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ARTICLE

Low-Budget Topographic Mapping: Systematic 360° Camera Surveys with Ground Control Points for Drone-Restricted Archaeological Contexts

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Abstract

This article introduces a low-budget approach to archaeological land surveying using spherical cameras, developed for contexts where drone photography is unavailable or where UAV regulations impede its use. The technique combines a 360° camera with standard accessories, making it affordable, portable, and deployable on demand across varied logistical conditions. It has proven to be quicker, more detailed, and more accurate than EDM-based survey sampling, and it produces results comparable to drone-based photogrammetry in terms of Ground Sample Distance, with the added capability to generate orthomosaics and vertical shots. This methodological article describes technology, equipment, and workflow, and it presents two case studies in which the technique was successfully tested and validated: Tell F6 (Failaka, Kuwait) and the Roman fort at Hiw (Qena, Egypt)—two sites with complex topography, under 4 ha, and with no or scarce vegetation. Quantitative results from both sites are reported, including the GCP RMSE value. We discuss the advantages and limitations of the technique, with the objective of proposing a reproducible, affordable, and legally viable method for archaeological topographic documentation when conventional remote sensing tools are unavailable.

ملخّص

تقدم هذه الورقة البحثية نهجًا منخفض التكلفة للمسح الطبوغرافي الأثري باستخدام الكاميرات الكروية (360°)، وقد طُوِّر هذا النهج للاستخدام في البيئات التي يتعذر فيها التصوير بالطائرات المسيّرة (الدرون)، أو التي تقيّد فيها اللوائح التنظيمية استخدام الطائرات دون طيار (UAV). تعتمد هذه التقنية على الجمع بين كاميرا بزاوية تصوير 360° وملحقات قياسية، مما يجعلها منخفضة التكلفة، سهلة النقل، وقابلة للنشر عند الحاجة في ظروف لوجستية متنوعة. ثبتت هذه الطريقة أنها أسرع وأكثر تفصيلًا ودقةً من أسلوب أخذ العينات المساحية المعتمد على جهاز EDM (قياس المسافات الإلكتروني)، كما أنها تنتج نتائج مماثلة للتصوير المجسم (الفوتوغرامتري) المعتمد على الطائرات المسيّرة من حيث دقة العينة الأرضية (Ground Sample Distance – GSD)، مع ميزة إضافية تتمثل في إمكانية إنتاج الصور المتعامدة (Orthomosaics) واللقطات الرأسية .تصف هذه الورقة المنهجية التكنولوجيا المستخدمة، والمعدات، وسير العمل، كما تعرض دراستي حالة جرى فيهما اختبار هذه التقنية والتحقق من فعاليتها بنجاح، وهما: تل F6 في فاليكا، الكويت، والحصن الروماني في هيو (محافظة قنا، مصر)، وهما موقعان يتميزان بطبوغرافيا معقدة، وتبلغ مساحة كل منهما أقل من أربعة هكتارات، مع غطاء نباتي معدوم أو محدود جدًا .وتعرض الورقة النتائج الكمية المستخلصة من كلا الموقعين، بما في ذلك قيمة الجذر التربيعي لمتوسط مربع الخطأ لنقاط التحكم الأرضية (GCP RMSE). كما تناقش مزايا هذه التقنية وحدودها، بهدف اقتراح منهج قابل للتكرار، منخفض التكلفة، ومتوافق مع المتطلبات القانونية، لتوثيق الطبوغرافيا الأثرية في الحالات التي تكون فيها أدوات الاستشعار عن بُعد التقليدية غير متاحة.

Keywords: photogrammetry; spherical cameras; topographic survey; UAV regulations

الكلمات الدالة: المسح الطبوغرافي; الكاميرات الكروية؛ التصوير المساحي؛ لوائح الطائرات بدون طيار؛

Archaeology, Maps, and the Bird's-Eye View

In archaeology, there are no panaceas for explaining or understanding the past, but some tools can make our efforts easier. The use of GIS in archaeology is widespread, yielding interesting results in research

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design, analysis, and reporting (Flor-Unda et al. 2026; McCoy 2021; Menéndez-Marsh et al. 2023; Ullah et al. 2024). Unmanned Aerial Vehicles (UAVs)—better known as drones—have likewise become part of the standard archaeological tool kit for mapping, recording, and surveying (Ciocani et al. 2025; Gutierrez and Searcy 2016; Hinojosa Baliño 2016; Orengo and Garcia-Molsosa 2019; Waagen 2019; Waagen and van Hilst 2025). Regrettably, the overuse of these flying machines by reckless enthusiasts has altered several countries' policies on the use of this technology, ranging from making flying technically legal but extremely difficult or expensive, to restricting flying to professionals only, with a strict system of identification for UAVs (Drone Laws 2024).

In 2017, Egypt passed Law No. 216 of 2017 (also known as the Drones Law), which states that "ministries, departments, agencies, local administration units, public authorities, companies, and other public or private legal entities and natural persons, are prohibited from importing, manufacturing, assembling, trading, possessing, trading in, or using automated or wirelessly propelled aircraft, except after obtaining a permit" (Drone Laws 2024; see also https://masaar.net/en/law-drones-egypt/, https://manshurat.org/node/44115, and https://manshurat.org/node/22908). In Kuwait, although regulations are less restrictive than in Egypt, permits are obtained through the Directorate General of Civil Aviation (DGCA). No drone imports are allowed without prior approval, and foreign visitors must comply with the DGCA / Ministry of Interior's strict regulations (Directorate General of Civil Aviation 2019).

When the use of drone technology is restricted or forbidden, complementary technologies such as photogrammetry are also limited in cases where the objective is to map or survey entire archaeological sites. Using UAVs, it would be an efficient use of time, pending good weather, to capture a set of aerial photographs—which could potentially be done in under one day of work—and then process them using photogrammetry. Depending on the context and the challenge, archaeologists have implemented techniques to overcome the difficulties encountered in the field. These technological innovations enhance the archaeological record, and in some cases their use may be the only way to document an otherwise inaccessible context (Pérez-García et al. 2019).

This article introduces a low-budget approach to archaeological land surveying using spherical cameras, developed for contexts in which drone photography is unavailable or in which UAV regulations impede its use. This technique brings together the qualities of nap-of-the-object photography, or NoOP (Cai et al. 2025), and oblique photogrammetry (Rupnik et al. 2015; Xie et al. 2016; Yang et al. 2015) with the accuracy (Saepudin and Nurmaulia 2025) and on-the-ground perceptual richness of a traditional survey.

The Ground and the Air: Aerial Photographs and Mapping

Cartography can be defined as "the set of documents that, in a selective, abstract, and symbolic manner, represent the physical and imagined features of the Earth's surface" (Alegre Nadal 1995:307); more than that, a map allows subjects "to situate themselves within a web of spatial relations" (Quintero 2000:187), and, being made by subjects, is inherently subjective (Pickles 2004). The bird's-eye view has long promised what ground observation cannot (Deuel 1969:3–4): from François Jean Dominique Arago's 1840 proposal of "photo-topography" following his daguerreotype's debut in 1839 to Gaspard-Félix Tournachon's (Nadar's) first aerial photographs in 1858 (Figure 1), James Wallace Black's (1860) first aerial photographs in the Americas in 1860, Colonel Aimé Laussedat's 1864 topographic map constructed with photographs taken from the ground, and Albrecht Meydenbaur's 1867 coinage of "photogrammetry"—culminating in Cornele Berrien Adams's (1893) patented aerial photogrammetric method and, decades later, in archaeological survey's own aerial turn (e.g., Franz Stolze at Persepolis in 1879, see Musson et al. 2013:18–19).

It is worth stressing that lifting a camera above the ground is not itself an innovation: it is over a century old. Tournachon's balloon Géant, Guy's (1932) balloon and extension-ladder rigs at Megiddo (Figure 2), and later, kites, poles, and compact cameras (Fussell 1982; Green et al. 2012; Sterud and Pratt 1975) all pursued the same principle—denser (heavier) than air to command the air (Tournachon 1978:24)—that now defines drone use. What has changed—and what constitutes the actual innovation proposed here—is not the gesture of elevating a camera but the systematization

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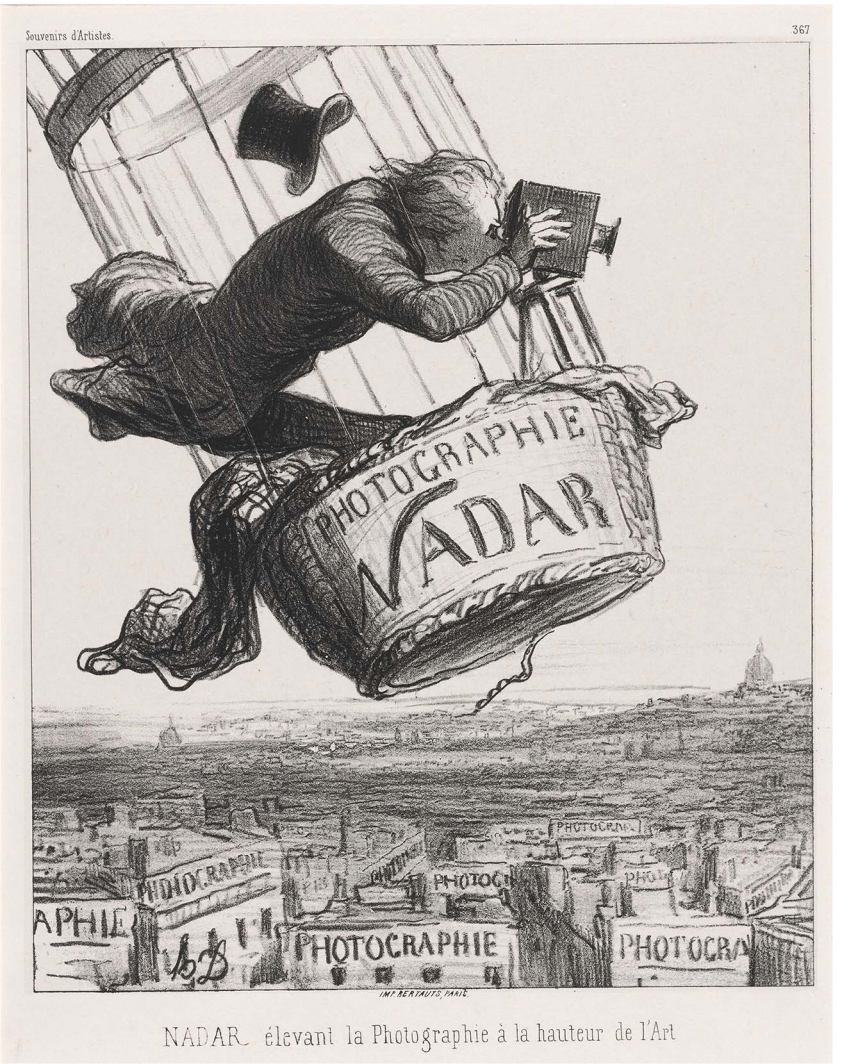


