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The MayaArch3D project: A 3D WebGIS for analyzing ancient architecture and landscapes

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Abstract

There is a need in the humanities for a 3D WebGIS with analytical tools that allow researchers to analyze 3D models linked to spatially referenced data. Geographic Information Systems (GIS) allow for complex spatial analysis of 2.5D data. For example, they offer bird's eye views of landscapes with extruded building footprints, but one cannot 'get on the ground' and interact with true 3D models from a pedestrian perspective. Meanwhile, 3D models and virtual environments visualize data in 3D space, but analytical tools are simple rotation or lighting effects. The MayaArch3D Project is developing a 3D WebGIS—called QueryArch3D—to allow these two distinct approaches to 'talk to each other' for studies of architecture and landscapes—in this case, the eighth-century Maya kingdom of Copan, Honduras. With this tool, researchers can search and query, in real time via a virtual reality (VR) environment, segmented 3D models of multiple resolutions (as well as computer-assisted design and reality-based) that are linked to attribute data stored in a spatial database. Beta tests indicate that this tool can assist researchers in expanding questions and developing new analytical methods in humanities research. This article summarizes the results of a pilot project that started in 2009, with an art historian and an archaeologist's collaborative research on the ancient Maya kingdom and UNESCO World Heritage site of Copan in Honduras—called MayaArch3D. The project researches inno-

vative approaches to integrate GIS, 3D digital models, and VR environments online for teaching and research on ancient architecture and landscapes. It has grown into an international, interdisciplinary project that brings together art historians, archaeologists, and cultural resource managers with experts in remote sensing, photogrammetry, 3D modeling, and VR. The Start Up Phase was funded by two National Endowment for the Humanities, Digital Humanities Start-Up grants to the University of New Mexico (PI: Jennifer von Schwerin) and developed and beta tested a pipeline and prototype 3D WebGIS—called *QueryArch3D*. The prototype version is available at http://Mayaarch3d.org/project-history/). Project results indicate that it is possible to bridge the gap between 3D and GIS to create a resource for researchers of Maya architecture to compare and analyze 3D models and archaeological data in the context of a geographically referenced, VR landscape.

## 1 The Gap between GIS and 3D Modeling Systems

1.1 3D modeling

Modern sensor and computing technologies are changing the practice of art history and archaeology because they offer innovative ways to document, reconstruct, and research the ancient world in 3D (El-Hakim *et al.,* 2008; Reindel and Wagner, 2009). State-of-the-art imaging technologies allow researchers to document 3D objects to the level of the micron (e.g. Grün, 2008), whereas Virtual Reality (VR) simulation programs enable reconstructions of ancient buildings in their ancient environments and landscapes. However, as Frischer has noted (2008), the perception is that 3D models are purely illustrative—ideal for education or conservation—whereas how 3D models can assist with comparative research on architecture is an ongoing question. Since 1998, Jennifer von Schwerin has addressed this question for ancient Maya architecture when she began collaborating with Harvard University archaeologists to analyze the collapsed façade sculpture of an eighth-century temple at Copan, Honduras, called Temple 22 (Ahlfeldt 2004; Fash 2011b; von Schwerin 2011a). As an art historian, von Schwerin seeks to correlate political and social changes in ancient Maya kingdoms with developments in architectural form over space and time. But the first challenge is simply to bring together data on the temple that is spread around the world in various archives

and museums and to determine how the building once appeared in the past. To test her reconstructions, von Schwerin turned to digital 3D tools.

