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THE PAST FORWARD

Drawing on new emerging technologies, Thomas E. Levy predicts the rise of the cyber-archaeologist

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It is interesting that we still excavate like our 19th-century predecessors with shovels, hoes, pick axes, trowels, small excavation hammers, brushes, dustpans, buckets made of old car tires and such. What is new, exciting and challenging is how we record the archaeological process and ultimately disseminate it. This has profound ramifications for research, teaching, public outreach and the conservation of archaeological sites and collections.

For the past five years, I have been fortunate to be a co-principal investigator of a unique five-year, $3.2 million National Science Foundation (NSF) grant called the Integrative Graduate Education and Research Traineeship (IGERT) program.[1] The aim of my project is "Training, Research, Education in Engineering for Cultural Heritage Diagnostics" (TEECH) with the beginning years focused on the deployment and development of many digital technologies for archaeological fieldwork in Biblical Edom, located in southern Jordan. Originally it was hoped that a new type of "cultural engineer" would be created. As the years went by with our IGERT grant, what did emerge was a new type of archaeologist; one that is rooted in "cyber-archaeology"—the marriage of archaeology with computer science, engineering and the natural sciences. By mastering the tools of cyber-archaeology, students are "pre-adapted" to the challenges of 21st-century archaeological research. Ultimately they have a "leg up" for employment over other young professional archaeologists who have not embraced the information technology revolution. How then can we conceptualize this new world of cyber-archaeology and how does it play out in the Holy Land?

The four main domains of cyber-archaeology—data acquisition, curation, analyses and dissemination—are at the center of what makes archaeology today a field science based on the observation of the physical world, just like oceanography, geography, ecology, geology, botany and zoology. Let's be clear—most archaeologists are embracing different kinds of digital tools; what is different with our group is the relatively seamless integration of the complete digital workflow from recording the excavation to publishing the work both in print and online. The four domains of cyber-archaeology can be conceptualized as a pie-diagram with each segment equally represented.

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As the excavation process destroys the very archaeological record that we are interested in investigating, over the last decade archaeologists have spent considerable effort on developing accurate and rapid digital data acquisition tools. The rapid development of inexpensive laptop computers, digital cameras, Global Positioning System (GPS) devices, electronic surveying instruments, and a wide array of handheld analytical instruments have influenced archaeologists to acquire and use these new tools. In general, data acquisition tools can be divided into terrestrial and aerial. Archaeologists' most precious commodities are "time" and "space." We need to control time to be able to measure cultural and historical change. This is achieved through epigraphic finds (such as Egyptian scarabs that are linked to well-defined dynastic chronologies) and objective chronometric dating methods (e.g., high-precision radiocarbon dating).

Ortho-rectified is the process of adjusting an image of the curved Earth to create a flat version. The perspective of the image must be adjusted so a feature can be represented in its "true" position for accurate measurements of distance and area.

Cartesian coordinate system uses a pair of numbers to uniquely define the positions of points in a plain (or in three-dimensional space). The points are defined by the location of two perpendicular lines, called axis (usually the X-axis and Y-axis).

Structure from motion (SfM) photography is a technique used to create 3D models by combining multiple photographs taken from different angles into a single 3D image.

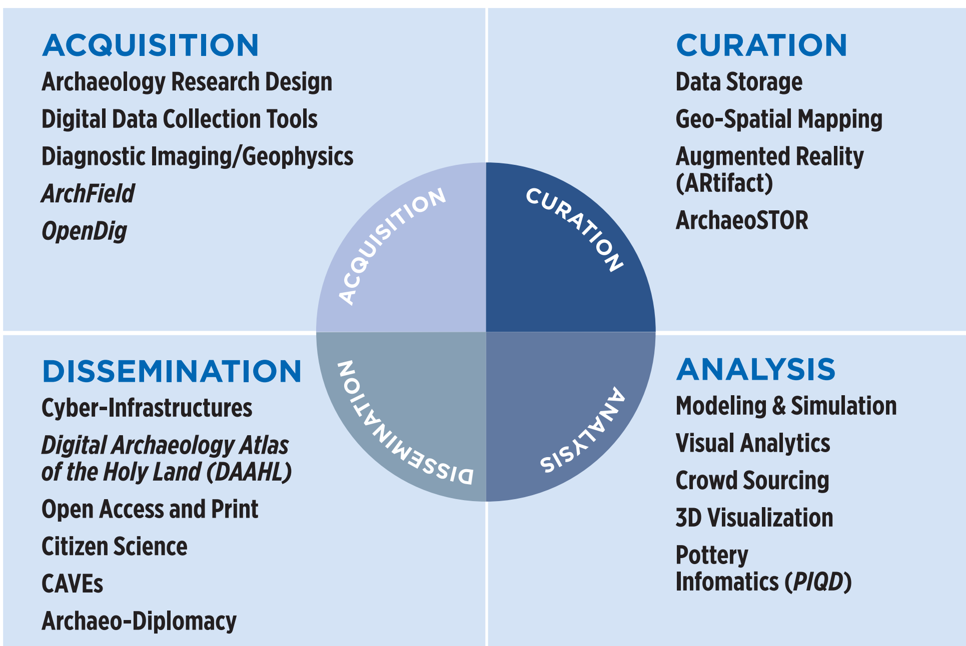
Digital elevation model (DEMs) is a 3D model of the elevation of a terrain or object's surface. Points are taken along the surface, then mapped using X, Y and Z coordinates to create the 3D model.

