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WORKFRAME FOR CLOSE-RANGE PHOTOGRAMMETRY DOCUMENTATION OF AN 11KM LONG ARCHAEOLOGICAL EXCAVATION, AL AIN, UAE

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ABSTRACT:

Over a six-month period from late January to early August 2021 the Historic Environment Department of the Department of Culture and Tourism (DCT) Abu Dhabi carried out archaeological monitoring along a 11.5km stretch of a project to renew the existing border fence between the United Arab Emirates and Oman within the oasis city of Al Ain.
The scope and sequence of the construction project determined the excavation and recording methodology employed. The trench was roughly straight-sided, 3.5m wide by 3-4m deep and entailed machine excavation of more than a million cubic meters. Documentation of this trench, which proceeded at an average distance of 80m a day, has informed our understanding of the landscape, identified locations for future archaeological work and assisted our ongoing efforts to manage and protect the historic environment. The project produced new data on the development of the historic oasis landscape of Al Ain, a UNESCO World Heritage property. Some of the most significant features revealed include a monumental stone tomb from the Late Bronze Age (2000-1300 BCE), an extensive Iron Age (1200-300 BCE) cemetery, high-status tombs of Late Pre-Islamic date (300 BCE-300 CE) and more than 50 ancient *aflāj* or underground water channels of various dates and techniques of construction, along with extensive evidence for distinct phases of Iron Age agriculture.
Photogrammetry recording sessions numbered nearly three hundred in total, together creating a series of consecutive overlapping 3D models from which ortho-rectified images in plan and section have been produced for each of the zones along the trench route.
This paper discusses the recording practice and workframe as it evolved over the course of the project, and the challenges found during the data acquisition phase in terms of the construction environment, lighting, geometry, tools, time and team size. It presents the system used to manage the digital data archive needed to keep track of 288 recorded photogrammetry sessions, along with the related ground control points survey. The paper discusses the challenges and available solutions for rapid processing and delivery of geo-referenced 3D models and ortho-rectified images generated throughout the project. It concludes with some general remarks on the peculiarly linear challenge of presenting the results of an archaeological excavation 11.5km long and 3.5m wide in both digital and hard-copy formats.

1. INTRODUCTION

The Oman Border Fence project (OBF) took place over the course of eight months from January to August 2021, during work by the UAE Armed Forces to renew an 11.5km stretch of the international border fence between separating the cities of Al Ain (UAE) and Buraimi (Oman). The Historic Environment Department (HED) of DCT Abu Dhabi carried out archaeological monitoring and excavation as it was clear the project had archaeological implications, with a number of *aflāj* alignments noted earlier in the area of the Qaṭṭāra, Jīmī and Hīlī oases that would cross the line of the excavation trench if extended eastwards. The project route ended up revealing a series of long cross-sections through the complex cultural landscape of Al Ain, divided by the changing alignment of the excavation into six consecutive zones (Aa, Ab, B, C, D, E). (Fig.1).

The scope and sequence of the construction project determined the excavation and recording methodology. The trench was roughly straight sided, 3.5m wide by 3-4m deep from ground level and entailed machine excavation of more than a million cubic meters, moving in a linear direction South to North at an average of 80m a day. For security reasons, excavation was coordinated with the removal and replacement of the existing fence to minimize gaps left open overnight. From our side we approached it as a 'rolling' evaluation trench producing a wealth of diverse data. With such an intense and destructive excavation, it was essential to have a rapid detailed and accurate documentation system to record the accumulated information from the excavation trench using a range of tools and software.

