Archaeological Data Visualization in VR: Analysis of Lamp Finds at the Great Temple of Petra, a Case Study

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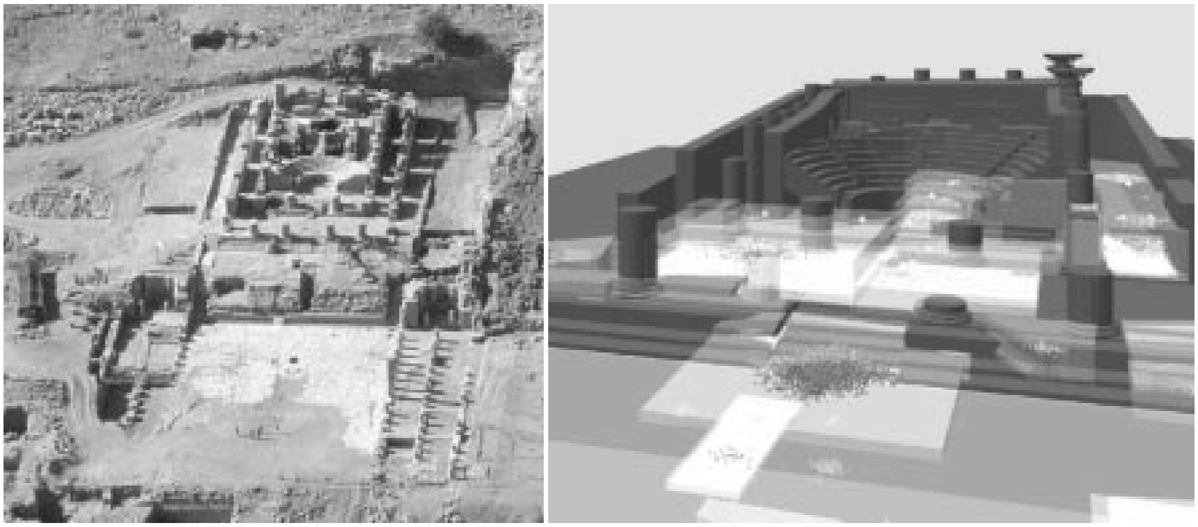

Figure 1: From real to virtual: Our system provides archaeology researchers access to excavation data within a virtual reality environment. Left: The Great Temple site [3] at Petra, Jordan is the source of our data and models. Right: Snapshot from the system showing the temple model with several trenches and with artifact information.

Abstract

We present the results of an evaluation of the ARCHAVE system, an immersive virtual reality environment for archaeological research. ARCHAVE is implemented in a Cave. The evaluation studied researchers analyzing lamp and coin finds throughout the excavation trenches at the Petra Great Temple site in Jordan. Experienced archaeologists used our system to study excavation data, confirming existing hypotheses and postulating new theories they had not been able to discover without the system. ARCHAVE provided access to the excavation database, and researchers were able to examine the data in the context of a life-size representation of the present day architectural ruins of the temple. They also had access to a miniature model for site-wide analysis. Because users quickly became comfortable with the interface, they concentrated their efforts on examining the data being retrieved and displayed. The immersive VR visualization of the recovered information gave them the opportunity to explore it in a new and dynamic way and, in several cases, enabled them to make discoveries that opened new lines of investigation about the excavation.

CR Categories: I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Virtual Reality; J.2 [Physical Sciences and Engineering]: Archaeology; I.3.6 [Computer Graphics]: Methodology and Techniques—Interaction Techniques; I.5.2 [Information Interfaces and Presentation]: User Interfaces—Evaluation/Methodology;

Keywords: Scientific Visualization, Archaeological Data Analysis, Immersive Virtual Reality Interfaces

1 Introduction

Archaeologists base the analysis of data from an excavation site on the physical descriptions recorded in trench reports, site plans, drawings, and photographs (Figure 1 left). Although these sources include three-dimensional information, current methodology in archaeology does not typically allow researchers to take full advantage of it. One of the main tasks researchers have to face is understanding the complex spatial relationships existing between the artifacts, the architecture, and the stratigraphy from the site. These provide crucial clues in comprehending how a particular site was used, when it was abandoned, or what activities were taking place in it [2].

