Use of Terrestrial Laser Scans for High-Resolution Documentation and 3D Modeling of "Desert Kites"

Two of the authors (R. Arav on the left, S. Filin on the right) using the LiDAR scanner inside the head of the Samar West B kite. Photograph by D. Nadel.

Reuma Arav, Sagi Filin, Uzi Avner, Guy Bar-Oz, Amnon Nachmias, and Dani Nadel

The term "Desert Kites" is used in Near Eastern archaeology when addressing large game drives found solely in arid environments. There are several types of such features (Bar-Oz and Nadel 2013; Betts and Yagodin 2000; Echallier and Braemer 1995; Helms and Betts 1987; Van Berg et al. 2004), and the ones addressed here are large triangular-shaped constructions, each built of two long converging stone walls (arms) with a more-or-less circular enclosure at the apex (commonly termed the "head"). The arms may extend for hundreds of meters; they are constructed of local stones and vary in thickness and height.

Based on historical accounts and rock engravings, Desert Kites are commonly interpreted as game traps for wild ungulates. Only a few kites have been directly dated radiometrically, mostly to the Early Bronze Age or later (see Holzer et al. 2010 for a recent summary). In some areas, like the southern Levant, *in situ* material remains and animal bones are very rare.

The topographic settings of some kites in the Negev suggest that animals were approached while grazing in a pasture area or crossing the landscape along established routes. They were then driven into the funnel-shaped arms of a kite, and frightened over a cliff or into a small enclosure (Meshel 1974, 2000; Perevolotsky and Baharav 1991; Rosen and Perevolotsky 1998).

Kites are built of undressed local stones, and thus in many cases are hardly visible on the landscape. Using traditional archaeological documentation techniques, such as field measurements, is time consuming and provides limited results due to rugged topography and problems with differentiating between *in situ* (wall) stones, collapsed stones, and naturally scattered stones. Furthermore, topographic details are hard to obtain this way, and apparently the kites' settings were chosen taking into consideration the general landscape and particular micro-topographic details.

We thus introduced the use of terrestrial laser scanning to our documentation protocol. Here, we use the two Samar West kites (figs. 1–3) as a case study for high resolution documentation of such features. The derived 3D models provide the basis for various analyses. Hence, better documentation results are achieved and incorporated with field observations, boom-photographs (taken with camera on long pole), and general photographs. The derived models provide an excellent platform for a range of geometric and quantitative analyses, some of which are addressed below.

Laser Scanner and 3D Modeling

Terrestrial laser scanners enable direct measurement of a dense and accurate set of three-dimensional points, facilitating a detailed surface and object description irrespective of their shape complexity. Generally, terrestrial laser scanners employ the principle of collimated and coherent energy pulse emission, measuring the round-trip travel time of the laser beam from the scanner to the illuminated object. Translated into range and adding longitudinal and latitudinal beam diversion mechanisms, the results provide a panoramic coverage of the surveyed scene. To guarantee total coverage, limit occlusions, and obtain a sufficient level of detail of the region of interest, the scene has to be scanned from several stations and then registered together into a common reference frame. Registration of the individual scans into a common point cloud is performed by using designated reflector targets, which can then be automatically recognized, and act as tie entities.

Field Scanning and 3D Modeling of Kites

There are three kites at Samar, the southern ʿAraba Valley, Israel (Holzer et al. 2010; Meshel 1974, 2002). Two are adjacent to each other (Samar West A and B, SWA and SWB, respectively) and are the focus of this study. We excavated a trench in the head of each kite, and several test pits along their arms (Nadel et al. 2010). SWA has a tumulus (burial cairn, fig. 2) built on top, with a minimum date of ca. 4,500 cal B.P. (Nadel et al. 2010); the SWB head was partially robbed of its stones for the building of a wide enclosure (fig. 3). The apex of the third local kite, Samar East, was also dismantled in order to build an Early Bronze Age habitation unit. In all three cases the secondary constructions took the kites out of order.

At the Samar site, scanning was performed using the Leica ScanStation C10 terrestrial scanner with an accuracy of ±4 mm in range measurements and ±12” in angle measurements. The vertical and horizontal angular scan resolution was ~0.057°, spanning 360° horizontally and 90° vertically. We stationed the scanner at 20 locations around and along the two kites, as well as one station within each head (fig. 4). The area covered was ca. 600 × 400 m. The complete point cloud consisted of ca. 100,000,000 points, with a density in the range of 4,000–10,000 points per m^2.