Zone Aa revealed that the first section through the ancient landscape consisted of mainly linear cut features such as covered *aflāj* or open channels coming from the southeast and heading towards Jīmī Oasis. Moving north from Zone Aa, Zones Ab and B presented a multi-period funerary, hydraulic and agricultural landscape with a dense array of well-preserved archaeological features and deposits. A number of walled modern and pre-modern cemeteries exist on both sides of the border here, and the longevity of this area as a funerary landscape was soon indicated by three Iron Age graves, partially preserved within the west-facing section. Further north the excavation encountered a large stone-built collective tomb (Tomb A). This tomb is at least 25m long (its eastern extent beyond the limits of the border fence trench remains unknown) and 3m wide, with carefully built stone walls lining the side of the cut and remains of a corbelled roof. Archaeological

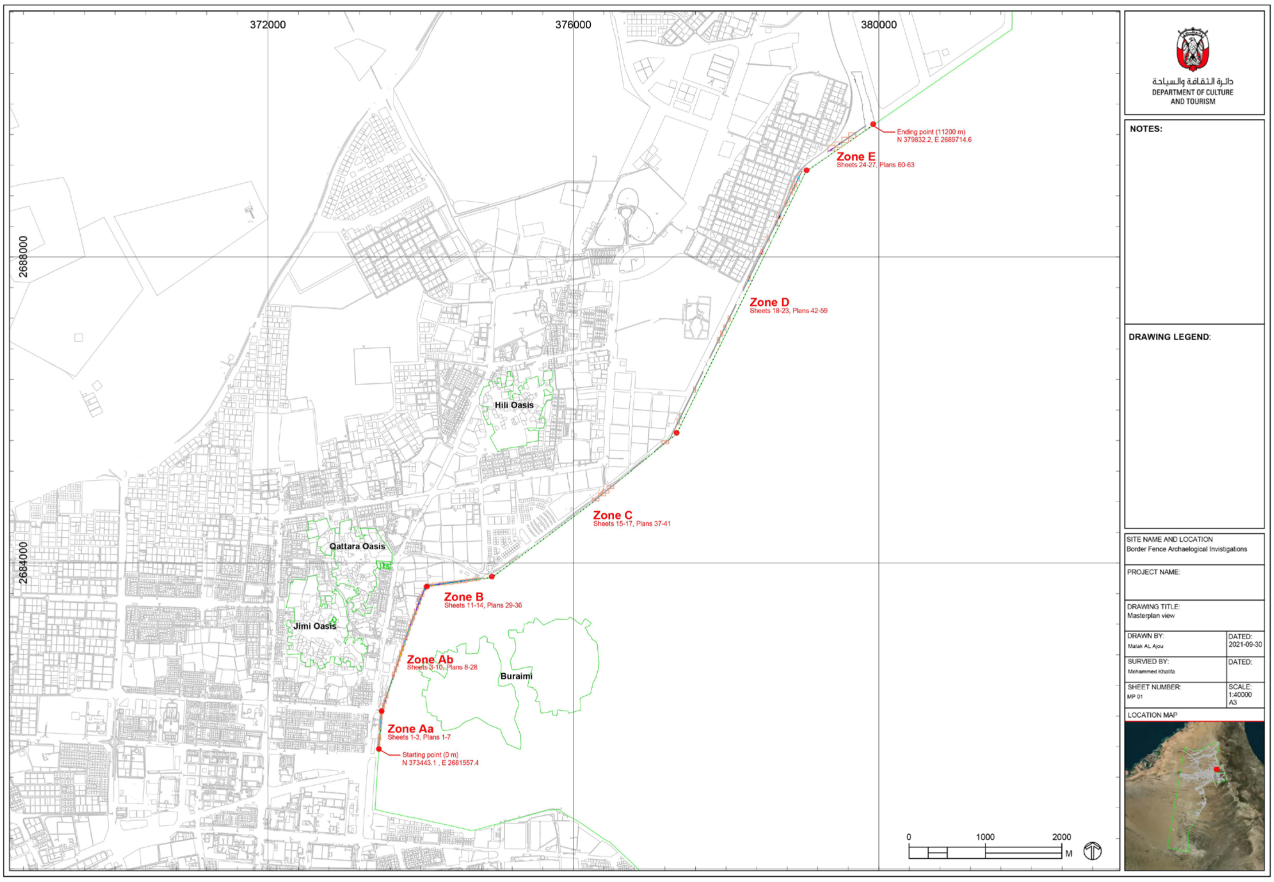

Figure 1. Zones along trench.