In this spirit, we created the ARCHAVE system (Figure 1 right), to evaluate the hypothesis that providing archaeologists with an immersive virtual reality system to analyze spatial data, together with artifact attributes, will allow them to realize more of the potential of their data. It will also help generate evidence to establish new hypotheses and to evaluate existing ones [9]. The term *Virtual Archaeology* refers to the use of virtual reality for archaeological research [6]. Indeed, although archaeologists are not often the originators of new visualization tools, they extensively use such tools and can have an important role as users in driving the development of novel approaches [7].

In this study, we focused on a specific analysis task posed by several archaeologists involved with the Great Temple site excavations in Petra [3]: the isolation and cross-comparison of lamp and coin

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Figure 2: User in the ARCHAVE system querying the database for pottery finds and visualizing several other artifact types

finds in the various excavated regions of the site. Two experienced archaeologists used the system to analyze these data. Both have been studying different aspects of the excavation for several years; one of them specializes in ancient lamp analysis. They used the system together, which allowed them to discuss observations about the site and the artifacts.

In the following sections we will first briefly describe the research plan we followed in developing the system. We will then present the implementation of the ARCHAVE system and how it evolved based on feedback from users. After that we will examine the process we followed to evaluate our system. Finally we will present the results of an experiment with the two archaeologists and discuss lessons we have learned through this testing process.

1.1 Our Research Plan

The development of ARCHAVE began in November, 1999 and was completed after several developmental phases:

- Petra Great Temple team archaeologists defined specific problems that required three-dimensional visualization and interaction techniques to solve.
- A realistic representation of the Great Temple site and excavated debris was generated to provide a context for visualizing specific artifact data variables such as *in situ* location, artifact typology, and cultural period.
- We tested different visual representations of the data with the team archaeologists. During this process we changed the physical articulation of the artifacts so that they could be visualized in clusters in their find locations throughout the seventeen test trenches. We also tested and modified color, luminosity, and texture used to articulate the data in the cave so that it could be easily recognized in relation to other site information.
- We built several graphical user interfaces to facilitate data access and interaction and for navigating the site (Figure 2).

The process described above was iterative and required us to work closely with the archaeologists slated to use the system for research and analysis. It was significant that they helped us define the initial visualization problem but were also able to guide system development through consistent testing. In developing the system, we wanted to create new visualization and interaction techniques adequate for this specific application. In addition, by evaluating its usefulness in its final field of application [1], and identifying some of the characteristics of typical user interaction, we hoped to define techniques that could also be used in other applications.

2 The Implementation

The ARCHAVE system currently runs in an 8x8x8 foot Cave-like immersive environment with four display surfaces, three walls and the floor. While wearing a pair of LCD shutter glasses, users see stereo imagery and have the illusion of being immersed in the virtual model. The graphics system calculates stereo imagery in synchrony with the glasses. These also have an attached tracker that relays their position and orientation to the computer. With that information, the graphics system can display the virtual environment so that it appears stationary to the user moving through it.

A three-dimensional model of the *in situ* architectural ruins from the Petra Great Temple excavations was used as a context for our experiment. Within this context we integrated realistic models of the excavated trenches as combinations of trench layers with approximately 5-30 layers per trench. Each layer looks like an irregular box and represents a unit of sediment unearthed from a specific area within a trench.

The surviving architectural ruins were initially rendered realistically with image maps from photographs taken on site. However, the rich detail provided by such a rendering tended to be visually distracting for users trying to focus on artifact information inside the trenches. Specific shapes, colors, and textures used to represent architectural remains, artifact type and cultural origin greatly affect the ability of the researchers to perceive anomalies and find patterns among data being visualized [5]. To allow users to concentrate on artifact finds, we eliminated textures from the architectural ruins and rendered them as dark gray. In contrast to the base model we selected fairly saturated colors with high lightness values for the artifact data types residing in the trench layers.