Results

Based on the 3D models, the first step in analyzing the two kites was to retrieve a set of data pertaining to dimensions. We calculated that the areas of the kites (between the arms) are 7,465.8 m^2 (SWA) and 4,876.2 m^2 (SWB). The angle between the arms, near the head, is 18° (SWA) and 25° (SWB) (fig. 5). The average inclination along each structure is 3°–5°, reflecting a generally flat topography.

The heads of these two kites are similar in some respects, despite their different shapes and dimensions. Heads A and B are almost identical in terms of area – 21.5 m^2 and 22.1 m^2, respectively (figs. 6, 7). The widths of their walls do not remain constant for each kite, averaging 2.0 m (SWA) and 1.9 m (SWB); the preserved average heights are once again similar between the two kites: 1.0 m and 1.3 m respectively. However, the volumes of the walls are vastly different: 32.5 m^3 and 45.95 m^3. We assume that the original heights of these walls were not preserved. Furthermore, in both cases,

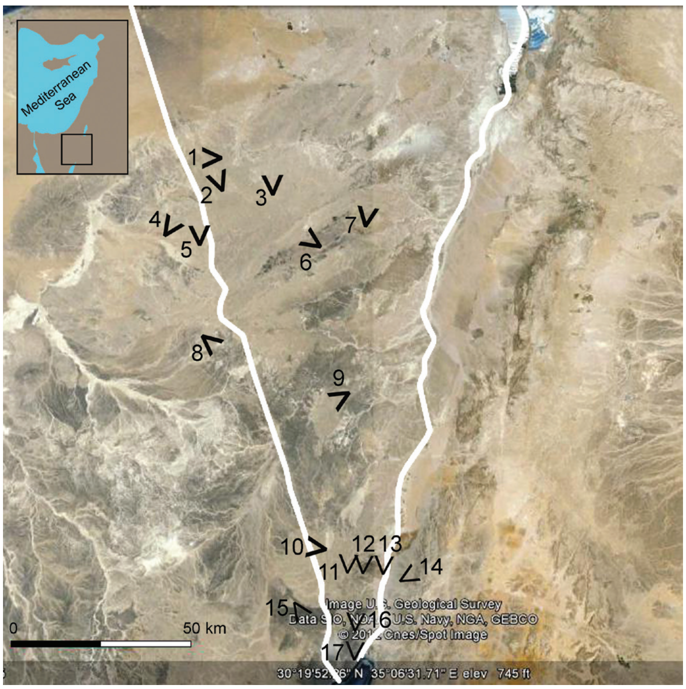
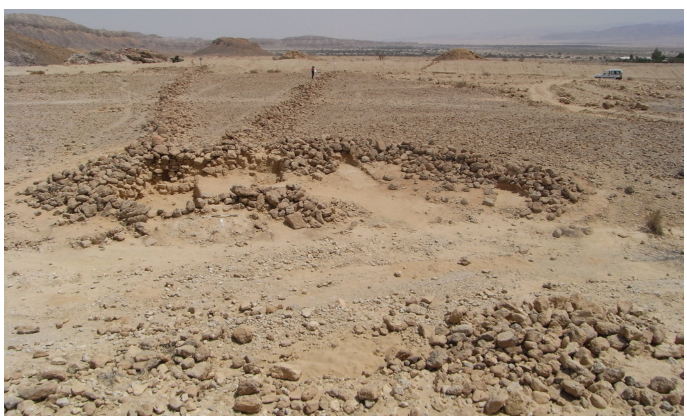


Figure 1 (above). Map of the Negev and northeast Sinai with location of known kites. Numbers 11 and 12 are the two Samar kites discussed. Prepared by A. Gisis-Regev.

Figure 2 (bottom left). A general view of the Samar West A kite looking northwest. The head with the excavation trench is in front, and a tumulus (an Early Bronze Age burial cairn) is visible at the junction between the two arms and the head (top center). Photograph by D. Nadel.

Figure 3 (bottom right). A general view of the Samar West B kite looking north. The head with the excavation trench is on the center left, with the two arms behind it. A later construction partially damaged the head while creating a wide curved wall (center right). Photograph by U. Avner.



stones were taken from the head for subsequent constructions during the Early Bronze Age. Thus, the original volumes of these walls must have been larger.