investigations here were extended beyond the border fence trench to define the western limits of the structure and establish indicated by another similarly aligned and rectangular collective tomb. Between these two collective tombs we recorded around 35 individual graves within the limits of the trench. North of the cemetery there was an extensive Iron Age agricultural landscape, characterized by intersecting channels with shallower rills branching off to feed rows of individual tree pits. The funerary aspect of the landscape reappears moving further north where the dense sand deposits that had accumulated over this earlier Iron Age field system are cut by two masonry-lined subterranean Late Pre-Islamic (PIR) tombs (Tombs B and C). To the north of the PIR tombs the Iron Age agricultural landscape continued in Zone B to around the 2600m mark of the border fence trench. Beyond this, natural deposits come gradually closer to the modern surface and a large section of Zone C produced no archaeological material until around the 4.8km mark, where two *aflāj* were noted. Zone D presented a 4km long section through the landscape as it approaches the rocky hills north and east of the archaeological site of Hīlī. Here we recorded the upstream sections of more than thirty *aflāj* of various typologies and depths. Zone E lies north of a buried spur of the adjacent hills cut through by the border fence trench. Here we noted three more *aflāj*.

2. EXCAVATION CONTEXT

The excavation produced a wealth of data that was recorded and documented along the evaluation trench. It was important to standardize a workflow very early in the project to ensure we could achieve the required data recording, in parallel with a the sequence of its construction, use and abandonment. The northern limit of this prehistoric cemetery is well-organized and logical structure to archive it for future retrieval. The system had to follow a logic common to all users for ease of communication and data searching. The structure for the digital records thus had to mimic the project division and echo the progress made on site.

A combination of field survey and photogrammetric survey produced a reliable set of highly detailed data. The job was done by an in-house team of three surveyors, except for a number of locations where 3D laser scanning outsourced assignments were needed to deal with complex geometry or when *aflāj* extended significant distances to the west or east of the border fence trench. The paper explains the practices used to achieve a full and thorough record of the project by conducting a close-range photogrammetric survey.

Each of the above-mentioned Zones had to have a case-specific approach for recording based on excavation methodology and the geometry of the features it contained. In Zones Ab and B initial excavation after removal of the old fence took place to the top of the underlying natural only. Each newly revealed area was then carefully cleaned by hand and the limits of individual cut features were recorded by total station survey and photogrammetry survey. This was referred to as ‘Stage 1’ of recording and took place as a ‘session’ along a specific distance of the rolling open trench. Next, the deeper features revealed at level of Stage 1 were explored by excavating further with hand tools to as great a depth as could be safely achieved, and the larger cut features which there was no time to fully excavate were explored by sondages. Recording after this excavation was referred to as Stage 2, and was captured in another round of total station and photogrammetric survey. After recording of

Stages 1 and 2 were completed, machine excavation continued to the full depth of the trench. A final round of total station and photogrammetric survey (Stage 3) was done before the installation of the fence foundations, recording this additional lower part of the sections and deeper cut features like *aflāj* in plan. As mentioned above, the tombs were explored beyond the limits of the trench, and the multiple sessions of recording in these areas were referred to as Stage 2 survey for the sake of consistency. It is important to mention as well that excavation of the next rolling section of the trench was proceeding simultaneously while the current window was being constructed, with a session of Stage 3 survey and a session of Stage 1 survey often conducted on the same day. In the other zones C, D and E, excavation took place only once to the full depth of the trench and was followed by cleaning and recording of the sections and excavation of any archaeological features noted in plan. As with the above mentioned standard approach, this was referred to as Stage 3 survey. Together these digital photogrammetric survey sessions created a series of consecutive and overlapping geo-referenced 3D models, 288 in total, from which orthomosaic photos in plan and elevations have been produced to later form an ‘unrolled’ section of the landscape.

