Puzzling tombs: virtual reconstruction of the Middle Kingdom elite necropolis at Dayr al-Barsha (Middle Egypt)

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CHAPTER 20

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Abstract

With the interdisciplinary project "Puzzling Tombs,"[1] a team of Egyptologists and engineers of KU Leuven aims to document and reconstruct the architecture and iconography of the Middle Kingdom elite cemetery at Dayr al-Barsha in a virtual environment. Such a tool allows the manipulation of the thousands of tomb fragments, and virtually solve the puzzle they represent. Structured light technology is used to accurately record the fragments, while the remaining standing architecture is documented by terrestrial laser scanning. The resulting 3D meshes are processed on a game engine which allows for coping with the dense polygonal structures that compose the digital models. In combination with this virtual reconstruction, digital epigraphy following the Chicago House method is carried out in the well-known tomb of the Twelfth Dynasty governor Djehutihotep. This detailed documentation will be integrated as an additional layer in the virtual environment.

Keywords

Digital Epigraphy – Chicago House method – laser scanning – digital modeling – virtual environment – Middle Kingdom – Djehutihotep – Dayr al-Barsha – structured-light scanning – game-engine

1 The research presented here features within the project 'Puzzling Tombs: Virtual reconstruction of the Middle Kingdom elite necropolis at Dayr al-Barsha (Middle Egypt)' (nr. 3H170337), funded by the KU Leuven Special Research Fund.

1 Introduction

At the outset of the Middle Kingdom, Ahanakht I, governor of the Hare Nome, selected a panoramic plateau on the desert hill north of the Wadi Nakhla to serve as his final resting place. His successors followed his example by building their own decorated funerary chapels with underground burial apartments nearby (Figure 20.1). These monumental governors' tombs were surrounded by the more modest graves of their chief officials, who sometimes had decorated funerary chapels of their own,[2] or were included into the complex of their lord.[3] Together, they make up the Middle Kingdom elite necropolis of Dayr al-Barsha,[4] with an uninterrupted sequence of mid-Eleventh to late Twelfth Dynasty burials. The last dateable tomb on the plateau is the funerary chapel of Djehutihotep, which was constructed and decorated during the reign of Senwosret III.[5] Although it is the largest and most intricately decorated monument at the site, the entire area seems to have been abandoned as a burial site soon after its completion.[6]

Not long after the cemetery fell into disuse, the first threats to its preservation started to emerge. The high quality of limestone, which had initially attracted the Middle Kingdom governors to the site, became a renewed subject of interest during later phases of pharaonic history. Several gallery quarries were excavated in the rock cliffs surrounding the Wadi Nakhla, with an early New Kingdom quarry[7] opening up only a few meters to the east of the tomb of Nehri II (Figure 20.1). An even more extensive quarry complex was dug out directly behind the decorated funerary chapels of the Middle Kingdom governors, and smaller scale limestone extractions appear throughout the area. In

2 For examples, see Willems et al. 2007.

3 One such group of subsidiary burials consists of five funerary shafts in front of the forecourt of the tomb of Djehutihotep (Willems 1988, 75–77; Pommerening and Willems 2021).

4 Zone 2 in the KU Leuven numbering system. Zone 1, which consists of two Middle Kingdom burial shafts on the hill summit, can also be associated with the cemetery. For an overview of the archaeological zones in Dayr al-Barsha, see Willems et al. 2004, 238–240.

5 His *cartouche* and *serekh* are represented on the facade of the outer chapel. While the royal names of Amenemhat II and Senwosret II also occur in this chapel, they are mentioned in reference to earlier stages in the governor's life (Newberry [1894], 6 and Pl. V).

6 The suggestion that Djehutihotep would have been followed in office by a Djehutinakht (VIII; Brovarski 1981, 25) is difficult to prove, as the coffin which would be the only evidence for the existence of such a governor can easily be assigned to another owner, perhaps Djehutihotep himself (Willems 2021, 477–479).

7 A stela at the entrance mentions Thutmose III as its benefactor. For a discussion of this stela and its content, see Luft 2010, 333–374.

