2013

Geospatial Virtual Heritage: A Gesture-Based 3D GIS to Engage the Public with Ancient Maya Archaeology

Heather Richards-Rissetto
University of Nebraska-Lincoln, richards-rissetto@unl.edu

Jim Robertsson
HUMlab, Umea University, jim.robertsson@humlab.umu.se

Jennifer von Schwerin
German Archaeological Institute, schwerin@dainst.de

Giorgio Agugario
Bruno Kessler Foundation, giorgio.agugiaro@ait.ac.at

Fabio Remondino
Bruno Kessler Foundation, remondino@fbk.eu

See next page for additional authors

Authors
Heather Richards-Rissetto, Jim Robertsson, Jennifer von Schwerin, Giorgio Agugario, Fabio Remondino, and Gabrio Girardi

Geospatial Virtual Heritage: A Gesture-Based 3D GIS to Engage the Public with Ancient Maya Archaeology

Heather Richards-Rissetto
Bruno Kessler Foundation (FBK), Trento, Italy and University of New Mexico, Albuquerque, NM, USA

Jim Robertsson
Umeå University, Umeå, Sweden

Jennifer von Schwerin
German Archaeological Institute, Bonn, Germany

Giorgio Agugiaro, Fabio Remondino
Bruno Kessler Foundation, Trento, Italy

Gabrio Girardi
Graphitech Foundation, Trento, Italy

Abstract:
This paper presents our research to develop a gesture-based 3D GIS system to engage the public in cultural heritage. It compares two types of interaction—device-based vs. natural interaction— and summarizes the beta-testing results of a 3D GIS tool for archaeology, called QueryArch3D, in which participants used device-based interaction (i.e. mouse and keyboard). It follows with a description of the gesture-based system—that we developed in response to these beta-tests. The system uses QueryArch3D and Microsoft's Kinect to enable people use body movements (in lieu of keyboard or mouse) to navigate a virtual reality landscape, query 3D objects, and call up photos, videos, and text. The case study is the ancient Maya city of Copan—today an UNESCO World Heritage site in Honduras. The low cost and portable system is ideal for museum exhibitions even in developing countries and can be adapted for archaeological content throughout the world.

Keywords:
3D GIS, Kinect, Virtual Heritage, Public Engagement, Ancient Maya

1. Introduction[1]

Cultural heritage plays an important role in understanding and shaping our past, present, and future and influences identity, community, and political and social processes. For these reasons, among others, it is important to engage and educate the public about the past. Cultural heritage includes both the tangible (e.g. artefacts, architecture, and landscapes) and intangible (e.g. cosmology, folklore, and oral histories) expressions of human culture (Vecco 2010). There are many ways to engage the public in cultural heritage, including on-site visits to monuments and archaeological sites, videos, documentaries, books/articles, songs, games, and re-enactments as well as websites, blogs, and even virtual worlds. In the last two decades, virtual heritage—the application of computer visualisation, virtual reality (VR), and information and communication technologies (ICT) to cultural heritage—is increasingly commonplace (Forte and Siliotti 1997).

Virtual heritage ranges from virtual displays at traditional museums to web-based applications (including online museums) to mobile devices (Ioannides et al. 2010). These different contexts include diverse media such as images, movies, maps, and 3D models and use a variety of visualisation and interaction tools to engage and educate the public (Beusing and Posluschny 2009, Pescarin et al. 2012; Pujol and Lorente 2012; Virtual Museum Transnational Network 2011). In order to reach broader audiences and to foster respect for cultural diversity, archaeologists, cultural resource

Corresponding author: hmrichards@fbk.eu

Published in Archaeology in the Digital Era: Papers from the 40th Annual Conference of Computer Applications and Quantitative Methods in Archaeology (CAA), Southampton, 26-29 March 2012. Edited by Graeme Earl, Tim Sly, Angeliki Chrysanthi, Patricia Murrieta-Flores, Constantinos Papadopoulos, Iza Romanowska and David Wheatley. Amsterdam University Press, 2013. Pages 118–130.

managers, and museum curators increasingly use digital tools (Dawson, Levy, and Lyons 2011; de Byl and Khan 2011; Fischer 2012). In 2009, the MayaArch3D Project begun to develop a prototype 3D GIS tool—called QueryArch3D—that integrates Geographic Information Systems (GIS), multi-resolution 3D models, and VR for archaeological research in the ancient Americas (Agugiaro et al. 2011). In 2011, project members began to collaborate with the HUMlab, Umeå University in Sweden (HUMlab 2012) to develop a gesture-based system using the QueryArch3D tool and Microsoft's Kinect that could be used to create a virtual heritage exhibit to engage the public in ancient Maya archaeology. The system is low-cost and portable and can easily be set-up in classrooms, community centres, or traditional museums. The exhibit uses two types of interaction technologies and two levels of immersion to appeal to different audiences and learning styles.

2. Interactivity and Immersion

The earliest applications of virtual heritage were often non-interactive with users simply watching a video or looking at static text or photos (Styliani et al. 2009); however, the use of interactive technologies to promote cultural heritage has been increasing for the past two decades. Interactive technologies "demand" users to observe, perceive, and manipulate objects and/or their actions through their own decisions and subsequent movements, offering a "more natural and instinctive way of learning" than non-interactive technologies (Carrozzino and Bergamasco 2010, 452).

Interaction technologies are often classified as either device-based or natural. The majority of virtual heritage applications employ device-based interaction systems that typically use a mouse, joystick, keyboard, or touch-screen to interact with content. In contrast, natural interaction systems use gesture-based or speech-based interaction systems, manipulating content with body movements or speech. Using gestures seems to create a sense of embodiment and spatial awareness that provides users with a better sense of space and consequently a better sense of place. Generally speaking, gesture-based navigation offers a different perspective or frame of reference (from device-based navigation) to explore cultural heritage.