3. DOCUMENTATION STRUCTURE

With 288 sessions of photogrammetric survey sessions, and nearly as many total station field survey sessions, managing the data input started by organizing the site work. Each feature was assigned a context number and type, with the number written on a tag card and placed securely with a nail next to the feature. To be able to geo-reference the photogrammetric survey, we had to place Ground Control Points (GCP) on site. These were initially square black and white checked targets which were also securely placed on site by nails in elevation and plan. To distinguish the GCP used for each of the different Stages of photogrammetric records we introduced an additional three types of coloured GCPs (Fig 2), using yellow, blue and green checked with black. The yellow was placed in two locations one at the beginning and one at the end of each session area both in plan and elevation regardless of stage number. The green was used for the interior of features excavated in Stage 2 (in plan only), and the blue in plan and elevation in the sessions of Stage 3. This type of color coding was reflected in the field survey codes as well.

Figure 2. Colour chart and GCP in ground.

To perform an accurate total station survey, we started by placing a benchmark on site using a GPS instrument, These benchmarks were coordinated with a known fixed station made by Al Ain Municipality. The total station was then calibrated based on the coordinates of these benchmarks prior to conducting the field survey. The surveyor then carried out a detailed survey for each of the individual features in plan and elevation, storing the context number and type as the point ID. The survey for the different GCPs followed the same principle; the assigned point ID was in the form of two letters, first is T for Target, second is either Y,B,G for the colour, followed by four numbers representing month and day of the survey, for example TY0324. The standard black and white targets were used in Stage 1 sessions and were assigned a point ID consisting of the T followed by MMDD format, for example T0324. With each field survey conducted we would have multiple GCPs, so this system allowed us to accurately identify the right ones to use for referencing each of the 3D models. The processing continued for a year after the end of excavation and such information in the survey made a great difference in retrieving the right data.

Production of drawing plans was a necessity as a rapid tool for understanding the site during the course of excavation, so field survey had to be prioritized in terms of producing annotated plan drawings. After successfully finishing a session of field survey on site, the file would be extracted as an AutoCAD file (.dwg) format and archived within a folder structure containing all field survey, each named after the date of survey in format of YYYYMMDD. Then within the AutoCAD drawing of the individual survey, points sharing the same point ID would be grouped together on a separate layer which was then named after the point ID followed with the date of survey of the same CAD drawing. Thus, each layer name identified type and date. In order to produce a holistic site plan each of these individual CAD drawings was collectively gathered in one drawing, eventually containing all the field survey data organized using the layering system. It was easy to validate survey accuracy and track any information that might be missed, or to recognize survey duplications. The data hierarchy system made it easy to track back source data in case of any error or miscommunication found.

As for the photogrammetric survey, we had two persons doing photogrammetric survey on site simultaneously, though each was conducting a different session, one doing the Stage 3 area and the other doing the Stage1\2 area. With such demand of data input for the records, which totalled up to 37102 photos, we developed a naming strategy to reflect the documentation system and to be able to use the right GCP for georeferencing. Each completed photogrammetric session was also archived within the folder structure, in a separate file for each of the Zones, and named as starting with a date in the format YYYYMMDD, followed by the name of the first feature in plan furthest to the south, and the last feature in plan furthest to the north, followed by the time of day (am or pm), then the stage number, then the initials of the surveyor conducting the survey. Following such an archiving system served as a map to navigate through the enormous data set, also reflected on the field survey information (Fig 3).

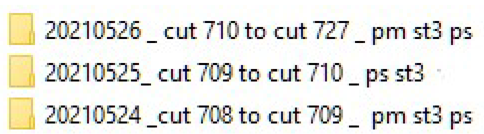

Figure 3. Archiving photo folders.

4. DATA ACQUISION CHALLENGES

The purpose of conducting a photogrammetric survey was to use the records to duplicate a digital 3D copy of the site from which secondary products can be generated such as topographic maps and orthomosaic images. A DSLR camera was used to conduct the photogrammetric survey. Since there were two persons working on the acquisition of images simultaneously on site, we used two cameras, a Nikon D7200 and a Nikon D90. This allowed us to generate large images of 4000x6000 pixels with a high resolution of 300 dpi. The file format was JPG in high definition which resulted in images of approximately 4 MP in size. The photo acquisition was carried out in sessions as explained earlier, with fixed lenses for each of the cameras. No tripod was used in this process due to the difficult geometry, the rough terrain and time constraints. No drone-based aerial photogrammetry survey was possible due to security reasons associated with the unique location of the project along an international border.