To navigate in the environment, users carry a wand and wear a tracked pinch glove to query the database site information. A standard database of artifact finds has been consistently updated since excavations began in 1993, and it can be queried in real time from the virtual environment. Users can interactively select different artifact types to visualize in specified trenches. Data types represented in the experiment are summarized here:

- *In situ* architecture: architectural evidence surviving from the remains of the Great Temple (Figure 1 left). It is represented with a dark gray color to contrast with trench and artifact evidence.
- Excavation trenches: volume of debris excavated in each area (Figure 3 top). Trenches are divided into layers.
- Excavation layers: important to understand sediment patterns and for keeping track of where artifacts were found inside a given trench.
- Bulk finds: objects that are eroded, damaged, or otherwise indistinguishable as individual objects. Examples of this type of finds are pottery fragments, metal pieces, stones, or bones. They are visualized as small geometries and are color-coded depending upon the artifact type.
- Special finds: they represent the most significant finds because they are usually in excellent condition and generally provide more specific evidence about their origin and use. This type of finds include lamps and coins, which are visualized as simple geometries such as tetrahedra and hexagonal prisms respectively, but are larger than life size in order to allow users to identify them in relation to the bulk finds, represented by smaller geometries. In addition, special finds are color coded to reflect their cultural origin, for example Nabataean, Roman, Byzantine, and Islamic.

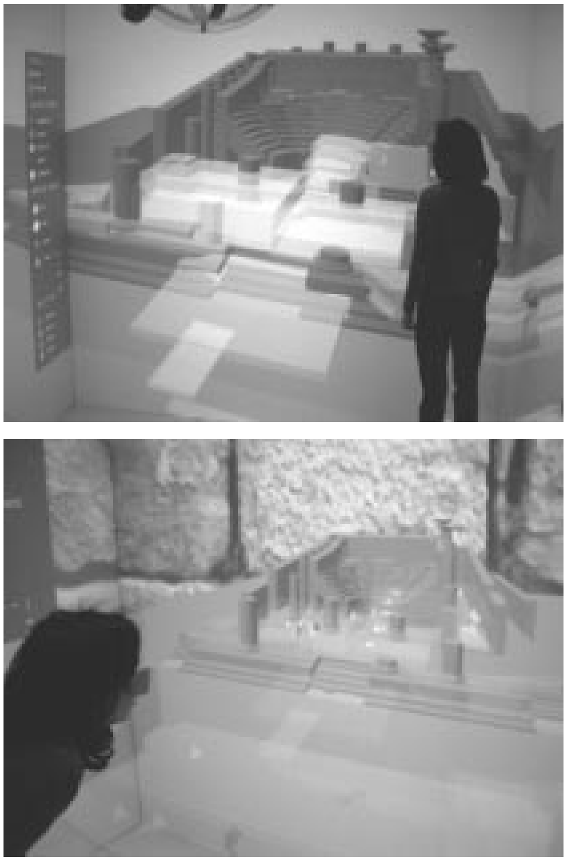

Figure 3: The ARCHAVE system in use. Top: full scale model. Bottom: miniature model.

2.1 Interaction Tools

While observing archaeologists using the system we realized that they consistently needed an easily accessible overview of the model, much like the experience they obtain by flying high up over the virtual model, so they could study how the different artifacts were distributed over the entire site. The Petra Great Temple site is the size of three football fields. Therefore, we created a miniature version [4] of the full-scale model that users can bring up at any point for reference and navigation. This miniature model is stationary relative to the walls of the cave and acts like a three-dimensional map. In addition to this navigation/exploration aid, we created a virtual room where the full scale site model is not visible. In this room users can access a two-dimensional site plan projected on the floor or the miniature version to discuss aspects of the site without having to focus on the full scale model. As they discover areas they want to investigate, they can be automatically transferred by choosing an area on the miniature model (Figure 3 bottom).

During investigation of the site, users can perform a variety of queries to the site database. Results are displayed as 3D geometries that represent different artifact types, which are stored and retrieved from the database on a per-excavation-layer basis (Figure 4). In this way we maintain a visual hierarchy that makes the information easier to understand.