The arms appear to have been built with the same method, where local stones of various dimensions (including very large boulders) were taken from the immediate vicinity and used for constructing the wall. The lack of many collapsed stones along all parts of the walls indicates that such a post-construction process was not common. Rather, the walls were built 2–3 stones in width and 2–4 courses high.

The volume of the arms was calculated as follows. First, we calculated the area covered by each wall. For example, the length of the right (western) arm of SWA is 151.6 m (this is the true length, while as a straight line the arm measures shorter at 149.9 m). We then calculated the average bottom (1.2 m) and top (0.5 m) width, as well as the average height (0.7 m) according to preserved *in situ* stones and the few scattered by the wall. Thus, the volume of this arm is 90.9 m^3, which is about four times the volume of wall of the head. The length of the longer left arm is 201.6 m, and the calculated volume is 121.0 m^3. The right arm of SWB is 140.8 m long, and the volume is 84.5 m^3. The left arm of SWB is 188.5 m long, with a volume of 113.1 m^3. The total construction volume of SWA is 244.4 m^3 and that of SWB is 243.5 m^3. Naturally, these walls were not uniform along their entire lengths, in width or height, as they were built with undressed

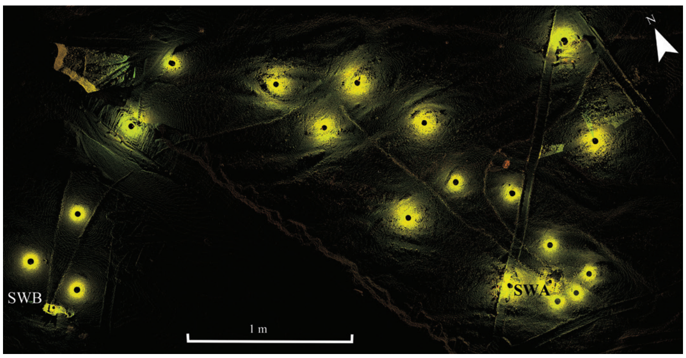


Figure 4. The Samar West kites as depicted in the scanned point cloud and the location of scanning stations (black circles in the middle of green circles). Prepared by R. Arav.

stones in a very simple manner. Still, the results provide good estimates (we would argue for a resolution of ±5–10%). Noteworthy is the fact that the total construction volumes of the two kites are very similar, although the shapes and areas vary considerably.

The models provide an excellent source for studying the way the arms of kites were set on the landscape. This is particularly important, as each kite can differ from another in a variety of ways, and deducing the reasons for those differences is relevant for understanding the parameters considered by the builders of these kites.

By combining field observations and the 3D models, it becomes clear that the arms of kite SWA are constructed on the highest available grounds, which ran along the main axis of the kite (fig. 8). The arms of SWB are built on a flat area (fig. 9). In both cases, no large boulders are present between the arms, or adjacent to them on the outside of the kite. It is likely that the builders used local boulders and stones for construction, leaving the ground between the arms clear. This may indicate the desire of the builders to provide a clear driving area to facilitate the frightened run of the target game.

Discussion

One of the advantages of modeling archaeological sites has nothing to do with immediate analyses. Rather, the archiving of a high-resolution model of the site is important for the future. Sites are always vulnerable, both to modern development and to environmental hazards. Thus, a digital model provides a back-up that could be stored for future generations. Naturally, it could be used at any time both as a cultural resource and for research purposes.

Desert Kites provide a challenge to archaeologists as they are commonly located in harsh environments where long term field seasons are not always easy to conduct. Furthermore, frequently the construction stones are not easily differentiated from nearby naturally scattered stones. Thus, in such a complex landscape, fieldwork should attempt to provide the best documentation in the quickest and cheapest way. Using laser scanners saves many field days compared to traditional documentation procedures, and provides much better results.