FIGURE 20.1 Plan of the Middle Kingdom nomarchal cemetery of Dayr al-Barsha (zone 2). Still visible portions of the original rock surface are indicated in dark grey and dark yellow; quarried, collapsed and inaccessible parts of the Middle Kingdom site are indicated in light grey and light yellow.

several cases, quarrymen cut straight through tomb floors or through decorated walls and ceilings.[8] Apart from the immediate destructive effect this inflicted on the rock-cut chapels, it greatly destabilized the overlying geological layer, causing it to crack and partially slide forward during a subsequent collapse. As a result, many of the superstructures of the cemetery partially collapsed, leaving only the tomb of Djehutihotep largely unharmed, with the exception of its east wall and outer chamber ceiling.

The fragmented monumental necropolis became a region of interest again during the Coptic era. Christian hermits and associates of the local monastery repurposed the still-accessible quarries and tomb chapels as dwelling places and places of worship.[9] The occupants made several adjustments to the architecture, cutting out separation walls, adding holes for doorposts and other such amenities. They also painted a large number of red Coptic crosses on the site, in many cases overlying original pharaonic decoration (Figure 20.2). This was most visibly done in the tomb of Djehutihotep, where the painting of hundreds

8 Evidence of this can clearly be seen in the tombs of Nehri I & II and Ahanakht I & II.
9 Clédat 1902, 66–67; van Loon 2016, 19–20.

FIGURE 20.2 Two Coptic crosses overlying the image of an official of Djehutihotep and his hieroglyphic legend (inner chamber, north wall)
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of Coptic crosses and the defacement of several human figures seems to have transformed the funerary chapel into a Coptic church.[10]

The "rediscovery"[11] of the pharaonic cemetery by early 19th century European travelers brought along a third wave of threats to its survival. The high quality of the preserved decoration in paint and relief made the tombs, especially the one of Djehutihotep, an obvious target for antiquities dealers. Already during the first decades after its rediscovery, clear traces of such looting activities became apparent, with "holes having been picked in the walls, and a considerable part of the rest nearly obliterated by the rain getting in".[12] The

10 Michael Johann Wansleben mentions this designation in his seventeenth century travel account of the site (Wansleben 1678, 238).

11 Although it is traditionally claimed (Newberry [1894], 3) that the first European travelers to discover the site were Charles Irby and James Mangles (Irby and Mangles 1823, 164–165), the site was already described a century before by Claude Sicard (Sicard 1717, 217–223), and even earlier by aforementioned Wansleben in 1672 (Wansleben 1678, 396–401). See also Berman et al. 2009; De Meyer and Willems 2016–2017, 37–44. These earliest descriptions of the tomb have remained largely unnoticed, however, and it was not until the nineteenth century rediscovery that the tombs of Dayr al-Barsha gained renown among western travellers.

12 Joseph Bonomi, in a letter dated July 28, 1833 (courtesy of the British Library; ADD 29859 ff. 30). He remarks that the tomb was in much better shape when he first saw it. He then follows up this comment with "by dint of scraping and sponging we have succeeded in getting the principal part of the subject of greatest interest," which cannot have improved the preservation of the already damaged decoration.

next documented major destructive event happened in late 1889 or early 1890, when large portions of the decoration of the funerary chapel were cut out to be sold on the antiquities market. It was at this moment that the famous colossus scene, which until that point in time had remained practically intact, was severely damaged.[13]

All these events have left the monumental site in a dilapidated state, with many tomb chapels and shafts inaccessible. Because of this, early archaeologists on the site resorted to extreme measures to gain access to them—on occasion even using dynamite—only further aggravating the problem.[14] Mountains of collapsed tomb debris were moved over and over again, scattering the remnants of single tombs across the plateau and its adjacent rock slopes. The most beautiful decorated wall fragments were selected and shipped to museums in Egypt and the western world.[15]

Although the rock-cut tombs have clearly been reshaped by these events (Figure 20.3), much of the information they contained can still be accessed. The many thousands of decorated wall fragments and *in situ* remains of architecture complement each other and allow us to perceive the outlines of what is now irretrievably lost. With this in mind, we launched a project in 2017 which aims to virtually document and reconstruct the remnants of pharaonic architecture in the area. The limited accessibility of the plateau, lack of stability of the remaining tombs, and danger of inflicting more damage to the fragile remains, rule out an on-site anastylosis. While the elite cemetery of Dayr al-Barsha is now a protected site, its fragmented remains are still under treat of vandalism and natural degradation, making it essential to document the current situation as completely as possible, so as to prevent any further loss of information. This documentation process is threefold: first, the standing architecture at the site is recorded in 3D; second the individual decorated wall fragments are scanned in 3D to allow for a virtual search of matches; and third, digital epigraphic drawings are made of all decorated wall surfaces.