Figure 1. *Nadar Élevant la Photographie à la Hauteur de l'Art* (*Nadar Elevating Photography to Art*). (Lithograph by Honoré Daumier, https://www.nga.gov/artworks/42966-nadar-elevant-la-photographie-la-hauteur-de-lart-nadar-elevating-photography-art. Rosenwald Collection, © 2025 National Gallery of Art, Washington, DC).

of that gesture into a light, mobile, and reproducible workflow rather than the heavier, static rigs of the past.

Traditional ground survey illustrates why this matters in practice. Total stations and theodolites remain accurate but slow; mapping the roughly 2 ha foundation of the Cuicuilco pyramid (Mexico City) with a theodolite and stadia rod required 300 points over five days of fieldwork, at 1–5 minutes per point for a learner (Figure 3). A total station's integrated EDM system speeds this up considerably (0.3–1.0 seconds per shot; Nikon Surveying Instruments 2017), but drone-based photogrammetry changes the calculus entirely (Lasaponara and Masini 2011). The same area, mapped from just 38 photographs, yielded over 2.5 million points in a single flight (Figure 4). Handheld or aerial lidar can match this speed but adds cost, specialized post-processing, and—in the case of aerial lidar—the same regulatory exposure as drones, while still depending on Ground Control Points or RTK for georeferencing.

This brief overview underscores both the advances of traditional and aerial methods and their persistent constraints: high precision does not equate to universal access, particularly where UAV regulations, budgets, or fieldwork conditions restrict their use. Building on experience across archaeological projects

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Figure 2. In 1929, Philip L. O. Guy came up with a few ideas for taking "aerial" photographs without a plane: (*left*) balloon for mosaic mapping in the Stables of Solomon, Megiddo (P. 21725 / N. 12352), https://isac-idb.uchicago.edu/id/9a60ef5f-d132-4ce0-94b1-a3624f68337b; (*right*) extension ladder for making air photographs, Megiddo (P. 21406 / N. 11591), https://isac-idb.uchicago.edu/id/d82e2b97-97fb-4a20-ac12-8b9fd970a55c. (Institute for the Study of Ancient Cultures Archives, University of Chicago).

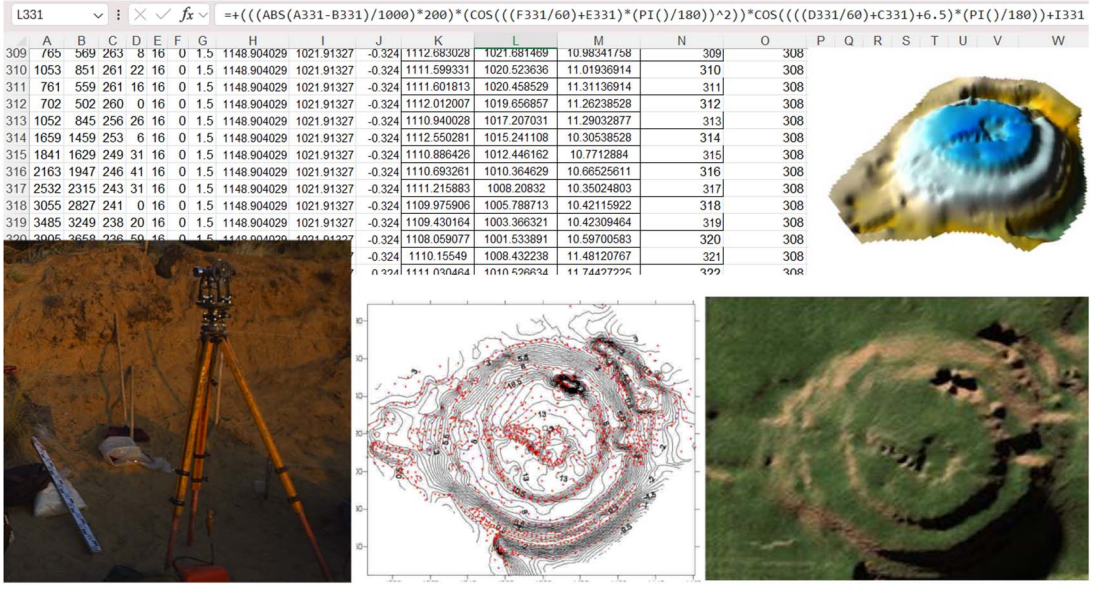


Figure 3. Mapping Cuicuilco: Javier López Camacho's class on archaeological topography (image by the authors).

in different countries, financial circumstances, and regulatory regimes, we describe a technique that combines a traditional systematic land-survey logic with 360° high-resolution photographs, ground control points, real-world coordinates, and photogrammetry to produce a detailed digital elevation model (DEM) and orthomosaic.

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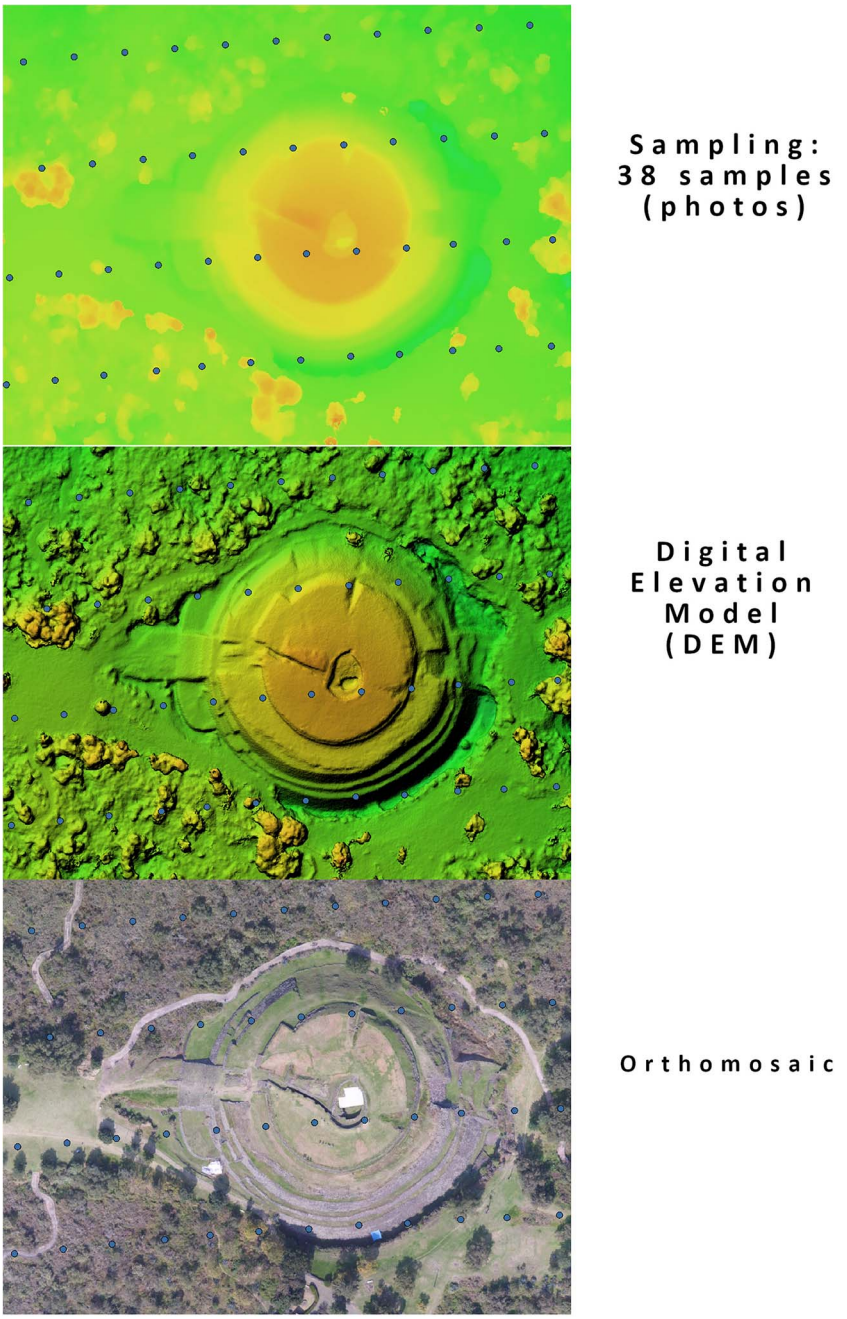


Figure 4. Cuicuilco mapped with a drone (figure by the authors; data courtesy of Gerardo Gutierrez).

