EUROGRAPHICS Workshop on Graphics and Cultural Heritage (2018)
R. Sablatnig and M. Wimmer (Editors)

Short Paper

On Combining Epigraphy, TLS, Photogrammetry, and Interactive Media for Heritage Documentation: The Case Study of *Djehutihotep's* Tomb in *Dayr al-Barsha*

Roberto de Lima[1], Toon Sykora[2], Marleen De Meyer[2], Harco Willems[2], Maarten Vergauwen[1]

KU Leuven, Belgium
[1]Geomatics Research Group, TC Construction, Department of Civil Engineering
[2]Department of Archaeology

Abstract

The governors' tombs located at Dayr al-Barsha are considered among the most important monuments of the Egyptian Middle Kingdom. Unfortunately, due to quarrying activities, looting, and natural catastrophes, the archaeological remains are now in a dilapidated state. Their documentation therefore becomes a necessary task towards the preservation and research of this provincial elite cemetery. Traditional geomatics-based heritage recording methods and sensors are, however, not sufficient to yield a full and comprehensive documentation. Inspired by emergent technologies, this paper proposes a symbiosis of digital epigraphy, Terrestrial Laser Scanning (TLS), image-based digitalization techniques, and 3D visualization platforms, to provide experts with a digital tool able to yield high-level information in terms of accurate digital drawings of decorated sections and dense 3D mesh models. Results show that the proposed approach provides a reliable alternative to answer research questions, especially in the context of ancient Egyptian heritage, as the level of detail captured enables the academic community to further explore decoration techniques, damage recognition, and digital reconstruction.

1. Introduction

Dayr al-Barsha is a village in Middle Egypt, positioned on the east bank of the Nile. The desert plain and rock hills which neighbour the village accommodate several ancient cemeteries, the most extensive of which was established in the Egyptian Middle Kingdom (ca. 2050-1650 B.C.), when the provincial governors were buried there. However, starting in the New Kingdom, the stability of the rock plateau necropolis was jeopardized by large-scale quarrying activity in the area. This caused many of the governors' tombs to collapse. Further damage was inflicted on the pharaonic imagery when looters hacked out decorated wall fragments, a process which, sadly, continues to this day [DeM]. Nevertheless, The tomb of Djehutihotep stands out among the rest because of its relatively good state of preservation and exceptionally high quality decoration (Figure 1 Left/Middle). The burial complex consists of a superstructure - the funerary chapel - and an undecorated substructure - the actual burial chamber (Figure 1 Right). This decorated sepulchre depicts a wide range of funerary and daily-life scenes, offering valuable insights into the Middle Kingdom world. Because of the attractive power of the tomb, it drew the attention of European travellers from at least the 17th century onwards [Syk15]. The 19th century saw a number of travellers and scholars who took a renewed interest in the tomb, and left records and drawings of their visits [Dec15]. This attention led to a full epigraphic survey and publication of the tomb in 1895 by the team of Percy E. Newberry for the British Egypt Exploration Fund [New94]. Although the efforts of the team were remarkable for the time, single registers or entire scenes were sometimes missed or left incomplete, details are often lacking, and indications of colour are missing entirely [DW17] . For researchers to be able to exploit the full potential of the tomb decoration, it is essential that a reliable and complete documentation is attained.

Given the degree of destruction of the site, conventional heritage recording techniques and sensors are not sufficient for its exhaustive documentation and digital reconstruction. Francesco Nex and Fabio Remondino [NR14] carried out a study on the performance of available 3D terrestrial acquisition methods and systems according to the dimensions and complexity of the recorded scene. They found that close-range photogrammetry [DDP*17] and terrestrial active sensors [HZK*14] are an efficient approach for the 3D recording of complex scenes, where physical acquisition requirements lie in high spatial resolution, more than 1 million 3D points within a range from 0.1m. to 100m. The latter holds true for obtaining a detailed digital understanding of the geometric properties of tangible heritage [Rem11]. However, these recording methods are not able to capture fine details of relief and painted decoration in ancient Egyptian monuments. A solution can be found in digital epigraphy, which combines the advantage of high-resolution

DOI: 10.2312/gch.20181367

Figure 1: ***Left/Middle***. *Two details of the decoration in the tomb of Djehutihotep from a fowling scene on the north wall (left), and a register of offering bearers in the niche (middle).* ***Right***. *Reconstruction drawing of the tomb of Djehutihotep (Martin Hense)*

photos with the clarity of the tracing method to produce a digital epigraphic facsimile of the original decoration. In order to get best functionalities from each of the mentioned approaches, a symbiosis of photogrammetric techniques, Terrestrial Laser Scanning (TLS) and Digital Epigraphy is proposed to perform a full documentation of the funerary chapel of Djehutihotep. Additionally, a 3D viewer is implemented to bridge the interaction with the deliverables obtained (digital epigraphy, 3D mesh) and the final user.