The Oxford Radiocarbon Accelerator Unit (ORAU) at the University of Oxford serves a similar role for deep-time study of mining and metallurgy. The application of advanced statistical methods to suites of radiocarbon dates processed from major excavation projects enables research teams to achieve sub-century dating accuracy so that it is possible to objectively investigate historical Biblical archaeology problems that were impossible a decade ago. Today, it seems that every major Biblical archaeology field project has its own physicist devoted to radiocarbon dating.

Archaeologists play a much more active role in the development of their other precious commodity—space. The control of space relates to the context in which archaeological material is found. Rip an artifact out of the ground, put it for sale on the antiquities market, and most of its historical and cultural meaning is lost. This is why archaeologists working in Israel have put increasing effort over the years in perfecting the recording process. By the early 2000s, every excavation project in the region incorporated computers, digital cameras, some sort of digital survey technology, and other digital technologies—but mostly in a nonintegrative way. This meant leaving the field with a wealth of data that was exceedingly difficult to collate. Frequently projects might excel in one aspect of data capture and curation—such as digital photography or a loci database—but other aspects of the workflow were not addressed. This is where the University of California San Diego Edom Lowlands Regional Archaeology Project (ELRAP) working in southern Jordan became a "game changer" and inaugurated one of the first fully integrative cyber-archaeology systems for Middle Eastern archaeology.

One of the most innovative aspects of our early digital archaeology recording system was to record all our data using a digital Electronic Distance Measurer (EDM) or Total Station to collect X, Y and Z coordinates of everything and to use Geographic Information System (GIS) as the main organizing principle for the input of all our data. A GIS is designed to capture, store, manipulate, analyze, manage and present all types of spatial or geographical data using a computer. Any kind of map, aerial photograph or satellite image can be geometrically corrected or "orthorectified" so that the scale is uniform and can be used to measure true distances, because it is an accurate representation of the Earth's surface. Thus, for our archaeological data recording, starting in 1999, all artifacts, loci, every sediment layer, building structure, and observation made in the field—each was given its own unique geo-spatial number linked to its real-world X (latitude), Y (longitude) and Z (elevation) coordinates. In geography, this is also known as the Cartesian

Workflow model for cyber-archaeology developed at the University of California, San Diego.



