Immersive Archaeology

Todd Ogle and Rick Skarbez
Virginia Tech

{jogle, rskarbez}@vt.edu

Abstract

We propose a system which integrates a high-fidelity immersive virtual environment based on ground-truth 3D scanning data from archaeological sites augmented with ethnohistoric data in the form of archival records, photos, models of artifacts, prior publications and reports, etc. for in virtuo *analysis of corroborating evidence and the results of fieldwork. The post-excavation analysis phase is typically the most time-consuming aspect of the archaeology process. The proposed Immersive Archaeology System would primarily contribute to this post-excavation phase, connecting to and drawing together potentially relevant ethnohistoric data from archival stores that can be rapidly identified and presented to the archaeologist for analysis and interpretation of a site and its artifacts. This in turn could enable more reflexive archaeological practices wherein both field- and lab-based scientists are in close and regular collaboration via the immersive environment. Additional benefits of the adoption a system could include the development of curated virtual environments that could be employed in K-20 learning environments to engage learners in the analytical component of archaeology.*

1 Introduction and justification

Archaeology is the study of human history and prehistory through the excavation of sites and the analysis of artifacts and other physical remains. Through the process of excavation, dig sites are disturbed to the point that reconstruction is impossible. The field archaeologist is privileged to the moment of discovery, and though the detailed and precise documentation of the process provides much data that can inform interpretation, the experience of seeing artifacts and physical remains within their original context is forever lost in the process of excavation. Digital reconstruction is, however, not only possible but has become fairly commonplace. At the same time archival research is a well-established practice that is made more powerful by access to digital records of documents, photographs, recordings, records, and 3D models of objects.

Typically the most time-consuming phase of the archaeology process, the post-excavation analysis, can consume many months and sometimes years of work. The proposed Immersive Archaeology System would enable a more streamlined workflow in this post-excavation phase of research, identifying and presenting potentially relevant data from a variety of sources (contemporaneous documentation from the excavation, including photographs, field notes, etc.; historical documentation; GIS data; etc.) *in the context* of the ground-truth 3D reconstruction of the dig site. This is the crucial component of our proposed system; digital reconstruction of archaeological sites and artifacts is not a novel idea, and even presenting these digital dig sites using immersive technology has been explored [1] [2] [8] [11]. However, the archaeologist typically has to abandon the virtual dig in order to seek corroborating information, in the form of field notes, sketches, books, articles, and the like—sources that are often 2D and analog. We believe that bringing these sources into the virtual dig site will yield not just more efficiency, but new and greater insight.

Given the potential gains to be made, we believe that this is a problem domain uniquely well-suited for the use of immersive virtual reality (IVR). As mentioned above, 3D scanning (LIDAR, photogrammetry, computer vision, etc.) is increasingly used in archaeology, enabling the rapid creation of high-quality 3D models of both dig sites and individual artifacts. Similarly, the introduction of mass-market head-worn displays (HWDs), such as the Oculus Rift and the HTC Vive, is serving to drive quality improvements in these devices while simultaneously making them cost-effective for real-world use. To us, it seems that these technologies are naturally symbiotic.

2 3D Reconstruction + IVR + Analytics: More than the sum of its parts

The proposed system would marry a high-fidelity 3D digital reconstruction of a dig site (and, ideally, not simply a single scan, but a model produced from multiple scans showing how the excavation evolved over time—in effect, a

4D reconstruction of the excavation) with immersive technologies for display of and interaction with this virtual dig site. This presents the archaeologist (who may or may not have been present at the physical dig) with a unique opportunity. As discussed above, historically, only the field archaeologist on the site has the opportunity to experience the dig in situ, with all of the context intact. In the system we propose, an archaeologist in the lab has the opportunity to view the site, with all its context intact, *in virtuo*.

It seems to us that this is already sufficient justification for using IVR in the archaeology domain. That said, once analysis is being performed in the digital domain, many other productive avenues open up as well. As mentioned above, scanning is commonly used not just at dig sites, but for producing 3D models of individual artifacts. In our proposed system, artifact models can be viewed and manipulated in 3D, and the original artifact can remain safely preserved. In addition, assuming the digital research products (3D models, digital photos, field notes, etc.) are appropriately stored and labeled, these can all be "hyperlinked" from the model of the dig site. So an archaeologist performing analysis in the lab setting can "pick up" an artifact from the virtual dig, and immediately have access to all the digital research products associated with that artifact. She can view and manipulate a 3D model of the artifact, see high-resolution digital photos of the artifact, and read the field archaeologist's notes regarding the discovery of the artifact, without ever leaving the immersive virtual environment (IVE).