First, this paper focuses on explaining the considered elements for digital documentation: equipment, methods, software and strategies. Next, we discuss the obtained results and outline the research opportunities that become attainable with the recording data.

2. The Digitalization of the Inner Chamber of Djehutihotep's Tomb Chapel

The work flow of the approach followed here consists of the following steps: digital acquisition, digital epigraphy, surface reconstruction and interactive virtual environment. Physical acquisition is carried out using three different recording methods: epigraphy, photography, and TLS. After that, digital epigraphy and surface reconstruction are treated independently. For the latter task, TLS and photogrammetry are combined aiming at an optimal trade-off between texture quality and metric accuracy. Finally, the symbiosis is performed by integrating all the processed data into an interactive application. The next paragraphs explain these consecutive stages.

2.1. Digital Epigraphy

As a first segment of the documentation process, the decorated wall surfaces are recorded using digital epigraphy, the study of paintings and relief on stone surfaces. This provides a useful tool for presenting the original decoration in a clear and unobstructed manner. While traditional analogue epigraphy serves the same purpose, it can inflict damage to the original surface, or is cumbersome to employ in the field. When executed well, its digital equivalent, where the drawing is traced on a tablet or computer on top of a photograph, can bypass these obstacles. The method employed here was recently developed by KrisztiÃąn VÃľrtes [Vér14, Vér17] of the Chicago House, and tested on the west wall of Djehutihotep's inner chamber in spring 2018.

The basic requirement to produce a trustworthy digital facsimile, is a geometrically correct photograph which can be used as a template for drawing. While no cameras are currently able to capture a sizable wall with the required resolution, such an image can be created by combining multiple, partially-overlapping, photographs with photogrammetry. Agisoft Photoscan (Professional) was used to align the 458 camera positions and resulting photographs of the west wall (8 by 4 meters). The aligned photos were then exported in Photoscan as a two-dimensional orthomosaic, to produce a geometrically corrected orthophoto. The photographs covered the full decorated wall surface, showed enough (60% or more) overlap, and were taken with the lens parallel to the wall's surface. For the highly detailed decoration, an ideal distance for the photographer proved to be approximately between 50 and 100 cm.

For the initial digital drawing, a 12.9 inch iPad Pro - with Apple Pencil - is used. The digital drawing application Procreate is used, because of its intuitive management. As the iPad is not able to handle large files, a first step consists of dividing the orthophoto into a regular grid. The resulting squares - we used a grid with squares of 50 by 50 cm at a resolution of 300 dpi - are then imported into Procreate to be used as the template for drawing. While doing so, it is best to preserve a slightly larger portion than the square which the grid encloses, as its overlap with the neighbouring square facilitates later alignment of the two. Thereafter, a digital pencil drawing is produced by tracing different features: paint, relief, damage, graffiti or overpainted sections, etc. These features are stored in different layers (Figure 4), to ensure that all information can be interpreted unambiguously, and managed more flexibly. Although the photograph is used as the main reference while drawing, this process should ideally take place in front of the original wall surface, or should at least be aided by different photographs of the same section to compare with. Poorly preserved and overpainted sections often necessitate additional examination under different angles or lighting conditions.

A crucial next step is the collation, during which the drawing is checked and corrected by different epigraphers. This minimizes possible mistakes and outtakes, and thus improves the, inevitably subjective, drawing as a reliable rendition of the original. When the epigrapher and collating colleagues have reached an agreement, the final phase in the epigraphic process can start. At this point, the individual squares are realigned and the final inking is done in Adobe Photoshop (CC 2018). We chose to use raster-based image manip-

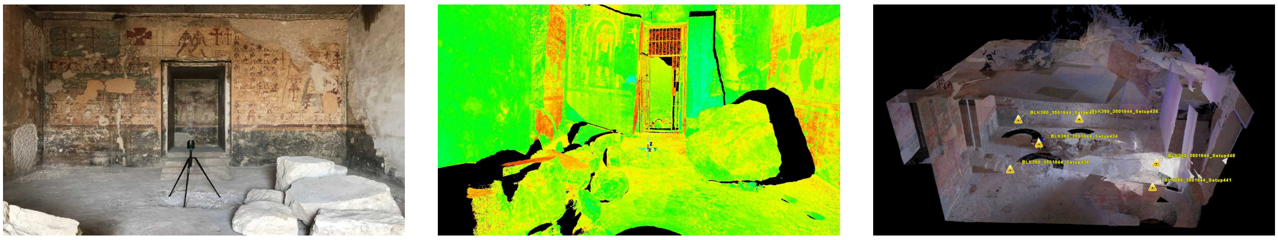

Figure 2: *TLS-based recording pipeline: Data acquisition, 3D points cleaning, point-clouds registration.*

