REVEAL: one future for heritage documentation

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***Abstract*—It can be frustrating to ensure that cultural heritage work, from archaeological excavations to historic surveys, is documented fully and that the evidence is recorded properly and thoroughly. Automated computer-based documentation and research tools would seem to offer many benefits. They can be more accurate and cost effective, saving time and ensuring that all finds and their contexts are appropriately and fully recorded. And if designed well, new digital field data acquisition systems can enable new types of hypothesis testing, new insight into the past, and new visualizations that in turn can lead to a paradigm shift in how heritage sites are managed and information disseminated.**

There have been many computer-based data collection systems for heritage management; many databases, many digital archives, and many digital publication options. REVEAL is special. REVEAL (Reconstruction and Exploratory Visualization: Engineering meets ArchaeoLogy), is the product of a US National Science Foundation collaboration among the Institute for the Visualization of History, Brown University's Division of Engineering, Laboratory for Man/Machine Systems, and the University of North Carolina, Charlotte's Department of Electrical and Computer Engineering. The project uses computer-vision, pattern-recognition, and machine-learning research to augment applications for archaeology and the humanities.

REVEAL is a single piece of (free and open-source) software that coordinates all data types (e.g., photos, drawings, 3D models, and tabular information) with semi-automated tools for documenting sites, trenches and objects, recording excavation and site-evaluation progress, researching and analyzing the collected evidence, and creating 3D models and virtual worlds. Search and retrieval, building interactive visualizations, and testing hypotheses against the recorded material can all happen in real time, as the work proceeds. That is an important advance. Thus, REVEAL could be the only one software package that heritage fieldworkers might ever need. This paper will discuss and demonstrate this ground-breaking software toolkit.

***Index Terms*—Virtual heritage, archaeology, integrated software, heritage documentation, photomodeling**

INTRODUCTION

Archaeology is tedious. The discipline demands exactitude, copious documentation, rigorous analyses, and prompt dissemination to peers. That rarely happens. Archaeology is also about understanding past cultures, and since the past happened in 3D, in color, and as a continuous set of actions, it would seem to make sense to study the remains of the past with similar parameters, rather than as the disconnected, 2D, black and white images that are still too common in the discipline's final excavation reports, teaching materials, and Websites. Plan, section, and elevation drawings (the fundamental "sacred triad" of architectural documentation for millennia; [1, 2]) have been central to archaeological visualization since the inception of the profession well over 200 years ago, and archaeologists persist in using them despite the availability of more appropriate and more accurate alternative image types.

Fieldwork in not only archaeology, but also heritage research in general, presents some key documentation challenges, such as trying to accurately locate structures, walls, trenches, features, and artifacts in 3D space. For a long time, the resolution has been to describe the finds, manually take measurements, do some sketches, and photograph contexts and details. These methods tend to suffer from inaccuracies, inconsistent terminology, transcription errors, and just taking too long. Some things or views are not recorded at all, because their significance is not recognized until it is too late.

Other issues confronting field teams include: working in all kinds of field conditions, noting everything that was found, who found it, what are the finds' characteristics, and figuring out how all the diverse data should be organized and how other researchers can assimilate it all. Further, understanding the meaning, context, and function of an object evolves over time, which often involves multiple specialists each of whom may submit data in different formats. Standard collocation methods do not effectively allow hypothesis testing on all the collected data in real time, nor allow for adjusting field strategies while the work is underway. Usually, it takes years before all the evidence has been collected, studied, and synthesized, and that is unfair to our colleagues.

With the onset of the digital information revolution, new opportunities to improve the efficiency of heritage fieldwork have emerged. From the outset, however, archaeological plunges into the computerized pool have too often produced digital versions of paper-based methods, rather than truly transformative uses of the new media potential [3]. With the expanded use of such tools as virtual reality, game engines, and agent-based modeling, heritage studies has begun to embrace multimodal and multidimensional visualization techniques that move well beyond static 2D imagery.

Such new semi-automated, computer-based documentation and research tools would seem to offer many benefits. They can be more accurate and cost effective, saving time and

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ensuring that all finds and their contexts are appropriately and thoroughly recorded. If designed properly, new digital field data acquisition systems can enable new types of hypothesis testing, new insight into the past, and new visualizations that in turn can lead to a paradigm shift in how all types of data gathering are managed and the resulting evidence disseminated.