3 Testing the System

In order to evaluate the ARCHAVE system we wanted archaeologists to try solve a problem that is currently difficult, if not impossible, to solve without the system's help. Since the beginning of excavations it has been difficult to analyze lamp finds in the context of the site, since team archaeologists do not have easy access to their three-dimensional find locations. Also, because there is a considerable dynamic among the lamps found on site, and in their relationship to other finds, it is a significant step forward for archaeologists to be able to trace these relationships in three dimensions. Therefore, we tested two team archaeologists on their ability to analyze significant characteristics of lamp finds using ARCHAVE and compared these findings to those derived from on-site observations and from database-based findings.

The two team archaeologists have worked on the Petra Great Temple site since the beginning of excavations. One specializes in the analysis of lamp finds in Petra and at neighboring ancient sites in Jordan and Israel. The other specializes in analysis of glass finds and, although that data type was not supported in our current visualization, she wanted to see possibilities for correlating the visualized artifacts with her glass data. In the course of the following experiment we encouraged the users to observe the site data from a variety of vantage points in the model and prompted them to explain their observations.

The experiment proceeded as follows:

1. We introduced both archaeologists to the cave environment and the navigation and visualization tools.
2. We asked both to state their current research hypotheses and how they planned to evaluate them.
3. We asked users to query the database for lamp finds in all available trenches, analyze their distribution first on the miniature model, and then attend to their vertical distribution per trench on the full scale model.
4. We asked users to do the same for coin finds.
5. We asked users to do the same for bulk finds.

After each of these tasks (Figure 5) we asked both users to explain if this visualization provided them with new evidence to support their existing hypotheses or if they discovered new possible lines of investigation they would like to follow.

At the end of the test, we asked users a series of questions, and used the two-dimensional map of the site and the miniature model as a reference for discussion:

- What do you want to take away from this experiment to help with your research?
- If you found evidence today to support some theories you already had, what evidence, if any, did you have before to evaluate those theories?
- Could you give an specific example of a research task that you would rather perform with ARCHAVE than with traditional methods?
- Could you give an specific example of a research task that you would rather perform with traditional methods than with ARCHAVE in its current state?
- Do you have new hypotheses about the data you have seen? How could you have developed these new ideas with traditional methods?

3.1 Test Results

The archaeologists used the ability to visualize the data in three-dimensions in the immersive virtual environment in order to understand the site and the excavated data better [8]. They achieved this by navigating in the site with existing architectural remains (Figure 5), by examining specific trenches and trench layers that they were not previously familiar with and had not personally excavated, and by examining artifact finds in this context in various combinations. They also attempted to synthesize some of their new

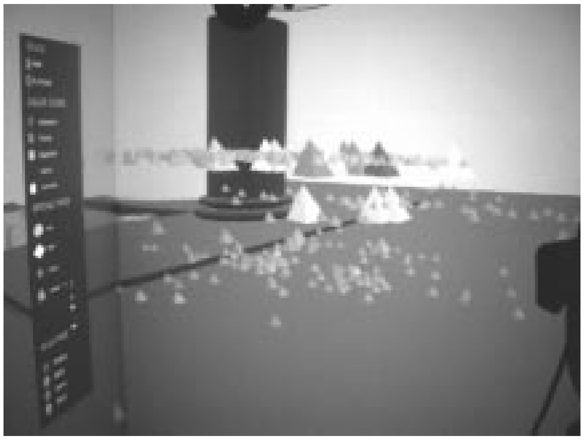

Figure 4: The artifacts are retrieved layer by layer, and visualized so that the layering is preserved.

observations with earlier on-site analysis of specific features. For example, our lamp specialist derived several observations in looking at the central stair region which did not agree with her on-site observations while excavating the trench in 1996. She commented that it would be an incredibly complex and time-consuming process to make this same observation using the traditional method. In short, she would have to derive reports on every object in the trench from the database of finds and relate those objects with a model of the trench and layers from excavator and surveyor notes.