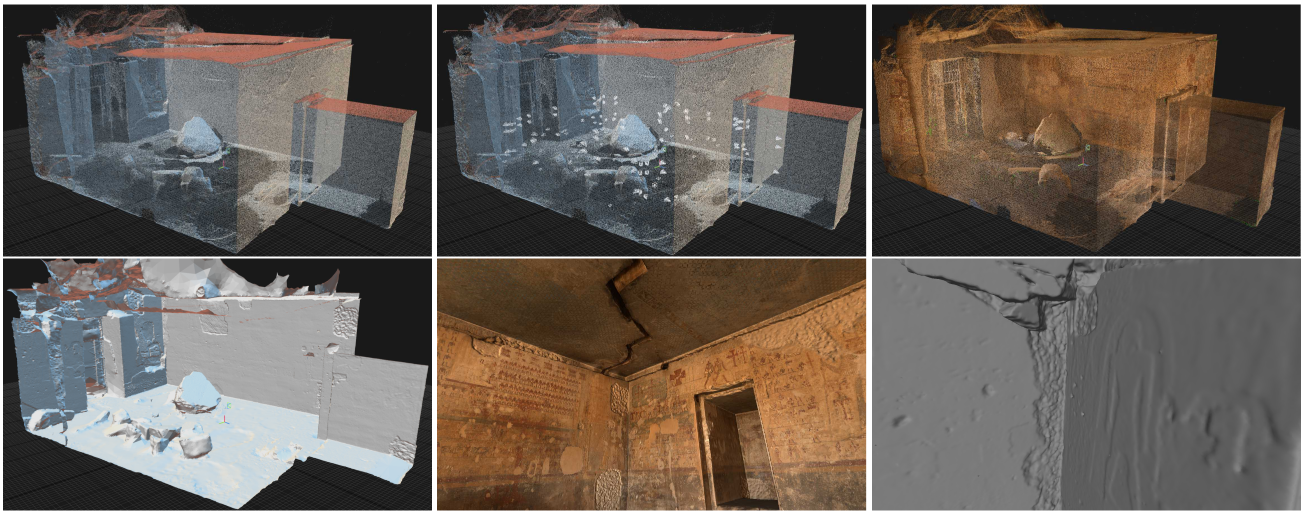

Figure 3: *Pipeline for surface reconstruction: 1. Point cloud input (TLS), 2. Images Alignment, 3. Colourization, 4. Meshing Process, 5. 3D mesh model with texture. 6. 3D mesh model without texture.*

ulation software, rather than vector-based [Man98], as its drawing method offers a less-stylised rendition which is closer to the original style of the painting or relief. The final 'inked' drawing, can then be completed by indicating shadow lines or 'trait de force' to highlight relief, and adding colour conventions - codes, patterns or greyscales - to indicate colour. Thus, a trustworthy and easily readable facsimile is produced.

2.2. Surface Reconstruction

Image Acquisition. Keeping in mind that the asset of high-quality texture when using photogrammetry is determined by the input visual sensor, the camera specifications used for physical acquisition are listed as follows: Camera-Nikon D800, ISO speed-ISO-200, shutter speed-0.62s, focal length-60mm. In order to digitize the whole area, 305 photos were captured trying to keep enough overlap, with the aim of providing the software the opportunity to find geometric relations among visual features of the images [SSLK13], thus ensuring a reliable 3D representation. To illustrate the above process, Figure 3 top-middle shows the different locations where photos were captured. Distinct heights and angles were considered so that even the large collapsed stones within the field of view could be modelled.

