ArtifactVis2: Managing real-time archaeological data in immersive 3D environments

Neil G. Smith
King Abdullah University
of Science And Technology
neil.smith@kaust.edu.sa

Kyle Knabb
Connor DeFanti
Philip Weber
Jurgen Schulze
Andrew Prudhomme

Falko Kuester
Thomas E. Levy
Thomas A. DeFanti
University of California, San Diego
tdefanti@soe.ucsd.edu

Abstract— In this paper, we present a stereoscopic research and training environment for archaeologists called ArtifactVis2. This application enables the management and visualization of diverse types of cultural datasets within a collaborative virtual 3D system. The archaeologist is fully immersed in a large-scale visualization of on-going excavations. Massive 3D datasets are seamlessly rendered in real-time with field recorded GIS data, 3D artifact scans and digital photography. Dynamic content can be visualized and cultural analytics can be performed on archaeological datasets collected through a rigorous digital archaeological methodology. The virtual collaborative environment provides a menu driven query system and the ability to annotate, markup, measure, and manipulate any of the datasets. These features enable researchers to re-experience and analyze the minute details of an archaeological site's excavation. It enhances their visual capacity to recognize deep patterns and structures and perceive changes and reoccurrences. As a complement and development from previous work in the field of 3D immersive archaeological environments, ArtifactVis2 provides a GIS based immersive environment that taps directly into archaeological datasets to investigate cultural and historical issues of ancient societies and cultural heritage in ways not possible before.

Keywords—Spherical photogrammetry, archaeology, cultural heritage, panorama, scientific visualization, virtual reality computational science, structure-from-motion, LiDAR, geographic information systems (GIS)

I. INTRODUCTION

Archaeology plays a unique role in the social sciences to peel back time to understand ancient societies that may have never been written about or remain little understood. Archaeology is data-driven, and only through grounded theory, rigorous data collection methodologies, and analysis can new information be extracted to understand ancient cultures. Moreover, the spatio-temporal nature of archaeological data is ideally suited for three-dimensional scientific visualization and visual analytics, and for the investigation of the cultural and historical nature of ancient societies. The application of scientific visualization opens the possibility for new objective methods of analysis to be performed at a breadth and scale not foreseeable before the invention of super computers, mathematical programming languages, and 3D immersive environments.

Fig. 1. ArtifactVis2 showing Khirbat al-Iraq excavations' datasets and menu system (see Fig. 11 for map of excavation location). The architecture and floors are rendered using dense point clouds from the combination of SfM (ca. 6 million points) and LiDAR (ca. 20 million points). The grey polyhedrons represent rough measurements of various walls made during excavations. The 3d symbols and models depict various types of artifacts recorded during excavations.

Over the last twenty years, the convergence of archaeology and computer graphics has produced photorealistic 3D visualizations of archaeological sites. Although these visualizations allow one to catch a glimpse of how an archaeological site may have once looked, they represent a single interpretation and do not facilitate analytical study. Several archaeologists [7, 10, 11, 15, 23] have argued that there must be a paradigmatic shift away from these static photorealistic 'reconstructions' and towards interactive, collaborative, and immersive environments with massive datasets that are dynamic, raw, complex and distributed globally. The reconstruction of the past 'as it was' is not possible, but one can construct models or simulations of the past that reflect multiple interpretations based on numerous variables that explain their occurrence within a system with measurable degrees of statistical relevance or goodness-of-fit [7]. Rather than presenting one model of the past, the goal of archaeological visualization should be to develop a virtual system in which multiple models can be simulated, analyzed and collaboratively shared with several users. Visualization serves to connect researchers with these datasets in a virtual environment where information can be adequately shared, analyzed and novel scientific breakthroughs can be made. This

Fig. 2. Aerial Map of Southern Edom research area, depicting the sharp elevation change between the lowlands and highlands of Ancient Edom. Sites excavated or sounded by the ELRAP/L2HE projects and accessible through ArtifactVis2 are labeled (Map data: Google, Digital Globe 2012, LandSat7)

is a new branch of computational science that enables archaeologists to study the complex systems of past human behavior, culture and society from massive amounts of digitized empirical data from archaeological excavation, survey, and conservation.