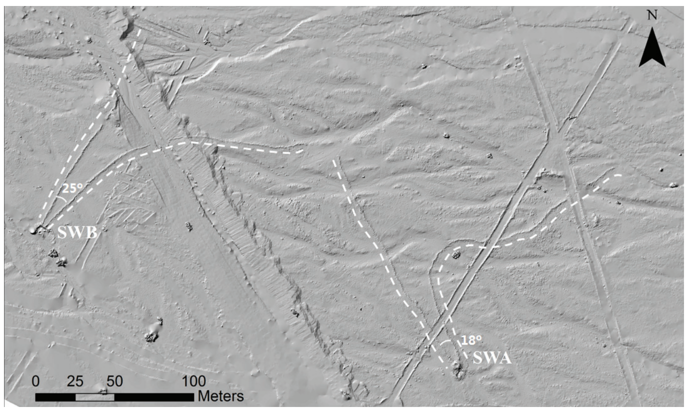
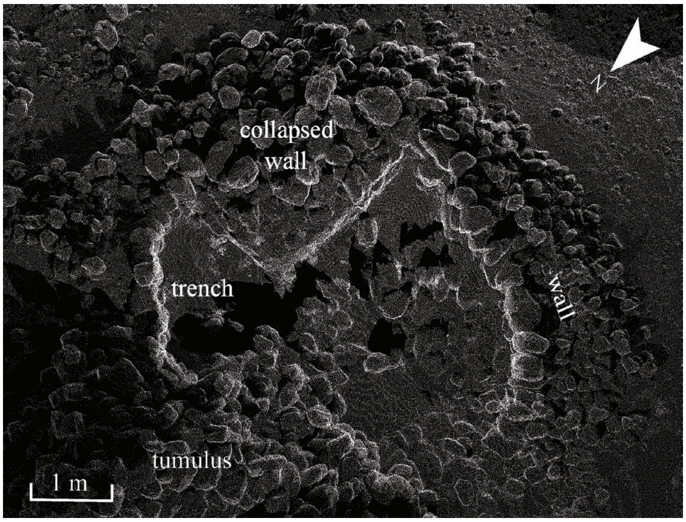


Figure 5. A model of the Samar West kites. A dashed line follows the exterior contours of the arms. Note the small water channels crossing from west (left) to east, and the modern dirt roads. A wide modern ditch crosses the Samar West B kite (from top left to bottom center). Prepared by R. Arav.

One should also stress that a 3D model serves as an excellent platform for current analyses, providing high-resolution images that can be easily manipulated by the appropriate software. When a 3D model of a site is documented, future research/analyses could be conducted easily without the need to return to the site.

The results presented here pertain to a pair of adjacent kites used as a case study. The construction volume of the arms and apex of each kite should be appreciated, as the construction of each kite must have involved hundreds of working days. This is especially outstanding considering that the kites are in a desert environment with no large cities or even villages nearby. In other words, either local nomads or groups of workers coming from faraway cities constructed the kites. Bear in mind that the Negev kites are much smaller than the formidable projects that are the large kite chains in Jordan and Saudi Arabia (Kempe and Al-Malabeh 2013).



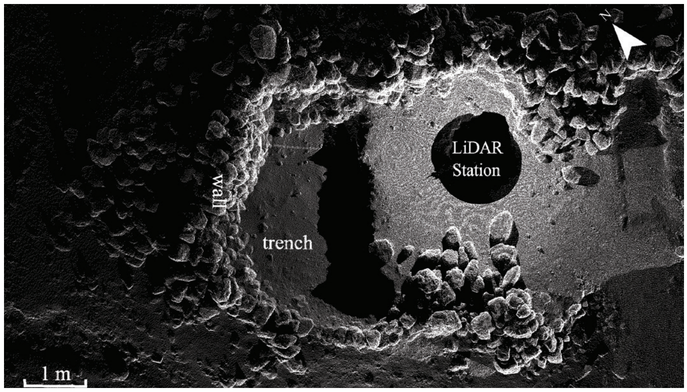


Figure 6 (top left). A model of the Samar West A head.
Figure 7 (top right). A model of the Samar West B head.
Figure 8 (bottom left). A cross-section through the arms of the Samar West A kite, at the bottleneck, 10 m from the head. Note the topographic elevated setting of the walls.
Figure 9 (bottom right). A cross-section through the arms of the Samar West B kite, 15 m from the head. Note that the inner area is clear of stones, which were removed and used for construction. Models prepared by R. Arav.

The dimensional and geometric characterizations provided here could be used for further analyses. For example, kites in different environmental settings could be compared in terms of funnel areas and volumes of walls, and new insights could be reached. Kites of different types (e.g. the V-shaped type and the enclosure type, see Bar-Oz and Nadel 2013) could also be compared in regard to their construction details and topographic settings. Questions such as correlations between slope inclination, wall thickness, and head size could be studied on local, regional, and long-distance scales.

Acknowledgments

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