Related to interaction technology is the level of immersion, defined here as the degree to which users feel part of a simulated environment. Three levels of immersion have been defined by Carrozzino and Bergamasco (2010): Non-Immersive, Low Immersion, and High Immersion. *Non-immersive* applications communicate cultural heritage content using, for example, a desktop/laptop computer or mobile devices (e.g. smart phones or touchpads). *Low immersion* systems include hand-immersive workbenches that use haptic hardware (such as gloves or glasses) and stereo display technologies to enable users to "see" and "touch" virtual 3D objects. They also include Augmented Reality systems that use head-mounted or handheld devices to modify and enhance real-world environments by overlaying digital information (such as videos, 3D graphics, etc.) on the real world (Noh, Sunar, and Pan 2009). Such low immersion systems, however, do not permit users to employ a full-range of body movements to control interaction with content, and they do not fully immerse users in their surroundings. *High immersion* systems such as a CAVE (cave automatic virtual environment), however, combine stereoscopic projection (on four to six surfaces), 3D computer graphics, and 3D sound to create a sense of full-body presence in a virtual environment (Acevedo et al. 2001). One example is the collaborative system for Teleimmersive Archaeology developed by the University of California, Merced, and the University of California, Berkeley that allows users, as 3D avatars, to interact in the same cyberspace with models of artefacts, monuments and sites (Forte and Kurillo 2010).

2.1 Virtual heritage in archaeology: some advantages

While virtual heritage content is not limited to the past, this paper focuses on archaeological applications. The use of computer visualisation, virtual reality (VR), and information and communication technologies (ICT) is ideally-suited to engaging the public in archaeology. Some reasons include:

- Web-based applications can reach broader and more diverse audiences than books or even films;

- Multi-media exhibits (museum, web-based, and others) comprising digital photos, maps, and

Figure 1. *The Etruscan Tombs-Panoramic Virtual Tours Exhibit illustrating use of diverse 3D technologies in a single exhibit; (left) using stereo glasses to view reality-based 3D models of artefacts; (middle) photo panoramas of modern landscape; (right) interactive, reality-based 3D reconstruction of Etruscan tomb (Photos courtesy of 3DOM, FBK).*

videos as well as 3D visualisations allow people to virtually "visit" archaeological sites—something rarely possible for most people;

- Museum exhibitions have space constraints and can display only a limited number of objects—virtual exhibits can store and display many more objects;
- Archaeological materials such as ceramics, bone tools, and textiles are often too fragile or delicate to put on public display, while digital replicas are not;
- Archaeological sites do not appear as they did in the past—overlaying 2D drawings and 3D reconstructions onto reality-based images (of sites as they look today) helps people understand how sites looked in the past;
- Digital tools can be used to turn on and off temporal layers to provide a sense of change through time;
- Remote-sensing technologies such as photogrammetry and laser scanning can be used to capture reality-based 3D data to create 3D digital objects that the public can virtually explore (Remondino 2011);

VR can simulate ancient cities and their landscapes to provide context for narratives creating a sense of space and place for ancient cultures (Barcelo, Forte, and Sanders 2000; Forte and Siliotti 1997; Frischer and Hild 2008).

In sum, virtual heritage has the potential to reach broad audiences, use multimedia to communicate archaeological information to address different learning styles, and facilitate interactivity allowing users to acquire and create knowledge as they take the lead in learning (Pantano and Tavernise 2009, Roussou 2008).

2.2 Virtual heritage in archaeology: device-based interaction vs. natural interaction

The use of 3D technologies and visualisations for cultural heritage education is rapidly increasing and the ways in which people are interacting with virtual heritage are changing as multimedia is integrated with new, diverse technologies. One example is Colonial Williamsburg, a living museum in Virginia (USA), which uses a range of digital techniques and tools to engage the public in cultural heritage: podcasts, 3D visualisations, videos, online exhibits, onsite games with PDAs, etc. (Fischer 2012). Another example is the Etruscan Project of FBK Trento, Italy where reality-based 3D data are

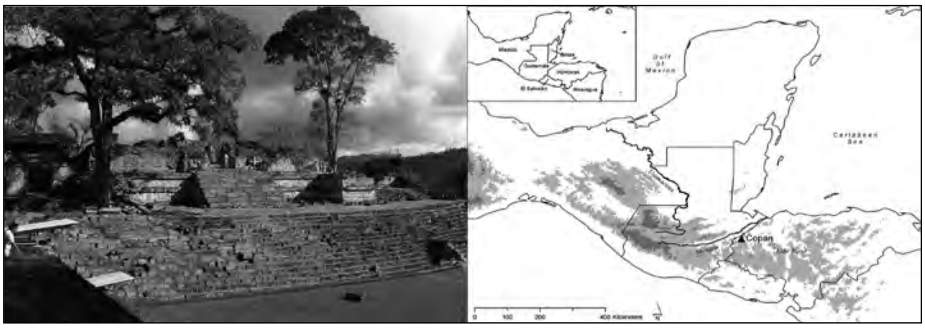

Figure 2. *Temple 22 in main civic-ceremonial complex at Copan, Honduras (left). Map showing location of Copan, Honduras (right).*