Methods

Proof of Concept

Structure-from-motion (SfM) and photogrammetry rely on stereoscopic vision and motion parallax—principles in computer vision and visual perception—to generate 3D representations of reality. In fact, in some domains, modern photogrammetry for 3D modeling is referred to as Structure-from-Motion Multi-View Stereo (SfM-MVS) photogrammetry. In archaeology, photogrammetry has been in use for almost a century, directly or indirectly (Fussell 1982; Garrison 1992; Reeves 1936). In the late 1970s and 1980s, computer vision and neuroscience converged around the problem of recovering 3D

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structure—from stereo image pairs and from 2D motion sequences—drawing on models of human spatial perception (see Dolins and Mitchell 2010; Rapoport 1977). This laid the computational foundations for what we now call SfM and modern photogrammetry (Jebara et al. 1999; Marr and Poggio 1976; Ullman 1979a, 1979b). Most archaeological projects use photogrammetric techniques to document and generate visual representations of the archaeological record and strata that might be destroyed, might deteriorate, or otherwise might be at risk of disappearing. It is also used to create colorful and realistic snapshots of heritage places and objects for documentation and further analysis (Bosco 2022; Opitz and Cowley 2013; Waagen 2019; Waagen and van Wijngaarden 2024).

The use of 360° cameras to produce 3D videos and images is not new (Anderson 2017, 2019; Barazzetti et al. 2017; Janiszewski et al. 2022; Pérez-García et al. 2024). Testing the suitability of spherical panoramas for the documentation of cultural heritage has been conducted for over 10 years (Fangi and Nardinocchi 2013), and there have been tests to survey open-air urban scenarios (Cera and Campi 2022; Rezaei et al. 2024) and historical buildings (Gottardi and Guerra 2018). In a manner similar to the way they are used for Real Estate Virtual Tours, 360° cameras have been used in archaeology for enclosed spaces (Pérez-García et al. 2019, 2024), as photo elicitation interviews to present panoramic photos to mimic walking interviews (Sesma 2021), or as static panoramic tours to showcase landmarks (Monterroso-Checa et al. 2020; Unger 2017). To the best of our knowledge, their use for the topographical survey of open-air archaeological sites has not yet been published. Some may feel that the use of 360° cameras in open spaces is redundant—given that each photo will capture the sky and unnecessary background—and irrelevant in circumstances where drones are not restricted and a competent pilot experienced with photogrammetry is available. Nevertheless, as shown in our two case studies, there are cases where ideal circumstances and tool availability are scarce; therefore, the technique we propose may be useful. The technique we are presenting is an adaptation and combination of topographic survey for archaeology, grid sampling—which is the sampling method that professional drone pilots should ideally use—and photogrammetry with a spherical camera. We tested and tailored our technique for use in archaeological contexts to produce both a high-quality DEM and an orthomosaic.

In the television series *MythBusters*, Jamie Hyneman and Adam Savage often used proof-of-concept models to validate their ideas before running full-scale experiments. The technique presented here followed a similar path: its development required access to high-definition, portable, and affordable spherical cameras, and the opportunity to test the underlying idea at real archaeological sites before scaling it up. From the outset, we had three basic precepts in mind:

1. The technique had to be affordable, relying on equipment accessible to small archaeological projects with limited budgets, without compromising the quality of the results.
2. It had to be portable. The equipment had to be lightweight, easy to transport, and deployable on demand under varying logistical conditions.
3. It had to be accurate, producing topographic models and orthomosaics comparable in quality to those obtained through traditional EDM-based survey and, where possible, to those achievable with drone-based photogrammetry.

These three precepts guided every decision made throughout the development of the technique—from the choice of equipment to the sampling strategy adopted in the field. We conducted a series of five tests across different archaeological contexts, each building on the lessons of the previous and bringing the technique closer to the standardized, reproducible method presented in the case studies below. The process was neither linear nor without setbacks, and we document both here because transparency about failure is as methodologically valuable as documenting success.

The first time this technique was tested and its concept proven was in 2018 in an enclosed space: a small room of about 3 × 9 m (referred to as the first test). On that occasion, a Samsung Gear 360 (2017) camera was mounted on a tripod, raised to about 1.25 m, and positioned in the center of the room. In total, five photographs were taken, barely enough to produce a 3D model; at the time, the priority was to learn whether the program could produce a model with the camera used; high resolution or quality were secondary in that instance.

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Figure 5. Second test: a Fujifilm T100 mounted on a boom pole supported with a flag holder belt (photograph by Elena Tiribilli, EES Delta Survey Project, Tell Mahar, Kafr Sheikh, Egypt).

Given the successful execution of this first simple model, we learned that the technique could produce the expected results using the available equipment. We therefore tested it in an archaeological setting during the 2019 field survey season of the Delta Survey Project in Kafr Sheikh, Egypt. Unfortunately, the first issue arose immediately: the low resolution of the photographs taken with the Samsung Gear 360 (2017) camera made it almost impossible for the program to find good matches and generate a model. That specific camera features two 8.4-megapixel (MP) CMOS sensors and two wide-angle (195), f/2.2 lenses, with a total output equivalent to 15 MP when the images are merged. In the field, the camera was held on a monopod 3 m above the ground, with photographs taken at intervals of about 3 m. The site has features too distant for the lenses to capture details on a featureless ground of dust and random fragments of fired brick and pottery. Positioning the camera closer to the ground and reducing the interval between photographs would have made the technique ineffective, slow, and futile. Consequently, an alternative test was performed at another site to generate a detailed DEM using photogrammetry. Here, the camera was a Fujifilm T100 with a wide-angle 15 mm lens (equivalent to 23 mm in 35 mm format), mounted on a pop-riveted reinforced 5 m boom pole originally designed to hold a "dead cat" microphone in a studio setting. These poles are lightweight but fragile and prone to breaking under field conditions if not adequately modified. Once reinforced, the pole can be comfortably carried over long distances using a flag-holder belt, supporting up to 500 grams when fully extended. Its soft foam handle improves grip in direct sunlight, and the whole setup is designed for single-person operation (Figure 5). This system captured wide-angle photographs covering approximately 8 × 9 m, making it possible to build a photogrammetric model of a relatively large area with continuous photographs at intervals of 3–5 m. This method also served as a proof of concept for the gear needed for a user to hold a heavier camera 4–5 m above the ground for extended periods while walking and taking photographs with a remote control.

During this second test, the technique was attempted at different sites. In Tell Mahar, the impact of a series of photographs in the same position, emulating a 360° photograph or a panoramic view, was also tested. Given that SfM relies on stereoscopy, if we consider the site as an object, its volume and topographic features can be captured with a minimum number of photographs, provided the photographs overlap and cover the entire site. For this test, 414 photographs were taken; however, only 293 were

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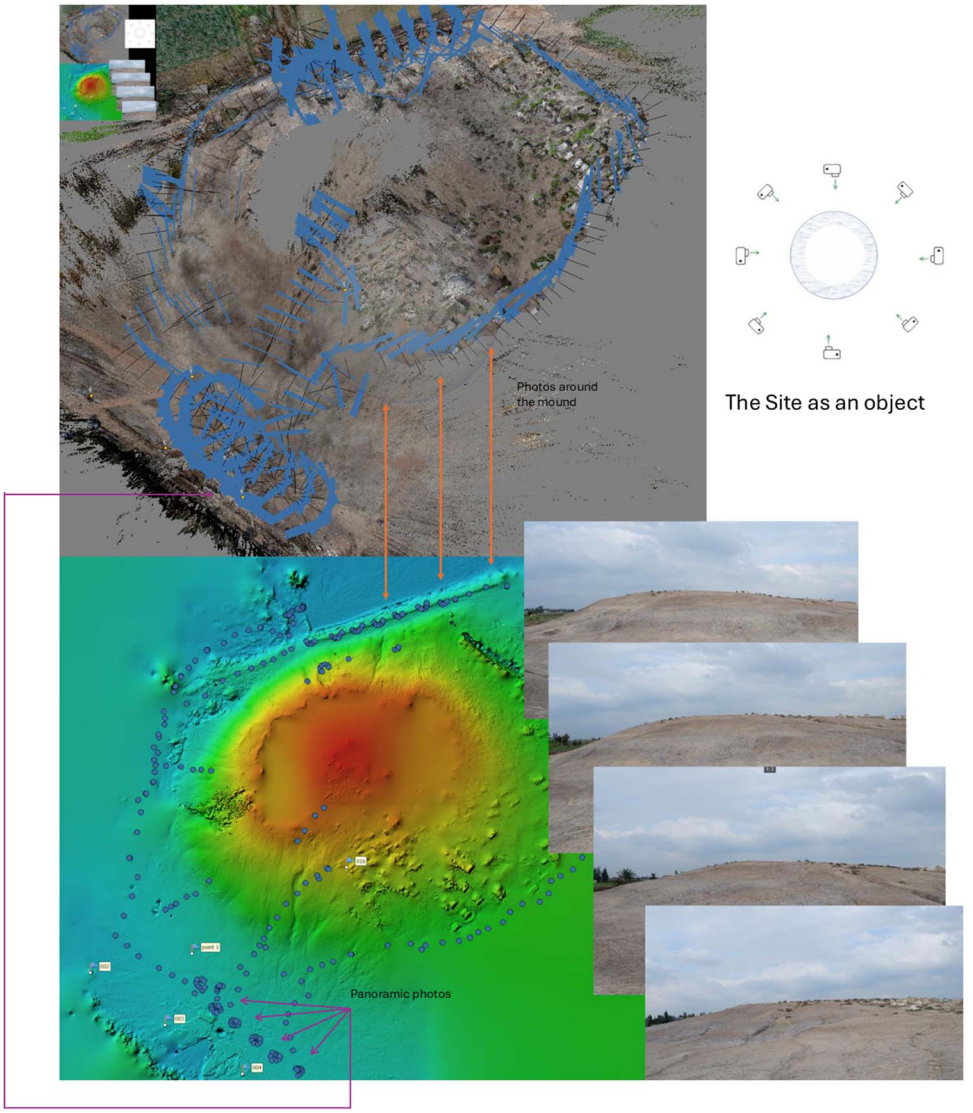


Figure 6. Second test: the site as an object (Tell Mahar, Kafr Sheikh, Egypt).

successfully aligned. Although limited, the coverage, as shown in Figures 6 and 7, captured the site's volume. In areas with good photographic coverage, it was possible to produce a more detailed topographic map of the site and a partial orthomosaic. For this test, we used ground control points recorded with a Nikon XF Series Reflectorless Total Station using UTM coordinates; therefore, the model was georeferenced, and it provided helpful information for further analysis.

