.10* Software.

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 *Geomagic Studio v.10* for further processing. Based on characteristic features visible in the contour line drawings and still traceable at the site the surface model could be orientated within the 3D model of the niche generated from the laser scans by manual alignments.

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 range in between 10–170 cm.

The results where presented first time on the occasion of 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 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 m x 3 m that allows a five sided projection of stereo images onto the walls and ceiling. 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 spaces is

Textured 3D model of the niche of the Eastern Buddha

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 connected to the projectors. One Master Station 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 every movement of the spectator in real time create a complete immersive 3D for the user of the CAVE.

These maps are used in the ongoing geological analysis of the preserved fragments and the geological profiling of the backside of the niche conducted by ICOMOS. The plans obtained from the high-precision measurements are the basis for the documentation of the geological profile of this portion of the cliff. Tests on site revealed that the geological features of each fragment allow a precise identification of the composition of the conglomerate stone which is suitable to identify its place of origin based on geological profile matching [Urbat 2004]. The plans also serve as basis for further planning of necessary consolidation works conducted by ICOMOS. They give precise information on the existing geometry and the location and gradient of dangerous cracks.

Based on these plans restoration works are currently underway by ICOMOS to reconstruct the destroyed separation walls between the ceremony halls at the bottom backside of the niche of the Eastern Buddha.

*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 aimed to support the practical preservation and restoration works on site primary aim was to generate a model serving as a means of communication that provides the general outline precise enough 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. Also 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. In 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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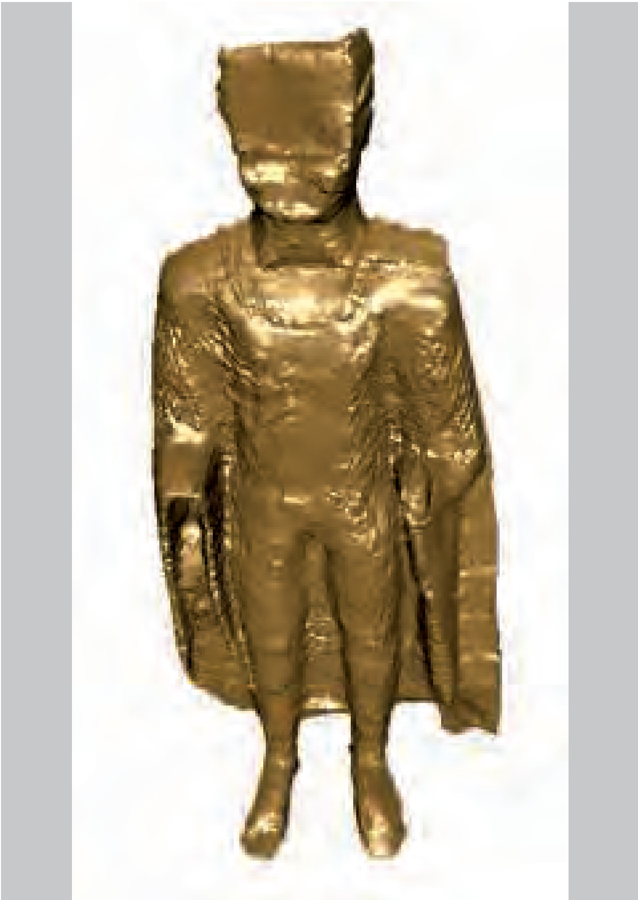
Model of the Eastern Buddha generated from isoline drawing of 1978



Virtual reconstruction of the Eastern Buddha with texture information

Left: view within the virtual environment. Right: view of Eastern Buddha in 1978

## PREMISES FOR THE DEVELOPMENT OF A UNESCO PROPOSAL FOR A DRAFT MASTER PLAN FOR THE BAMIYAN VALLEY

### PRESSURES AND INFLUENCES ON THE CULTURAL HERITAGE OF BAMIYAN

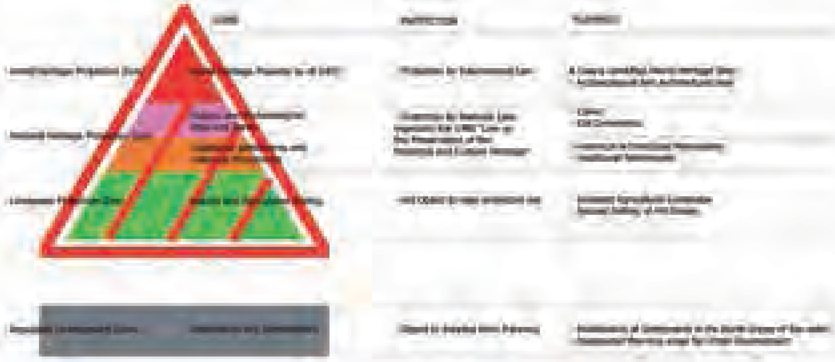

The Bamiyan Valley with its Monuments and Landscape inscribed in the World Heritage List represents a fragile equilibrium of uses and demands.
The master plan to be developed has to reflect these coactions and the stresses and demands put on the valley.
Thus, we encounter five main premises for the planning and controling of the future development of the valley:

1) Prevent any further damage of historic buildings and monuments
2) Prevent any destruction or damage of historic architecture
3) Avoid stresses produced by road traffic in immediate vicinity of the World Heritage Site
4) Avoid stresses produced by presumably increasing air traffic in the valley
5) Respecting the boundaries of the World Heritage Site and its setting

These premises lead to five predominant actions:

1) Relocation of the main road through the Bamiyan Valley away from the World Heritage Site
2) Relocation of the air field outside the valley
3) Registration and monitoring of traditional architecture possible subsidizing of repair measures through the authorities
4) Proposals for a new urban development zone outside the cultural landscape
5) Avoidance and/or relocation of disturbing uses and structures

## ZONING OF THE WORLD HERITAGE SITE AND CULTURAL LANDSCAPE OF BAMIYAN VALLEY, AFGHANISTAN



extended World Heritage boundary