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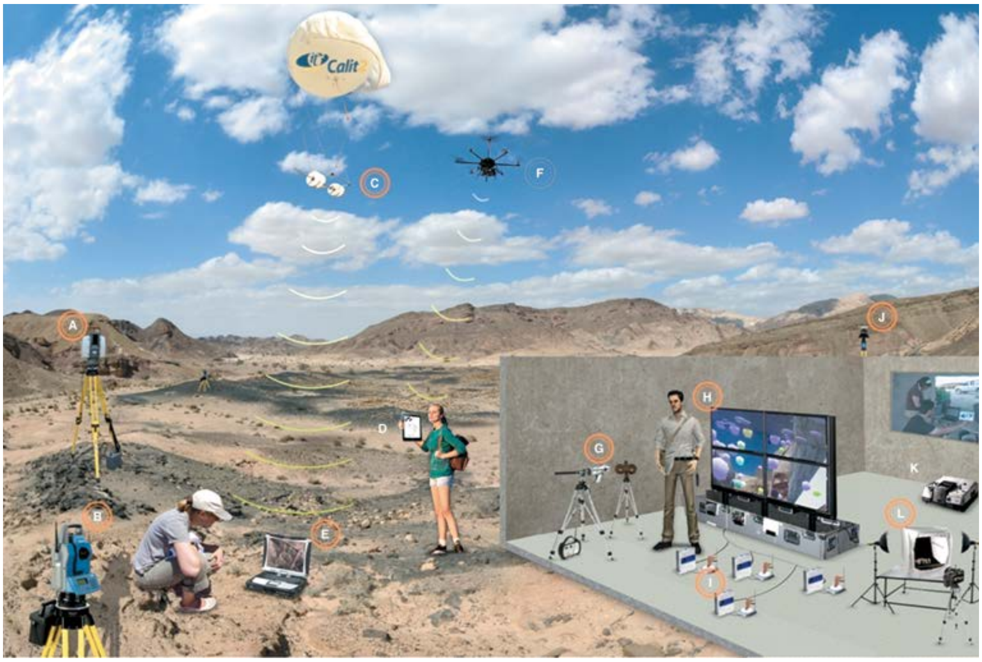

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A model depicting the range of terrestrial and aerial data recording tools used in the UC San Diego-Department of Antiquities of Jordan excavations.

- **A** LiDAR
- **B** Total Station
- **C** Helium balloon aerial photography
- **D** OpenDig database for collecting excavation metadata
- **E** ToughBook computer for wireless connection to cameras
- **F** OctoCopter
- **G** Handheld X-ray fluorescent (XRF) analyzer for nondestructive elemental analysis
- **H** OptiPortable display wall
- **I** Portable 3D scanners
- **J** Differential GPS base station
- **K** Fourier transform infrared spectroscopy (FTIR), for mineral components of raw materials
- **L** Digital photography lab—every recorded artifact

coordinate system. At the time, I did not know that by adopting a GIS data-recording system as the nexus of our archaeological recording system in Jordan, and collecting every piece of data with X, Y and Z coordinates, we had "pre-adapted" our research to the new world of 3D scientific visualization and virtual reality (VR) that is increasingly important for research, scientific story-telling, gaming and entertainment today.

Over the years, it has become essential to have a wide range of experts on-site to analyze the disparate types of data retrieved in the archaeological process, including archaeobotany, archaeozoology, archaeometallurgy, ceramics, lithics, ground stone artifacts and more. Technical experts have also become a critical part of the excavation team, including artifact illustrators, architects, conservators, photographers, surveyors and other specialists. Whereas in the predigital archaeology period, dig directors needed an architect on site, today larger projects need an IT specialist.

ArchField—a "real-time" GIS that was developed by Neil Smith and me—is our solution to enable any archaeological dig project to adopt inexpensive real-time 3D digital recording techniques for their field methodology. The software solves one of the fundamental bottlenecks in archaeology: the curation and analysis of massive datasets recorded over multiple excavation seasons. It enables highprecision data recording, data organization, visualization and analyses in real-time and back in the lab.

In an effort to create accurate 3D maps and models of sites, archaeologists have turned to a number of tools that enable them to create "point clouds." Whereas a Total Station or GPS unit collects one data point with X, Y and Z coordinates (that indicate the exact location of the external surface of an object), point clouds can consist of billions of accurate geo-referenced points. Each point also has the advantage of being characterized by real color. Point clouds are created by 3D scanners and a relatively new technique called Structure

Leica ScanStation 2 is a 3D laser scanner that utilizes the time-of-flight measurement method—it measures distance by analyzing the amount of time it takes for a beam of light to travel from the scanner to the object, architectural feature or physical feature and back to the ScanStation 2. This data is imputed into a computer which creates a 3D map of an object, building or area.

Point cloud technology utilizes 3D scanners—which record thousands of points on a building or object's surface—to produce a data file that can be used to create a 3D image or map.

CAVEs are walk-in immersive virtual reality environments situated typically in a larger room. They can have rear-projection screens or are made up of an array of flat screen 3D TVs. Larger CAVEs are powered by multiple computers and high-speed networks to data sources.

from motion (SfM) photography. Laser scanners, also referred to as LiDAR (light detection and ranging), calculate distance by illuminating a target with a laser and analyzing the reflected light. Each measurement represents a point in the "point cloud." Both land and airborne LiDAR can be used to produce high-resolution digital elevation models (DEMs) of archaeological sites. Once a DEM is created, it is possible to "drape" high-resolution satellite and other data over the DEM to create a textured 3D surface or model of an ancient site and its regional setting. Airborne LiDAR can reveal microtopography that is otherwise hidden by vegetation because airborne LiDAR uses different laser sensors from the stationary terrestrial instruments. Archaeologists working in jungle and forest zones tend to use airborne LiDAR to discover ancient sites covered by vegetation. We want to experiment with airborne LiDAR over sand dunes to detect large archaeological sites that may be hidden by shifting sands.

