# Enabling Archaeological Hypothesis Testing in Real Time using the REVEAL Documentation and Display System

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***Abstract***

*This paper focuses on a system that can ensure that excavations are indeed fully documented and that the record is accurate. REVEAL is a single piece of software that coordinates all data types used at excavations with semi-automated tools that in turn can ease the process of documenting sites, trenches and objects, of recording excavation progress, of researching and analyzing the collected evidence, and even of creating 3D models and virtual worlds. Search and retrieval, and thus testing hypotheses against the excavated material happens in real time, as the excavation proceeds. That is the important advance.*

***Keywords*:** *VIRTUAL REALITY, AUTOMATED 3D MODELING, DATABASES, EXCAVATION TOOLS, DATA INTEGRATION, GEOLOCATED IMAGES, SITE RECORDING, EXCAVATION DOCUMENTATION*

## I. INTRODUCTION

From my field experience as a dirt archaeologist, I understand traditional excavation methods and how frustrating it can be to ensure that everything is being noted properly, dug efficiently, and that inferences about the evidence allow for a successful interpretation of the site's history. Therefore, any automated computer-based documentation and analysis tools would seem beneficial. They can be more accurate and cost effective, saving time and ensuring that all finds and their context are appropriately and thoroughly recorded.

I also admit that cool software tools and fancy hardware can create new problems and headaches. But if designed properly, with safeguards in place, 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 excavations are managed and evidence disseminated.

As I made my transition from dirt archaeologist to virtual heritage practitioner, I discovered that interactive 3D computer models permit more innovative inquiries than are possible when using traditional 2D paper-based media (Figure 1; SANDERS 2008). Afterall, the past happened in 3D, so that is the way it should be studied. Only then can we accurately envision historic places and events.

But, projects like these assume excavations have already happened and that the virtual environments that re-create the past are using a complete record of the excavated evidence and that the data are correct.

This paper focuses on a system that can ensure that excavations are indeed fully documented and that the record is accurate. We call our initiative REVEAL (**R**econstruction and **E**xploratory **V**isualization: **E**ngineering meets **A**rchaeo**L**ogy*)*. It is a new collaborative project between the Institute for the Visualization of History, Brown University's Division of Engineering, Laboratory for Man/Machine Systems, and the University of North Carolina's Department of Electrical and Computer Engineering.

Those are questionable assumptions.

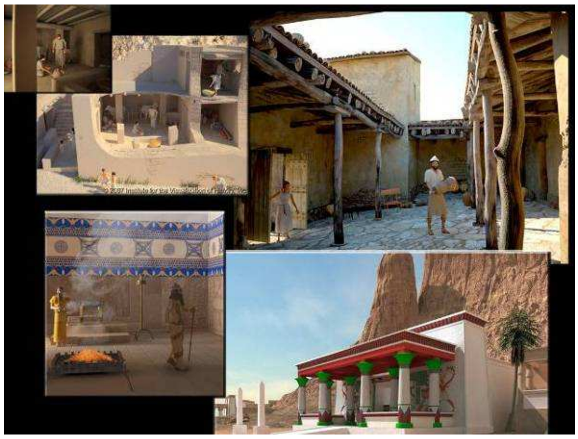

*Figure 1. Montage of sample project renderings from Learning Sites, Inc. and the Institute for the Visualization of History, Inc.; directed by Donald H. Sanders.*

There have been many computer-based data collection systems for archaeology; many databases, many digital archives, and many digital publications for the discipline. REVEAL is special, because it is a single piece of software that coordinates all data types with semi-automated tools that in turn can ease the process of documenting sites, trenches and objects, of recording excavation progress, of researching and analyzing the collected evidence, and even of creating 3D models and virtual worlds. Search and retrieval, and thus testing hypotheses against the excavated material happens in real time, as the excavation proceeds. That is an important advance.

## II. CURRENT ARCHAEOLOGICAL METHODS

One of the key problems in archaeology is trying to accurately locate things like trenches, walls, and artifacts in 3D space. Traditionally, archaeologists describe their finds, manually take measurements, and use hand-drawn sketches and occasional photographs to record the contexts of artifacts, strata, and architectural features. This methodology suffers from inaccuracy, inconsistent terminology, transcription errors, and just taking too long. Some things are not recorded at all because their significance is not recognized until too late.