13 Davies 1999, 29; De Meyer and Willems 2016–2017, 39 n. 31.

14 Berman et al. 2009, 96; De Meyer 2015, 107.

15 These can now be found in the British Museum in London (https://research.britishmuseum.org/research/collection_online/ [accessed on 28/04/2020] BM EA1147, 1150–1152, 7521, 71517–70, 90619, 90628, 90631, 90633 and 90662), the Egyptian Museum in Cairo (Smith 1951, 322: TR 10.4.22.2; 18.4.47.3–4 and 19.4.22.12), the Museum of Fine Arts in Boston (https://collections.mfa.org/collections [accessed on 28/04/2020] MFA 47.1659–1660 and 1972.984) and the Museo Egizio in Florence (De Meyer and Willems 2016–2017, fig. 11: Nº 7596–7597).

FIGURE 20.3 The current state of the Middle Kingdom elite cemetery in Dayr al-Barsha (zone 2), as seen from the south hill. Note the debris heaps from previous excavations which line the edges of the plateau
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2 Towards a Virtual 3D Reconstruction of the Governors' Tombs

The 3D documentation of heritage is by now an established tool for researchers to enhance their study. However, documentation and registration are only the first steps in a process that should provide the researcher with new possibilities to interpret and work with the data in ways that were impossible without such type of documentation. Therefore, the 3D models of both the standing architecture as well as of loose wall fragments are integrated into a newly developed interface with a game engine that allows the reassembly of the thousands of fragments in a virtual three-dimensional space. This virtual space is further enhanced by adding layers of digitally produced line drawings of the decoration, both in terms of what is still preserved today, as well as by adding archival records[16] that provide information on parts of the monuments that no longer exist.[17]

16 These archival records generally consist of old sketches and drawings, as archival photographs of the tombs at Dayr al-Barsha are hardly preserved. Several squeezes taken by the Lepsius expedition in 1843 (preserved at the Berlin-Brandenburgische Akademie der Wissenschaften) and by Prisse d'Avennes in 1859–1860 (preserved at the Bibliothèque Nationale de France in Paris) will also be integrated into the digital model.

17 See for instance Bassier et al. 2018.

2.1 *Terrestrial Laser Scanning*

The first stage of the process consists of the 3D digitization of the site. Working in a remote and difficult to access area such as the Middle Kingdom necropolis on top of a hill poses an unusual set of challenges in this regard. Portability was an essential condition in the choice of hardware since it also needed to perform in narrow underground burial shafts and chambers. Another challenge to deal with is the occlusion caused by the many collapsed tomb fragments. Therefore, terrestrial laser scanner (TLS) data, structure from motion (SfM) and total station (TS) control points are combined to comprehensively record all the accessible architectural elements of the site in 3D.[18] A Leica BLK-360 was chosen for the terrestrial laser scanning, because its small form factor combined with its accuracy give it the flexibility and portability that are essential elements in the field. This device allows for capturing a high-resolution colorized point cloud within a range from 0.5 up to 60 m with a maximum point accuracy of 6 mm. The recorded scans were accurately registered on the software Leica Cyclone.

Given the numerous occluded areas, over 50 scans were necessary to capture all the architectural elements of the tombs above ground. In order to mitigate registration errors, the point clouds were aligned with respect to the TS control points. Although the resulting point cloud (Figure 20.4) is geometrically accurate, its texturing is subpar due to different light conditions preventing the capturing of homogeneous colors. To enhance the texture, a photogrammetry-based approach was conducted to blend the 3D points with photorealistic colors. The process of registering TLS data with photogrammetric models was performed using the software package Reality Capture. To complete the post-processing stage, high-resolution mesh models are created from the enhanced point cloud, an example of which is depicted in Figure 20.5, being a polygonal model of the outer chamber of the tomb of Djehutihotep that is made of 997,797 faces and 499,656 vertices.