Different methods are possible for creating 3D models of ancient monuments—such as computer graphics, procedural modeling (models created from sets of rules), and reality-based modeling (models created from real-world data such as laser scanning)—and increasingly, these are being combined to create multi-resolution 3D reconstructions. Although this combination can expand research possibilities, it is critical to identify optional modeling techniques based on researcher needs and to define the workflow for dealing with multi-resolution models in a 3D WebGIS tool. The MayaArch3D project is addressing this by creating test data of multi-resolution 3D models from Copan, including various 3D simulations of Temple 22 (Remondino *et al.*, 2009, von Schwerin *et al.*, 2011b). The 3D models are being generated at different levels of detail (LoD) and resolutions ranging from individual buildings to archaeological complexes using methodologies based on image data acquired with passive sensors (e.g. digital cameras), range data acquired with active sensors (e.g. laser scanning), classical surveying, and procedural modeling using existing maps. The choice depends on the required accuracy, object dimensions and location, the surface characteristics, the team's level of experience, the project's budget, and the final goal. For example, computer-assisted design (CAD) models such as the 3D Studio Max model of Temple

22 depicted in Figures 1 and 2 offers the ability to test hypothetical reconstructions and to analyze a building from multiple perspectives (e.g. bird's eye, exterior versus interior view) with rotation or lighting effects (Figure 3).[1] Reality-based models created using active and passive sensors allow for comparison against CAD reconstructions (Figs 4 and 5). VR such as this low-resolution SketchUp model of Copan's landscape (Figure 6) — created using georeferenced building footprints — provides an urban context for high-resolution 3D models of individual structures and allows users to virtually navigate through ancient cities and landscapes and to increase their awareness of mass, space, and spatial relationships. This interaction facilitates a sense of embodiment and place (Forte and Bonini, 2010), and it also is useful for visualizing the results of archaeological research — for example, an affiliated project is working to display the results of archaeoastronomical studies at Copan (see Figure 10).

These are just a few reasons that counter the common perception that 3D models are purely illustrative (e.g. Frischer and Dakouri-Hild, 2008). Increasingly, projects are demonstrating the value of 3D models for scientific analysis. Researchers developing tools for viewing and analyzing sophisticated 3D architectural models include the two big VR environment re-creation laboratories — the Experimental Technology Center at University of California, Los Angeles and the Institute for Advanced Technology in the Humanities at the University of Virginia, who have collaborated on the project 'Rome Reborn' (romereborn.frischerconsulting.com). In Europe, 3D models of architecture are used to analyze building plans and phases [for instance, the projects on Roman emperor palaces in Rome and Serbia (Weferling *et al.*, 2001) and analyses of the Cologne cathedral (Schock-Werner *et al.*, 2011)]. More recently, a few researchers have begun to explore how digital models might be used for comparative online research. One example is Stephen Murray's "Mapping Gothic France" project — a collaborative project linking text, Quick Time VR, and 2D and 3D images to an interactive map of Gothic cathedrals. One promising opportunity — the approach taken by the MayaArch3D Project — is to use 3D models as visualization "containers" for different kinds of
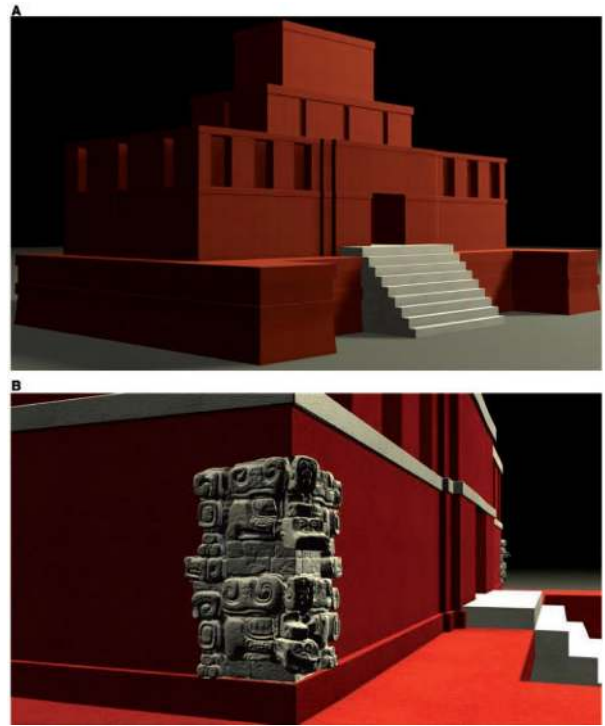