Other issues for field teams include noting what was found, who found it, what are the find's characteristics, figuring out how all this data should be organized, and how other researchers can assimilate all this information. Understanding the meaning, context, and function of an object evolves over time as it is examined and categorized, which often involves multiple specialists each of whom may submit data in different formats. The standard collocation methods do not effectively allow hypothesis testing on all the excavated data in real time; nor allow for planning field strategies while the dig is underway. Normally, we have to wait until all the evidence has been collected, analyzed, and synthesized--that often takes years and is unfair to our colleagues.

Has the transition to digital acquisition technologies improved the situation? We now have the choice of laser scans, LIDAR, digital photography, databases, CAD, GIS, GPS, total stations, and even smartphones with high-res cameras and custom apps that can be tailored for use during excavations.

Using total stations and related equipment to survey a site is time consuming, only those points that were considered important at the time are recorded, and the points are hard to collate with the rest of the datasets from the site. GIS is superlative for 2D spatial data, but not so useful as a general purpose data exploration tool, and generally has poor integration with interactive 3D visualizations. Harris Matrix tools focus on displaying stratigraphic sequences, with little integration with other datatypes. Custom site-specific databases are uneven in the comprehensiveness of their features and cannot be easily generalized to other excavations.

What site directors really need is a complete package that keeps things digital from acquisition to publication, integrates all data types, and can be used across different excavations with minimal modification. The goal would be to ease recording and recall for researchers of all backgrounds. That is exactly what we set out to do.

## III. REVEAL

REVEAL is a four-year US National Science Foundation-funded project. We are currently nearing the grant's midway point. Our consortium is creating an all-digital toolkit for acquiring, coordinating, and presenting archaeological data in a way that streamlines the excavation documentation process, supports and enhances understanding of the data, and allows for many output formats. REVEAL leverages three aspects of information technology: computer vision algorithms to speed up or replace manual imaging tasks; computer automation tools to speed up data entry tasks; and integrated 2D and 3D media resources to enhance comprehension and dissemination.

More specifically, our goals are to enable real-time hypothesis testing during excavation by improving data acquisition through automation, including zero-additional-cost geo-located position recording; 3D model generation from photographs; and full integration of all other user data, from laser scans to chemical analyses (GALOR ET AL. 2009). REVEAL has a single common repository for all data about an excavation, 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 located 3D models of excavated remains. This means that from any single data type there is, via context-sensitive menus, direct access to and display of all other related datasets. REVEAL can also export data and query results in a number of file formats. Thus, REVEAL combines multiple modes of input, a back-end database, and a sophisticated user interface.

The alpha version of REVEAL, used on-site last summer, tested low-frame-rate continuous video to capture the entire excavation process, allowing the users to "roll-back" and replay the excavation to determine exactly where and when an artifact or wall was discovered. To solve issues of occlusion, multiple cameras were mounted around the trenches to record from many viewpoints. However, the cameras lacked sufficient resolution for locating small finds, and positioning them around the excavation so their cables did not get in anyone's way proved difficult. We concluded that this process was not worth the effort and expense.

*Figure 2. Photos of the REVEAL I camera and scaffolding arrangement from the 2009 alpha tests.*

In addition, REVEAL I used multiple high-resolution still cameras placed surrounding trenches to photograph finds as they were uncovered, to provide data for 3D reconstructions of the area, and to enable detailed analysis and measurements from any angle (Figure 2). The photography and its automated processing were combined with more traditional form-based object recording into a database whose entries are linked to the digital images. Based on last summer's tests, the REVEAL interface, image input methods, and automated tools were redesigned.

REVEAL II, our current pre-beta version, is programmed for acquiring and analyzing highly integrated tabular data, plan views, photographs, and 3D models. It is being field tested at archaeological sites in Israel this summer. We have significantly reduced the equipment cost and enhanced flexibility by replacing the fixed still and video camera array with a single handheld digital camera and a specific picture-taking process. We trade off simplified hardware for more complex software challenges.