2.2 *Object Scanning*

Not only the remaining standing architecture of the tombs is recorded, so are the thousands of broken decorated wall fragments that come from them. In this case, the recording poses a different set of challenges, pertaining mainly to the fragility, varying sizes and erratic shapes of the blocks. Hence, structured light technology is employed to digitize them. The EinScan Pro+ scanner was chosen

18 De Lima and Vergauwen 2018, 293–298.

FIGURE 20.4 Screen shot of the point cloud of Zone 2, showing both the above ground landscape as well as the subterranean shafts and burial chambers

FIGURE 20.5 Screen shot of the mesh model of Djehutihotep's outer chamber obtained by combining TLS with photogrammetry

for recording because of its versatility and specifications. It offers the opportunity to employ two different scanning modes: hand-held and fixed scan using a turning table. This is useful to digitize both small and medium-sized fragments with irregular surfaces. Moreover, it is capable of generating dense polygon meshes since its recording rate is up to 550,000 points per second and is equipped with a separate camera to capture the texture in sufficient detail. The resolution of the digitized models ranges from 300K to 1.3M triangles and point density from 0.2 to 3 mm. This high level of detail is sufficient to apply sophisticated 3D processing algorithms. However, it entails a cumbersome rendering process to visually explore the fragments' properties. Therefore, the models are loaded into a game engine for smooth visualization and interaction.

2.3 *Towards a New Integrated Interface*

To handle all recorded data, the scanned fragments are instantiated into a virtual interface. This is developed on the game engine Unity[19] to cope with the high mesh density of the 3D models. On the one hand, the virtual environment allows the user to explore high level properties of the models by adjusting rendering features such as shades, light conditions, textures and so on. On the other hand, the user is able to intuitively alter alignment of the fragments in 3D space. To facilitate this task, the decorated surface of the fragments is aligned parallel to an imaginary XY plane, restricting translation motion in the z-axis and rotation in x and y-axes.[20]

To automatically implement these steps, we assume that the decoration footprint is located on the dominant planar surface of the fragment. The robust parametrized algorithm RANSAC[21] is deployed to find the dominant and best fitting plane in the fragment's point cloud. The fitted points are projected into an XY plane. Finally, the translation vector and rotation matrix that relate the original model's position to the planar projection are computed. This transformation is applied to the fragments in the global space of the virtual interface so that the user has an isometric view of the decorated surface. This way of displaying the fragments notably reduces the complexity of inferring matching cues. Additionally, the engine extracts the contour region of the decorated planar surface in order for the user to intuitively align counterpart matching regions. Once the user proposes a rough alignment, the Iterative Closest Point[22] algorithm is used to reduce the distance between the matched fragments, thus refining the previous alignment. As a result, the developed virtual environment not only serves as a platform to visualize the recorded data but also empowers experts with tools to reassemble broken fragments.

To test the developed virtual platform, the engine was employed to reassemble the handpicked fragments depicted in Figure 20.6. In total, the input data is encompassed of 1,736,656 vertices and 3,477,954 faces. On average, the engine renders the models at 30 frames per second, ensuring a seamless user-computer

19 Nicoll and Keogh 2019, 1–21.
20 De Lima et al. 2019.
21 Chum et al. 2003.
22 Rusinkiewicz and Levoy 2001.

FIGURE 20.6 Example of a puzzle of decorated wall fragments from the tomb of Nehri I, solved through the developed virtual interface on Unity

interaction. As for the alignment tools, the plane extraction method successfully extracted both the main decorated surface and its contour for all fragments. The proposed tools allow experts to easily identify matching cues based on relief decoration traces as well as on the contour's shape. In spite of the fact that the alignment accuracy and reassembly effectiveness still rely on user expertise, the registration tools proved to be a useful asset to the virtual environment.

3 Beyond Newberry: Digital Epigraphy in the Tomb of Djehutihotep

In addition to automated digital recording of the monuments, a second type of documentation brings in the knowledge and expert eye of the Egyptologist to register and interpret their decoration by using digital epigraphy. Here the focus lies on the remains of elements in two dimensions.[23]

Of the originally at least ten tomb chapels with decoration in zone 2,[24] the funerary chapel of Djehutihotep is the only larger one which retains most of its painting and relief.[25] For this reason it was selected to serve as a pilot study for the documentation of Middle Kingdom tomb decoration. Moreover, the scenes in paint and relief contain a high level of detail (e.g. Figure 20.7), making this tomb a suitable candidate to experiment with various techniques. Its deco-

23 No historical monument contains exact plane surfaces. Even if the decorated surface approaches a plane, decoration is often carved in relief. Instead, we use the term here to include surfaces which can easily be converted into a two-dimensional plane without significant loss of information.