The data acquisition phase started by taking a series of good photos. All the images were taken using auto mode without flash. For the best results the photos were taken with consistent lighting conditions early in the morning with ambient sunrise light, or in the afternoon with ambient sunset light, both timings which ensured no shadow was cast on site. Within all recording sessions, a colour chart was used within the photo frame in the first image for later colour calibration process using Adobe Lightroom. This step was crucial to ensure the outcome would be visually coherent. However, in some cases we had to do the photogrammetric survey at mid-day, which meant over exposure of light and harsh cast shadows. Such conditions were not convenient and did not serve the purpose of the survey. To overcome this problem, we improvised shading the required area with geotextile held over the open section (Fig 4). Use of this material allowed ambient light and coherent shading. In some of the longer sections, we improvised by gradually moving the shading geotextile along to cover the area that the camera frame would capture, then moving to shade the next frame and so on, so that eventually all the captured images had the same lighting conditions. Even in such improvised conditions, we also used the colour chart to calibrate the image colours.

Figure 4. Documentation conditions on site.

While capturing the photos on site we also established a systematic workflow to ensure no gaps were left unrecorded. The person conducting the survey would capture the photos from the inside of the trench with the camera aligned parallel to the vertical sides of the trench. Since the trench was around 3m wide, standing at the far side would fit the whole height of the trench section within the vertical frame of the camera. Single frames with a 70% overlap were captured while marching towards the other end of the open trench. This was repeated to capture the other side as well. The surveyor would then capture photos from the higher ground level outside the trench with the camera held parallel to the lower portion of the trench, then again at an oblique angle towards the section, again making overlapping frames by marching along. This was also repeated on the other side. This approach has guaranteed that each session of photos would produce a complete 3D digital replica of the trench, and also guaranteed capturing all GCPs located in the trench in multiple frames and making them usable for georeferencing the 3D model. (Fig 5) More importantly, it guaranteed that the generated orthomosaic image would have high detailed visual information.

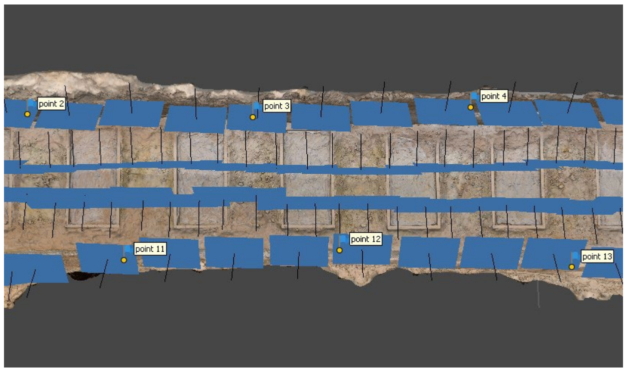

Figure 5. Frame location and GCP in stage 3 model plan view.

For more geometrically complex features that were not large enough to assign to 3D laser scanner, a similar approach of close-range photogrammetric survey was followed. First, the standard system of recording explained above was completed, then within the same session of recording more close-range photos would be captured for each of the features contained within the open trench. With the surveyor inside the trench, recording started by capturing frames all around the feature at an oblique angle, followed by others taken parallel to the ground at head height, then lowering the camera to the inside of the feature to capture the inner sides while maintaining a parallel frame. For the cuts that were large enough to move inside, the surveyor would get in physically. And for the deeper features such as wells, the surveyor descended via a ladder, capturing frames at the bottom, using the same techniques described above, then capturing frames from the mid-height of the ladder all around. We had GCPs placed on the interior of the wells and *aflāj* shafts. These were initially intended to be used as a tie-point in case the software was unable to match photos from the rest of the session due to the drastic light change of light on the inside of the well compared to the exterior which would have resulted in visually unmatched areas. However, the technique of recording was successful because of the sufficient overlapping between the frames, whilst performing colour calibration prior to processing minimized the difference. Colour charts were also used on the inside of the deep features. The GCPs on the inside of deep features were therefore able to be used as supporting georeferencing data.