In addition, one could imagine this tool being able to "hyperlink" not just to one's own database of objects, artifacts and evidence, but to the vast array of supporting material available in archives on the Internet. For example, software "helpers" could be provided that enable the archaeologist to search LexisNexis for contemporaneous newspaper articles referring to an event under investigation, or to search museum collections for other artifacts from the same period and region as the ones under investigation, or simply to use Google to get a map of the dig site. These tasks and tools are examples of analytics, "the science of analytical reasoning," applied to assist the archaeologist in both analysis and interpretation.

In short, we propose to combine 3D scanning and reconstruction, immersive virtual reality, and analytics in order to enable a new workflow for archaeological research.

3 The Process, Illustrated

Figures 1 through 4 present several stages of the proposed work process, culminating in a shared IVE used for education, illustrating also the software "helpers" that can be used to view additional details and corroborating evidence regarding some aspect of the dig.

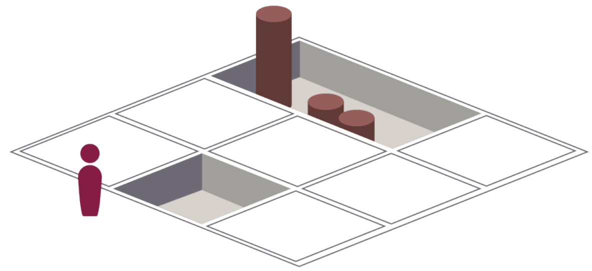

Figure 1. Conventional archaeological fieldwork, with an archaeologist physically present at the excavation site.

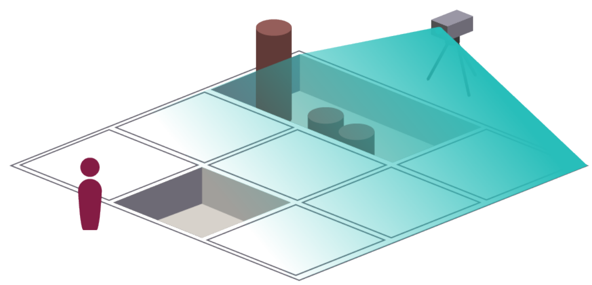

Figure 2. Conventional fieldwork, with the addition of 3D scanning (LIDAR, photogrammetry, etc.) to document the ongoing excavation.

4 Components of the proposed system

In Section 2, we presented a high-level description of the technologies we propose to combine in this system. Here, we discuss the key components of the system: 3D Scanning, 3D Reconstruction, Immersive Virtual Reality, Analytics, and Best Practices.

4.1 3D scanning

We propose to be agnostic regarding the source of 3D scan data: airborne LIDAR, ground-based LIDAR, photogrammetry, computer vision, etc. (Forte presents an excellent comparison of the strengths and weaknesses of some of these systems in [6].)

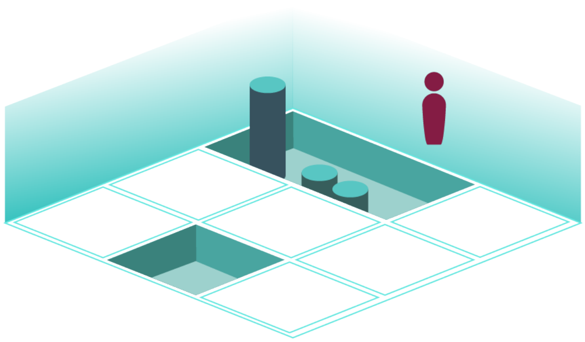

Figure 3. An archaeologist viewing an immersive virtual reconstruction of the excavation at a particular stage, made possible via the 3D scanning illustrated in Figure 2.

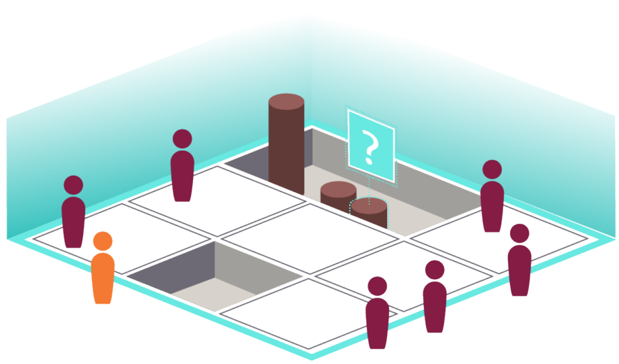

Figure 4. Immersive archaeology applied to an educational setting. Note that the instructor is able to "query" a particular artifact in order to bring up additional information about it, possibly including high-resolution photographs, 3D scans, field notes, corroborating evidence from the Internet, etc.

4.2 3D reconstruction

Per Forte, "Post-processing, archiving, accessibility and migration of digital models are always the bottleneck of any digital archaeological research" [7]. To mitigate the post-processing problem, we propose to directly visualize the point clouds, rather than reconstructing a 3D mesh from the data. This has the beneficial side effect of preserving the fine spatial details in the scanned data, which can be lost in the meshing process.