One of the advantages of this process is that it allows a user to solve specific problems. However it also allows them to make general observations about the entire dataset and find anomalies they were not specifically looking for. For example, using this method the lamp specialist was able to identify a few areas of mixed deposit that had not been formerly identified. This finding is significant because it confirms archaeologists' longstanding suspicions about the various sedimentary levels within the site and brings into question their ability to trust earlier on-site findings. Areas of mixed deposit are those areas where objects from different cultural periods are found together in the same stratigraphic level. The system allowed her to confirm a site wide trend and to provide evidence for this finding that could not have previously been evaluated.

In addition to these general observations the lamp specialist had specific questions about the lamp finds she had been attempting to analyze with traditional approaches. Through a query of lamp finds with coin and bulk finds, she was able to isolate a cache of Byzantine lamps in a trench of the western aisle, which indicated that there may have been habitation in that area during the Byzantine occupation. It would have taken her months to come to these preliminary conclusions using traditional methods of analysis in areas of the site she is not readily familiar with.

4 Summary and Conclusion

We have described a virtual reality application for archaeological analysis and presented a case study of its use. The development of our application was driven by a specific archaeological problem: the analysis of lamp and coin finds at the Great Temple of Petra site in Jordan.

We built a geometric model of the site and of the trenches used to excavate it and populated that model with visual representations of the artifacts that had been unearthed. The user interface permitted navigation using models at varied scales and of differing types. Each of these navigation strategies proved useful in different contexts.

Archaeologists using the system were able to synthesize findings, test hypotheses, and pinpoint anomalies. They reported that ARCHAVE allowed them to understand on-site findings well and explore excavated areas they were not previously familiar with. But perhaps most striking, they were able to formulate new hypotheses based on connections they made that would have been virtually impossible to make using traditional analysis methodologies. In particular, those connections tended to pull together information from disparate parts of the site. This supports our belief that access to site data in its 3D context can greatly facilitate archaeological analysis and that immersive virtual reality is a natural way to provide that context.

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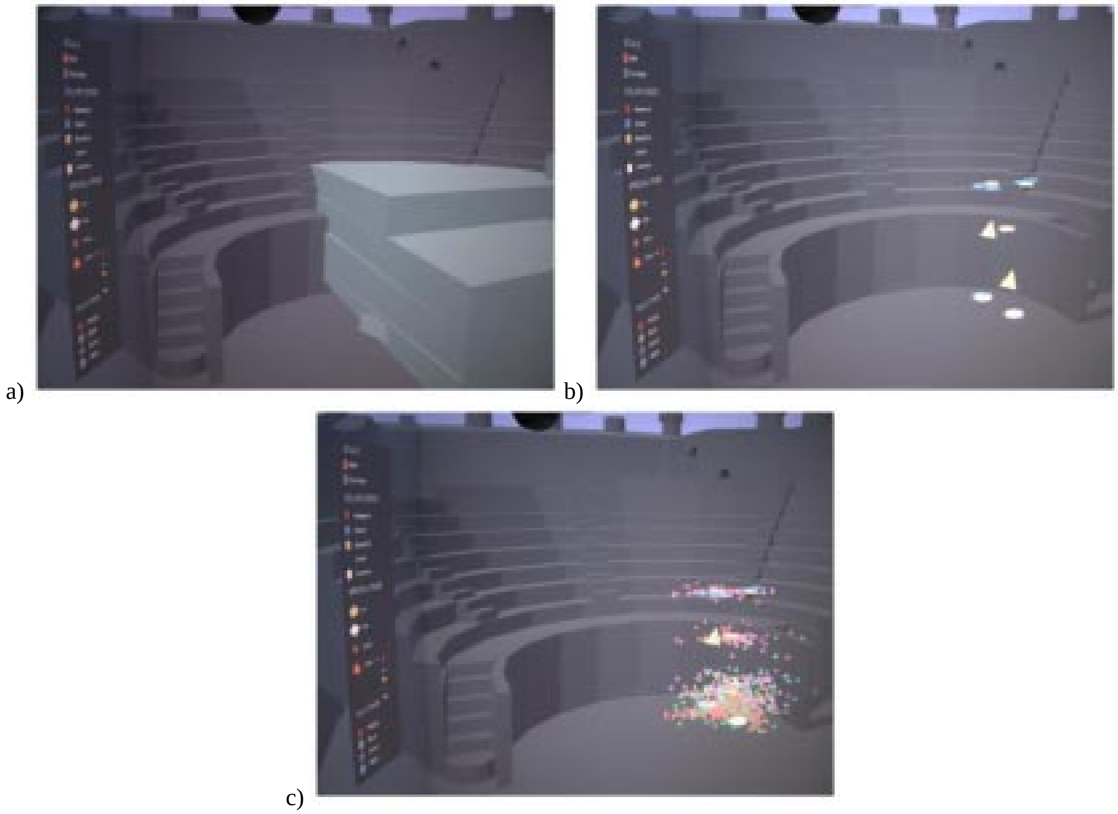