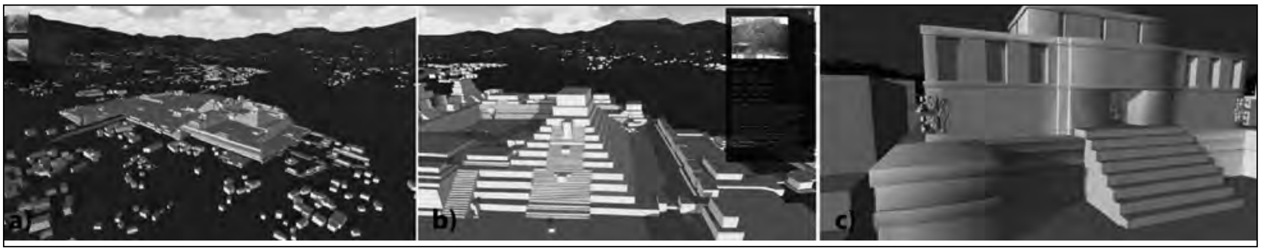

***Figure 3**. Views of QueryArch3D tool. a) aerial view with LoD1 models b), Queries on geometric models) and c) LoD3 with interior walls/rooms and some simplified reality-based 3D elements.*

used as multimedia material to exhibit heritage that is not fully visible and accessible to the public (Remondino et al. 2011). Users can move through panoramas of the present-day landscape, observe 360 degree views at set points, and enter and explore several frescoed tombs and use an Augmented Reality platform to interact with digitized artefacts located in other museums (Fig. 1).

All of the above-mentioned examples offer device-based interaction—the norm in virtual heritage. This is because the technology necessary for systems that use natural interaction (gesture or speech-based systems) was expensive and required expertise in computer programming. For the past few years, however, since the release of Microsoft's Kinect (in November 2010) and other low-cost multi-purpose sensors (e.g. Axu Xtion) that allow touchless remote control to interact with a computer (Lange et al. 2001, Suma et al. 2011) applications that use natural interaction are increasing. Archaeologists are exploring their potential for virtual heritage applications (Abate et al. 2012, Giles 2010, Villaroman, Rowe, and Swan 2011). One example is the Aquae Patavinae Project, which uses a range of interaction technologies including a web camera for gesture-based interaction in a virtual landscape of Aquaea Patavinae, Italy (Aquae Patavinae 2012). Both device-based and natural interaction technologies offer important opportunities to engage the public in virtual heritage.

3. MayaArch3D Project: The Case Study at Copan, Honduras

The MayaArch3D Project is exploring both device-based and natural systems for education and research on the ancient Maya city of Copan, Honduras (MayaArch3D 2012, von Schwerin et al. 2011). Copan, located on the southern periphery of the Maya civilization (600 B.C. - A.D. 1521), was an important centre for commercial and cultural exchange (Fig. 2). Copan is one of the most thoroughly excavated Maya sites, and its long history of excavation and research provides voluminous data that form the basis for many interpretations about the ancient Maya (Andrews and Fash 2005). In 1980, Copan became a UNESCO World Heritage Site and is one of the top tourism destinations in Honduras for international visitors. The more than 150,000 visitors each year to the archaeological park can sense the city's past grandeur; however, because much of the ancient city does not fall within park boundaries, it is difficult for visitor to imagine Copan's size and complexity, and for cultural heritage managers it is difficult to convey this information through traditional means. To convey a sense of the city's spaces to people who never visit the site, is even more difficult. A promising avenue to provide both onsite and virtual visitors a sense of the scale and size of the city as well as engage visitors in the archaeology of the ancient Maya are interactive 3D visualisations.

To explore the possibilities of 3D digital tools and GIS for archaeological and art historical research on ancient Maya architecture and landscapes, the MayaArch3D project began in 2009 to bring together art historians and archaeologists with computer scientists and remote sensing specialists to develop a prototype 3D WebGIS tool called QueryArch3D (Agugiaro et al. 2011, von Schwerin et al. 2011). QueryArch3D is a visualisation and query tool that links multi-resolution 3D models to archaeological data that are accessed while navigating in a VR environment. The prototype tool contains a virtual landscape of Copan that covers 24 km^2 and contains 3D schematic models of over 3,000 ancient structures. It also contains a 3D Studio Max model of an 8th century temple, and reality-based models of sculptures and stelae linked to archaeological data (Fig. 3). The prototype integrates three technologies:

1) Geographic Information Systems (GIS), 2) three-dimensional digital models, and 3) virtual reality.

3.1 The QueryArch3D tool: benefits of 3D GIS to archaeology

By connecting 3D models in a VR environment with a GIS (i.e. spatial database), 3D GIS—of which the QueryArch3D tool is one—offer a number of benefits to archaeologists and also museum visitors. The advantage of such a system is that users can move through a virtual landscape and query and interact with 3D models of objects and their associated archaeological data. This new capability allows users to actively and more intuitively engage with archaeological information, and thereby generate new knowledge. To go briefly into more detail:

This system has the ability to provide the user with access to different types of 3D models of individual objects or whole archaeological sites via an interactive, virtual environment. The advantages include:

- access to virtual artefacts when original artefacts cannot be transported or handled due to fear of damage;
- a sense of mass and space;
- analysis of objects from multiple perspectives (e.g. bird's eye, exterior vs. interior view, anterior vs. posterior view);
- interaction with reality-based 3D models—derived from technologies such as laser scanning and photogrammetry—that illustrate what can been seen today of an archaeological site or individual artefacts (Manferdini and Remondino 2012);
- interaction with 3D models generated using computer graphics (based on historical and archaeological data) that provide alternative reconstructions of how individual buildings, architectural complexes, and entire cities may have a looked in the past (and at different time periods), which is useful for archaeological investigations and to educate the public about archaeological methods and theories (Sanders 2008);
- comparisons of data and hypothetical reconstructions;
- metric and quantitative analysis.

Because this system links these 3D models with a GIS, users also have the capability to overlay and link datasets, and therefore a range of new ways to interact with archaeological data. While archaeologists can use the database back-end feature of the tool to bring together buildings, sculpture, and artefacts into an integrated landscape to reveal relationships, patterns, and trends that are not evident when using traditional (non-spatial) databases (Conolly and Lake 2006, Wheatley and Gillings 2002), a more simple interface is offered to the public so that they can interact with the data connected to the 3D models in the following ways:

- search using pre-set queries such as "show me all excavated temples";
- turn layers of information on/off, for example, vegetation layers to illustrate different paleo-environmental interpretations;
- use time sliders to visualise changes through time, for example, the construction campaigns of different rulers (Zerneke et al. 2006);
- click on 3D models to access text, 2D media such as photographs and maps, or videos (Huk, Steinke and Floto 2010).