Digital acquisition and documentation technologies are primary in today's toolbag, but have they improved the situation? The choices now include laser scanners, LIDAR, digital panoramic photography, massive databases, CAD, GIS, GPS, total stations, and even smartphones and tablets with high-res cameras and custom apps that can be tailored for all kinds of projects (e.g., [4]). However, learning how to work and then using total stations, laser scanners, and related equipment are time consuming, only those points that were considered important at the time are recorded, and those points are hard to collate with the rest of the datasets from the site. GIS is great for 2D spatial data, but not so effective as a general purpose data exploration tool and generally has poor integration with interactive 3D visualizations. Harris Matrix tools focus on displaying stratigraphic sequences, barely integrating with other datatypes. Custom databases are uneven in the comprehensiveness of their features and cannot be easily generalized across projects.

What is needed is a single complete package that keeps things digital from acquisition to publication, integrates all datatypes together, can be used at different types of sites with minimal modification, and places interactive 3D contexts at the heart of the matter. The goal would be to ease recording and recall for researchers of all backgrounds for all types of field conditions. That is exactly what our team set out to do.

There have been many computer-based data collection systems for heritage management; many databases, many digital archives, and many digital publication options. REVEAL (Reconstruction and Exploratory Visualization: Engineering meets ArchaeoLogy), is special. REVEAL is a single piece of (free and open-source) software that coordinates all data types (e.g., photos, drawings, 3D models, and tabular information) with semi-automated tools for documenting sites, trenches and objects, recording excavation and site-evaluation progress, researching and analyzing the collected evidence, and automatically creating 3D models and virtual worlds. Search and retrieval, building interactive visualizations, and testing hypotheses against the recorded material can all happen in real time, as the work proceeds. That is an important advance. Thus, REVEAL could be the only one software package that heritage fieldworkers might ever need. This paper will discuss and demonstrate this ground-breaking software toolkit.

WHAT IS REVEAL?

REVEAL is the product of a multiyear US National Science Foundation-funded collaboration (grant #0808718; entitled *III-CXT-Core Computer Vision Research: Promoting Paradigm Shifts in Archaeology*; see also: http://www.vizin.org/projects/reveal/project.html) among the Institute for the Visualization of History, Brown University's Division of Engineering, Laboratory for Man/Machine Systems, and the University of North Carolina, Charlotte's Department of Electrical and Computer Engineering. The project combines computer-vision, pattern-recognition, and machine-learning research to augment applications for cultural heritage and the humanities in general (additional online resources: REVEAL Web sites-- vision.lems.brown.edu/project_desc/Reveal and http://www.vizin.org/projects/reveal/project.html; REVEAL overview video-- www.youtube.com/watch?v=1OJkiEMiMSg; and the REVEAL installation kit and sources: sourceforge.net/projects/revealanalyze/).

Our consortium devised a single, all-digital toolkit for acquiring, coordinating, studying, and presenting archaeological data that streamlines the excavation documentation and analysis processes. REVEAL uses: computer automation tools to speed up data entry tasks via an open-source Web interface; computer vision algorithms to replace manual imaging tasks; and integrated tabular, 2D, and 3D media resources to enhance querying, comprehension, and dissemination. Although we began with archaeological excavations as our focus, the resulting software can be used for any heritage documentation project.

Our initial goals were to enable real-time hypothesis testing during excavation by improving data acquisition through automation, including geolocated position recording, advanced photomodeling, and full integration of all user data. REVEAL thus becomes a single repository for everything about an excavation, or any other heritage site, with integrated multimedia analysis functions (including immediate access to tabular, photo, video, and 3D data) and integrated display of that data on plans or in spatially geolocated 3D models of trenches, architecture, or small finds. This means that from any single data type there is direct access to and display of all other related datasets. REVEAL thus combines multiple modes of input and data browsing, a database, and a sophisticated user interface.