In most cases, archaeologists use laser scanning as a conservation tool, to record accurately sites and monuments in 3D. The Department of Antiquities of Jordan has done this for monuments at the famous Nabatean site of Petra and our lab worked with King Abdullah University of Science and Technology in Saudi Arabia to record contemporary Nabatean monuments 300 miles south of Petra at the site of Madain Salah with laser scans and SfM from airborne drones. Our team has taken laser scanning and archaeology to a new level by using the point clouds as "data scaffolds" on which other archaeological data can be embedded. For example, at Khirbat en-Nahas, we spent ten days creating a more than one billion point cloud over the 25-acre site. As we excavated about 75 percent of the Iron Age fortress gate house at the site, we took all our excavation data recorded in real-time GIS with ArchField and embedded it into the massive point cloud we collected using a Leica ScanStation 2. The result was spectacular, as it was now possible to view the Iron Age gatehouse in 3D along with all the artifacts, ecofacts, sediment layers and architecture, and precisely date exactly when the fortress was built. In the case of Khirbat en-Nahas, the construction of the massive fortress was accurately dated to the early 10th century B.C.E., providing evidence that a local complex society (kingdom) established the monumental structure. We believe either the Biblical Edomites or possibly the Israelites carried out the construction.

Helium balloons and drones (UAVs), are another important set of data capture tools used by archaeologists for photography, mapping and 3D model building of archaeological sites. A helium balloon system has proved most useful for us. The balloon (Kingfisher™ Aerostat) is tethered to an operator on the ground who can position it over an excavation area and cover up to 2,153 square feet. A stable aluminum platform was designed to hold two 15-megapixel digital single lens reflex cameras for stereo photography monitored with

LiDAR scan of the Iron Age fortress at Khirbat en-Nahas, Jordan.

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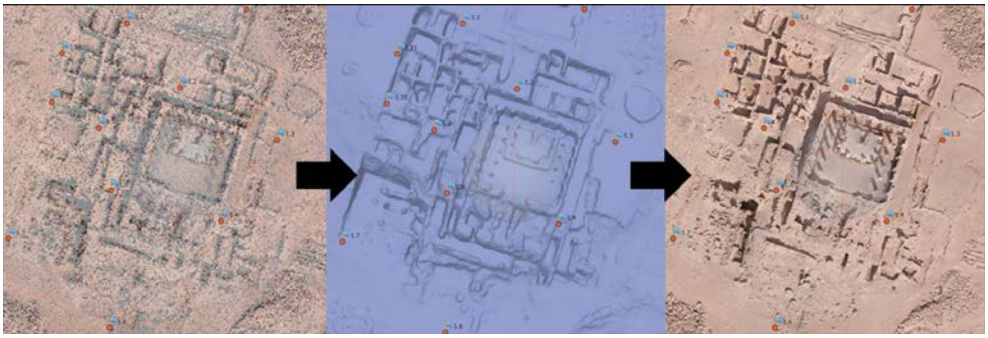

The Temple of the Winged Lions in Petra, Jordan, using SfM shows the process going from a point cloud, to the geometry of a site, to a final 3D color textured model.

Bluetooth live-feed on a Panasonic Toughbook computer. The system can capture images from up to a height of 656 feet at high resolution and excellent stability. The system can be brought down to lower heights for even higher resolution image capturing.

Drones are an alternative to balloons and gaining in popularity among archaeologists. Chinese off-the-shelf drones built by companies such as DJI are the real game changer. For less than $800, you can purchase DJI's out-of-the-box Phantom 3 Standard quadcopter drone that is easy to fly with an automated flight system, a wonderful video/12-megapixel camera, a gimbel to stabilize the camera, a live video feed so you can view what the camera sees on your mobile device (smartphone or tablet) and a 25-minute single charge for the battery. This allows you to make stunning videos and capture SfM of your archaeology site to make 3D models and maps as described below. The downside of drones is that they are delicate and can fly only for as long as you have charged batteries. While balloons require expensive helium, for excavations that last longer than a few weeks, they are great workhorses for day-to-day recording, needing only occasional top ups of helium.

