3D Scanning of Stone Blocks and the Avalokeshvara Base Relief of Banteay Chhmar Temple for 3D Virtual Reassembling and Documentation

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Introduction

Banteay Chhmar temple is one of the Khmer temple complexes that have been very seriously destructed. Only about 20% of the main structure are still standing of which the majority still has to be stabilized, see figure 1.

Hundreds of thousands of stone blocks are lying around the temple structure that needs to be identified, and restored in its original position in the temple structure. Before this is done all available information related to the stones and the temple must be very well documented. All these tasks are mainly for the purpose of preservation especially for restoration of the stone blocks.

With these problematic in mind and based on the close collaboration between the Interdisciplinary Center for Scientific Computing (IWR), Heidelberg University, Germany and the Global Heritage Fund (GHF) – Banteay Chhmar Conservation and Training Project as well as with the Ministry of Culture and Fine Arts, IWR managed in the year 2009 to get a Breuckmann 3D laser scanner which is specialized for highly detailed three-dimensional recording of archeological objects and cultural structures with following focuses:

1. Improvement of the methods for reassembling of the stone blocks that are scattering around the temple structure.
2. High precision recording and documenting of the still remaining structure.

In this report we will present some of the results we obtained at this first stage of data acquisition and introduce its application versatility. At the end we will provide an overview of the next stage of the projects and the long term outlook.

1. 3D Scanner and Data Acquisition

The scanner requires relatively dark environments for operating the scans. GHF team organized to construct a scanning tent and a suitable turn-table for scanning the stone blocks at day time, see figure 2.
For this first stage of data acquisition we will require two months stay in Banteay Chhmar. IWR organized five students, Anja Schäfer, Julia Freudenreich, Holger Altenbach, Christian Seitz and Martina Trognitz, from its research group, who has been trained in scanning and handling the equipments to come to Banteay Chhmar to do the scanning tasks under great supports from GHF administration as well as technical people and manpower who had years of experiences concerning identifying and handling stone blocks.

We have selected a five meters long section of the east-south gallery including the curved wall, column, roof and quarter-roof, beams, etc. in which stone pieces all together counts about 400. Figure 3 gives an overview of the wall of the section.

The wall section in figure 3 alone counts 129 pieces, and Anja Schäfer and her GHF team have spent about 25 days to successfully accomplish the scans.
The aim of the project of scanning the stone blocks is to support and improve the stone puzzling task. The nowadays puzzling methodology is based 100% on human capability of recognitions and identification the stone neighborhood. Mr. Nhok Lo, senior technician for stone puzzling, plays the main roll together with Mr. Mab – GHF under the supervision of the architect Mr. Han Ritha. The real puzzling work had to be carried out as a group of stone blocks had been identified for composing a certain structure, see figure 4.

![Figure 4: test of puzzling a quarter-roof](image)

This method works very well and is irreplaceable with any kind of virtual representation or simulation. It is impossible to copy the real world. However, some problems occur during such puzzling work process.

1. Stone destruction rate is very high when moving.
2. Dangerous for manpower.
3. Miss-match of a selected stone group/pair still occurs which requires repeating the puzzling process anew or many times.

Working with scanned 3D data on the contrary could avoid or limit the danger of both human and stone, and improve the complexity of work drastically. The stone blocks needed to be moved only once from its existing location for the scanning, and documentation such as numbering, photography, etc. after this task everything could be handled virtually since the 3D data of the stone are extreme precise and much easier to handle and examine.

Another meaningful way to use the scanner is recording the still remaining temple structure. For our experiment we have selected the most well-known wall of Banteay Chhmar - the 32 arms *Avalokeshvara* including the 22 arms *Avalokeshvara* at the west-south wall of the out enclosure wall of the temple complex, and has been scanning by the team of Julia Freudenreich, see figure 5.

For the scans of the base relief we need to enhance the precision of the data for which the smaller measurement fields (45.9 cm (width) x 35.1 cm (height) x 24 cm (depth)) of the hardware had to be installed. This settings provides a very high resolution 3D data which is crucial for the priceless base relief however, it requires a large number of scans to cover the whole structure. By now (31\textsuperscript{th} March) we have...
done 977 scans producing a 90 Gigabytes of raw data, and still incomplete. We expect to finish the scans within one week.

One of the main purposes here is to document three-dimensionally the current condition of the structure for further studies. Later in this report we will see considerable results we could obtain from the scan data, and how much computer aided methods could support archeology.

The work environment is very much depending on the actual condition of the surrounding including ground surface and height of the structure. In this case we are facing to a very rough ground surface caused by the fallen stone blocks, and therefore hard to place the scanner tripod to fit the required distance and height from the wall. Again here we need to dim down the sun light by using the multi-purpose plastic cover available in local market. GHF team has installed us a perfect scaffolding to reach the upper part, see figure 6.

2. Results and Conclusion

3D Puzzle: with the initial (yet not the end-product) scan data of the stone blocks we are able to work on a manual virtual 3D puzzle as shown in figure 7. The puzzle work on most of the Computer Aided Design (CAD) tools allows us to handle such as
rotate, switch on/off certain stones, zoom, etc. for the study of their geometric properties very easily and effectively. Figure 7 allows you to access the 3D data of a stone block with the ID: W.J.10.01.S to demonstrate the process. Figure 8 also shows that much more information of the stone and puzzling work are depicted at once, like here the isometric view, top, and front view which again accelerates the puzzle work.

![Figure 7: 3D data of a stone block with ID: W.J.10.01.S](image)

Instruction: (with Adobe Acrobat 9 pro) click on the image to activate 3D view. Use the left mouse button to examine the 3D stone data, and use the right button to zoom.

![Figure 8: virtual 3D puzzle of the scan data.](image)
3D scan data

Figure 9: improvement of information presentation of the base relief
The result of scanning the base relief is a breakthrough. The base relief is partly deeply carved but other parts very shallow. In the case of time in this tropical climate the stone has gathered moss which causes the majority of the wall to appear in dark green color. With the ambient- and the unfavorable light source of the sun the shallow carvings are not visible. But with the high precision scan data and the adjustable light source in the computer allows us to reveal the hidden information. A perfect example here is the multi-faces, probably 16 faces – 8 of the main head and 8 on top of them, of the Avalokeshvara. On the photo it is not visible but clearly on the scan data, see images of figure 9.

3. Next Step and Outlook

Because of the limited power supply in Banteay Chhmar and limited time for our German students to stay in Cambodia, we are not able to immediately finalize the 3D data of the scans. The post-processing work of the data will be done in IWR.

As the initial scanning work in Banteay Chhmar is accomplished, we are going to continue scanning two more pieces of base relief which originally belong to the west-south gallery of Banteay Chhmar temple, and since the year 2000 have been keeping in the National Museum of Cambodia in Phnom Penh. This scanning will start at the beginning of May 2010. Our aim is to combine these two pieces with the scanned wall in Banteay Chhmar.

The virtual reassembling of the stone blocks is a long-term project which requires years for some initial results of (partly) automated 3D stone puzzling. Based on these scanned data we expect to unlock some hidden keys of construction behind the characteristics of the stones which in reverse might lead us to the rules for restoration or reassembling. In order to have the control on the immense of data that are critical for the puzzle work as well as for general use in the Banteay Chhmar project it is very urgent to develop an efficient database system which is also one of our future plan.

Figure 10: two pieces of Banteay Chhmar base reliefs in National Museum of Cambodia.