In this paper, we present ArtifactVis2, an immersive stereoscopic research and training environment that embeds the archaeologist in a visualization of full-scale excavations and all the individual artifacts that can be studied from the first day of excavation to the last (Fig. 1). ArtifactVis2 provides a seamless integration of massive 3D datasets (e.g. LiDAR, SfM) dynamically updated in real-time. The GIS-based query system provides a solution for multivariate analyses of archaeological datasets that are co-referenced with the 3D datasets. It is designed to run within broader scientific visualization middle-ware software as a visualization library for computational archaeology. Currently, CalVR serves as the VR framework used by ArtifactVis2 and thus it is fully scalable from the use of a single 3DTV to a fully immersive CAVE environment [9, 25, 27]. ArtifactVis2 enables any researcher to re-experience and analyze the minute details of a site's excavation enhancing their visual capacity to recognize deep patterns and structures, perceive changes and reoccurrences, and visualize massive cultural datasets at once. Its visualization and exploration methods strictly maintain and represent the difference between evidence and hypotheses, creating advanced tools for data annotation, research logs, and comparison of conclusions made by experts so that they may, like the field supervisor, possess first-hand knowledge of the site and pose similar hypothetical tests and simulations. We demonstrate in this paper ArtifactVis2's current application in southern Jordan (Fig. 2).

II. LITERATURE REVIEW

Previous work has sought to integrate archaeological data into 3D immersive environments. The first significant 3D stereoscopic environment developed for archaeology was the ARCHAVE-a four-sided cave environment used for immersing researchers within Brown University's Great Temple excavation project conducted in Petra, Jordan [1]. A 3D model of the temple was constructed from architectural plans and imported into ARCHAVE along with the 3D locations of artifacts found at the site. Beyond being able to navigate through the site, users are able to query the imported datasets and display them within the environment. Although the ARCHAVE project provides access to a database server, it is limited to only several predefined queries. The Visual Interaction Tool for Archaeology (VITA) project first published in 2004 [3, 4, 5] provides an augmented reality 3D environment. The VITA project allows collaborative interaction within the environment using see-through head mounted displays and several interfaces for head and hand tracking. Users can point or grab objects to select them for further analysis or real-time manipulation. The VITA project introduced a 3D modeling pipeline that enables the integration of triangulated and textured models of range scans, site terrain models, video, panoramic photographs, surveyed architectural plans, and geo-spatially located artifact models with textual labels [3, 4]. A major advantage of this system over the ARCHAVE is the ability for multiple users to interact collaboratively and walk through the site without the limited restrictions that would be experienced in a CAVE environment. The work of [12, 17] is focused on the ability to create a more natural tele-immersive 3D collaborative environment for archaeological study. Users interact with a shared archaeological environment even though they are geographically separated. This method for collaborative archaeological work is enhanced with interactive tools to perform Linear and Angular measurements, mark/annotate areas, or select an manipulate an object. In 2010, [16] developed a VR-GIS that optimizes the visual rendering of high poly count geometric models in a 3D archaeological environment. Their system supports path animation of the camera for fly-through's and skeletal animation. Objects loaded into the scene can be manipulated or selected to access associated metadata.

Although the QueryArch3D project was not designed for immersive stereoscopic viewing, it is a highly collaborative archaeological visualization system that enables web-based interactions of archaeological content [2]. This paper provides a novel solution to handling levels of detail (LOD) so that massive triangulated models can be efficiently served and rendered within a web based environment. The Copan archaeological site representing a massive dataset of architectural features and artifacts is used as the main investigation area. Similar to ArtifactVis2, tabular data from the excavations are hosted using a PostgreSQL PostGIS database. The use of a PostGIS database enables QueryArch3D to provide a method to query architectural features and their individual elements with access to their individual documentation and site photographs. However, the PostGIS database in QueryArch3D designed for storage and retrieval of metadata pertaining to only the currently documented architectural features (e.g. buildings, stele), it does not provide a solution for excavation datasets.

Although ArtifactVis2 shares similar goals as previous projects to create a stereoscopic 3D immersive environment with various forms of digital archaeological content, it improves upon past efforts by fully integrating dynamic content and conducting real-time spatial queries on the datasets generated from daily field excavations. Expanding upon the ARCHAVE project, ArtifactVis2 can query dynamic artifact and loci datasets from a full GIS over a distributed network (including in-the-field recording), with potential for expansion into more complex studies and analyses. ArtifactVis2 utilizes a PostGIS similar to QueryArch3D, but is comprehensive handling diverse material assemblages. ArtifactVis2 is a fully scalable system that can be distributed on any computer system (HMD, single 3D screen, CAVE, 2D monitor) and incorporate any current visualization tracker or controller system similar to VITA. Geographically distributed collaborative research is integrated as a core feature of CalVR [8, 9]. Finally, similar to [17]'s work, we present here the ability to annotate, markup, measure and manipulate any dataset within a virtual collaborative environment. As a complement and development from previous work in the field of 3D immersive archaeological environments, ArtifactVis2 provides an organic real-time system that taps directly into archaeological datasets being generated in the field and laboratory. Any project that has gone digital and already using a GIS can visualize and analyze their data through ArtifactVis2.