24 Most of these decorated tombs are listed in Griffith and Newberry [1895].

25 For a recent overview of the tomb's decorational scheme, see: Sykora 2015.

FIGURE 20.7 Detail of one of the marsh scenes in the tomb of Djehutihotep (inner chapel, north wall)
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rative program not only stands out because of its execution, but also because of its subject matter, containing unique scenes such as the well-known scene of the dragging of the colossus.

3.1 *Early Epigraphy at the Tomb and Its Limitations*

The tomb was already visited by several early Egyptologists who copied parts of its decoration.[26] A first attempt to completely document the tomb was undertaken by a mission of the Egypt Exploration Fund, led by Percy E. Newberry in 1891/1892. In less than six weeks' time, they not only finished their facsimile of the tomb of Djehutihotep, but also completed their renderings of the other known decorated tombs on the plateau. Their activities resulted in two publications: *El Bersheh* I[27] & II,[28] which are still the most complete and accurate copies of the tombs in Dayr al-Barsha, and remain the basic source for scholars.

Despite the great efforts exercised by the EEF team members, these facsimile drawings cannot be considered to be a complete record. As has been shown already, Newberry's version omits complete scenes[29] and often ignores portions of the decoration that were difficult to access. A clear example of this can be seen in the drawing of the upper part of the south wall of the inner chamber,

26 Especially notable are the descriptions and copies of Nestor l'Hôte (1840, 46–52, "Deyr Naçarah") and Lepsius (1849, Bl. 134–135).
27 Newberry [1894].
28 Griffith and Newberry [1895].
29 De Meyer and Willems 2016–2017.

where only a small part of the—broken but largely preserved—title sequence is published (Figure 20.8). The fragments above the break were never recorded. Repetitive ornamental patterns, like the ceiling decoration and *ḫkr*-frieze, only appear as abbreviated sketches, or not at all. Furthermore, the mission focused exclusively on the original Middle Kingdom decoration, leaving out any record of later additions such as ancient pictorial graffiti, painted Coptic crosses and nineteenth century travelers' inscriptions. And finally, damage patterns were not recorded, which can also be informative to highlight deliberately erased images. This is for instance the case for the eldest son of Djehutihotep, who has been erased from all scenes in which he was originally depicted.[30] In Figure 20.8a (from Newberry's Plate X), Newberry still partially suggests the presence of this figure with a single line, while on the photograph below the entire outline of Djehutihotep's eldest son is clearly visible. In other instances where traces of the erased son are still preserved on the wall, Newberry merely leaves a void in the drawing.

When studied in more detail, the EEF line drawings are also lacking in accuracy and precision. Although especially the drawings made by Howard Carter display a high degree of detail,[31] specific elements such as clothing, hair styles, feather patterns or interior details of hieroglyphs often do not match with their original painted counterparts. In other cases, no interior details at all are indicated, and figures and hieroglyphs are shown as monochrome black characters.[32] Moreover, the line drawings lack any information regarding the color scheme of the decoration. This is especially unfortunate in a tomb like that of Djehutihotep, where a broad color palette was used in masterful ways. Newberry already acknowledged this problem, which is why Carter was sent back a second season to produce watercolors of selected scenes.[33] While the twenty-three watercolors from the tombs of Djehutihotep and Djehutinakht VI form stunning renderings of the scenes,[34] they only highlight a small fraction of the complete decoration, and remain largely unpublished.

30 The erased son was originally present in all scenes which also depict his brothers (Newberry [1894], Pls. VIII–XI, XIII, XX and XIX).
31 For the differences in methodology between Newberry and Carter, see Reeves and Taylor 1992, 27–30; James 2001, 25–27; Cortebeeck and Willems 2015, 66–70.
32 This is the case for drawings made by Newberry; see Newberry 1894, Pls. V–VI, XIV, XVI, XXIV, XXVII–XXXI; Griffith and Newberry 1895, Pls. V, VIII–IX, XI, XIV–XVII.
33 Newberry [1894], VII.
34 Now stored in the Griffith Institute in Oxford (GI w&d 67; 72; 148–167; 214); see http://www.griffith.ox.ac.uk/archive/GI-watercolours/Deir-el-Bersha/GI_wd_Deir_el_Bersha_Djehutihotep_1.html (accessed on 14-05-2020); Cortebeeck and Willems 2015.