In the field, the REVEAL data entry process is made up of two parts. Text is entered onto Web browser-based (customizable) forms and can happen via laptops, tablets or smartphones (fig. 1). Photographs of all work and contexts (and thus all information about the site, all records of fieldwork activity, and even some information that teams may not realize were captured) can be dragged and dropped from the device to the REVEAL screen and can be taken with regular consumer digital cameras (or handheld device cameras; fig. 2). No special lighting, no camera calibration, and no special equipment of any kind is needed.

As soon as the photos have been dropped into and associated with the objects in view, the REVEAL Sentinal photomodeling process can begin (fig. 3). The REVEAL photomodeling process moves through the following steps: (1) find common points in the photos (called SIFT--Scale Invariant Feature Transform); (2) calculate the camera positions (called bundling--a structure-from-motion system for unordered image collections); (3) shoot rays through each pixel to find, intersect, and define common points across all images; and (4) create the 3D models from the common points. Photographs can also be used to geolocate the 3D models. Overlapping features or specific markers placed in the scenes are shot at the site level, the building or trench level, and the artifact level so that a continuous set of models can be built and the results geolocated accurately within each succeeding larger-scale model. The models can be viewed in REVEAL Anaylzer.

Analyzer is the REVEAL data analysis module, which has been designed for nontechnical users. REVEAL Analyzer integrates geo-aligned satellite photos, geo-aligned plans, geo-aligned 3D models, photographs, and tabular data in a single program. The main screen has a persistent and context-sensitive master information panel and index (at the left edge of the window) and (at the right) space for several individual browser windows that each display photographs, plans, satellite images, tabular data, or 3D models (fig. 4). Any object in the database that is displayed in one of the windows will automatically link to other data types for that same object, which can be viewed singly or in conjunction with contextual information.

Data analysis, visualization, and querying can happen across plans (fig. 5; to view 2D contexts and assemblages), across data tables (fig. 6; to compare objects or select custom sets of fields for specific data retrieval), across sets of photographs (fig., 7; to view thumbnail sets or high-resolution images), and interactive models showing (fig. 8; to view 3D contexts of artifacts, features, and structures). Data are integrated from any REVEAL browser window to any other within the software; all data are internally linked; and all screens, views, and tools have context-sensitive help. The package is presented in a simple interface that allows sophisticated analysis, hypothesis testing, and visualization.

REVEAL allows researchers and fieldteams to ask new questions of the data, and the visualizations and data analysis results from REVEAL permit immediate field-level decision support. Anyone using the system at one site or comparing data across many sites can understand 3D spatial relationships from data collected today, yesterday, or last month with equal ease, whether the evidence has been removed or not. Contexts can be viewed and compared in color, interactively, and in 3D simulations of their original contexts of assemblages and features. These types of inquiries are simply not possible using traditional methods or even using most of the current digital methods individually.

Users of REVEAL can export single or sets of photos, plans, or 3D models and can filter and arrange data in a variety of file formats. Thus, REVEAL supports post-excavation research, teaching, and publication preparation. For example, the software allows for 3D contextual visualizations, viewing artifact distributions over time, drawing cultural inferences across large sites, and filter, organize, and export tables, plans and other images. Further, REVEAL can be loaded in to a variety of hardware configurations, from standalone systems using a single computer and camera, to centralized distributed systems via local wifi connections from laptops and handheld devices and multiple cameras.

In summary, data can be input into REVEAL via laptops, smartphones, and tablets; photomodeling can happen using images taken with consumer-grade cameras without special equipment. REVEAL has a flexible data configuration system, flexible system configuration, integrated media and database explorer windows, and can export to the popular file formats. The software is free and open-source and has been in use for two years for all sorts of documentation and recording projects (e.g., Catalhöyuk, Turkey; Ammaia, Portugal; Chavin de Huantar, Peru; Tel Eton, Tel es-Safi, and Apollonia-Arsuf, Israel; Middleborough, USA; Surtshellir, Iceland; and for recording and photomodeling cuneiform objects at Cornell University).