III. METHODOLOGY

Archaeology is an inherently destructive science necessitating all efforts to be made to adequately record data on the field and store it in an as accurate and comprehensive record as possible. In the past, traditional analog methods of data recording forced archaeologists to have to make judgments on what data was relevant and should be collected/analyzed and what should be discarded. These filters immediately limited the possible outcomes of interpretation and slanted the subsequent interpretation towards the excavator's methodology and the data they chose to preserve. We have introduced a comprehensive set of evolving data
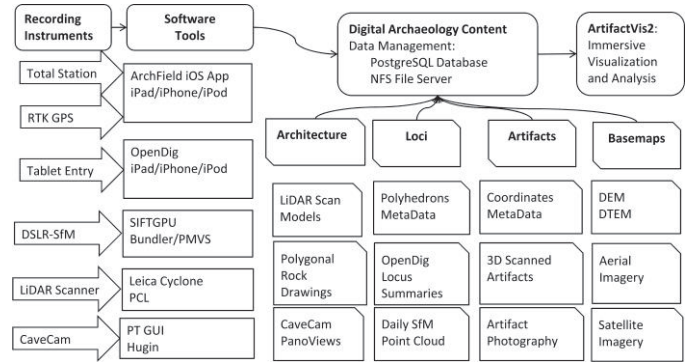

Fig. 3. Flowchart depicting the types of digital archaeological content and the workflow of their acquisition->curation->analysis ->visualization by several recording instruments and open source software tools. ArtifactVis2 serves as the primary analysis and visualization environment in which the generated digital archaeological content can be accessed and studied.

acquisition technologies and rigorous recording methodologies to our archaeological field excavations to resolve this inherent problem in archaeology. This cyber-infrastructure promotes proper curation of the data that integrates data acquisition, analytical tools and dissemination that together comprises what several scholars have called 'Cyber-Archaeology' [11, 12, 18, 21] (Fig. 3). It is through this methodology that it is possible to fully take advantage of our 3D visualization environment for analysis and dissemination.

A. Acquisition and Digital Archaeological Content

At the core of our system is a geographic information system that is capable of storing and organizing all of the spatial location data, related databases, and generated 3D and 2D media with minimal loss of fidelity (see [18,24,26]). This acquisition pipeline provides real-time access of an excavation's generated digital datasets directly into ArtifactVis2.