5. DATA PROCESSING CHALLENGES

We had a limited team size, with only one person responsible for drawing production and 3D production, which restricted the ability to process the 3D models of the photogrammetric survey to a minimum during the course of the project. In a few cases production and sharing of the 3D models with the wider project management had an actual impact on the decisions made in favour of conserving the tombs found in Zone A. Rather than completing the excavation in those areas to the full depth of the trench, it was decided to redesign the foundations of the fence to accommodate its installation over the level of the archaeology to protect it. A 3D model for the concerned area was generated from the recorded session, and georeferenced using the GCPs. A properly scaled and oriented 3D model was then exported to Rhino software where further interpretation can be achieved. This was used to create the foundation pillars in 3D in their respective locations within the model and was modified to incorporate the archaeology in 3D. This was then used to produce a guide drawing for the contractor to modify the design and construction. (Fig 6)

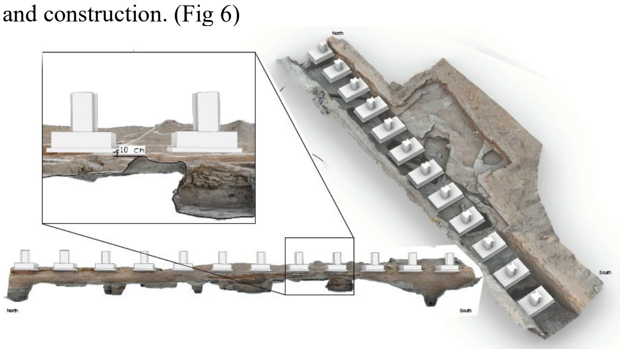

Figure 6. Foundation design interpretation with archaeology.

After a few attempts to process the data by individual sessions, we soon realized that we needed better technical solutions to be able to process such enormous data within a realistic time frame. At the beginning the available computer capability was RAM - 24G/GPU, 8G/CPU – Intel core i7. Attempting to run multiple individual sessions simultaneously resulted in crashing the software due to not having enough memory. On the other hand the files were only accessible through the office network, which meant the processing session had to be performed during office hours only. Such circumstances allowed processing only one session a day, which did not sound like a smart choice considering that 288 sessions were lined up. The IT department offered a solution of Virtual Desktop Interface (VDI) that served best for file accessibility and computer capability, that worked wonders in running multiple individual sessions simultaneously, making it possible to monitor and initiate processing of different sessions even when out of the office. That phase was focused mainly on processing all the sessions up to the production of a 3D textured mesh model. Then each of the models was georeferenced by inputting the surveyed three-dimensional coordinate for each GCP visible in the model by copying the point coordinates from the CAD drawing into Agisoft Metashape, the software used for processing. This process relied on visually matching the required GCP in the model with the ones in the drawing after identifying both ends of the 3D model based on visible feature tags and filtering the GCP layer based on date and colour. After georeferencing all the models it was time to generate orthomosaic images for the elevation and plan view. The first thought was to combine all the models of one Zone together, merging them into one, then generating the orthomoasic photo from that. This sounded promising at first but failed for a few reasons. When we tested that with part of Zone Ab, using only 8 models, the software showed many mismatches in the photos used in the generated orthomosaic. It was not wise to spend time correcting it as it would be wiser to generate the individual sessions with no errors. The other reason is geometry. Although the trench seemed linear and straight sided, once we tried generating an orthomosaic photo that stretched for 500m long of sessions, the result showed the section of such a length is not orthographically projected in plane, because it was impossible to achieve that on site. Since the desired outcome of this exercise is to produce an unrolled section of the trench, we decided to take a different path by producing the orthophotos for individual sessions and aligning them inside the CAD drawing using the field survey as an overlay, guided by GCPs, in a similar approach to image rectification. We did not perform rectification because the exported orthomosaic images would be imported into CAD with the correct geographical parameters of measurement, location , and orientation because the models were geo-referenced. This worked well for the orthophotos in plan. The ones in elevation, although they were imported in the right measurement and orientation, all stayed at the same location in the drawing because CAD cannot read geographic data in the vertical plane. That is why manual matching to the respective GCPs was needed, and was achieved simply by moving the photo. Completion of processing and post-production of the complete records took about 8 months after the completion of the excavation project. Eventually, we had a CAD drawing for each of the zones, unifying in a single document the result of multiple surveys.