The next test was conducted during the 2024 field survey season of the Delta Survey Project in Beheira, Egypt. The long hiatus between the tests was due to the COVID-19 pandemic. This third field test included the implementation of an Insta360 X3 (details below), which produces images 4.8 times larger than those produced with the Samsung Gear (2017). The camera is controlled remotely by the camera app, allowing the user to hold the boom pole with one hand and the smartphone with the other to take photographs and view a preview of the image before capturing it. The importance of using a lightweight camera, such as the Insta360, lies in its portability and ease of transport. With the camera mounted on a boom pole, the user can walk across an archaeological site, exerting effort comparable to that required to carry a prism rod or a stadia rod.

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Figure 7. Second test: contour map of Tell Mahar (Kafr Sheikh, Egypt), generated with photogrammetry, over a Google Earth satellite image.

The model produced for this test corresponds to an unnamed archaeological site where locals found marble fragments, and we were tasked with documenting the adjacent area using magnetometry. Nevertheless, we also documented the extent of the area affected by the farmers' excavations. There was little to record archaeologically, except for massive holes in the ground and a pile of dirt. Still, it was a perfect opportunity to test the technique because the documentation had to be conducted quickly—in under 30 minutes—and accurately. With only 27 images, an area of 900 m^2 was covered. Consequently, the team mapped the excavated trenches and obtained a georeferenced image and a topographic map (see Figure 8).

Case Studies

Following the successful implementation of the technique in the Nile Delta, the next step was to expand the testing of the technique. It was necessary to put it into practice in a more complex scenario, where not only are permits for drone photography difficult or impossible to obtain, but even traditional topographic sampling would take several days or weeks to document the surface's complexity. We had the opportunity to test this technique at two different archaeological sites: Tell F6 in Failaka, Kuwait, and the remains of the Roman fort at Hiw, Qena, Egypt.

In both cases, the photographs were taken with an Insta360 X3 camera featuring two 48 MP cameras with 1.27 cm (½-in.) sensors, capable of capturing a 72 MP 360° photograph. The camera was mounted on a 5 m Newer Boom pole, held in place by a shoulder strap with a pouch for the pole. The photographs were taken between 11:00 a.m. and 2:00 p.m. to minimize the shadow cast by the surveyor and the boom pole.

The photogrammetry data was processed across two different computers. For the site of Failaka, a Razer Blade 14 laptop was utilized, equipped with an AMD Ryzen 9 7940HS CPU, 16 GB of RAM, a 1 TB Solid-State Drive (SSD), and a dedicated NVIDIA GeForce RTX 4070 graphics card. For the site of Hiw,

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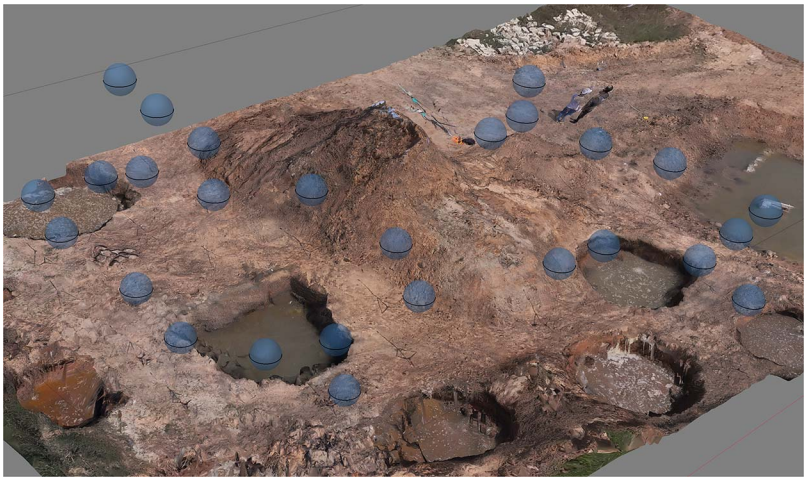


Figure 8. Third test: photogrammetric 3D model carried out with the spherical camera. This model made it possible to produce an impromptu topographic map to record a site that was damaged by agricultural activities.

processing was conducted on a Dell XPS 15 9560 laptop featuring an Intel Core i7-7700HQ CPU, 16 GB of RAM, a 512 GB SSD, and a dedicated NVIDIA GeForce GTX 1050 (4 GB GDDR5) graphics card. All photographs were processed using Agisoft Metashape Professional (version 2). To maximize efficiency, GPU acceleration via CUDA was enabled exclusively for the dedicated NVIDIA graphics cards; the integrated AMD Radeon 780M and Intel HD graphics processors were deliberately deactivated to prevent performance bottlenecks. Agisoft Metashape Professional natively handles equirectangular and fisheye imagery, performing automatic internal camera calibration during the alignment stage. This corrects for radial and tangential lens distortion inherent to dual-fisheye sensors without requiring manual calibration parameters. Although several alternative photogrammetry suites are available—ranging from free and open source options to commercial packages—not all of them support 360° imagery natively, and some require an intermediate preprocessing step (e.g., cubemap decomposition) before feature extraction can begin. Table 1 summarizes these alternatives, comparing pricing, ease of use, processing speed, offline accessibility, and their native support for equirectangular and unprojected (dual-fisheye) imagery, which informed our choice of Metashape for this workflow. The following case studies demonstrate the potential for implementing this technique.

Case Study: Tell F6, Failaka, Kuwait

Danish surveys and excavations in Kuwait began in 1958 at the southwest corner of Failaka, where a cluster of four tells—Tell F3, Tell F4, Tell F5, and Tell F6—was investigated between 1958 and 1963. Two of these tells, F3 and F6, date to the second millennium BC. Tell F3 contained mostly small domestic buildings, whereas Tell F6 revealed a large, approximately 400 m^2 building known as the Palace. In the 1980s, French archaeologists continued excavations at Tell F6 and found a temple roughly 15 m east of the Palace (Højlund and Abu-Laban 2016:7). As part of the Danish-Kuwaiti 2024 mission in Failaka, Kuwait, an updated topographic map of Tell F6 was designed not only to cover the areas of excavation and their surroundings but also to get a more detailed and extended map of the Dilmun area of interest—from an excavation area named G3, up until F3, and from F3 to F6. The 2024 survey focused on the immediate surroundings of Tell F6. This area is relatively shallow and featureless, has a gentle slope, and is covered with scattered bushes. The entire area is no more than 5 m asl, and it lies between 200 and 300 m from the shoreline. In addition to Tell F6, the remains of the Dilmun temple and Palace have been exposed to the public, and our model also covers these areas.

Semisystematic sampling began around the excavation area known as FH1. A 360° photograph was taken approximately every 10 m, as the surveyor walked in transects from FH1 to F6 and F5, from F6 to

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Table 1. Comparison of Photogrammetry Software for 360° Image Processing.

Software	Price	Ease of Use	Processing Speed	Accessibility (Works Offline)	Native 360° Equirectangular Support	Preprocessing Required If Not Native	GIS Ready (DEM/Orthophoto in GeoTIFF)
Agisoft Metashape (Pro)	Moderate/Expensive (~$500–3,499 USD perpetual)	High (intuitive interface and guided workflows)	Moderate to Slow (excellent quality but takes time)	Yes (100% offline;license activation requires Internet)	Yes (just change the camera type to "Spherical")	None (stitched JPG/TIFF can be opened directly)	Yes, Excellent (exports DEMs and orthophotos with one click, with integrated coordinates)
RealityCapture	Free (if you bill under USD $1M per year)	Medium (modern interface with many technical menus)	Extremely Fast (fastest on the market with a GPU)	Yes (but be careful; has an offline mode, but if the security token expires, locks you out without an internet connection)	No (does not understand spherical maps directly)	Cubemap (360° image must be split into 6 flat images)	Yes, Excellent (exports native GeoTIFFs [BigTIFF] and world files [*.tfw])
3DF Zephyr	Moderate/Expensive (Lite version, ~$200; Pro, ~$4,000 USD)	High (beginner-friendly step-by-step wizard)	Fast (very good optimization using Nvidia cards)	Yes (works fully offline once installed)	Yes (native support for importing panoramic images and 360° videos)	None (maps the sphere directly and natively)	Yes (generates contour lines, DEMs, and orthophotos ready for GIS [in Pro/Aerial versions])
WebODM	Free (open source; split from OpenDroneMap in April 2026)	Low/Medium (local web interface)	Moderate (heavily dependent on the CPU)	Yes (if you use the local version; cloud version "WebODM Lightning" excluded)	Yes (change the flag camera projection type to "equirectangular")	Conversion (flat perspectives must be extracted from the 360° image)	Yes, Excellent (native mapping software for DEMs and orthophotos)
Meshroom	Free (open source)	Low (node based; intended for experimentation or research)	Very Slow (not optimized for fast commercial workflows)	Yes (runs 100% offline on your computer)	No (no dedicated button for spherical photos)	Cubemap (360° image must be split into 6 flat images)	No (does not natively generate georeferenced maps or GIS formats without unusual extensions)
COLMAP + 3D Gaussian Splatting **(**Open-Source Pipeline**)**	Free (open source; COLMAP, 3DGS repo, and custom scripts)	Very Low (command-line , environment setup [Conda, CUDA, Visual Studio], Python scripting, and custom GUI)	Slow to Very Slow (feature extraction and matching computationally expensive, training depends on GPU VRAM and the number of images)	Yes (runs 100% offline once dependencies are installed)	No (neither COLMAP nor 3DGS natively support equirectangular images)	Rectilinear Perspective Projection (custom Python script [py360convert] extracts multiple perspective views per equirectangular image [configurable yaw/pitch/FOV]; to be processed by COLMAP's SfM pipeline before 3DGS training)	No (photorealistic neural radiance representations [Gaussian Splats], not georeferenced maps; output viewable in dedicated viewers [e.g., superspl.at]; not directly usable in GIS software)

