Use of leading edge laser scanning and modelling technologies for heritage conservation

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1. The Ancient Merv Project and CyArk

1.1. An introduction to CyArk

CyArk has been pioneering the use of laser scanning and 3D modelling techniques for heritage conservation for almost a decade. We are a not-for-profit organisation, and our mission is to digitally preserve cultural heritage sites through collecting, archiving, and providing open access to data created by laser scanning, digital modelling, and other state-of-the-art technologies. We have established a partnership approach involving heritage organisations, academia, technology companies and many others to effectively apply cutting-edge technology for a wide range of conservation, research and education purposes. We have an ambition to take this approach forward to be used to digitally document at least 500 of the world’s most important heritage sites. The criticality, relevance and potential benefits from realising this ambition are well illustrated by the work we have carried out so far, and the project at the UNESCO World Heritage Site at Merv in Turkmenistan provides a very pertinent case study.

1.2. An introduction to the Case Study Site: UNESCO World Heritage Site Ancient Merv

At an oasis in the Karakum Desert of Central Asia, the ancient remains the Silk Route cities of Merv lie dormant. The histories of the three cities of Merv date back two and half millennia and represent thriving metropolises of merchants and scholars, the capital of empires, the home of revolutionaries, and the graves of the conquered and pillaged. The UNESCO World Heritage site encompasses 1200 hectares of land, occupied by three ancient walled cities, Erk Kala (the oldest), Gyaur Kala (the Hellenized expansion of Erk Kala), and Sultan Kala (the rebuilt city, next door to Gyaur Kala), as well as their unwalled suburban sprawl. The remains include unique urban architecture such as the köşks (fortress-like buildings) which are believed to be unique, over 12 kilometres of defensive walls that reach 4 metres in height, and the massive suburban structure known as the Greater Kyz Kala [Hermann, 1999, xv-18]. The Greater Kyz Kala is the largest extant single structure remaining at Merv. It originally had two to three internal stories at over 12 metres tall, and is 40 metres across with corrugated exteriors (ibid). For centuries, since Sultan Kala’s siege and conquest by the Mongols in 1221 CE, the earthen brick structures of Merv have been gradually sand-blasted by the desert winds. However, erosion escalated after the Soviet-era building of the world’s largest earthen canal within the region, drastically changing the water table and causing unprecedented decay of the structures’ foundations. The erosion of the foundations has resulted in catastrophic collapse. Conservators face the considerable challenges of working to not only prevent collapse through reactive conservation measures, but also seek out better preventative efforts.
for the ongoing protection the original fabric of Merv. Current archaeological work and research at Merv is headed by the Ancient Merv Project (AMP) of University College London’s Institute of Archaeology (www.ucl.ac.uk/merv) in collaboration with the Turkmenistan Ministry of Culture.

1.3. Scope of the initial project
In 2007, the AMP teamed with CyArk to execute the recording of eight significant, at-risk structures (and two on-going excavation trenches) at Merv. The goal of the project was to employ rapid, accurate and detailed digital documentation tools to create a base-line data set for the development and/or improvement of conservation tools and preservation capabilities of the AMP staff and local site authorities.

2. Digital Documentation
2.1. Reality Capture Technologies
The digital documentation project employed terrestrial LiDAR (3D laser scanning), precise-relative GPS (a differential GPS survey that uses a reference base-station receiver and a roving receiver to obtain substantially better accuracies over typical hand-held devices, such as 5-50mm), total station survey, and digital photography.

2.2. Data Capture
The initial data capture project lasted six weeks (through September and October 2007). Several hundred individual 3D laser scan setups took place, circumnavigating the structures as well as moving about the interiors to achieve as near a complete as possible recording of the earthen monuments. Individual scans for each structure included the recording of special LiDAR survey targets. These targets were then surveyed with the total station, which itself was acting as the roving receiver for the GPS unit. This allowed all surveyed points (the targets) to be precisely recorded to the Universal Transverse Mercator (UTM) global coordinate system. All points in a scan are positioned relative to one another, thus the simple assignment of the geo-referenced targets’ coordinates automatically geo-locates all of the over 600 million surface data points captured by the 3D scanner. Accompanying each scan was also a mosaic or panoramic set of high-dynamic range (HDR) images. HDR imaging involves bracketing the exposure of multiple photographic frames to

Fig.1 - The left image shows the project’s survey technician operating a total station with GPS receiver to survey targets while the 3D laser scanner operates unmanned next to him. The blue disks in the right image, placed upon wall tops, are 15cm diameter 3D laser scanning targets.
post-process them into a composite image with a greater tonal range (i.e., capturing areas of the scene that would otherwise be shadowed or over-exposed). Some of the HDR mosaic and panoramic images were used in the post-processing of the data to assign colour pixel values from the image to either the laser points or to be overlain on a solid-surface mesh derived from the scan; this process is called “photo texturing” and creates a more photo-real 3D data set.

3. Data Processing for Conservation
The collected data created a point-in-time record of the selected eroding monuments of Merv. The record was vastly more detailed and accurate than previous traditional methods employed (string, plum, and measuring tape). The new data, in combination with 3D modelling, computer aided design (CAD), and geographic information systems (GIS) software, was immediately put to use to aide on-going conservation work as well as verify previous records.