The current data acquisition instruments integrated into ArtifactVis2's visualization pipeline include Total Stations, RTK GPS units, DSLR Cameras for site photography and Structure-from-Motion, LiDAR Scanners, X-ray fluorescence (XFF), portable FTIR (Fourier Transform Infrared Spectrometry) and aerial photogrammetry (Fig. 3). It is the attention to detail of their recording in the field and the precision of tools used to extract this information that enables us to properly handle the visualization of these datasets in ArtifactVis2 and manage the 'data avalanche' [24]. Although there are proprietary software tools available for processing the data of many of these devices, they are not necessarily designed for incorporation into a cyber-infrastructure or adapted specifically to the needs of archaeological excavation or cultural heritage. Therefore, corresponding to each recording device, our own software tools have been developed to provide full control over the raw data acquired and properly organize it within the information system. By controlling how the data is organized according to their respective digital contents, we are able to generate self-describing data formats that can be immediately accessed for analysis and dissemination in ArtifactVis2. These datasets that are visualized in ArtifactVis2 can be sub-divided into four main groups: basemaps, artifacts, loci, and architecture.
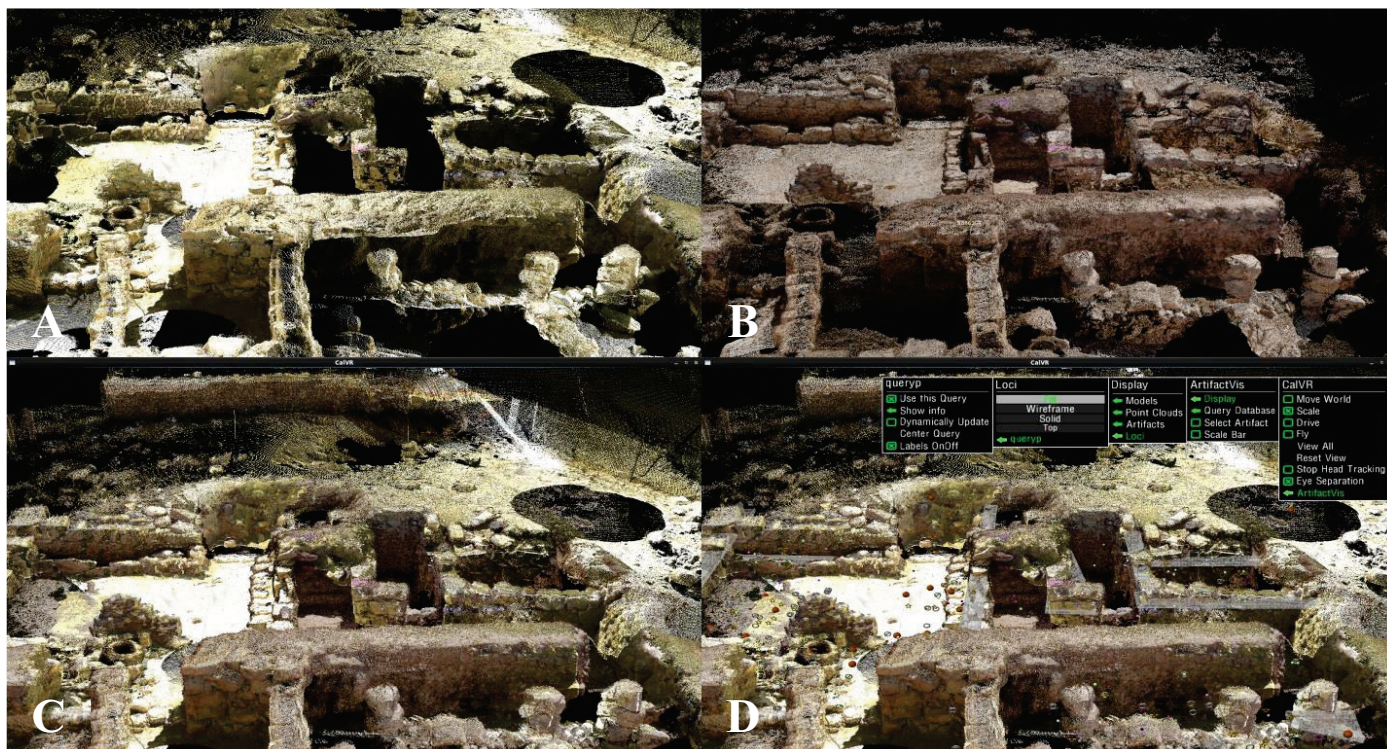
Fig. 4. Screenshots of ArtifactVis2 with combined point cloud models: a) LiDAR scan of KIS; b) SfM scan of KIS; c) SfM geo-referenced to LiDAR scan (note black occluded areas of LiDAR now filled in by SfM); d) LiDAR and SfM point clouds co-referenced with artifacts (radiocarbon samples) and wall loci in their proper spatial position.

1) Basemaps

As a research strategy, data acquisition starts with extensive regional archaeological site surveys. Therefore, prior to excavation, digital acquisition techniques have already been applied to recording multi-period site locations, digital elevation models, contour maps of the region, ground penetrating radar, and geo-referencing of geological, cartographic, aerial and satellite imagery. These various datasets serve as basemaps for ArtifactVis2 and allow the user to study the excavated site in its larger regional context.

2) Artifacts

The artifacts dataset consists of sub-centimeter 3D recordings (x, y, and z) of individual artifact locations. We use a total station or RTK-GPS connected to a data recording program called ArchField to record everything digitally with sub-centimeter precision. ArchField is an open-source solution to archaeologists' digital field recording needs [26]. ArchField functions as the front end for handling all data entry needs during field excavation and connects to PostGIS where the data is stored and then queried for visualization. Since ArchField records data as excavations are on-going, ArtifactVis2 is able to access this data and render it in real-time as it is stored to the server.

All of the significant artifacts are photographed at multiple angles and 3D scanned then imported directly into ArtifactVis2 in their original three-dimensional location. Specialist analyses of the artifacts are digitally recorded during and after excavations. The integration of these rich studies back into the excavation data enriches the complex analyses that are capable within ArtifactVis2 (see [14]).