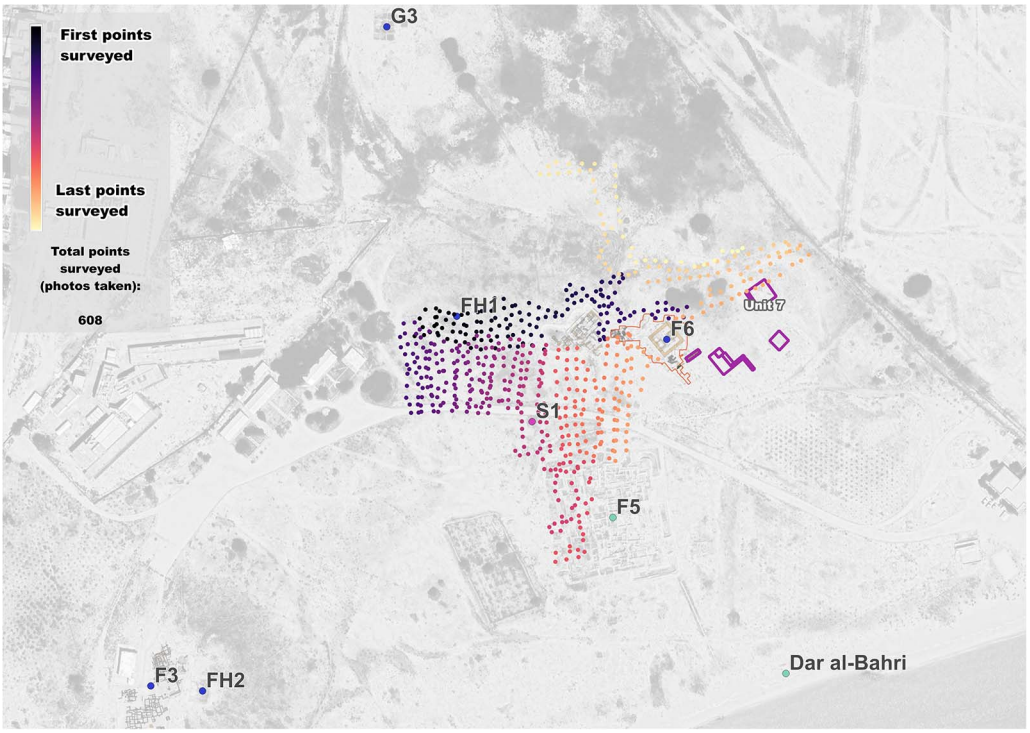


Figure 9. Fourth test: survey at Failaka showing the progression of the survey (background base satellite image © 2025 Google).

Unit 7, and from Unit 7 to G3, covering an area of approximately 5 ha (see Figure 9). In total, 600 photographs were taken in pure raw format over three consecutive days. With this setup, each session lasted approximately two hours. Each photograph has a resolution of 72 MP, with a size of at least 100 MB. One important aspect to note is that the memory card used on this occasion was a low-speed 32 GB MicroSD card, which took approximately 30 seconds to capture, process, and save each photograph, making the sampling considerably slow. Once the photographs were converted to an equirectangular image and in a recognizable format for Metashape (Digital Negative format), their sizes ranged from 200 to 300 MB. The processing is computer intensive; nonetheless, image handling and processing are relatively fast and accurate, because each photograph has GPS coordinates obtained from the mobile phone, given that the camera itself does not have a built-in GPS. The phone coordinates, however, ease the Matching process of SfM. The ground control points were landmarks on the landscape (rocks, corners of standing structures, or fence posts) or known station points that allowed us to fit the model in our system of reference (UTM WGS84 39N), and they were taken with a Leica TS02. The model was then processed in chunks that were stitched together in QGIS using the GDAL module Merge. The logistics of the field survey and details of data processing are provided in Table 2 and Table 3. In Figure 10, we present this result alongside a legacy drone survey captured in 2022 by Hamid Al-Mutairi—head of excavation and survey for the Department of Antiquities and Museums under the National Council for Culture, Arts and Letters (NCCAL)—who holds specialized institutional permission for aerial operations on Failaka Island. The surveyor of the Danish archaeological mission subsequently processed these aerial images. Although a complete merging of the datasets was successful, a gray color ramp is used in this figure to delineate the spatial extent of the drone data clearly and to demonstrate how it directly compares with our proposed 360° photogrammetric model, showing spatial continuity between the two models without observable metric disparities.

The method was tested successfully in Failaka, and it took three days of survey (2–3 hours a day) to take the photographs, and one to two days of computer processing and office work to produce it. The

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Table 2. Rundown of the Logistics of the Field Survey Carried Out at Failaka and Subsequent Data Processing.

Task/Tools/Reference	Description
Area Covered (ha)	5 (rounded up; does not include noisy edge)
Photographs Taken (Sample Points)	608
Ground Control Points	26
Time in Field (Hours)	6 (over 3 days)
Time in Office (Hours)	31, of which: 8 h photograph processing; 15 h photogrammetry; 8 h tuning, cleaning
Equipment	Camera: Insta360 X3 SD card: SanDisk Ultra PLUS 32GB MicroSD HC I Boom pole: Neewer 5 m Flag holder: Neewer long shoulder strap with pouch for pole Smartphone: Sony Xperia 1 V
People Involved (Number)	1
Sampling Type	Semisystematic transects; photographs every ca. 10 steps

survey took longer than expected due to the SD card's speed; this issue was addressed and resolved in the following case study, which used a refined, more systematic sampling technique.

Case Study: Hiw, Egypt

The archaeological site of Hiw is located in the Governorate of Qena, about 5 km southeast of Nag Hammadi, roughly 45 km south-southwest of the city of Qena, along the southern bank of the River Nile (in the only section where the river flows east–west). Since 2024, the site has been investigated by the Swiss-Egyptian Archaeological and Epigraphic Mission in Hiw (Egypt),[1] which is reprising the work begun in 2009 (Collombert 2010) following a 15-year hiatus. The research efforts are currently concentrated on the remains of the site that lie below the modern settlement of Hiw and the remains of the Roman fort, located about 2 km south of the modern settlement. These two parts of the ancient settlement differ significantly; the former is situated in the floodplain, adjacent to the river; the latter lies in the desert plain, which is almost void of modern buildings, except for the cemeteries. The topographic survey was carried out specifically in the area of the Roman fort.

The remains of the fort comprise a large rectangular mudbrick enclosure wall measuring approximately 180 m in length and 80 m in width. Archaeologically, few efforts have been directed toward the Roman fort, given that attention has primarily been given to the ancient necropolises sited in the desert area. In 1898–1899, the fort was first investigated by a team led by W. M. Flinders Petrie on behalf of the Egypt Exploration Fund. The digs focused on the cemeteries, and a couple of weeks of work were also dedicated to the remains of the Roman fort. The fort, allegedly located over the remains of a former temple enclosure, was investigated by Petrie and his team through a series of survey pits dug within the enclosure walls. They identified the remains of a Ptolemaic temple, a Roman temple, a stone-paved causeway leading to the latter and skewed with respect to the enclosure axis, and several mudbrick buildings described as houses, with one notable for its brickwork craftsmanship (Petrie 1901:54–57). There is mention of *sebakheen* activities having already taken place on the site before Petrie's digs.[2] In 2018 and 2019, the Ministry of Tourism and Antiquities conducted excavations along the southwest corner of the fort's enclosure wall, which revealed evidence of reuse in antiquity, including the addition of a round bastion and reinforcements to the original enclosure wall. The Swiss-Egyptian mission was therefore the first to perform a topographical documentation of the full extent of the fort.

The topography of the area is complex: the ground surface is characterized by humps and bumps of uneven depths and heights, likely the remnants of the pits that Petrie and his team excavated. The desert ground is covered with a copious quantity of scattered pottery sherds and several epigraphed sandstone blocks; the western side of the fort's enclosure wall stands a few meters above the ground. Looting episodes at the site occur prevalently in the cemetery areas; almost no modern pits were identified in

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Table 3. Agisoft Metashape Processing Summary: Tell F6, Failaka, Kuwait (4 Chunks).

Parameter	Chunk 1	Chunk 2	Chunk 3	Chunk 4	Notes
Image Alignment					
Images (Aligned/Total)	140/140	188/188	183/183	106/106	100% alignment of all chunks
Alignment Accuracy	Highest	Highest	Highest	Highest	
Reference Preselection	Source	Source	Source	Source	
Tie Points (Retained/Detected)	146,129/ 182,273	181,014/ 239,679	155,112/ 209,313	82,724/ 111,505	74%–80% retention
Reprojection Error (px)	2.14	3.77	2.90	2.49	
RMS Reprojection Error (px)	0.28	0.51	0.36	0.32	
Ground Control Points (GCP)					
GCP Count (Control/Check)[a]	7/0	7/0	5/1	6/0	
RMSE X (cm)	4.01	2.56	4.24	2.01	
RMSE Y (cm)	4.23	3.87	2.34	1.41	
RMSE Z (cm)	1.24	0.78	0.76	0.49	Z error consistently <1.5 cm
RMSE XY (cm)	5.83	4.64	4.84	2.45	
RMSE Total— Control (cm)	5.96	4.71	4.90	2.50	
RMSE Total—Check Point (cm)	—	—	13.57[b]	—	
Survey Coverage					
Camera Altitude (m)[b]	6.48	6.33	6.84	6.46	
Coverage Area (km^2)	0.0185	0.0128	0.0259	0.0253	
Ground Resolution / GSD (mm/px)	3.4	3.3	3.6	3.4	
Digital Elevation Model					
DEM Resolution (cm/px)[c]	2.83	3.08	3.01	3.14	
Point Density (pts/cm^2)	0.125	0.105	0.110	0.101	
Depth Map Quality	High	High	High	High	
DEM Source	Mesh	Mesh	Depth maps	Mesh	

Notes: CRS: WGS 84 / UTM zone 39N (EPSG::32639). Final merged model produced in QGIS (GDAL Merge) at 6 cm/px resolution. GCPs recorded with total station (projected CRS).