REVEAL SPECIFICS

For example, REVEAL has been used for basic excavation recording at Tel es-Safi, Israel, under the direction of Aren M. Maeir, Bar Ilan University. The site, located between Jerusalem and Ashkelon, has been identified as Canaanite and Philistine Gath and dates mostly to the Early and Late Bronze Ages, but has been continuously occupied for over 6,000 years. During the course of their fieldwork, the team quickly realized that data entry was greatly streamlined in the REVEAL environment versus using traditional physical binders and paperwork. Another advantage was that REVEAL possessed the ability to rapidly search for and edit items in the database. This feature was of immense help to the registrar, who was able to find incorrect data and immediately provide detailed corrections to the field staff. As an extension, packing and tracking artifacts sent from the field lab to the university lab was made more efficient. The photograph-to-3D recording and modeling methods were of special interest to the fieldteam providing 3D georeferenced area models and detailed in-trench 3D models of features that were linked to the full trench models (fig. 9).

The current Apollonia-Arsuf, Israel, excavations are directed by Oren Tal, Tel Aviv University, who has been testing and using REVEAL for four years [5, 6]. The site (on the shore of modern Herzliya) is comprised mostly of a Crusader period castle, but also encompasses a Roman villa, Byzantine Church, and Islamic market (and remains date back to the Chalcolithic period). All aspects of REVEAL were in

play across the trenches of the site, but the focus was on the advantages of digital data entry, photomodeling in-situ remains, and photomodeling large architectural features (fig. 10).

The site of Çatalhöyük is located in the Konya Plain southeast of the present-day city of Konya, Turkey. The eastern settlement dating from the Neolithic period (c. 7400-5900 BCE) forms a mound that would have risen about 20 meters above the plain. There is also a smaller settlement mound to the west which is Early Chalcolithic in date. The site is being excavated by a large number of independent international teams; the Polish contingent is led by Arek Marciniak. His field team desired to test REVEAL in comparison with other systems and evaluate its usefulness for archaeological sites where data must be collected and recorded quickly and accurately, and photographs taken of all major features and artifacts. The testing demonstrated that REVEAL, in comparison to other field software, is cheap, easy to use, proves highly accurate 3D models, and produces 3D models faster than commercial alternatives.

A completely different and difficult situation occurs at the site of Surtshellir, western Iceland, which sits inside a 1.6km-long lava tube and once housed a series of Viking structures and ritual pits. The expedition to document the site is led by Kevin P. Smith, Brown University [7]. His team needed a reliable and quick method to record thoroughly all the rapidly disappearing architectural remains inside the cavelike environment. It was a test of using REVEAL to record in accurate 3D locations inside a complex, dark, and wet environment. REVEAL demonstrated how more satisfying it is to view such situations in 3D rather than conventionally in 2D, where the sense of space cannot be appreciated (fig. 11).

At the other end of the scale, REVEAL has been used also at the 10,000 cuneiform tablet Rosen collection housed at the Cornell University Department of Near Eastern Studies and curated by David I. Owen. Their use of the photomodeling module of REVEAL constitutes a heritage documentation, long-term digital preservation, and rescue operation. Since the objects will soon be repatriated back to Iraq and most are still untranslated, they needed to be imaged as quickly as possible, so that they could be studied before access to them is lost. The project called for high-resolution high-quality 3D models, and REVEAL proved to be the most efficient means to capture all the information on and about the tablets. The software demonstrated its ability to capture minute detail on often minuscule objects (fig. 12).

CONCLUSIONS

REVEAL is agnostic software that has applications well beyond heritage documentation, with its integrated browsing environment that does not require technical expertise in databases, 3D modeling, or geolocation systems. The toolkit is designed to be customized to fit user-configured data of all kinds.

As REVEAL continues to improve and expand, new features will be added, including full GIS layer support, improved customization, semiautomatic artifact fragment reassembly, automated procedural architectural reconstructions based plans or elevation data via a semantic grammar, and automated 3D from video (as would be captured by UAVs, like quad- or octocopters). Such additional functionality immediately brings to mind an exciting vision for the future of heritage documentation.