3) Loci

A three dimensional recording of each locus and all of its contextual metadata is recorded digitally in the field on a daily basis. The contextual metadata inputted in digital locus sheets includes sediment composition, density, types of artifacts, associated features, stratigraphic relationships, and excavation strategies. These data are tied to the unique id assigned to the locus. Later in ArtifactVis2, all of the essential contextual information of the locus, its digital photographs, and polyhedron volume can be linked together using its id.

4) Architecture

The architectural features and immobile installations uncovered during excavations are recorded using LiDAR complemented with Structure-from-Motion (SfM) [see 6, 13, 28]. LiDAR scanning of architectural features allows highly precise captures of the ongoing excavation up to an accuracy of +/- 2 mm. GCP's of LiDAR targets are recorded using a TotalStation so that the resulting point cloud models can be loaded into the same geographic space as the recorded artifacts, loci, and photographs. SfM is employed to supplement the LIDAR scans and provide more frequent capture of locus surfaces and occluded areas inaccessible by LiDAR (Fig. 4). The initial geo-referenced LIDAR point-cloud is used as the reference for all future SfM recordings so that as new scans are produced they can be registered in proper position.

B. Content Curation and Organization

ArtifactVis2 fully integrates PostGIS for organization of incoming data. PostGIS was chosen due to its broad adoption by various GIS applications (e.g. QGIS, GRASS, ArcGIS),
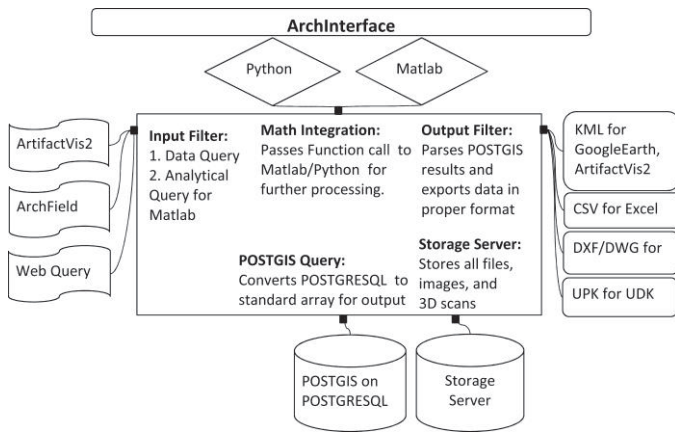
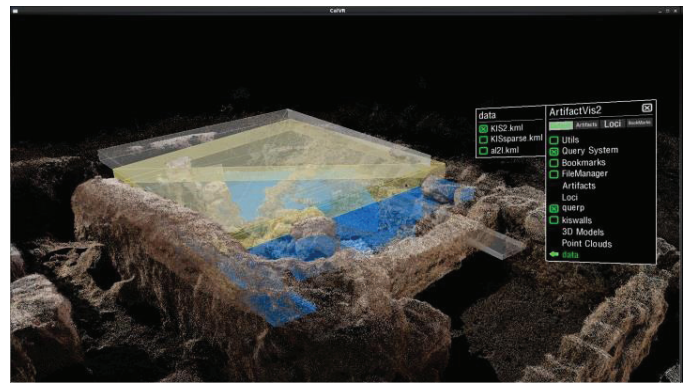Fig. 5. ArchInterface Server Diagram showing input and output systems.

Fig. 6. A query of all loci and reconstructable vessels found in square A2 at KIS. Image shows semi-transparent loci and artifacts in context of SfM point cloud model.

WMS servers (e.g. MapServer, GeoServer) and the Open Source GeoSpatial Foundation (http://www.osgeo.org/). Although all the spatial data is stored in UTM this is not a requirement for other projects, as any projection including custom formats can be stored in PostGIS. The DBMS enables multiple clients using ArtifactVis2 or other software to dynamically access the data during and after excavations. PostGIS provides a long-term solution as ArtifactVis2 evolves integrating new systems and types of data into the spatial database.

1) ArchInterface

Since ArtifactVis2 needs to access, retrieve, and store data on the PostGIS database we created a middle-ware API called ArchInterface (Fig. 5). ArchInterface provides an abstraction layer allowing the user to conduct complex queries and updates to the DBMS without having to manually construct PostgreSQL syntax commands. It runs independently of ArtifactVis2 and can be accessed remotely by other programs or through a command shell. ArchInterface is also built to handle multiple PostGIS servers and sync across them. It automatically configures the PostGIS database on new installs or for newly created tables that require specific predefined schemas. It also has the capability to import or export PostGIS tables when syncing is not possible or the user wants to use the data in another program that currently does not support PostGIS. It functions as the core gateway from which other types of datasets can be retrieved, organized, stored, and translated into other formats.