[a] Check point error in Chunk 3 reflects observer ambiguity when placing a GCP on a natural stone corner feature. Excluded from optimization; retained as an independent accuracy check.

[b] Camera altitude is derived from smartphone GPS coordinates used as camera location input, not from the physical boom pole height (~5 m). This value reflects the combined effect of GPS vertical uncertainty, topographic variability across the survey area (75–82 m asl), and pre-GCP camera placement by Metashape, and it should not be interpreted as the operational capture height.

[c] Chunk 3 DEM generated from depth maps; all other chunks from mesh. Chunk 3 coverage area (0.0259 km^2) is the largest of the four.

the Roman fort zone. Overall, between the enclosure wall and the surrounding areas, there is a gentle slope, with two exceptions. The northern side presents a more dramatic drop in elevation, given that it is closer to the nearby modern houses, the canal, and the beaten-earth road. In contrast, the ground on the eastern side slopes into a likely gorge, either related to a wadi or perhaps a product of the *sebakheen* activities.

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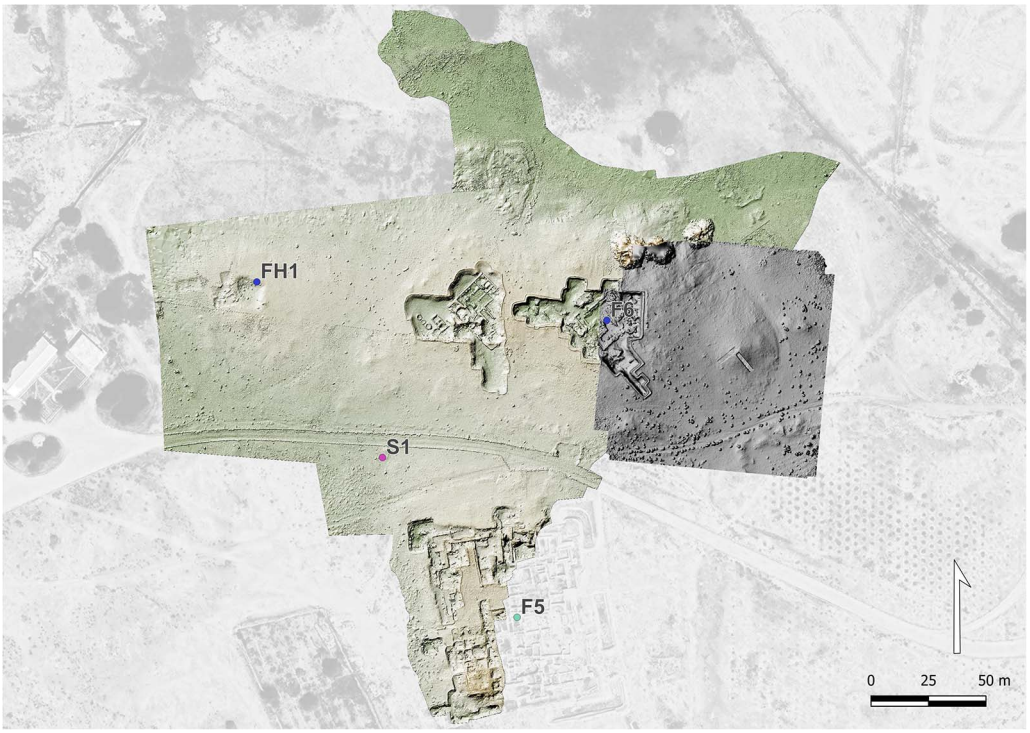


Figure 10. Fourth test: hillshade map created with the photogrammetric model, merging all surveys shown here, with a color ramp ranging from light greens to light browns. In this figure, we included a drone survey created in 2022 by Hamid Al-Mutairi, presented here in dark gray (background base satellite image © 2025 Google).

The size of the site, the complex topography, the need for a high-quality topographic map of the fort area, and the surveyor's limited time in the field made this the perfect setting for the fifth field test of the proposed technique. The sampling method for the photographs was regular, given that the fairly even shape of the fort enclosure facilitated it. The surveyor walked systematic transects, moving east to west and then vice versa, covering the entire width of the research area in intervals of roughly 10 steps (Figures 11 and 12). Due to the size and complex ground conditions, two people were placed on either side of the enclosure to assist the surveyor in walking reasonably straight lines—a task made arduous by the heterogeneous ground conditions and elevations. The use of the high-speed MicroSD card was pivotal in reducing the capture and processing time of each photograph from roughly 30 seconds to 10 seconds.

The survey covered an area of about 3.4 ha. The photographs were taken in two instances, with a half-hour break in between to charge the camera's battery. Overall, the photographic sampling took 2 hours and 15 minutes to complete. Twenty-four ground control points had been placed throughout the area in the days leading up to the photographic survey; the decision to set a high number of points was largely due to the lack of surveillance at the site, anticipating the possibility that some might be removed, rather than a necessity for photogrammetric modeling. The control points ranged from metal to wooden stakes, which were surrounded by stones and painted white or yellow to increase visibility. The points were first recorded using a total station (Leica TS03) in a local coordinate system; a few weeks later, the same points were rerecorded with a GNSS receiver using a projected coordinate reference system (UTM WGS84 36N). Despite the lag in the photographic recording, the photographs aligned without issue (Figure 13). The logistics of the field survey and details of the data processing are provided in Table 4 and Table 5, respectively.

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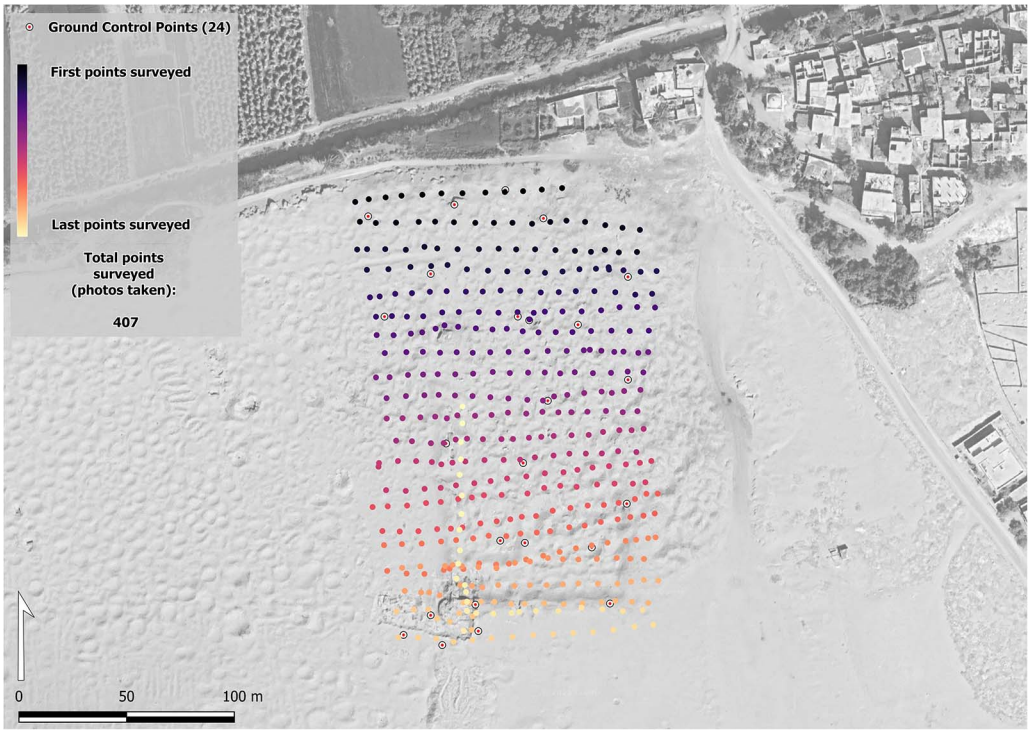


Figure 11. Fifth test: survey at Hiw showing the progression of the photographic sampling (background base satellite image © 2025 Google).



Figure 12. The photographic recording of the area of the Roman fort at Hiw (photograph by Audrey Eller, Swiss-Egyptian mission in Hiw).