6. GRAPHIC PRESENTATION AND SHARING

Presenting an extended plane with huge extents is a challenging exercise. We wanted to present the 'unrolled' series of orthomosaic photos as a primary element for the representation of the landscape section, combined with the overlaid field survey to provide the necessary tool for the understanding of the site. Both elevations on the side of the evaluation trench can be considered as a section through the cultural landscape. Although the records from Stage 3 served as an extension of Stage 1, it was decided to consider it as a record of its own because it also revealed new information in elevation view. Therefore eventually for each side we had two elevation views to present. In conjunction with the orthomosaic of the plan view, it was decided to show only Stage 2 records in plan because it showed the features fully excavated. We decided to reflect upon this information by stacking elevations from Stage 1 and Stage 3 vertically while showing the Stage 2 plan view in a third row beneath. All were aligned to reflect the same location on site with virtual 10m marks along the trench, at scale 1:50 on A3 size paper (Fig 7).

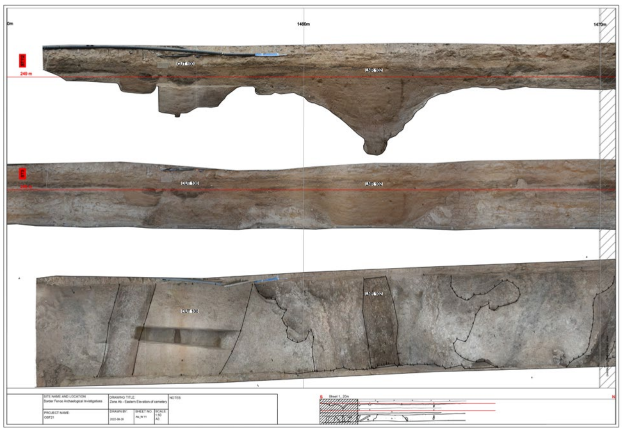

Figure 7. Drafts for presenting the unrolled section.

Although the result of this exercise looked good on screen, it is still challenging to find a way to present, in hard copy format at a readable scale with convenient paper use, the unrolled series of orthomosaic images, to be used as a working tool that can be annotated and commented on. When we tried experimenting by producing the drawing at a scale of 1:50, the unrolled elevation would require a 25m long piece of paper.
Even as a digital 3D models, combining 288 geo-referenced individual models into one is a challenging task. The concept of putting together such a wholistic 3D model means sacrificing the visual quality and simplifying the mesh face count to bare minimum, which in such case if achieved, would not be visually informative or geometrically accurate, and thus cannot be used to reflect true measurements. The 3D models provide a great comprehensive record available at our fingertips. We used an online sharing platform called SketchFab to host the 3D models for the purpose of internally sharing and viewing them through a private account. However even with such a convenient and available tool, more post processing is needed such as mesh decimation before being able to upload it due to file size constrains, which means more time and effort is needed. Considering this information, the graphic presentation and solutions for sharing the output is still a work in progress.

7. CONCLUSION

The Oman Border Fence project has significant implications, both from the cultural and operational points of view, in the field of archaeological digitization and photogrammetric survey practices. Documenting such a case has facilitated the transfer of technology from the measurement sciences into heritage documentation. Ideally, the highly accurate models and drawings produced by the project will serve as an archive for further development.. These new insights into landscape archaeology in Al Ain can help to refine our earlier observations. The OBF has demonstrated the survival of numerous previous episodes of site formation, and how detailed documentation can continue to transform our understanding of the development of the oasis landscape of Al Ain.

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