The REVEAL user interface allows direct, multiple window access to drawings, photos (stills and videos, whether taken on site or via satellite or from scans), 3D models (of objects, trenches, and reconstructions, including GIS, point cloud, and laser scan data), and any text about the site and its finds.

The following screen shots of some sample queries will demonstrate a bit of the power and flexibility of the system. The explanations will focus on the query and hypothesis-testing side of REVEAL, assuming that the front-end database forms are being filled out while a (hypothetical) excavation progresses.

REVEAL's screen consists of a side panel (for adding to or changing elements in the display); the main display space, and various context-sensitive pull-down menus (Figure 3). All data types and visualization methods are always available and linked from all other interface and image modes. Users can choose from a set various display preferences, such as, selecting the size and color of icons, the zoom depth for resolving dense clusters of objects, or the transparency and order of stacked images. User navigation methods and menu options are consistent across all screens.

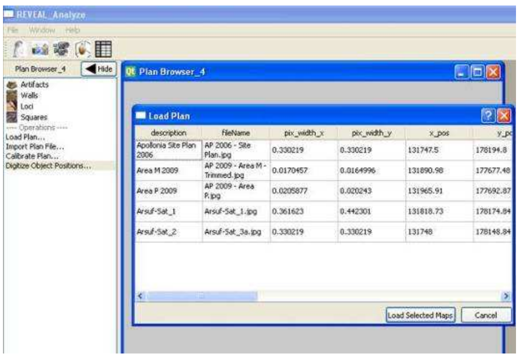


*Figure 3. Screen grab of REVEAL showing the main panels and selection options from the plan browser.*

The easiest way to get oriented is to click on the plan icon, which opens the plan browser window and a list of available top-down images of the excavation (in this case, the Crusader castle at Apollonia-Arsuf, Israel; Figure 3). After selecting (for example, the site plan and a satellite photo), top-down images display as a series of automatically geo-referenced stacked layers and can include site plans, satellite images, trench plans, or any similar top view of a location. Layers can be sorted, and there is a transparency slider to aid understanding of superimposed images (Figure 4).

Suppose we want to study the distribution of artifacts in relation to the architecture in a particular trench. Clicking on the Load Plan operation brings back the list of available top views; Area M is selected, which is added to the stack. The *Zoom to This Plan* feature in the fly-out menu focuses the plan browser on the selected image (Figure 5). Images in the stack can still be sorted here or their transparency changed so that different aspects of each view can be seen.

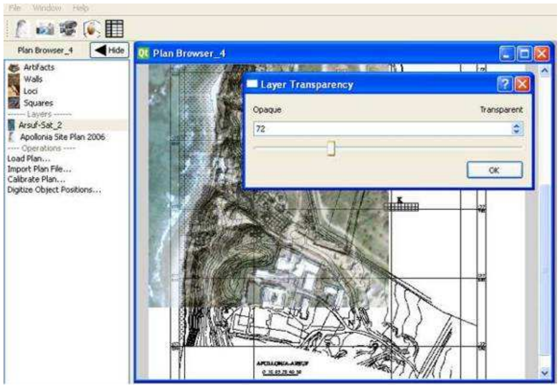


*Figure 4. Screen grab of REVEAL showing stacked site plan and satellite views of the castle site and the transparency slider.*

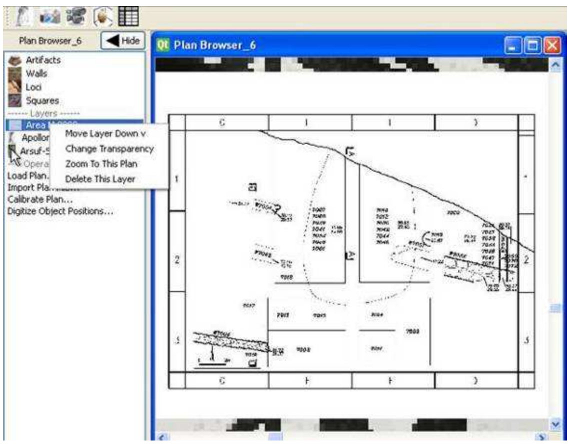


*Figure 5. Sreen grab of REVEAL showing the plan browser focused on Area M in the stack and showing the flyout menu options for this top image.*

What pottery was found in association with the walls in Area M? To graphically visualize the answer to that question, open the Artifacts filter (from the menu at the left) and choose Pottery from the material list (Figure 6).