TLS acquisition. Given the fact that the ultimate priorities when designing TLS devices are accuracy and range, many manufacturers have ignored the characteristic of portability. This results in a wide variety of bulky equipment that prevents the recording of difficult-to-access locations, like in the case of various ancient Egyptian sites. However, recently Leica's *BLK 360* emerged as a TLS alternative by offering a trade-off between portability and accuracy. More specifically, its main features are: range from 0.6m-60m., accuracy 4mm @10m/ 7mm @20m, imaging HDR 15Mp camera, temperature robustness of +5° to +40°. These specifications make it a suitable scanner to record our case study. To this end, 6 scans are set up across the chamber to avoid occlusion of collapsed stones and to capture all the hidden spots, as shown in Figure 2 left. After capturing, undesirable points of each scan are removed manually, especially those belonging to the outside. Afterwards, by using a process commonly known as registration, the scans are aligned into the same coordinate system to unify the point clouds. To this aim, we used the software package *Cyclone* [Lei], that enables us to visually align a pair of scans and then run the Iterative Closest Point (ICP) [RL01] algorithm to minimize the difference between point clouds. In terms of numerical results, the unified point cloud exhibits an average error of *0.005m*. Figure 2 shows the TLS pipeline: data acquisition by using the BLK 360, points removal, and scans registration.

Merging Technologies. The previous stages focused on describ-

Figure 4: *Example of a square with the initial drawing finished (top), and the different layers shown (bottom).*

ing the data acquisition process by using visual sensors and TLS, delivering both a set of images well-suited for photogrammetry and a dense point cloud; in other words, the input elements for surface reconstruction or meshing. The 3D modelling engine *Reality Capture* [Cap] is used to carry out the meshing process. This software is the state-of-the-art for surface reconstruction since it is capable of merging different input sources to create a realistic-based model, on the basis of the following work-flow: data alignment, colourization, and texturing.

First of all, camera images are aligned with the TLS point cloud by using computer vision algorithms [Bou18] that link the set of high-resolution pictures with the images captured by the scanner, thus calculating the camera position relative to the TLS points. The latter is crucial to colourize the dense point cloud based on high-resolution images, in such a way that those points within the camera field of view take colour from HD images, and otherwise keep TLS image colour. Finally, the realistically colourized point cloud is transformed into a textured mesh by the well-known process of meshing, the basic definition of which consists in transforming an unstructured set of 3D points into a set of vertices and polygons. Moreover, *Reality Capture* also provides the user with post processing tools such as simplification, smoothness and filtering to enhance the mesh surface. The resulting realistic 3D model is made up of *1,245,580* vertices and *2,485,200* faces. For the sake of illustration, Figure 3 depicts the different steps of the aforementioned process, from TLS points acquisition, data alignment, to the polygonal model. To clearly show the importance of highly detailed and textured 3D models within the field of Egyptian heritage documentation, note that from Figure 3 bottom-middle, the current cracked state of the ceiling is detectable due to the high quality texture. On the other hand, the mesh model without texture depicted in Figure 3 bottom-right, contains the necessary geometric information to interpret the decorated region where raised relief was employed. The latter is an illustrative example of the advantages of using 3D meshes for heritage documentation, since decoration techniques like sunk and high relief would have been almost impossible to distinguish from traditional imagery archives.

2.3. Interactive Application

In order to facilitate the interaction between the digital results and egyptological experts, an interactive environment is implemented on the cross-platform game engine Unity [Uni]. First, the tool *Exploring Djehutihotep* is built that allows navigation through the chamber's details by using the keyboard and mouse, thus simulating the experience of walking around or flying over the mesh model. The instantiation of the high-resolution mesh into a game engine, allowed us to cope with the vast amount of geometric data. Secondly, *Drawing Djehutihotep*, a fading in/out application is developed to contrast orthophoto and epigraphy by using a slider bar, in such a manner that by tuning the brightness of the photo, the epigraphy can be compared to the image data and verified.

3. Conclusions

We have presented a novel approach that combines emergent technologies for a full and comprehensive documentation of Djehutihotep's chapel on the archaeological site of Dayr al-Barsha. By employing state-of-the-art hardware and software solutions it was possible to overcome the specific challenges of recording an ancient Egyptian site, that underwent transformations and damage throughout the years because of natural catastrophes, looting, quarrying activities, etc. The obtained results show high resolution, both in terms of the 3D points quantity and image quality, thus offering experts digital tools to further study the site at levels of detail that are unattainable with traditional recording methods. In addition, the problem of high-resolution heritage documentation management was addressed by incorporating the acquired data into a game engine for content visualization purposes. Naturally, new features can be added to the application towards enriching the interaction between realistic-based 2D/3D models and human expertise, for example automatic damage detection from digital drawings, real-time mesh rendering or VR visualization tools compatibility.

Acknowledgements

The research presented here features within the *Puzzling Tombs* project (nr. 3H170337), funded by the KU Leuven *Bijzonder Onderzoeksfonds*. All images belong to the authors, except when stated otherwise. The authors wish to express their special gratitude towards Kristián Vértes for generously sharing and instructing his methodology for digital epigraphy.

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