2) Auto-organizing File System

ArtifactVis2 requires an organized file system in order to automatically load various datasets that may be generated during or after the season's excavations. These datasets include artifact 3D scans, models, point clouds, photographs and geo-referenced digital elevation models. A predefined folder structure was designed around the unique identifier system assigned to each artifact or locus in the PostGIS database. When new data is generated it just need to be copied into this structure for ArtifactVis2 to automatically find it, no manual importing or saving of data locations is required. The updated timestamp of the file is used to notify ArtifactVis2 while it is running that the data has changed and needs to be reloaded. When a specific artifact is selected by the user,

ArtifactVis2 can traverse the organized file system automatically to determine whether a 3D scan, drawn model, or photographs are available for that specific object. If any of these datasets are found, then they are loaded into ArtifactVis2 according to their specific position and orientation. Once new 3D scans or photographs are saved into to the organized file system they will be found automatically by ArtifactVis2 at runtime. This method provides dynamic interaction for the user and allows them to access their data as it may be generated from a different computer on the network.

C. Query System and Analysis

A robust query system is integrated into ArtifactVis2 that allows hypotheses to be tested and semantic relationships to be made across various datasets. At runtime, a dynamic menu system is generated from the currently available tables stored on the PostGIS server. Users use the menu system to traverse each table's unique structure and select the specific columns or data desired for constructing queries. Once the query is generated, ArchInterface is triggered to process the query, translate it into PostgreSQL syntax, handle projection information, and output the results in a KML file format. When ArchInterface completes its task, ArtifactVis2 loads the generated KML to display the results. Similar to how models and images are handled, this allows backward compatibility with other GIS programs that natively read KML. Since the actual queries are conducted by ArchInterface the server database can be located online and is generally not located on the same system running ArtifactVis2.

For each individually returned artifact all of its spatial and metadata information is returned along with specific details on how it should be symbolized within ArtifactVis2. Loci are generated on-the-fly as color coded volumetric polyhedrons. Since elevation measurements for the loci are queried real-time, the polyhedron grows in depth as the locus is excavated. The locus can be dynamically examined including the study of artifacts contained within it at each point in time (Fig. 6).

D. Hardware Platform and Portability

In its current rendition, ArtifactVis2 serves as a visualization system for computational archaeology running on top of CalVR. CalVR is an open source 3D immersive visualization

Fig. 7. ArtifactVis2 running in the Immersive TourCAVE, showing 3D model of Khirbat al-Iraq Shmaliyeh (Jordan) (photo by T. DeFanti; see [22]).

framework, capable of extensively supporting clustered-environments, multi-screen displays, various tracking interfaces, and fully customizable menu system [25]. It integrates OpenSceneGraph (OSG) as its underlying graphics API. CalVR has multi-platform support for Linux, MacOS, and Windows. CalVR is fully scalable from a single 2D screen laptop to fully immersive CAVE environment (see Fig. 7).

The ideal 3D environment is a CAVE system employing a multi-tile display and tracking system. The primary drawback for archaeologists is that these systems are beyond the budget of any anthropology department or archaeological grant. The lowest cost solution for archaeologists wishing to work in a 3D environment is a single 3D display with basic hand and head tracking and single workstation or laptop with decent GPU. A more expensive but complete package is the Z Space which has a built in 1080p Passive 3D display and very precise head and hand tracking. Alternatively a head mounted display could be used such as the Sony HMZ-T2, Epson Moverio BT-100, or Oculus Rift.

E. Real-time visualization and Interactive Environment

1) Measurement, Selection and Manipulation
As an immersive stereoscopic 3D environment, ArtifactVis2 functions in a 1:1 real world scale. Therefore, moving through the site gives real-world feedback on dimensions of architecture and artifacts. Smaller screens or the HMD function like real-world windows that can be peered through and objects can be pulled through the screen. Scale is further inferred through the use of digital meter sticks and measuring tapes. Artifacts, loci, and models can be dynamically selected for 6DOF manipulation or to pull up a window graph displaying all information on each object. Selected artifacts can be organized and placed in specific places to be picked up and studied by other users. When the user completes their study of the artifact it can be reset to its original position and scale. There is no limit to the amount of artifacts selected or amount of annotation windows are left open, which allows
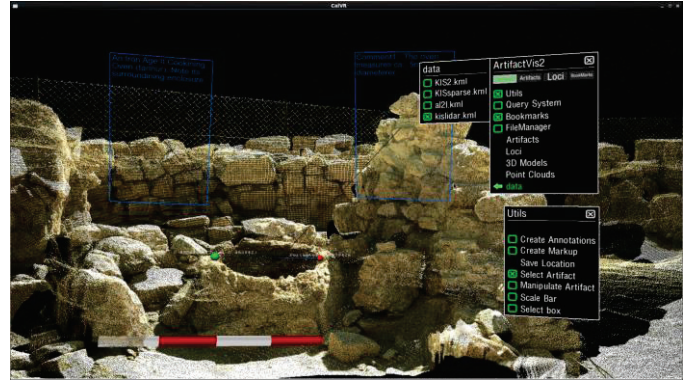