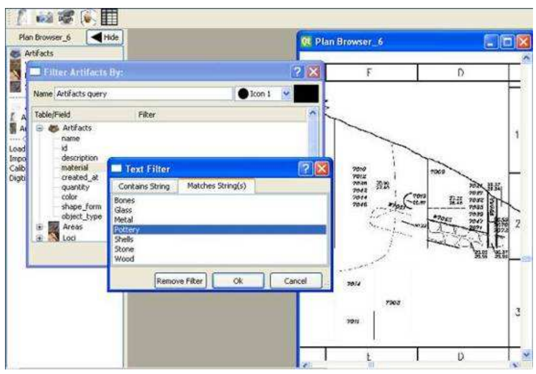


*Figure 6. Screen grab of REVEAL showing the selection of pottery artifacts*

The type, color, and size of the icon used to represent the selected artifacts can be customized by the user (in this case, red triangles; Figure 7).

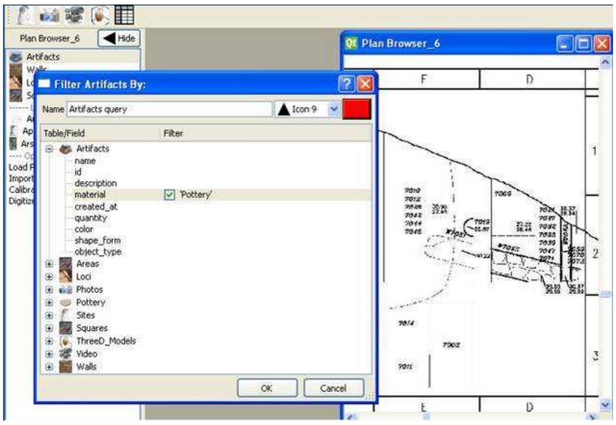

*Figure 7. Screen grab from REVEAL showing the choice of icon shape and color.*

The interface knows that Area M is already open, so the chosen artifacts are displayed on the plan (Figure 8). In the plan browser, hovering the cursor over each icon brings up a flyout that shows the object ID, material, color, type, and locus for the artifact represented by that icon; clicking on the icon pops up a menu with further options on how to view the object and what other media are available for that selected object.

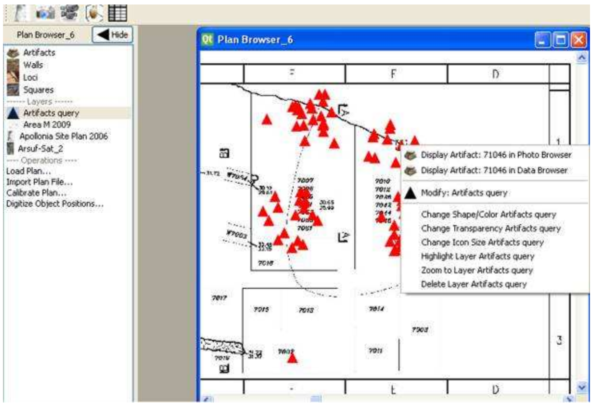

*Figure 8. Screen grab of REVEAL showing the distribution of pottery in Area M, in the chosen icon shape and color, as well as the flyout menu resulting from hovering the cursor over an artifact icon.*

To study how metal objects array with the pottery, the selection process is repeated and a different icon shape and color are chosen. These types of queries can be repeated as many times as relevant to the research. Drawing a bounding box around a group of objects generates a flyout showing related options (Figure 9). For example, selecting to look at photos of these objects opens the photo browser which displays thumbnails of the selected group. Clicking on any thumbnail pulls up the high-res image of that object in a window that is zoomable (Figure 10).