Rather than developing tools from scratch, we intend to adopt and build upon the Point Cloud Library (PCL), an open-source library that already implements numerous state-of-the-art algorithms for point cloud processing.

4.3 Immersive virtual reality (IVR)

As discussed above, IVR technologies, and particularly head-worn displays such as the HTC Vive and Oculus Rift, are rapidly increasing in quality and decreasing in cost. We expect that such systems will be the most common way to interact with these data and tools in IVR. However, it would be preferable if this system could be deployed in other immersive systems, such as CAVEs or CAVE-like systems [5], and also that users who do not have access to IVR systems can interact with these data. To that end, we propose to implement our system using the open-source Vrui toolkit [10].

4.4 Analytics

(Immersive) analytics can be defined as the science of analytical reasoning facilitated by (immersive) human-computer interfaces. Pirolli and Card identify two main subtasks of an analytical reasoning task: foraging (i.e. gathering information) and sensemaking (i.e. developing hypotheses) [12]. We expect that in this system, the sensemaking will be performed by the archaeologist. However, there are a variety of ways computer assistance could be productively applied to foraging tasks. For example, Keel describes "Transformation Agents" (roughly equivalent to what we've referred to as "helpers") that propose new information to the analyst based on various heuristics [9].

4.5 Best practices

Perhaps the most important piece of our proposed Immersive Archaeology System is not actually a technological component at all, but a sociological one. In order for this system to deliver the proposed benefits, archaeologists will need to incorporate regular 3D scanning into their excavation process. This is not impossible, as Forte describes a system that has become "robust and consistent" after several seasons of fieldwork, and provides guidance in this respect [6]. In addition, field and laboratory staff should, whenever possible, record information digitally, as described in [3]. This would enable the "hyperlinking" of information described above. Finally, the proposed system will only achieve its fullest potential if these digital data can be shared and searched for among multiple researchers, sites, and labs.

We propose to work together with archaeologists in order to derive a specific set of best practices that enable capturing, archiving, and sharing of archaeological information.

5 Computer Science Research Agenda

We propose to undertake this work in the spirit of the computer scientist as toolsmith [4], with the primary goal of producing tools that will enable archaeologists to make new discoveries that we cannot begin to anticipate. That said, there is clearly interesting computer science research that must be undertaken as well, if we are to achieve this goal. This work falls broadly into two categories: user interface techniques for such an immersive workspace, and techniques for working with point cloud data.

5.1 New user interaction techniques

- How best to enable searching from inside the VE?
- How to display/interact with "constellations" of data objects regarding a single artifact or feature?
- How to display/interact with multiple layers of geometry in a time sequence (i.e., you have 3D scans of every layer of stratigraphy on a site, how to make the user aware of how many layers there are and how to navigate them)
- How to navigate within a point cloud? (Real-walking is generally best for spatial navigation, but how should it work when you don't have a flat ground plane? Also, some/many users will likely want to work in a "deskVR" [13] configuration, which suggests the need for another travel technique.)

5.2 Working with point clouds

- How can point cloud data be rendered efficiently with maximum perceptual fidelity?
- Is it possible to automate the "tying up" of multiple point clouds? Or, if not, can we develop a suitable user-guided semi-automatic process?
- How to render multiple layers of point cloud data (such as from stratigraphy scans)?
- How to deal with multiple scans of the same location with varying resolution? (For example, consider the case where one has an aerial scan of a site, a ground-level scan of the site, a scan of a single pit, and a scan of a single artifact?)
- Is it possible to enable physical interactions with a point cloud? (i.e. can an immersed user stand on the "ground"?)

6 Proposed Development Roadmap

Projecting software development forward over a five year period, the following features would be incorporated as the versions progress:

- Version 0.1 focuses on the question, "Can we rapidly reconstruct a dig site based on ground truth data (visualizing dense point clouds with as little post processing as possible) in such a way that you can see what artifacts were discovered in their proper location/orientation/depth while maintaining archaeologist control of that data and its processing?"
- Version 1.0 incorporates the hyperlinking to existing resources that YOU have in your database (photos, scans of artifacts, etc.).
- Version 2.0 integrates the ability to corroborate your data with extent data (machine assisted identification of potentially related materials from someone else's holdings/data/archive if they are available online).
- Version 3.0 rolls the affordances of the previous versions into a set of educational tools, and adds a crowdsourcing/citizen science component.

7 Sustainability Plan

In order to continue development as well as maintain the software so that an international user base could employ it, a consortium model is proposed. The model would have the following features:

- Member institutions (education, museum, library, archive or other government agency, private and industry members)
- Annual membership fees would support management and development team: tiered membership options from access-only to voting rights, to developer time
- Annual meeting/conference for idea sharing and development planning

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