Overall, the most important benefit of a 3DGIS for museum visitors is that the QueryArch3D tool can situate 3D models of objects or buildings in their larger spatial contexts within a virtual environment, thereby extending the scale of analysis and experience. This offers a sense of embodiment in architecture or landscape (sense of place) (Forte and Bonini 2010), and increases awareness of spatial relationships between objects and associated data (Frischer and Hild 2008), and most importantly, helps the public to better understand archaeological information.

3.2 Beta-testing results of QueryArch3D Tool

Firstly, the project wanted to understand and evaluate the advantages and limitations of virtual

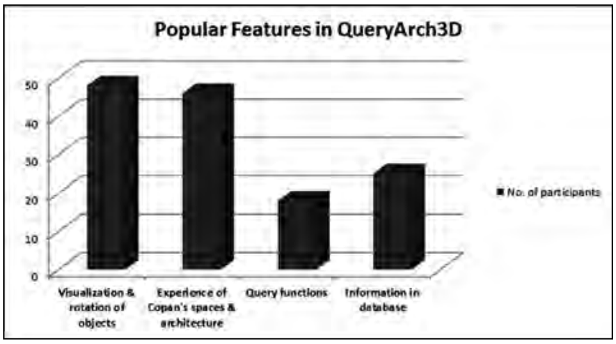

***Figure 4**. Most popular features in QueryArch3D tool.*

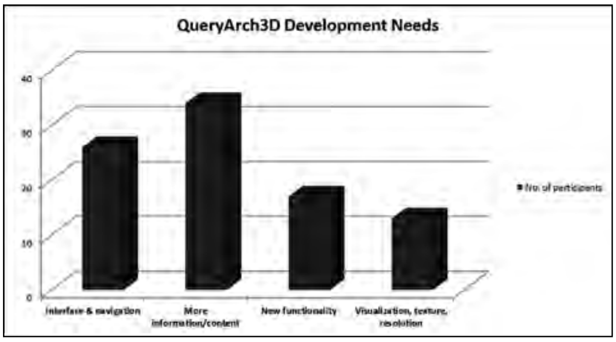

***Figure 5**. Development Needs in QueryArch3D tool*

heritage in terms of engagement and education (Champion, Bishop, and Dave, 2012, Flatman, Chidester and Gadsby 2012). For this reason, in September-October 2011, the MayaArch3D Project conducted beta-testing of the QueryArch3D tool at five universities—University of New Mexico (USA), University of Merced California (USA), California State University Stanislaus (USA), University of Bonn (Germany), and Umeå University (Sweden). Most participants were anthropology and art history students (graduates and undergraduates) between the ages of 15-35, who had little experience with 3D models and were interested in the tool from an educational standpoint. Five professors of anthropology and archaeology also participated in the beta-tests. Participants were provided with background information about the MayaArch3D Project and the QueryArch3D tool and received instructions on how to open and navigate the tool. They spent approximately 30 minutes exploring the tool and then filled out a survey. The survey included 14 questions about user demographics (i.e. age, gender, work area), computer specifications (e.g. platform (MAC or PC), browser, RAM), most and least popular features, and most important features for immediate development. The survey also asked participants: What did you learn from the tool? And, how was this different from your traditional classroom studies?

Figure 4 shows that the most popular features were the "visualization and rotation of objects" and the "experience of Copan's spaces and architecture". However participants would have preferred to see more textured and less blocky models. Along these lines, they also wanted a transparency feature to indicate the degree of certainty in the 3D models (i.e. procedural vs. 3D Studio Max vs. reality-based). With respect to learning, participants cited a better understanding of the size and scale of Copan and of the heights and spatial relationships of buildings than from 2D photos and textbooks. They also mentioned that while the VR gave them the sense that Copan was a large city, and not simply a ritual centre, the lack of people and objects made the city seem unrealistically vacant. The participants liked being able to access information in the database via the 3D models; however, they mentioned that more data are needed in the database before they could adequately assess the value of this feature for educational purposes. The Query Functions were the least popular. These are the functions at LOD 1 where users can select, for example, all stelae that were erected by ruler 16 and they will be highlight in the VR. This may be because these were designed with researchers in mind.

Fig. 5 illustrates that, according to beta-testers, the most important feature needing immediate development is "interface and navigation". In response to this question, several participants suggested that the addition of avatars and/or more realistic movement within the VR would enhance user experience and engagement. Building on this feedback, we reviewed the state-of-the-field for virtual heritage employing maps, GIS, and 3D zs, and investigated device-based and gesture-based virtual heritage. Based upon our findings, we began a collaborative project with the HUMlab at Umeå University (Sweden) to link the QueryArch3D tool to Microsoft's Kinect in order to offer an alternative way for users to navigate the QueryArch3D tool.

4. QueryArch3D-Kinect: System Components, Development and Set Up

The gesture-based 3D GIS system is low-cost and portable requiring four items:

Keyboard Command	Onscreen movement	Kinect gestures
W	Move Forward	Right arm forward
S	Move Backward	Left arm forward
Q	Left Turn	Rotate body left
E	Right Turn	Rotate body right
Y	Look Up	Lean backwards
H	Look Down	Lean Forwards
T	Start walkthrough or enter LOD4	Right arm down
O	Open information (access database)	Right arm up
I	Close information	Left arm up
Keyboard Command	**Queries/Interaction with high-resolution 3D objects**	**Kinect gestures**
Z	Zoom in	Right arm forward
X	Zoom out	Left arm forward
←	Rotate object left	Left arm out
→	Rotate object right	Right arm out
↑	Rotate object up	Lean backwards
↓	Rotate object down	Lean forwards
O	Open information	Right arm up
I	Close information	Left arm up

Table 1*. Keyboard commands and Kinect gestures for the gesture-based 3D GIS.*

- QueryArch3D tool- free and available online using a free Unity 3D plug-in or offline,
- Kinect,
- standard desktop/laptop,
- display device.