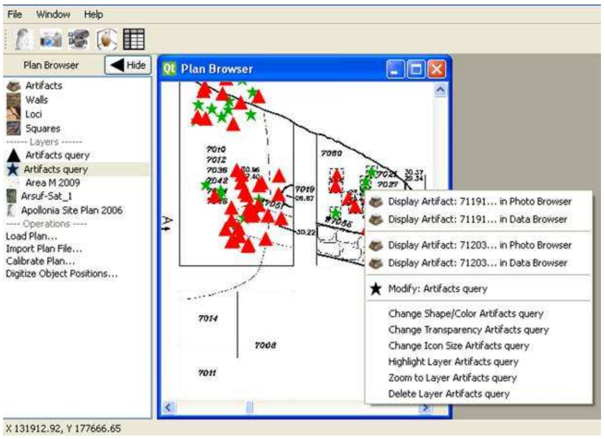

*Figure 9. Screen grab of REVEAL showing the flyout menu generated from a group of selected icons.*

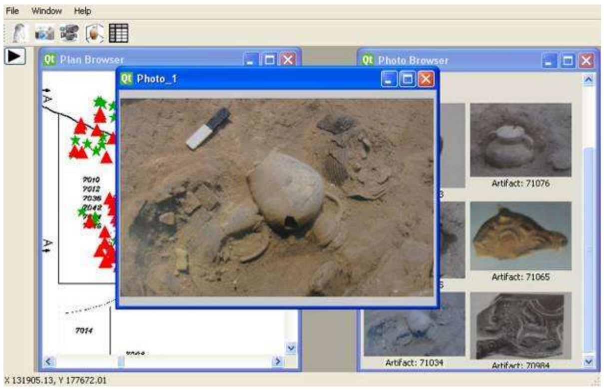

*Figure 10. Screen grab of REVEAL showing the photo browser and a high-res image of a selected thumbnail.*

Returning to the same group of highlighted objects, the artifacts can instead be studied in a data browser. Each of the fields in the data browser can be sorted and the individual artifacts can be compared by as many different fields as there are in the database (preselected characteristics display here, but a wide variety of categories can be viewed as needed simply by clicking in an object's row; Figure 11).

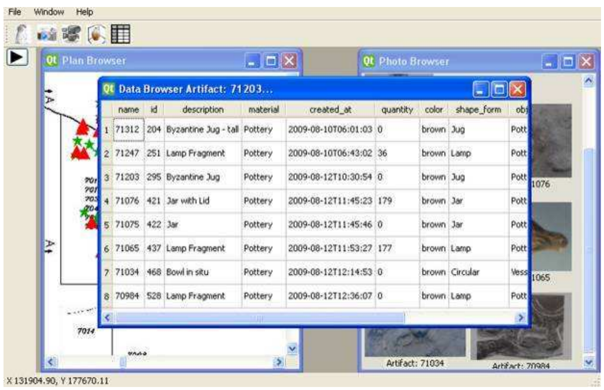

*Figure 11. Screen grab of REVEAL showing the data browser.*

As before, clicking on any object brings up a flyout indicating which other media are available for that object, such as the photo browser or the plan browser, demonstrating that any type of information is directly available from any one of the display options.

Further, multiple data browsers can be open simultaneously so that researchers can compare groups of objects and their characteristics and context information. Any query made on an object in the data browser can, also, display on the plan.

However, plans are too limiting; excavated evidence should really be studied in 3D. REVEAL also has a 3D model browser. This can be accessed by selecting the 3D model icon, then, for example, chosing the name of the excavation square in which the preselected group of artifacts is located. This sequence brings up a window displaying thumbnails of available 3D models. Clicking on the thumbnail brings up an interactive 3D browser in which the model can be rotated and zoomed. Researchers can now more fully understand the group of selectede artifacts by seeing them in a 3D spatial distribution of their excavated contexts (Figure 12).