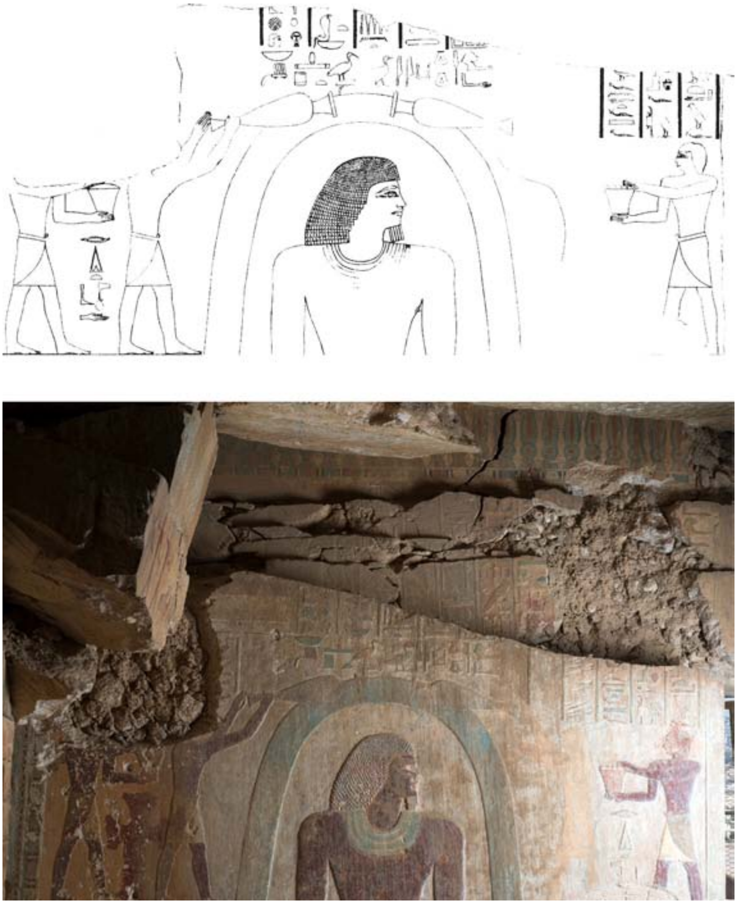

FIGURE 20.8A–B Detail from Newberry's [1894] Plate x (above, Figure 20.8a) as compared to a photograph of the same scene (below, photograph by Marleen De Meyer, Figure 20.8b), showing an example of an undocumented portion of the tomb chapel of Djehutihotep and the erased eldest son (second from the right)

3.2 *Documenting the Decoration Anew*

In order to address these shortcomings, we set out to document the tomb of Djehutihotep anew. In the first stage of this process a complete photographic record of the wall and ceiling decoration of its inner and outer chamber was produced. These photos were used to create orthorectified images of each wall surface in Agisoft Metashape (formerly PhotoScan), which were scaled using on-site measurements. Any areas which may have been blurred or distorted were manually corrected by aligning clearer photographs with the underlying orthophoto. In addition to the orthophotos, we use a large set of close-up images taken with a 60 mm macro lens on a DSLR, which at full size give a magnification of the decoration that is impossible to achieve with the naked eye. These close-ups allow us to really catch every detail that the ancient artist created with his brush.

The final orthophotos serve as base layers for on-site epigraphy following the digital Chicago House method developed by Krisztián Vértes.[35] In the same way that a practical and workable field methodology is essential for 3D scanning on site, this also goes for making facsimile drawings of the decoration. We use an iPad Pro (12.9 inch) embedded in a custom-made wooden drawing tablet, which provides the flexibility needed to make the base drawings in front of the tomb walls. Since the current iPad cannot handle the high-resolution large scale orthophotos directly—the largest complete wall surface in the tomb of Djehutihotep measures over 30 m^2—they are divided into smaller squares of 50 by 50 cm with an overlap of 2.5 cm on each side. Each square is then drawn separately in front of the original wall, to allow the epigrapher to change lighting conditions and his own perspective. The software used during this process is the iPad app Procreate, which allows using different layers to store information separately. In general, six layers are used:

1. Orthophoto
2. Painted decoration
3. Decoration in relief
4. Damage
5. Graffiti
6. Painted Coptic crosses

The resulting multilayer image forms the best possible documentation of these walls. This initial drawing (Figure 20.9a) is then collated by another Egyptologist who corrects errors and detects omissions, a process that is repeated until there is a consensus on the final base drawing. Once this is agreed upon, the squares are realigned, and a final 'inked' drawing is produced in Adobe Photoshop. At this stage the *trait de force* is added in case of relief decoration, a convention of varying line thicknesses to indicate raised or sunk relief, and the color variation in the decoration is rendered in different shades of grey (Figure 20.9b).

The digital facsimile that is obtained by this method is a reliable reproduction and permits the representation of the tomb of Djehutihotep throughout the different stages of its use: from an unobstructed representation of its Middle Kingdom decoration, through its Coptic reuse and into its present state.

35 Vértes 2017.

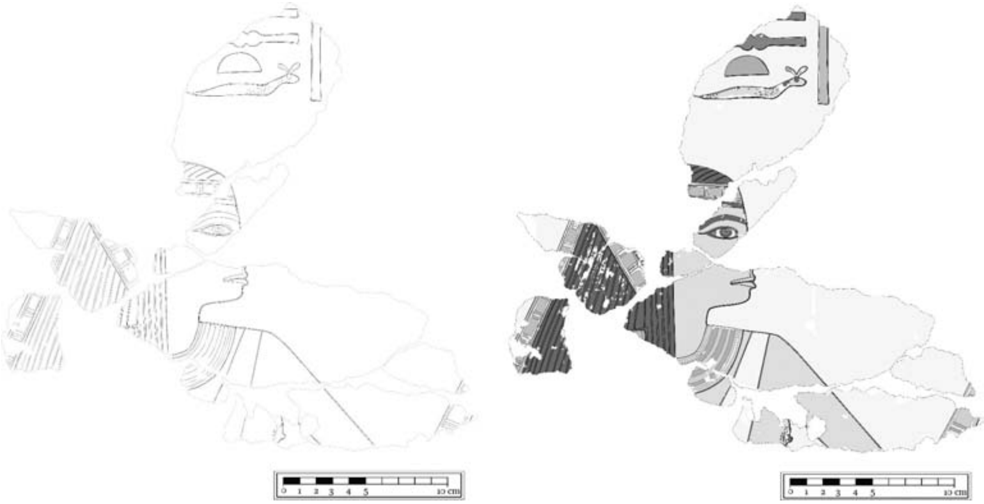

FIGURE 20.9A–B Initial line drawing (left, Figure 20.9a) and final inked drawing (right, Figure 20.9b) of a reconstructed part of the procession of ladies on the east wall in the inner chamber of Djehutihotep's funerary chapel (scale: 1:4)
Note: This reconstructed scene consists of fragments 1058/9–12, 14, 16–18 and 1290/144.

4 Work in Progress and Future Goals

Documenting a tomb, let alone an entire site, with the methods described above is a time-consuming effort and requires long term goals. While at present the 3D digitization of the standing architecture is to a large extent completed, many individual decorated wall fragments still await scanning. Of the digital epigraphic copy of Djehutihotep's tomb a first draft is complete at the time of writing, which still largely needs to be collated and corrected before being digitally inked. As a final step we plan to integrate the 2D digital drawings with the virtual 3D model of the tomb into one user interface, which will be made accessible online, allowing scholars to explore and study the tomb of Djehutihotep in the most detailed way possible.

The interactive virtual platform shows promising results in terms of its capability to handle multiple high-resolution models. Along the same lines, it has successfully served as a support tool for experts to digitally reassemble fractured fragments. However, its degree of automation is at the moment of writing still limited in the sense that the engine itself does not provide the user with automatic matching clues. Therefore, computational modules that suggest matches based on geometry are being developed, and the future goals aim towards matching and alignment algorithms to aid manual reassembly. In this regard several options are being explored, such as extraction and description in 3D of points of interest to estimate sets of correspondence points, extraction of relief-decoration to join continuous decoration lines or curves, and shape-based matching based on the decorated surface's contour. Additionally, machine learning techniques are also considered, so that the engine can progressively learn to align fragments based on the expert's operations.

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