3.1. CAD
The 3D laser scan data was linked directly into CAD software with appropriate available software plugins, allowing the creation of traditional hard-line drawings derived directly from the 3D scan data. This allowed CyArk to compare the new data with previous records for the conservators. For some structures, this showed new changes (degradation), and for others it brought to light erroneous documentation records (likely the result of human error). For example, a comparison of the CAD plans created for both Icehouse 1 and Icehouse 2 from the geo-referenced 3D scan data with previous CAD plans (created by digitising hand-drawn plans and then scaling and geo-locating those to ICOMOS satellite imagery in ArcGIS software), shows multiple discrepancies in scale and orientation. While a comparison of the previous CAD plan of the Palace of Shahryar Ark to the new plan created from the digital survey also shows discrepancies such as material loss and modern conservation additions (buttress).

3.2. GIS
New GIS-based analyses were derived from the LiDAR data to aide preventative conservation efforts. The digital elevation model (DEM) of Merv within the ArcGIS database originated from the digitisation of Soviet-era topographic
surveys and showed contours at multiple-metre intervals. Areas where the LiDAR survey captured surrounding topographic information at resolutions of 10-20 centimetres, along with differential GPS data, received updated DEMs with much greater frequency contours. With these more ‘micro’ DEMs, hydrological analysis was conducted within the GIS software. With the substantial erosion of structural foundations due to the water-table change created by the Karakum Canal, good drainage is essential to preservation at Merv. Moriset specifically drew attention to this in his 2001 monitoring survey conducted in collaboration with CRATerre-ENSAG (the International Centre for Earth Construction), recommending the seeking-out of drainage weak points to prevent damage to wall foundations [Moriset, 2001a, 19]. The results of the hydrological...
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3.3 Monitoring

The data was not only used to update, add-to, or improve upon Merv’s documentation records, but also created the baseline data set needed for long-term erosion monitoring, a much sought after conservation goal of the AMP. The AMP conducted a preliminary erosion monitoring program in collaboration with CRATerre-ENSAG in 2001, but its results were varied and the conclusion was that regular, more extensive monitoring was needed “to help decide where urgent attention is needed and where it is not” [Moriset, 2001b, 31]. The 2007 3D survey data became part of the first step toward a state-of-the-art, long-term monitoring scheme at Merv. The data collection methodology for this project was specifically established for repeatability, including extensive metadata records for every scan location, to allow continued re-documentation for direct comparison between 3D data sets (via measurements, volumetric analysis, or other techniques). At the basic level, it was used to compare against previous records, photographs, and measurements for a more gross estimate of observed degradation [Barton, 2009, 496], as is demonstrated above in the CAD example of the Palace of Shahryar Ark. Now, six years after its original capture, the LiDAR data is proving to be useful for ongoing monitoring and conservation efforts. In early 2013 the AMP received a grant for conservation work from the US Ambassador’s Fund. The AMP returned to CyArk and asked for new elevation drawings of the Greater Kyz Kala. The exact scope of the drawings is being determined at the time of writing this paper; however the detailed brick-by-brick elevations to be created will provide the conservators with baseline data to plan their conservation work of the Greater Kyz Kala during the Fall 2013 field season.

4. Conclusion

It has long been recognised that new technological developments would become important for the future of archaeology and conservation, e.g. [Dorrell,
The work at Merv is an excellent practical example of the application of 3D laser scanning and modelling to provide an accurate assessment of conservation issues, and a means of allowing effective planning and monitoring of the longer term conservation measures. The data captured in 2007 improved the level of information on a few significant structures within Merv by an order of magnitude. As Cleere et al have stated, "[the] recording of a site’s current condition is a fundamental first step … for any conservation project" [2006, 3-5]. With the new data set, Merv’s conservators have been able to improve the accuracy of their previous data, develop new preventative conservation methods (versus mostly reactive measures of the past), and begin some basic erosion analysis through comparisons of new data with previous information. It is important that laser scan data should be collected methodically toward a well-defined long-term conservation objective. In the case of Merv, this objective is erosion monitoring, and the initial and subsequent scan data have, and will be, mined for information for years to come. A current example is the creation of new CAD elevations for upcoming conservation efforts six years after the initial scanning. As a conclusion, it is worth noting that the application of laser scanning and modelling technologies can only be really effective when it is aligned to deliver conservation objectives, and that this has the best chance of happening when there are project partners who are able to work collaboratively to achieve a common goal.

Notes
1 Each target has a 1mm diameter central point made of a highly reflective material. This allows the scanner and survey total station to locate the centre axis of the target for coordinate capture. Multiple targets were placed in a random dispersal pattern (varied heights, distances, etc.), but always allowing between 4 and 6 targets to be visible between any two scan locations, creating an overlap of information for better survey control.

References
Cleere C., Trelogan J., and Eve S., 2006, Condition recording for the conservation and management of large, open-air sites, «Conservation and management of archaeological sites», 8:1, 3-16.