Fig. 8. Screenshot of ArtifactVis2 showing an oven exposed at Khirbat al-Iraq. Annotation windows allow notes to be taken on the oven. Red and white 1 meter scale bar allows proper scale to be determined. Measurement markers (Red and Green spheres) measure diameter of the LiDAR scanned oven.
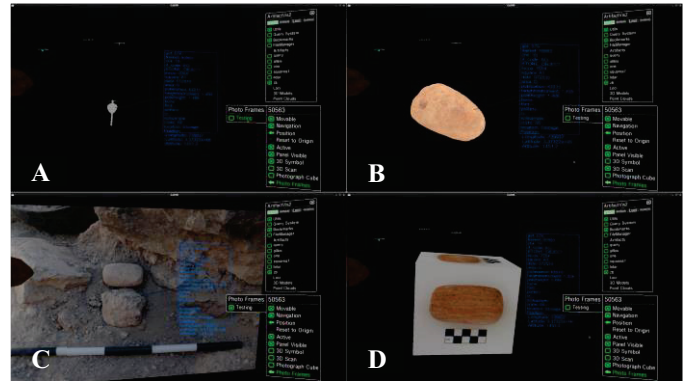

Fig. 9. Selected artifacts can be studied in various ways dependent on available content dynamically loaded into the visualization environment. In this figure, we demonstrate the four different ways of studying an Iron Age stone roller. a) Generic 3D symbol with metadata annotation; b) 3D high polygon count dynamically shaded model; c) *Insitu* artifact photograph; d) Six sided cube, texture mapped with differently angled digital photographs of the artifact.

users to setup a full display of the various visual data they may want to juxtapose and compare (Figs. 8, 9).

2) Markup and Annotation
Users can tag annotation graphs to any area and use markup and highlighting tools (Fig. 8). The markup tool allows users to draw vector lines or polygons around objects or areas for demarcation. Annotation windows are created to tag any object of interest in the Archaeological environment. Annotation windows receive text input from either an attached keyboard or streamed tablet input. Once tagged, the annotation window can be moved in 3D space but remain connected to its tagged object by a vector line. The tools allow the users to fully log their research and share collaboratively their results.

IV. PRELIMINARY STUDY RESULTS

A. Investigation Area
Iron Age II (1000-586BCE) Southern Jordan was chosen as the preliminary investigation area for utilizing ArtifactVis2. This area is known in textual documents during this period as Ancient Edom (Fig. 2). Within the geographic and environmental boundaries of Southern Jordan there are three

Fig. 10. Khirbat al-Iraq-Excavated Iron Age domestic village dating to the 8th-7th C. BCE. Facing North with courtyard in foreground. The site is situated on the edge of Trans-Jordanian plateau known as Edom in antiquity (photograph by N. Smith).

Highly diversified and unique geomorphologic/phyto-geographic areas resulting from the sharp vertical shift in elevation from the Wadi Araba lowland valley to the highland plateau. The close proximity of the lowlands, steppe, and highlands to each other is significant for understanding the trajectory of increasing social complexity in the region of Edom during the Iron Age sequence [19, 20].

After two previous seasons of extensive survey and soundings at various sites on the plateau, Khirbat al-Iraq (KIS; UTM: 739915/3373027) was selected in 2010 for full scale excavation. Due to its excellent preservation it serves as an ideal candidate for digital recording techniques needed for ArtifactVis2. Khirbat al-Iraq is a large domestic Iron Age village located ca. 10 km north of Petra, Wadi Musa. It belongs to a series of Late Iron Age II (800-500 BCE) domestic villages located along the western steppe of the Ash-Showbak region. KIS is located on a limestone outcropping surrounding rich agricultural fields still used today. It is a single period site dating to the Late Iron II (ca. 800-600 BCE). An area of ca. 15x10 meters was excavated to bedrock utilizing the on-site digital field research methodology. Five rooms in 2010 were exposed including one large courtyard (ca. 5.5x5.5m; figure 12). The courtyard contained a central main entrance with a limestone slab threshold, large stone bench along the western wall and three ovens (tannûr) located in the northeast corner (Figure 10).