Imagine, if you will, the fictional archaeological site of Trogitz, where the excavation team arrives with its usual equipment, that is, nothing but a few handheld devices (fig. 13). As the dig proceeds, sets of progress photographs are taken, showing all changes in depth, all soil changes, and all in-situ finds. While the fieldteam works, entering observations and object descriptions onto their Web forms via the handheld devices, photos are automatically linked to finds and geo-referenced from trench to trench. Simultaneously, data extracted from the images are automatically converted into virtual reality models, each fully textured, dimensionable, and linked to the database notes and daily finds (fig. 14). Every time an artifact is uncovered, it, too, is fully photographed during its excavation and after its removal and cleaning. These images also are used to automatically create and geo-reference virtual reality object models (fig. 15). This process continues as the season unfolds. No laser scanners, no survey equipment, no architects, no waiting until the end of the season for the results.

Documenting every aspect of any excavation (or any type of heritage endeavor), uploading new data, taking notes, doing hypothesis testing, preparing interactive 3D models of architecture and features, querying the evidence so that project strategies can be readily adjusted, and preparing publishable output ALL happen in real time, as the work unfolds. This is the new, more efficient and effective, world that innovations like REVEAL are promising.

However, the story of this remarkable paradigm shift does not end there. While all the new field data are being linked, modeled, and analyzed, envision that the continually updated database and the linked virtual reality models are uploaded to the Trogitz online collaborative portal. There, 'friends' of Trogitz can explore the excavation and artifact models in realtime, search the database as new entries appear, and comment on the results by posting e-notes inside the virtual worlds of each trench. These digital comments can be instantly read by other 'friends' or by the fieldteam, creating unprecedented opportunities for global collaborations in real-time while the work progresses. Experts can advise the fieldteam in ways that would normally take years; publication-ready analyses, visualizations, and reports can be created and disseminated on demand rather than waiting years; and classroom-ready materials await the next semester's courses so that teachers and students always use the most recent, most accurate, and most comprehensive data possible (fig. 16). This wild-and-crazy Trogitz scenario is slowly becoming a reality as the functionality of REVEAL expands.

Given the rapid pace of change in computer technologies, what may seem outrageously far-fetched today will likely become old hat in less time than it would take me to describe it. We already have location-aware smart eyeglasses with embedded computers and high-resolution cameras. Link that system to a 3D-based semantic Internet with the capability of projecting holographic images of your REVEAL-created virtual reality models and the result is your very own personal virtual timemachine. Please use it wisely.

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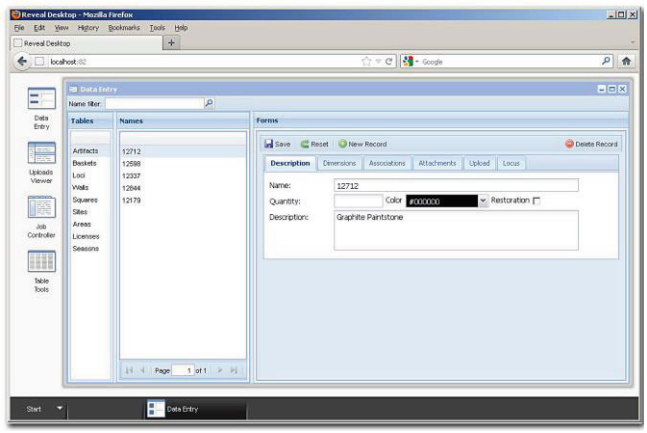

Fig. 1 – REVEAL Webform; sample input screen.