QueryArch3D uses a DBMS for data modelling and storage, and 3D visualisation to link multi-resolution 3D models to archaeological data that are accessed while navigating in a VR environment. The DBMS consists of PostgreSQL with the PostGIS extension to reduce data heterogeneity and allow storage of both non-spatial and spatial data. For the interactive navigation and 3D visualisation, the tool uses Unity3D, a game engine development tool for the creation of 3D interactive contents accessed off-line and on-line using a free web player plugin. Finally, a PHP interface links Unity 3D and PostgreSQL allowing the data retrieval from the database and the (online) visualisation.

The initial development of QueryArch3D programmed movements with mouse navigation. To allow gesture-based control of QueryArch3D, we selected Microsoft's Kinect—a motion sensing input device composed of different sensors (RGB camera, infrared depth sensor, motorized tilt function, and a microphone array) that enables users to control and interact with video games (or PCs) without the need to touch a game controller. Originally designed as motion sensing input device for playing videos games with Microsoft's XBOX 360, developers and researchers are now exploring alternative applications for the Kinect beyond its original entertainment purpose (Giles 2010). There are currently four options to use Kinect with the QueryArch3D tool: (1) employ the Flexible Action and Articulated Skeleton Toolkit (FAAST), (2) use the ZDK Unity3D bindings in the Zigfu Development Kit (works with OpenNI/NITE and the Microsoft Kinect SDK, but it is not free), (3) develop a custom interface in the .NET framework using Kinect for Windows SDK, or (4) develop a custom interface in the OpenNI framework. For our initials tests we have selected the FAAST option because it is open source and quickly and easily customizable. The mouse navigation commands, in Unity 3D, were reprogrammed to keyboard commands and then the keyboard commands were correlated to body posture and specific gestures (Table 1). At this

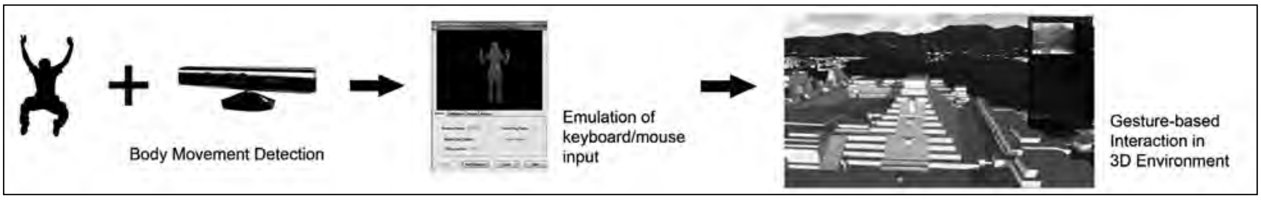

***Figure 6**. The system set-up, with the Kinect recording the human movements and FAAST emulating the keyboard input to control the QueryArch3D tool.*

***Figure 7**. Set-up of the gesture-based platform to control the 3D environment.*

point, these commands can be emulated using the Flexible Action and Articulated Skeleton Toolkit (FAAST) allowing for gesture-based control of the QueryArch3D tool (Suma et al. 2011).

The system set up is simple and straightforward (Figs 6 and 7):

- Download FAAST onto a PC;
- Connect Kinect to the PC via a USB adapter;
- Open the QueryArch3D tool on www. MayaArch3D.unm.edu (for first use the Unity 3D plug-in must be installed on the PC);
- In FAAST, open the configuration file (.cfg) that indicates how the keyboard commands are translated to body posture and gestures;
- FAAST performs a skeleton calibration (specific to the user);
- Begin gesture-based navigation of QueryArch3D tool.

4.1 The interactive display(s) set-up: interaction and immersion

For a public display/exhibit, five options based on different interaction and immersion technologies were identified:

Non-immersive/Device-based - This option uses device-based interaction technologies, i.e., visitors use a mouse and keyboard to control the QueryArch3D tool. The display device consists of a large monitor or a projector and screen/wall.

Non-immersive/Natural-based - This option uses natural-based interaction technologies, i.e. visitors use gestures (via the Kinect and FAAST) to control the QueyrArch3D tool. The display device consists of a project and screen/wall.

Non-immersive/Device and Natural-based - This option uses both device-based and natural-based technologies, i.e. two stations are set up. For example, a desktop with monitor for the device-based interaction and a large screen/wall with projector for gesture-based interaction. This option better serves the needs of diverse visitors and their different learning styles.

Low-immersion/Device-based - This option uses a 3D stereo display with device-based interaction with the mouse and keyboard requiring stereoscopic driver software and glasses. The display device consists of a screen or projector and one or three screens. This option is more expensive, but allows visitors to see stereoscopic 3D objects, providing a more realistic sense of space for users as they navigate and explore Copan's architecture.

***Figure 8**. Using gestures to navigate and query information in the QueryArch3D tool*

Low-immersive/Natural-based- The set up for this option is the same as option #4; however, the system uses the Kinect and FAAST instead of a mouse and keyboard. Using gesture-based interaction gives visitors a sense of using their own body to walk through the ancient city of Copan, offering a sense of embodiment that may be lacking with device-based interaction.