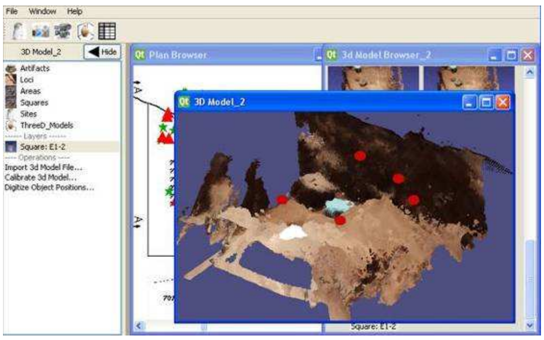


*Figure 12. Screen grab of REVEAL showing the selected group of artifacts displayed in a 3D model of the trench in which they were found (a bit difficult to read the 3Dishness of the model in this image, however).*

A key feature of REVEAL is its ability to automatically generate accurate 3D models of trenches and in-situ artifacts as the dig progresses with just standard digital camera photographs. REVEAL archaeologists take lots of overlapping photographs to create a chain of images that have sufficient information for a Scale Invariant Feature Transform (or SIFT) algorithm. REVEAL then automatically locates the photos relative to each other. By strategically including patterned markers in the shots and using feature extraction, camera calibration, and position algorithms, REVEAL can locate any object and feature in the photos in real-world coordinates.

REVEAL includes the ability to extract accurate and precise measurements from the 3D models to augment or replace traditional measurement methods. The 3D model interface can also import externally created 3D models. Such models can then be geo-located and used in conjunction with the rest of the REVEAL data to examine an archaeological site in great detail. Soon, it will include an automated fragment re-assembly application for creating 3D models of reconstructed pots from sherd photographs, which will then be extended to handle virtual reassembling of wall fragments, based on inferences about architectural features.

When REVEAL is used during an excavation, with photos and database information input as the dig proceeds, it is not difficult to imagine how easy it becomes to ask new types of questions about the excavated evidence in real time while the dig ensues, thus enhancing the field team's ability to grasp the significance of daily activities in each trench and more effectively plan excavation strategies accordingly.

## IV. CONCLUSION

REVEAL will provide a new level of timely and comprehensive exploration of excavation data. It provides the ability to visualize relationships among related artifacts found at different times and to take additional measurements, both during and after excavation, from 3D models of in-situ finds. The user interface reinforces the uniquely flexible data integration, enabling precise contextual examination of data in the field, providing unprecedented analysis detail and support for daily excavation decisions. Powerful tools for post-excavation analysis and publication are welcome byproducts of the system. These features are combined with strong search and filtering capabilities, flexible data export to external applications, and an extensible architecture designed for adding new functionality. By providing all of an excavation's datasets in a single interface, REVEAL encourages real-time hypothesis testing as the dig ensues; while also providing advantages for use across multiple sites.

Thus, REVEAL offers a more complete, coordinated, and accurate solution to excavation data gathering, site documentation, and research querying in comparison to current methods that employ hand-written field notebooks or standalone computer databases, conventional hand-drawn 2D plans or CAD files, or reliance on occasional photographs and other non-geolocated or non-linked image sets. When seen in combination with REVEAL's ability to automatically build geo-located 3D models, semi-automatically reassemble artifacts from fragments, and infer architectural features from minimal remains, archaeologists can appreciate the dramatically new and potentially paradigm-shifting nature of the package. To be able to see in detail what happened at an excavation last year, last week, or even just three hours ago in a fully textured, virtual re-creation, and to be able to query all the recovered data in real time, frees the field team to test hypotheses about the evidence in unprecedented fashion.

Future REVEAL releases will be even bolder. We envision a potential scenario whereby the full package becomes a series of linked smartphone apps using the device's camera and data input features. Photos, videos, data descriptions, automated virtual world generation, and automated artifact reassembly and architecture reconstruction will occur in the cloud. There will be global access to the data for real-time querying as the evidence comes out of the ground. Instant feedback from colleagues around the world using social networking tools, wikis, and virtual memos posted inside the virtual models of the excavation progress and reconstructions will enable timely shifts in excavation strategies, comprehensive analyses of the newly uncovered material, and innovative querying on an unprecedented level of detail so that we can begin to truly understand cultural change, spatial function, and even ancient behaviors.

The study of the past need not be constrained by the technology of the past.

## ACKNOWLEDGEMENTS

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