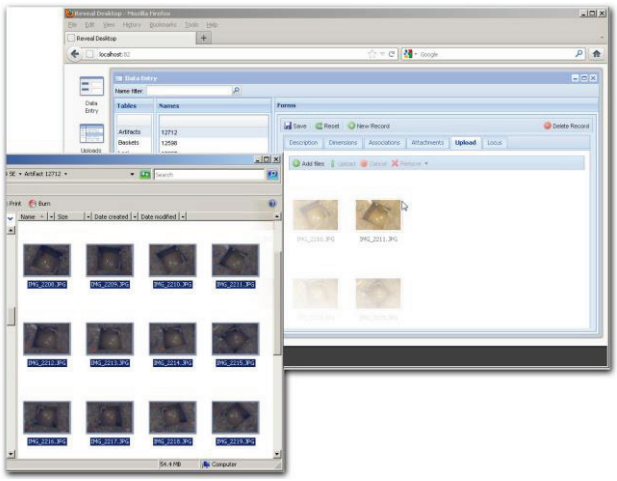

Fig. 2 – REVEAL photo import screen

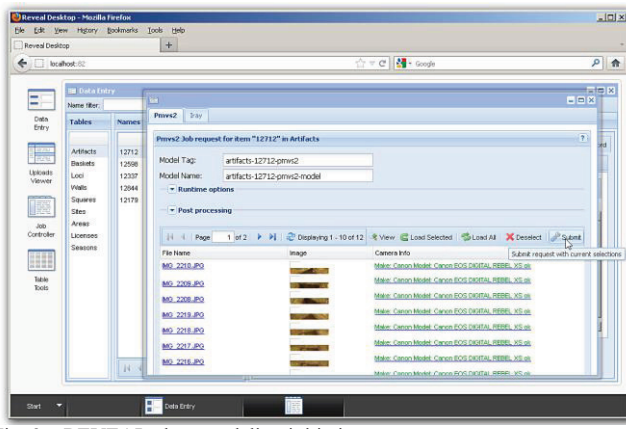

Fig. 3 – REVEAL photomodeling initiation screen.

Fig. 4 – General layout of the REVEAL Analyzer screen.

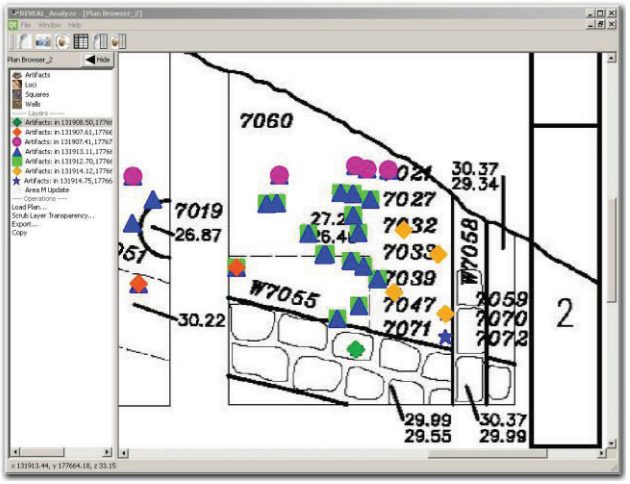

Fig. 5 – REVEAL georeferenced plan with artifact distributions.

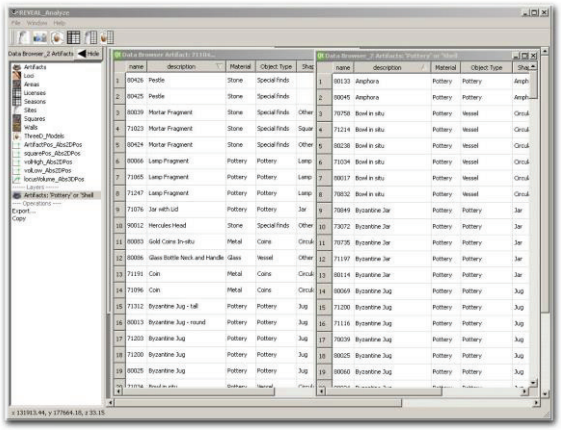

Fig. 6 – REVEAL tabular data.

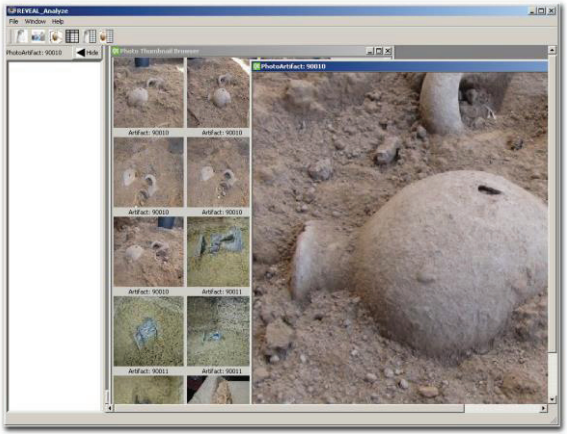

Fig. 7 – REVEAL photo browser window.