4.2 Practical factors to consider for the gesture-based 3D GIS exhibit

While the system set-up is straightforward, there are several factors to be considered for when using the gesture-based system for a public exhibit:

While the range limits of the Kinect as a hands-free controller are 1.2–3.6 meters, our tests indicate that the performance of the gesture-based system increases the closer the user is to the Kinect. However, the small field of view (FOV) of the Kinect might not entirely capture a user who stands too close to the sensor. Thus, when setting up a public exhibit, markers notifying users of appropriate distance to stand from the display device should be made. The ideal distance that a visitor stands from the display depends on user height. For example, while children need to stand closer to the display, taller adults must stand further away to enable the Kinect to perform the skeletal calibration and gesture recognition. To accommodate and overcome these problems, we programmed and tested FAAST for two skeleton modes: (1) Full Body and (2) Upper Body. Our tests indicate that a solution to poor system performance due to distance can be overcome by using the Upper Body mode;

FAAST requires that different body movements be programmed to certain distances or degrees to trigger specific keyboard commands. This factor corresponds directly to the angle of the Kinect and thus, the optimal height placement of the Kinect is at the torso level of the user. The latest version of FAAST (v.1.0) includes a manual pitch (up/down angle) function for tracking users in order to account for people of different heights. Additionally, the actions in FAAST are programmed to be triggered at specific distances, for example, an information table can be programmed to be opened when a user raises his/her arm 15 inches above the head; however, if a child or person of small stature is using the system, the action will not be triggered if he/she cannot raise his/her arms high enough above the head;

The system's performance increases when the user directly faces the Kinect; vice versa, when the Kinect is positioned off-centre, maybe due to room-size constraints, the system's performance decreases. To avoid this problem, markers should also be used indicating where users should stand. In other words, a "boundary box" (perhaps tape on the floor) identifying the ideal distance and placement of visitors should be marked to facilitate maximum performance of the gesture-based system. Along these lines, markers indicating the ideal distance/ placement of children compared to adults are also important. We suggest a set-up test that allows visitors to identify the optimal distance and placement from the display;

According to our tests, the system's performance increases when user gestures are relatively slow and well-defined. We suggest that the set-up test also guides visitors through each of the gestures required to navigate the system, providing them with feedback on the success of their movements. In other words, the set-up test should inform them on the range of movement and speed required to optimally use the system;

The upper or entire skeleton identification and gesture recognition are fully automated procedures; therefore, the illumination conditions of the environment are crucial for correct gesture identification and command transmission. For example, our tests indicate that the system's

Figure 9. *East Court as it looks today (left) and 3D digital reconstruction of East Court in QueryArch3D showing now collapsed buildings (right).*

performance decreases with larger amounts of ambient light (i.e. natural light) and it also decreases in the presence of highly reflective objects such as glass. It is suggested that the display be housed in a relatively dark space with few objects.

In summary, the gesture-free display should be mounted in a separate room with floor markers telling users of different heights where to stand, and include a set-up text for each user or training session or "game" or "test" in which they briefly learn the proper gestures.

4.3 Exhibit content: sample experiences

An important advantage of virtual heritage is the ability to include many types of media such as photos (including panoramas), drawings, videos, maps, and 3D visualisations—the QueryArch3D tool not only does this in a single, navigable VR, but it also allows users to perform attribute queries by clicking on 3D virtual objects (i.e. stelae, buildings, and sculpture) and call up photos, maps, drawings, and textual descriptions that are stored in a spatial database. Moreover, because the tool is a 3D GIS it also allows users to perform spatial queries; for example, they can select all structures belonging to a specific sub-community within the ancient city of Copan and these structures will be highlighted in the VR (Fig. 8). Coupled with the ability to simultaneously query 3D models, the integration of 3D GIS and controller-free interaction technologies offer a unique and innovative to engage and educate the public about the ancient Maya (see video at http://vimeo.com/50673261).

Another advantage of virtual heritage is that it is easier and less expensive to devise different ways to communicate cultural heritage content to the public. We offer four options that offer different levels of interactivity:

Non-interactive Narration: Videos are played that present a storyline, or narrative, that was created from the VR environment in QueryArch3D tool; visitors are not free to explore the VR environment.

Interactive Narration: self-guided virtual tours where a storyline, or narrative, in chronological or sequential order unfolds as visitors "walk" along pre-set paths; visitors are free to explore the pre-set path at their own pace.

Hot-spots: visitors select highlighted locations from overview map to explore; at each of these locations a specific theme(s), e.g. cosmology, are described through interaction (e.g. rotation of 3D virtual objects such as a stelae to "read" hieroglyphs).

Unguided exploration—visitors move around freely and click on any object to retrieve data from database; this option allows visitors to move through the city at their own pace, inspect specific features, or read hieroglyphic texts; new knowledge creation is likely.

An exhibit—based on the QueryArch3D tool and the case study of Copan—could be used to engage and educate the public about the ancient Maya, and archaeology more generally. Some topics include:

- Explain archaeological methods and theories using the 3D digital models of buildings with linked excavation photos, drawings, etc. to tell the history of archaeological research at Copan. For example, excavations could be selected and highlighted based on year excavated to illustrate broader changes in the discipline of archaeology from focus on civic-ceremonial centres to settlement patterns;

- Use the reality-based and 3D Studio Max models to illustrate ancient Maya construction techniques and materials;

- Visualise buildings that have been completely destroyed in a landscape context (Fig. 9);
- Explain ancient Maya indigenous concepts such as cosmology, astronomy, time (Maya calendars), social organization, or divine kinship. For example, excavations in the city's main civic-ceremonial complex (Principal Group) have uncovered layers of architecture with sculpture, imagery, and hieroglyphs showing that Copan had a dynasty of sixteen kings that ruled over five centuries (A.D. 427-820) (Andrews and Fash 2005). Visitors could a guided virtual tour that traces the city's dynastic history using the temples and other monuments that city's various kings commissioned.