Once archaeological data has been recorded and geo-referenced with ArchField and AgiSoft Photoscan[2], the next challenge is to describe all the archaeological contexts in a way that is systematic, meaningful and not prone to data entry mistakes. This refers to establishing metadata for the archaeological materials excavated; that is, data that describes other data. For archaeology, metadata summarizes basic information about site or artifact. Let's say you took a digital photo of the floor of an excavated Iron Age house. Metadata associated with the photo could include: date of photo, locus, basket numbers associated with the room, archaeological period, stratum and more. This metadata can make finding and working with particular instances of the archaeological data easier. If we have photos of 20 Iron Age rooms from a large mound site and different strata, having the ability to filter through that metadata (say, only Iron Age IIA rooms) makes it much easier for someone to locate a specific issue of interest.

Today, computer programs and portable digital devices make the recording of archaeological metadata much easier. Perhaps the most innovative program is known as OpenDig developed by my student Matt Vincent, initially for excavations at the Biblical archaeological site of Numeri in Jordan but now used at a number of sites.[3] Using iOS-based portable devices, OpenDig works on technology many people already have: iPads, iPhones and iPods, which all can work to record excavation metadata. With OpenDig, sloppy hand-written notes are a thing of the past; thanks to pull-down windows and other tools, one can rapidly sync data from the field to the lab to permanent storage with the touch of a button, and finally you can publish your primary data online with a robust platform built on web standards.

Other projects are making strides to go paperless. An excellent example is the Jezreel Valley Regional Project (JVRP) in Israel. The JVRP takes full advantage of using SfM photography for photogrammetry—a computerized process that produces spatially accurate images from photographs. When dropped into a GIS, these maps can be used to create accurate maps that can be "inked" and "labeled" in the GIS computer program and ready for publication. If dozens of photos are taken, there are now open-source or proprietary computer programs that carry out photogrammetric processing of digital images and generate 3D spatial data, (i.e., SfM). It is a process

3D view of an inscription from the Sanctuary of Athean Pronea, Delphi, Greece. The image was created with 20 digital photos shot all around this small standing stone and processed using Structure from Motion software.

COURTESY OF THOMAS E. LEVY

that estimates three-dimensional structures from two-dimensional image sequences. SfM is revolutionary for archaeology, because one doesn't need an expensive laser scanner to create a point cloud. You can even do it by taking pictures on your smart-phone. The key is to take a plethora of overlapping photos of the archaeological object or area of interest. Then the specialized software matches each photograph up to other photographs of the same area, and it builds a 3D surface from the 2D photographs. Use of GIS and SfM means it is now possible to create geo-referenced maps ready for publication and 3D models of archaeological objects—such as pots and other artifacts—entire sites and sites in their regional terrain.

Using crowd-sourcing, Steve Savage—with whom I developed the MedArchNet (Mediterranean Archaeology Network—http://medarchnet.org)—recently created an online cultural heritage project called Terrawatchers (http://terrawatchers.org). Terrawatchers provides web-based, crowd-sourced satellite image monitoring and monitoring tools for critical missions related to current events. It uses interactive Google Maps© and interfaces to display the latest freely available, high-resolution satellite imagery to create mission "footprints" so that citizen scientists can monitor military and other damage to archaeological sites in the Middle East and share this data. The American Schools of Oriental Research (ASOR) Syrian Heritage Initiative has a staff that also uses satellite data to monitor the situation on the ground and produce weekly reports for the public.

With the widespread use of digital data acquisition tools and software, for each individual archaeology dig, there is an exponential growth in the amount of digital data produced. How can this data be curated in the short (years) and long (permanent) run? Our lab has developed a web-based database for the field and lab called ArchaeoSTOR, spearheaded by Aaron Gidding. Many archaeology digs, like ours in Jordan, take place in remote areas with poor Internet service. Consequently, we developed ArchaeoSTOR as a web-based system that can work on a local network. In the field we use a portable MacMini as a server for ArchaeoSTOR. When we get home, the ArchaeoSTOR software mirrors the season's data on to the university server. ArchaeoSTOR integrates a wide range of data formats (laser, Microsoft Word, Excel, digital photography, video, chemical, etc.). All these data can be used in tandem to describe different archaeological phenomena and viewed spatially through an open-source GIS program. ArchaeoSTOR keeps track of all the artifacts and samples recovered on the dig by using a barcode system whereby everything collected on the site gets one when recorded using ArchField. From the moment an object is recorded, ArchaeoSTOR tracks its passage in the field from the "dirty lab" and initial processing to the photo lab, analytical lab, storage crate and physical storage.