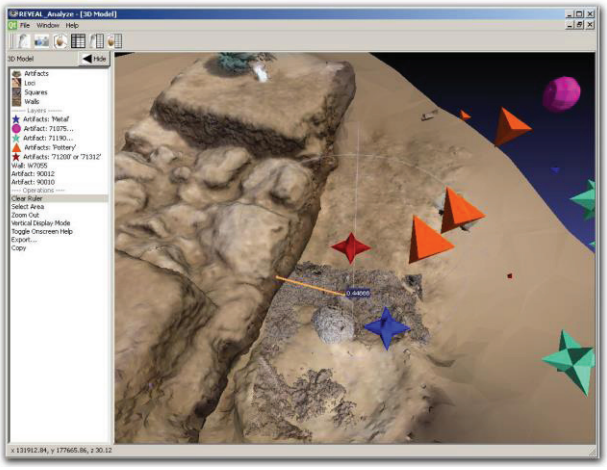

Fig. 8 – REVEAL virtual reality 3D model browser window with 3D artifact distributions

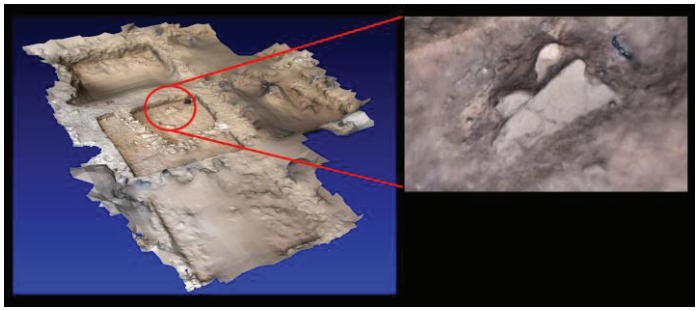

Fig. 9 – Tel es-Safi photomodels of trenches and features using REVEAL.

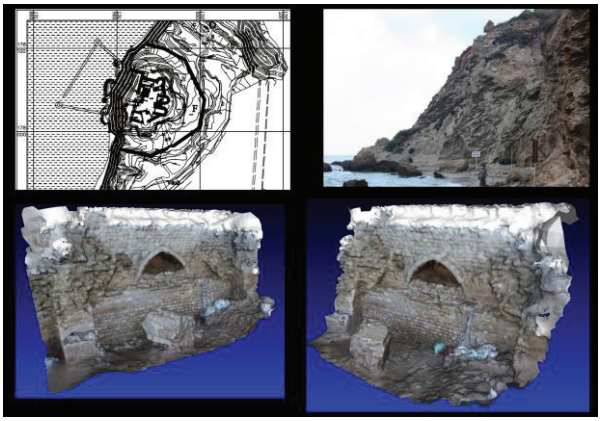

Fig. 10 – Apollonia-Arsuf photomodeling cliff-side remains.

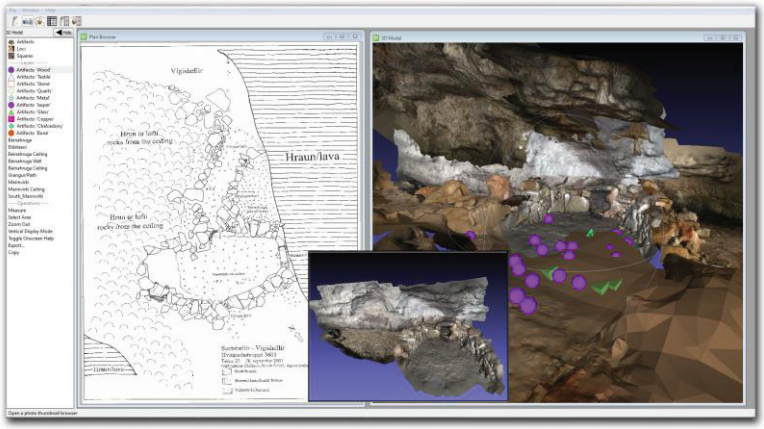

Fig. 11 – Using REVEAL inside the Surtshellir lava tube; preliminary 3D model results.