5. Conclusions and Future Direction

This paper has explored the potential of interactive technologies to facilitate teaching and learning by linking two technologies, 3D GIS and gesture-based interaction, for the purposes of developing a new system to engage the public in ancient Maya archaeology. Beyond the practical requirements of setting up a public gesture-based 3D GIS exhibit, it is important to establish learning objectives and take into account diverse learning styles, educational background, and informatics skills (Hsu 2011). By offering different interaction (device vs. natural) and immersion technologies combined with multimedia and different levels of interactivity (ranging from a passive experience such as watching videos to a highly active experience using the gesture-based system for unguided exploration through the ancient city of Copan) exhibition curators can engage a range of visitors in the cultural heritage of the ancient Maya. The gesture-based system is suited to today's youth—visual learners who are intrigued by, and proficient in using interactive and dynamic technologies. The system is also well-suited to individuals lacking experience with computers (specifically using mouse and keyboard) or have physical constraints because it can be programmed in multiple ways to have body movements correspond to a range of different gestures (upper body vs. full-body interaction). In the future, the project will continue to evaluate the advantages and disadvantages of using a touchless control system to navigate a 3D GIS for archaeological outreach, keeping an eye on technological developments and exploring the range of benefits for cultural heritage.

Acknowledgements

This project was partly supported by two Digital Humanities Start-Up Grants from the National Endowment for the Humanities (#HD50583, #HD5097910), National Science Foundation (#1064648), Alexander von Humboldt Foundation (Germany) and HUMlab, Umeå University (Sweden). Thanks to Maurizio Forte of the University of Merced for assistance with beta-testing and for advice about the direction of the project, and to Keith Prufer of the University of New Mexico, Nikolai Grube of the University of Bonn, and Ellen Bell of the University of California Stanislaus for assistance with beta-testing. We also thank the Honduran Institute of Anthropology and History (IHAH) for the collaboration and permission to work at Copan.

References

Abate, D., G. Furini, S. Migliori, and S. Pierattini. 2012. "Virtual Hands Free Interaction with 3D Objects and Environments." Paper presented at the *Computer Applications and Quantitative Methods in Archaeology Conference, Southampton, UK, March 26-29*.

Acevedo, D., E. Vote, D. Laidlaw, and M. S. Joukowsky. 2001. "ARCHAVE: A Virtual Environment for Archaeological Research." *CAA 2000 Proceedings: Computing Archaeology for Understanding the Past*, edited by T.Z.V. Stancic, 313-316. Oxford: Archeopress.

Agugiaro, G., F. Remondino, G. Girardi, J. von Schwerin, H. Richards-Rissetto, and R. De Amicis. 2011. "A Web-based Interactive Tool for Multi-Resolution 3D Models of a Maya Archaeological Site." In *Proceedings of the 4th ISPRS International Workshop 3D-ARCH 2011: "3D Virtual Reconstruction and Visualization of Complex Architectures" Trento, Italy, 2-4 March 2011,* edited by F. Remondino and S. El-Hakim, 23-30. International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences (on CD-ROM).

Andrews, W.E., and W.L. Fash. 2005. "Issues in Copán Archaeology." In *Copán: The History of an Ancient*

Kingdom, edited by E. Wyllys Andrews and W.L. Fash, 395-425. Santa Fe: School of American Research Advanced Seminar Series.

Aquae P. 2012. "La Visita Virtuale." Accessed June 23, 2012. http://www.aquaepatavinae.lettere.unipd.it/portale/?page_id=2174.

Barcelo, J.A., M. Forte, and D. H. Sanders. 2000. *Virtual reality in archaeology*. Oxford: Archaeopress.

Beusing, R., and A. Posluschny. 2009. "The NetConnect-Project – New Access to Ancient Sites." Paper presented at *Computer Applications to Archaeology, Williamsburg, Virginia, USA. March 22-26, 2009.*

Carrozzino, M., and M Bergamasco. 2010. "Beyond virtual museums: Experiencing Immersive Virtual Reality in Real Museums." *Journal of Cultural Heritage* 11: 452-458.

Champion, E., I. Bishop, and B. Dave. 2012. "The Palenque project: evaluating interaction in an online virtual archaeology site." *Virtual Reality* 16: 121–139.

Conolly, J., and M. Lake. 2006. *Geographical Information Systems in archaeology*. Cambridge: Cambridge University Press.

Dawson, P., R. Levy, and N. Lyons. 2011. "'Breaking the fourthwall': 3D virtual worlds as tools for knowledge repatriation in archaeology." *Journal of Social Archaeology* 11(3): 387-402.

de Byl, P., and M. Khan. 2011. "Preserving our Past with Toys of the Future." *Changing Demands, Changing Directions. Proceedings of ascilite Hobart 2011*, edited by G. Williams, P. Statham, N. Brown, and B. Cleland, 718-728. Hobart: University of Tasmania. .

Flatman, J., R.C. Chidester, and D.A. Gadsby. 2012. "What Public Engagement in Archaeology Really Means." In *Archaeology in Society*: *Its Relevance in the Modern World*, edited by Marcy Rockman, Marcy and Joe Flatman, 65-76. London: Springer.

Fischer, L. E. 2012. "Virtually Visiting Williamsburg: The Use of 3D Modelling to Enrich the Museum Guest Experience." Paper presented at the Computer Applications and Quantitative Methods in Archaeology Conference, Southampton, United Kingdom, March 26-9.

Forte, M., and A. Siliotti. 1997. *Virtual Archaeology*. London: Thames and Hudson.

Forte, M., and E. Bonini. 2010. "Embodiment and Enaction: A Theoretical Overview for Cybercommunities." In *Heritage in the Digital era*, edited by M. Ioannides, A. Alonzo, A. Georgopoulos, L. Kalisperis, A. Brown, and D. Pitzalis, 45-56. Essex: Multi-Science Publishing.