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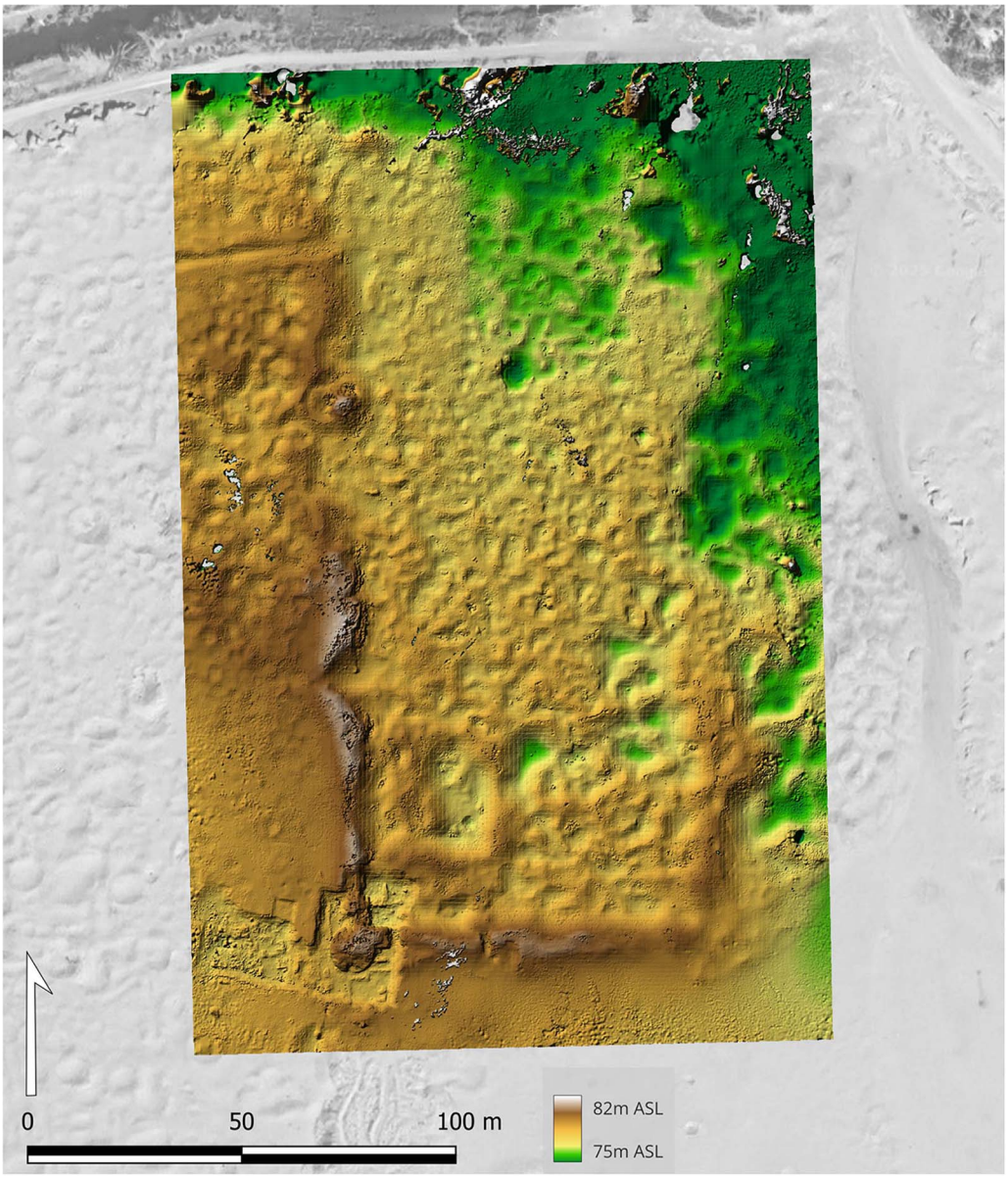


Figure 13. Fifth test: hillshade map created with the photogrammetric model and overlaid with the DEM (in color) (background base satellite image © 2025 Google).

Results

As shown in Tables 3 and 5, the quantitative outputs from Agisoft Metashape Professional (version 2) confirm the accuracy and consistency of the proposed technique across both case studies. At Tell F6, Failaka, the four processing chunks achieved 100% image alignment, with Ground Sample Distance (GSD) values of 3.3–3.6 mm/px and RMS reprojection errors of 0.28–0.51 px—well within acceptable thresholds for archaeological survey. GCP-based georeferencing yielded RMSE Z values consistently below 1.25 cm across all chunks, with total control point RMSE of 2.50–5.96 cm, reflecting the semisystematic sampling strategy and the use of natural landscape features as control points. At Hiw, where field conditions were refined and sampling was fully systematic, results improved across every metric: all 407 photographs aligned successfully (100%), RMS reprojection error was 0.32 px, GCP RMSE Z reached

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Table 4. Rundown of the Logistics of the Field Survey Carried Out at the Roman Fort of Hiw and Subsequent Data Processing.

Task/Tools/Reference	Description
Area Covered (ha)	3.4
Time on Field (Hours)	Walked in two instances: from 11:40 to 13:25, interrupted because the camera battery ran out, missing about 18 transects in the south part to finish, reprised at 14:01 and finished at 14:33. In total: 2 hours 15 minutes of walking
Photographs Taken (Sample Points)	407
Ground Control Points	24
Time in Office (Hours)	Alignment: 10 hours and 18 minutes. This was done on a different computer (Dell XPS 15 9560). Depth map: 1 hour and 30 minutes Model: 4 hours Texture: 1 day and 5 hours DEM: 1 hour and 50 minutes Orthomosaic: 4 hours and 52 minutes (Razer Blade 14) Orthomosaic correction: Several hours distributed in a time span of about 15 days (ca. 2 hours a day). This was done on a different computer (Dell XPS 15 9560).
Equipment	SD card: SanDisk Extreme 256GB MicroSD XC I V30 A2 Boom pole: Newer 5 m Smartphone: Fairphone 5
People Involved (Number)	3
Sampling Type	Systematic transects; photographs every ca. 10 steps.

1.15 cm, and the DEM achieved 1.00 cm/px—the best result of the project. The GSD of 7.24 mm/px at Hiw reflects the greater topographic variability of the site—standing enclosure walls, excavation pits, and uneven desert ground creating significant elevation differences across the survey area—rather than any reduction in technique or equipment performance. Taken together, these results show that the technique produces georeferenced topographic models with subcentimeter vertical accuracy, comparable to those achievable with drone-based photogrammetry in equivalent contexts (Barazzetti et al. 2017; Rezaei et al. 2024).

Comparison with other methods (e.g., lidar) is not currently possible at our case study sites. In Failaka, an authorized drone survey was available for partial comparison, conducted under an institutional permit rather than by the research team. In January 2026, a surveyor from Cairo visited the Roman fort at Hiw for two days with a LiGrip O2 Lite Lightweight Handheld SLAM LiDAR Scanner, but the file was corrupted during processing, so no point cloud could be generated. This highlights the value of the January 2025 photogrammetric survey, which remains the only high-resolution DEM, 3D model, and orthomosaic of the fort to date. The results achieved are nonetheless outstanding, improved further by GCPs for meter accuracy (Barazzetti et al. 2017), and truly rival those obtained with drone sampling. Tests by other researchers comparing sensors in urban settings attest to the comparable results produced (Rezaei et al. 2024). The benefits of the technique are as follows:

- A highly accurate, high-resolution DEM that provides much more information than a traditional survey can yield.
- A high-resolution orthomosaic, usually only achievable with a photogrammetric model built from photographs taken close to the ground. With a drone, this resolution would have required low-altitude flights and the processing of possibly thousands of photographs.
- A fast method to create a topographic model that combines the best of traditional survey, drone photographs, and photogrammetry, thereby saving time in the field.
- A relatively affordable solution for small projects that does not require a professional drone pilot, programmed flights, or even drones, and that can easily be adopted by archaeological surveyors.

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Table 5. Agisoft Metashape Processing Summary: Roman Fort, Hiw, Qena, Egypt.

Parameter	Value
Image Alignment	
Images (Aligned/Total)	407/407 (100%)
Alignment Accuracy	Highest
Reference Preselection	No (GPS-based)
Tie Points (Retained/Detected)	202,435/332,063 (61%)
Reprojection Error (px)	1.84
RMS Reprojection Error (px)	0.32
Ground Control Points (GCP)	
GCP Count (Control/Check)[a]	22/1
RMSE X (cm)	2.02
RMSE Y (cm)	1.33
RMSE Z (cm)	1.15
RMSE XY (cm)	2.32
RMSE Total—Control (cm)	2.68
RMSE Total—Check Point GPS02 (cm)	20.55[3]
Survey Coverage	
Camera Altitude (m)[b]	13.8
Coverage Area (km^2)	0.0474
Ground Resolution / GSD (mm/px)	7.24
Digital Elevation Model	
DEM Resolution (cm/px)[c]	1.00
Point Density (pts/cm^2)	1.00
Depth Map Quality	High
DEM Source	Depth maps
CRS	WGS 84 / UTM zone 36N (EPSG::32636)

Notes: Single-chunk model. GCPs were recorded with a GNSS receiver (projected CRS).
[a] We recorded 22 control points and control point GPS02 was used as independent check point. The high checkpoint error (20.55 cm) is attributable to the GPS receiver's accuracy at the time of rerecording, not to the photogrammetric model.
[b] Camera altitude is derived from smartphone GPS coordinates used as camera location input, not from the physical boom pole height (~5 m). This value reflects the combined effect of GPS vertical uncertainty, topographic variability across the survey area (75–82 m asl), and pre-GCP camera placement by Metashape, and it should not be interpreted as the operational capture height.
[c] Hiw DEM resolution (1.00 cm/px) reflects improved field conditions: high-speed SD card, systematic 5–10 m grid sampling, and clearly marked GCP targets, demonstrating the reproducibility and scalability of the method.

The edges of our models exhibit more artifacts and noise, suggesting that an additional set of photographs beyond the study area is needed to compensate for deformation. Artifacts and noise are present in every photogrammetric model, including those from drone photographs; in the latter, however, deformation is minimal because drone photographs for photogrammetry are often taken zenithally rather than obliquely.

At Hiw, a map from the beginning of the twentieth century (Petrie 1901:Plate XXIV) shows that its depicted features are clearly visible in the DEM, alongside others hardly recognizable on the ground. This is invaluable: the technique not only produces a new map for Hiw but also offers new insights into the site. The features resembling craters inside the fort are real, not artifacts or noise; the camera has enough resolution to capture these irregularities, and its height and oblique perspective yield a better representation of the surface than a standard zenithal drone survey, enhancing the 3D representation of space and visual realism (Figure 14). Some drone applications for programmed flights can achieve this

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Figure 14. Fifth test: comparison at Hiw between the real-life landscape and the photogrammetric model of that same landscape (photograph by Audrey Eller, La Mission Archéologique de l'Université de Genève à Hou).

by repeating the same path with a tilted camera, but the 360° survey does so without flying and without taking hundreds of additional photographs.