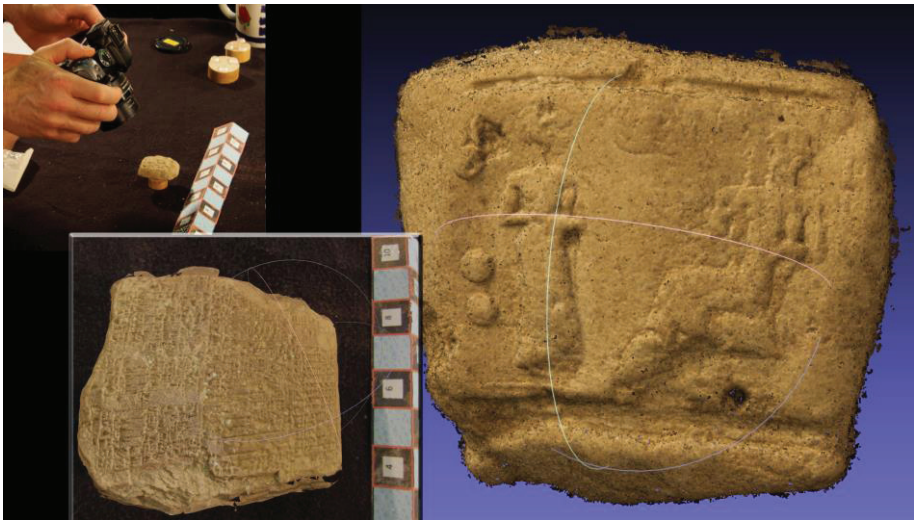

Fig. 12 – Photomodeling cuneiform tablets with REVEAL at Cornell.

Fig. 13 – One possible future for archaeological fieldwork documentation.

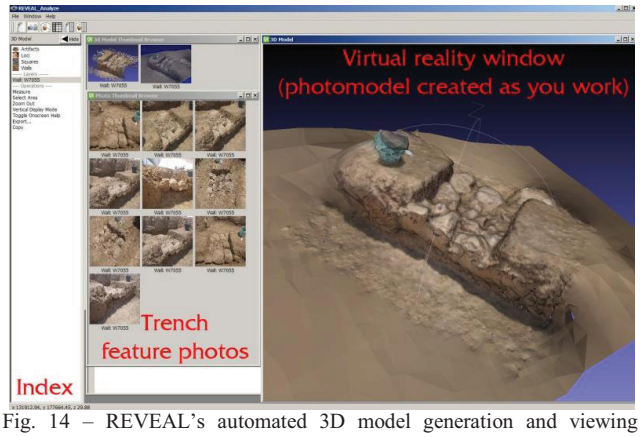

Fig. 14 – REVEAL's automated 3D model generation and viewing window.

Fig. 15 – REVEAL's collocated object models within a larger trench model.

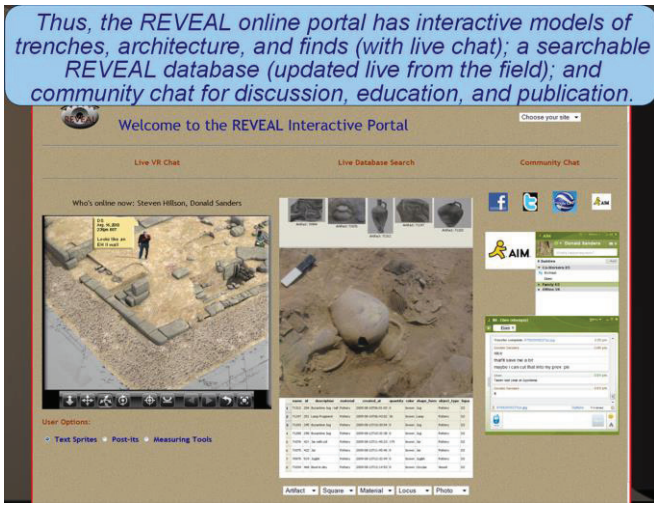

Fig. 16 – REVEAL future online interactive globally accessible site portal.