The initial dataset of Khirbat al-Iraq provides a strong demonstration of the potential for archaeological visual analytics. The excavation dataset includes 1,300 geo-referenced artifacts with spatial coordinates, 95 loci, 3,000 digital photographs, 80 3D artifact scans, DEM terrain data, orthoimagery and comprehensive SfM and LiDAR point cloud models of the site. We were able to study every component of the data within ArtifactVis2. This has allowed archaeologists to continually return to the site examining its architecture, spatial distribution of artifacts and stratigraphic layers. We found visitors to the virtual site were better able to understand its architectural layout and nature due to the three-dimensional
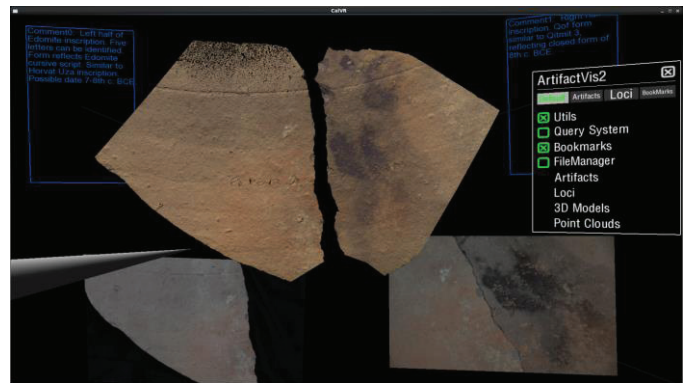

Fig. 11. A screen shot of the loaded halves of the scanned inscription moved adjacent to each other. Bottom two photographs for comparison to scans. Top blue panels show initial annotation notes made during its preliminary translation inside ArtifactVis2.

immersive presentation and ability to make their own dynamic queries [27]. We also could show other archaeologists the excavations and discuss in detail various aspects of the excavation process and theories on its use. Finally, ArtifactVis2 has been extensively used to facilitate the archaeologists' publication of a full report on the Khirbat al-Iraq excavations.

At the end of the 2012 lab season when many of the ceramic vessels were analyzed and sorted, an Edomite inscription was found. Do to the fragile nature of the inscription the archaeologists chose not to restore the two pieces back together. Instead, the two halves were extensively photographed and 3D scanned the night before the inscription had to be properly packed for storage. ArtifactVis2 was used to load all of the digitized photographs and two halves of the 3D scanned sherds into the 3D virtual system (Fig. 11). Using the interaction tools it was possible to move, rotate, and scale the 3D scans and photographs. ArtifactVis2 has enabled all data available on the inscription to be accessed in one system, which facilitated its decipherment. Currently, screenshots within ArtifactVis2 of the translation and digital inking of the inscription have been produced and will be sent to other epigraphers for confirmation.

V. CONCLUSIONS AND FUTURE WORK

ArtifactVis2 allows any archaeologist to examine a site's excavation within an immersive 3D environment. It enables one to see the site as the field archaeologist saw it from start to finish of the excavation. Moreover, it provides a managed system and tools, originally not available during the excavation, to examine significant patterns of artifacts and loci information recovered at the archaeological excavation. Researchers are able to collaborate, discuss and propose questions together concerning a site's function, organization, and artifact distribution in a fully immersive environment as if they were standing at the site when it was excavated. We have shown in this paper several improvements in ArtifactVis2 that are not found together in any other visual environment of its kind for archaeological research. These include dynamic content loading, real-time spatial queries, full GIS integration, auto-organizing file system, fully scalable stereoscopic system, merged SfM, LiDAR, DEM and orthophotos, and interactive

tools for measurement, markup, selection, and annotation. All data are generated from a case study in Southern Jordan of a modern full scale excavation.

The goal of ArtifactVis2 is not to recreate a fictional virtual model of what a site might have looked like 3000 years ago, but to visualize and examine the excavated evidence and data of a site. As this rigorous digital recording methodology and virtual system becomes more readily adopted with in the archaeological community, we envision that new breakthroughs in scientific understanding in archaeology will occur that will go beyond simple photorealistic demonstrations. ArtifactVis2 is designed to spur on this type of collaborative research and investigation, including recording and interpretation of archaeological sites in an immersive environment that truly brings reproducibility to archaeology.

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