Final digital archiving of archaeological data is an increasingly important concern. This is being achieved by a number of researchers such as Sarah and Eric Kansa of the Alexandria Archive Institute, which develops web technologies to help share their archaeological data in an open manner that emphasizes collaboration with as many organizations as possible to improve global access to knowledge.[4] To achieve this, their Open Context project is an open access, web-based publication system. Openness and data sharing should be the norm today and many government agencies require grantees to have a data-sharing plan attached to their research projects. At UCSD our work is part of the Research Data Curation Program where we integrate ArchaeoSTOR with the university library system to develop a permanent data management, sharing and discovery, and digital preservation plan that makes every piece of digital data citable by other researchers. Thus the digital data from our excavations at Khirbat en-Nahas can now be accessed as a digital collection housed online at the UCSD library.

In conclusion, we have seen how cyber-archaeology is transforming archaeology in the Middle East with important ramifications for world archaeology. This is done through new data capture tools, curation methods, analyses and dissemination that are all part of the cyber-archaeologist's toolbox. In the predigital age and even today, dissemination of data meant the publication of results in printed books, journals and magazines. Today we must also use the Internet and 3D visualization platforms to engage both scholars and the public. One Internet dissemination tool is the MedArchNet we developed, which is an online series of linked archaeological information nodes or digital atlases, each of which contains a regional database of archaeological sites that share a common database structure in order to facilitate rapid query and information retrieval and display within and across nodes in the network. Accordingly, it is a research, conservation and "scientific storytelling" tool. The most developed node is the *Digital Archaeology Atlas of the Holy Land* or DAAHL with over 30,000 archaeological sites and a range of applications, such as thematic summaries and summaries of all the periods of human occupation in the region from the Lower Paleolithic to late Ottoman times, GIS and spatial studies, online query and mapping tools.

One of the most exciting new directions in dissemination is the use of 3D virtual reality (VR) for archaeological research and dissemination. VR is a computer-generated artificial environment that is created with software and presented to the user in a way that simulates a real environment. VR is primarily experienced through sight and sound. The earliest advances in VR were made in the military with flight simulators that made it possible for pilots to practice flying expensive jets and practice combat, landing, ejecting and other tasks without damaging a multi-million dollar plane. Today there are 3D immersive environments called CAVEs that my colleague Tom DeFanti has pioneered, such as the StarCAVE, TourCAVE, and WAVE. UCSD's StarCAVE is a five-sided VR room where scientific models and animations are projected in stereo on 360-degree screens surrounding the viewer, and on to the floor as well. As all our excavation data from Jordan has 3D coordinates the precise location of each recorded artifact, feature and locus can be put back together. We can also add all the GIS data into the VR model and perform spatial and statistical analyses just as in standard GIS programs. We used the StarCAVE to revisit excavations at Khirbat en-Nahas—a site at the center of debate concerning the tenth century B.C.E. and the historicity of aspects of the Old Testament. In the StarCAVE, we could see the exact location of processed radiocarbon dating samples and pottery in relation to monumental building and industrial-scale copper-working activities, proving that a local complex society ("kingdom") was responsible for these feats. This data disproves the view of scholars who claim there were no local kingdoms during the tenth century B.C.E., the time of David and Solomon, in the Holy Land. Very recently a number of new inexpensive personal VR headsets have been developed, such as Google Cardboard and Oculus Rift. Our team and others are busy adapting these new VR tools for archaeological research. From a digital perspective, the future of the past in the Middle East is very good.

[1] Falko Kuester, a structural engineer and computer scientist, is the Principal Investigator for this National Science Foundation grant (NSF 0966375). The author serves as co-PI focused on archaeological applications.

[2] http://www.agisoft.com

[3] Developed by Matthew Vincent (http://opendig.org); Matthew L. Vincent, Falko Kuester and Thomas E. Levy, "OpenDig: Digital Field Archaeology, Curation, Publication and Dissemination," *Near Eastern Archaeology* 77 (2014), pp. 204 – 208.

[4] http://alexandriaarchive.org