Forte, M., and G. Kurillo. 2010. "Cyberarchaeology: Experimenting with Teleimmersive Archaeology." Paper presented at the 16th International Conference on Virtual Systems and Multimedia, Oct 20-23, 2010, Seoul, South Korea.

Frischer, B., and A. Dakouri-Hild. 2008. *Beyond Illustration: 2D and 3D Digital Technologies as tools for Discovery in Archaeology*. Oxford: Archaeopress.

Giles, J. 2010. "Inside the race to hack the Kinect." *The New Scientist* 208 (2789): 22-23.

Hsu, Hui-mei J. 2011. "The Potential of Kinect in Education." *International Journal of Information and Education Technology* 1 (5): 334-338.

Huk, T., M. Steinke, and C. Floto. 2010. "The educational value of visual cues and 3D-representational format in a computer animation under restricted and realistic conditions." *Instructional Science* 5: 455-469.

HUMlab. 2012. "HUMlab Homepage." Accessed June 11, 2012. http://www.humlab.umu.se.

Ioannides, A., A. Addison, A. Georgopoulos, L. Kalisperis, A. Brown, and D. Pitzalis. 2010. *Heritage in the Digital Era*. Essex: Multi-Science Publishing.

Lange, B., A. Rizzo, C. Chang, E. Suma, and M. Bolas. 2011. "Markerless Full Body Tracking: Depth-Sensing Technology within Virtual Environments." Paper presented at the Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC) 2011.

Manferdini, A., and F. Remondino. 2012. "A review of reality-based 3D model generation, segmentation and web-based visualization methods." *International Journal of Heritage in the Digital Era* 1(1): 103-124.

MayaArch3D Project. 2012. "MayaArch3D Project Homepage." Accessed 11 June 2012.

http://mayaarch3D.unm.edu.

Noh, Z., M. Shahrizal Sunar, and Z. Pan. 2009. "A Review on Augmented Reality for Virtual Heritage Systems." In *Learning by Playing. Game-based Education System Design and Development, 4th International Conference on E-learning, Edutainment 2009 LNCS 5670*, edited by M. Chang, R. K. Kinshuk, G. Chen, and M. Hirose, 50–61. Berlin and Heidelberg: Springer-Verlag.

Pantano, E., and A. Tavernise. 2009. "Learning Cultural Heritage Through Information and Communication Technologies: A Case Study." In *Learning Culture and Languages through ICTS: Methods for Enhanced Instruction*, edited by Maiga Change and Chen-Wo Kuo, 103- 119. London: IGI Global.

Pescarin, S., W. Hupperetz, A. Pagano, C. Ray, and M. Wallergård. 2012. "Evaluating Virtual Museums: archeovirtual test-case." Paper presented at the *Computer Applications and Quantitative Methods in Archaeology Conference, Southampton, United Kingdom, March 26-9.*

Pujol, L., and A. Lorente. 2012. "The Virtual Museum." Paper presented at the Computer Applications and Quantitative Methods in Archaeology Conference, Southampton, United Kingdom, March 26-29.

Remondino, F. 2011. "Heritage Recording and 3D Modeling with Photogrammetry and 3D Scanning.“ *Remote Sensing Journal* 3: 1104-1138.

Remondino, F, Alessandro Rizzi, Belen Jimenez, Giorgio Agugiaro, Giorgio Baratti, Giorgio and Raffaele De Amicis. 2011. "The Etruscans in 3D: from space to underground." *Geoinformatics* 6:283-290.

Roussou, M. 2008. "The Components of Engagement in Virtual Heritage Environments." *New Heritage: New media and cultural heritage,* edited by Yehuda Kalay, Thomas Kvan and Janice Affleck, 225-241. London and New York: Routledge.

Sanders, D.H. 2008. "Interactive 3D Computer Graphics for Teaching, Research, and Publication in Cultural Heritage." In *Proceedings of the International Symposium on Information and Communication Technologies in Cultural Heritage, Oct. 16-18, University of Ioannina, Greece*, edited by T. Mikropoulos, N. Papachristos, 143-158. Ioannina: Graphic Arts.

Styliani, S., L. Fotis, K. Kostas, and P. Petros. 2009. "Virtual museums, a survey and some issues for consideration." *Journal of Cultural Heritage* 10: 520-528.

Suma, E., B. Lange, A. Rizzo, D. Krum, and M. Bolas. 2011. "FAAST: The Flexible Action and Articulated Skeleton Toolkit." *Proceedings of IEEE Virtual Reality*, 247-248. Singapure.

Vecco, M. 2010. "A definition of cultural heritage: From the tangible to the intangible." *Journal of Cultural Heritage* 11 (3): 321-324.

Villaroman, N., D. Rowe, and B. Swan. 2011. "Teaching Natural User Interaction Using OpenNI and the Microsoft Kinect Sensor." In *Proceedings of the 2011 SIGITE conference on Information Technology Education*, edited by B. Goda, E. Sobiesk, and R. Connolly, 227-232. New York: ACM.

Virtual Museum Transnational Network. 2011. "What is a Virtual Museum?" Accessed May 30. http://www.v-must.net/virtual-museums/what-virtual-museum.

von Schwerin, J., H. Richards-Rissetto, F. Remondino, G. Agugiaro, M. Forte, and R. Maqueda. 2011. "The MayaArch3D Project; Digital Technologies for Research in Maya Archaeology." Final Performance Report and White Paper for NEH Digital Humanities Level II Start-Up Grant, 2011. https://securegrants.neh.gov/PublicQuery/main.aspx?f=1&gn=HD-50975-10.

Wheatley, D.W., and M. Gillings. 2002. *Spatial technology and archaeology: a guide to the archaeological applications of GIS.* London: Taylor & Francis.

Zerneke, J.L., M.K. Buckland, and K. Carl. 2006. "Temporally Dynamic Maps: The Electronic Cultural Atlas Initiative Experience." *Human IT* 8 (3): 83–94.