Despite the relatively limited number of photographs used for the 360° survey and the excellent results, we found that the technique has some disadvantages. The size of the images to be processed is massive, and a dedicated hard drive—preferably solid state—may be necessary to handle all the processing. For these two projects, Failaka and Hiw, we required one full terabyte (1 TB) to store the images. Fortunately, this does not pose an issue for image processing within Agisoft Metashape, given that the software is capable of processing the images in a relatively short amount of time and solely requires sufficient RAM (16 GB). Nonetheless, a powerful computer with a dedicated graphics card is needed to process the data and produce the orthomosaic.

Regarding the generation of the orthomosaic, each 360° photograph produces an artifact below the camera: a depiction of the camera holder and their shadow (Figure 15). This is an unavoidable yet solvable outcome. Given that the area around the camera will be captured photographically by the surrounding cameras, these areas can be amended either by removing the problematic camera and using the surrounding cameras to generate the mosaic in the orthomosaic in Metashape or by masking the

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Figure 15. Fifth test: the orthomosaic with artifacts, showing the camera holder during the survey.

artifact before processing the model. This process is straightforward but time consuming and computer intensive. The higher the computer's specs, the less time it takes to complete this task.

Although this technique saves valuable field time—enabling users to allocate more effort to excavation, documentation, and other survey activities—it is important to acknowledge that it introduces additional post-fieldwork demands. Specifically, more time must be devoted in the office to processing and stitching the raw fisheye photographs, as well as to conducting photogrammetric processing. Although undertaking these prolonged tasks is worthwhile given the benefits and quality of results afforded by the proposed technique, the lengthy processing time should nonetheless be taken into account when planning its application.

Discussion

In view of the analyses and results obtained thus far, we have identified the main advantages of utilizing this particular method, which altogether fulfill the three basic precepts of being affordable, portable, and accurate:

- Cost effectiveness: This survey method utilizes equipment more economical than a drone with a decent camera (>12 MP, global shutter, ideally RAW format), making it more accessible to researchers with smaller budgets without compromising quality. As of July 2026, the Insta360 X3 costs about USD $300, compared to USD $759 for the DJI Mini 4 Pro—currently the only consumer drone in the Mini series (one of the cheapest) that supports the Mobile SDK (MSDK) for programmatic, automated flights. It is low budget without compromising quality.
- Visual realism: Whereas drone mapping primarily produces zenithal imagery, 360° photography captures both vertical and oblique views of standing structures, enhancing geometric completeness and yielding a more comprehensive, detailed model. The results are accurate and consistent.

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- Safety: The equipment is not contingent on authorization or safety regulations and does not require certification.
- Applicability: The method is reproducible on different sites with different terrain conditions, very portable, and deployable on demand under expedited or controlled circumstances.
- Time saving: Fieldwork time is reduced, given that large-scale contexts and entire sites can be recorded in hours or a day, compared to a traditional manual survey with a total station. A DEM and a 3D model can be generated the same day, ready to use in GIS software.
- Multiple results: The outcomes include a 3D model, DEM, and orthomosaic.
- On-the-ground topographic survey: Contrary to UAV recording, where the surveyor acquires topographic information "remotely," this technique is more akin to traditional survey with a theodolite or EDM, requiring the surveyor to walk the site, observe it, and gain a closer understanding of its features and conditions. Eyes are on the ground, not on the equipment.

Beyond the immediate outputs described here—DEM and orthomosaic—the image dataset produced by this technique carries significant potential for future reprocessing. The spherical nature of each photograph, combined with the ground-level capture height, provides the angular diversity and surface coverage that photogrammetric pipelines based on nadir drone imagery typically lack.

Because nadir UAV acquisition records vertical surfaces at grazing incidence, it produces significant foreshortening, reduced effective GSD, and occlusion (dead ground) on standing structures, typically yielding a 2.5D surface model. Ground-level spherical capture, by contrast, records the same surfaces at near-normal incidence from multiple convergent viewpoints, improving ray-intersection geometry, reducing occlusion, and enabling a geometrically complete 3D reconstruction of both horizontal and vertical elements.

This makes the dataset particularly well suited for 3D Gaussian Splatting (3DGS) workflows (Kerbl et al. 2023), an emerging technique for producing photorealistic neural representations of space, already implemented in programs such as 3DF Zephyr 9.0. Unlike drone-based nadir surveys, which struggle to reconstruct vertical surfaces, or terrestrial lidar, which provides geometry without photometric density, the 360° ground-level dataset captures both horizontal and vertical surfaces simultaneously in high resolution and full color. The same images collected for topographic mapping can therefore serve as input for 3DGS processing at no additional fieldwork cost, extending the life and utility of the dataset well beyond its original purpose.

Beyond 3DGS, the resulting models also lend themselves to virtual and immersive reuse. Consumer VR headsets such as the Meta Quest 3, paired with software such as Hyperscape, can now produce high-quality 3D models that combine 3DGS and photogrammetry. The relatively straightforward process of importing a photogrammetric 3D model into a VR headset using engines such as Unreal Engine or Unity allows these models to be repurposed as immersive experiences, letting users walk through and explore archaeological contexts as if physically present. These outputs come with their own digital curation demands—chiefly, long-term storage and format migration for large 3DGS and VR-ready assets—yet they open a valuable avenue for digitally preserving sites and landscapes that might otherwise never be scanned, whether due to remoteness, resource constraints, or the very drone restrictions discussed above. Where drone use is not restricted, the same approach can be implemented with 360° cameras mounted on a UAV rather than a boom pole. In 2025, Insta360 released the first consumer drone with a built-in 8K 360° camera system (Antigravity A1), which has been successfully used for photorealistic 3DGS capture (Corridor Crew 2026; CyArk 2026; CyArk and Antigravity 2026a, 2026b).

Photogrammetric software such as Agisoft Metashape and WebODM natively support equirectangular images as input for SfM processing; other pipelines—Meshroom, RealityScan, or COLMAP—require an intermediate step in which equirectangular images are converted into rectilinear perspective projections (a process sometimes called "cubemap decomposition") before feature extraction and matching can be performed. Regardless of these advantages, we have also identified a few disadvantages:

- A high-spec computer is required, especially for large-scale surveys, because individual photograph sizes range between 200 and 300 MB.

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- A dedicated external hard drive, preferably solid-state, is needed for storing and processing the photographs.
- Additional work on photograph masking and/or artifact removal for the orthomosaic can be considerably time consuming. A DEM and 3D model can potentially be produced on the same day as the sampling, but extensive post-processing is needed for a high-quality orthomosaic.
- Software licensing is a hidden cost of processing. Although the survey equipment itself is inexpensive, full processing capability may still depend on licensed software (e.g., Agisoft Metashape, or a RealityScan seat above its free-use threshold), reintroducing a financial barrier at the desk that the field method was designed to avoid. This means savings in the field, but expenses at the desk.
- Free/open-source options (Meshroom, WebODM, RealityScan within its revenue-based free tier) remove the licensing cost but relocate it onto the researcher's technical proficiency—self-hosting server infrastructure, working through node-based pipelines, or manually converting equirectangular images into cube faces before feature extraction and matching can begin. Support is largely community driven rather than vendor provided, which can slow troubleshooting in time-sensitive fieldwork or publication schedules. The absence of a price tag is offset by a steeper learning curve and a dependency on in-house technical expertise that not every research team has. Money is spent on time and skill rather than on software.

Reflecting on the above-listed advantages and disadvantages, it can be inferred that the identified drawbacks relate to the processing phase of the photographs recorded during the survey rather than to data acquisition in the field. Data-intensive analysis requires a high-spec computer. Although it is preferable to perform these analyses in the field to assess the quality and effectiveness of the recorded data and, if necessary, repeat the survey, it is also possible to postpone this phase until after fieldwork and carry out data processing in informatics laboratories or research facilities. Although the procurement of an external hard disk has become a prerequisite for archaeological missions due to the increasing volume of digital and digitized data produced during and after fieldwork, the size of the photographs produced by this survey method will likely require a hard disk with greater storage capacity.

Conclusions

The purpose of this article is to show that spherical cameras can be used as a low-budget alternative to record archaeological open-air contexts of considerable dimensions using low- to medium-cost tools—in this instance, a 360° camera—in those circumstances where the use of UAVs or lidar tools is either not possible or out of budget. The article presents the authors' development of a method, demonstrated through its implementation in five tests across different archaeological contexts with significant topographical discrepancies and characteristics. Photogrammetry in archaeology is widespread, and it is used in various contexts. The use of 360° cameras is becoming increasingly popular, and the quality of the photos has improved dramatically over the past 10 years, enabling the production of high-quality photogrammetric models with fewer photographs.

Overall, we are confident that there is no compromise in quality with this more economical survey method, making it less elitist and more budget friendly. Ever since its introduction into archaeological methodology, one of the critical drawbacks of photogrammetry has been its cost (Anderson 1982:201, 205). Over the years, its implementation has become more user friendly and accessible, precisely due to advances in technology. With this contribution, the authors aspire to add to this ongoing trend.

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Competing Interests. The authors declare none.

Author Contributions. Formal analysis: IH, GM; Investigation: IH, GM; Methodology: IH; Resources: IH, GM; Writing – original draft: IH; Conceptualization: GM; Writing – review & editing: GM.

Notes

1. University of Geneva and Ministry of Tourism and Antiquities: https://www.unige.ch/Hout-Sekhem/.
2. The *sebakheen* were local workers hired by companies between the 1830s and the 1930s to remove *sebakh* (Nile silt)—in which archaeological sites were rich due to the majority of buildings being constructed with mudbricks—therefore subjecting many Egyptian sites to invasive nonarchaeological excavations. *Sebakh* was used for the industrial production of saltpeter, resulting in fertilizer, gunpowder, and fired bricks (Bailey 1999:211, 213; Davoli 2015:94).

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