Figure 5: Images of an immersive virtual environment for analyzing an archaeological excavation database. a) Excavation layers in an area of the archaeological site, b) important artifacts in the locations where they were found, and c) multiple artifact types can be visualized at the same time.

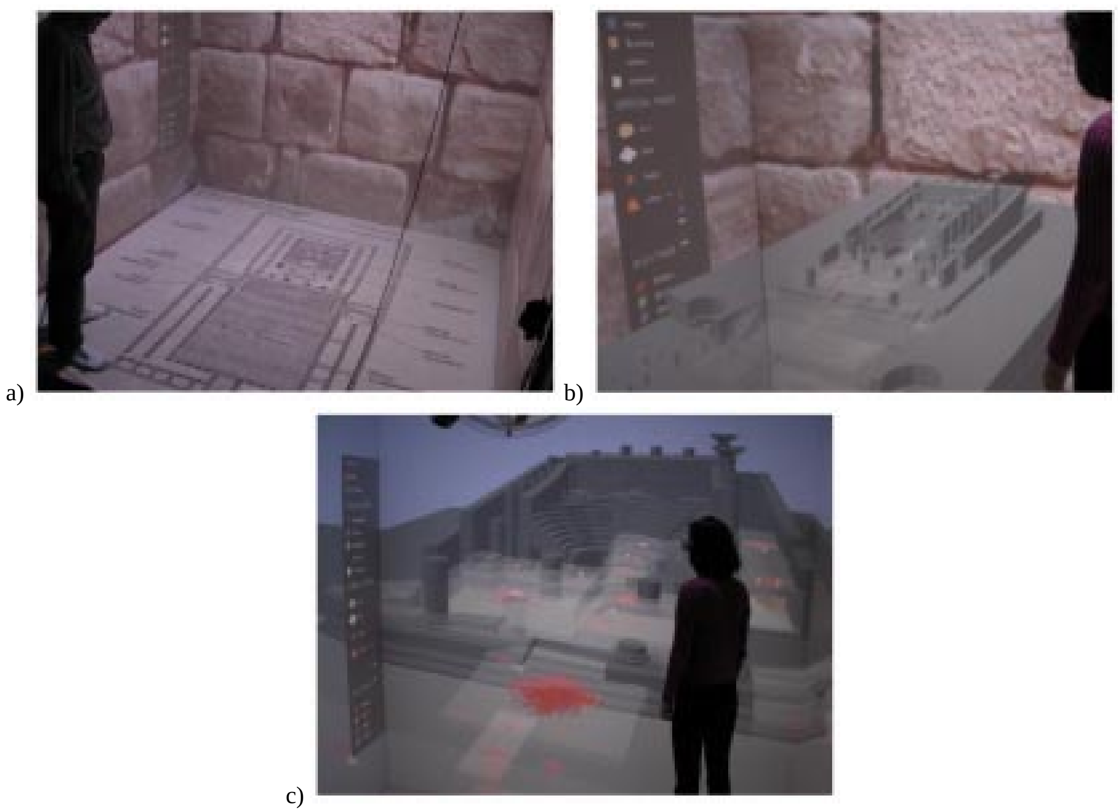

Figure 6: Archaeologists can navigate the data in three scales, which provides them with different levels of abstraction. This allows them to easily access specific regions while keeping a broader context for the information. a) 2D map, b) miniature model, and c) full size model.