Figure 1. The 3D low-resolution CAD model of Temple 22 used for testing hypothetical reconstructions integrated with high-resolution reality-based 3D models of architectural sculpture (3D model created by F. Galezzi)

Figure 2. Preliminary high-definition model of Temple 22 used to test the process of integrating various data sources into the reconstruction process. (3D model by R. Maqueda and J. von Schwerin)

information (Manferdini *et al.*, 2008). These recent advantages have initiated a broader interest in 3D modeling for archaeology and cultural heritage, which is evident at conferences such as CAA

WEST ROOM

NORTH ROOM

EAST ROOM

DOORWAY
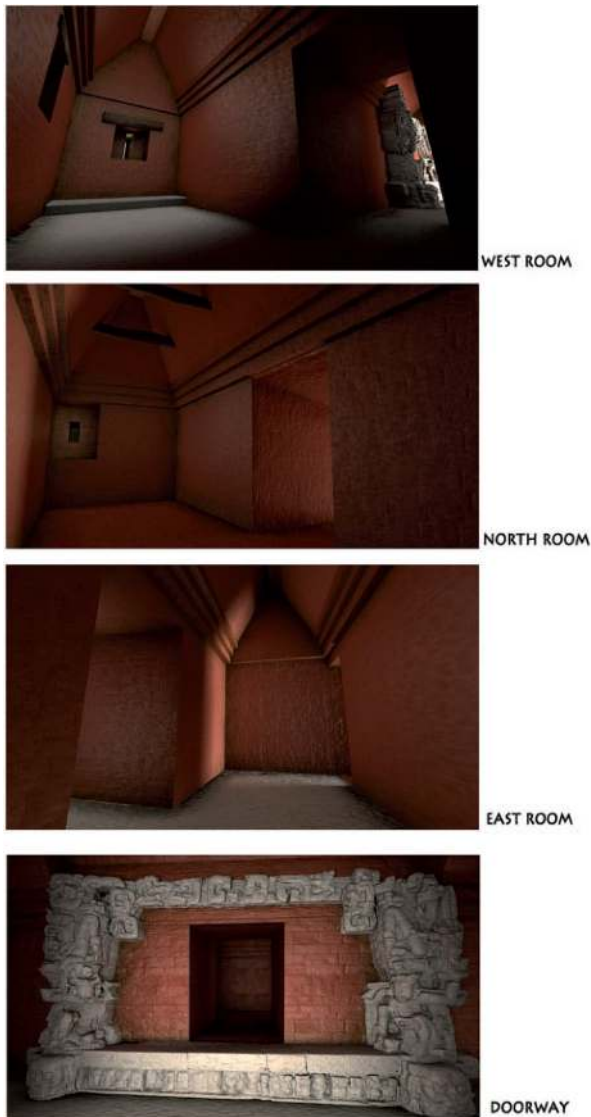
Figure 3. Interior views of high-definition model of Temple 22 used to simulate lighting in the interior rooms. (3D model created by R. Maqueda)

(Computer Applications and Quantitative Methods in Archaeology), CIPA (International Committee for Documentation of Cultural Heritage), and the recently founded peer-reviewed journal Digital Applications in Archaeology and Cultural Heritage.

1.2 3D models in ancient American archaeology

Most applications of 3D archaeology focus on archaeological sites in Europe or the Middle East;

however, the acquisition of reality-based data for 3D models also is increasing for the archaeology of the ancient Americas (e.g. Reindel and Wagner, 2009; Lambers *et al.*, 2007). As for current 3D projects that deal with the remains of the ancient Maya specifically, some are engaged with high-resolution scanning of individual sculptures for conservation and analysis and are considering ways to offer them online. These include Harvard University's Corpus Project (Tokovinine and Fash, 2008; Fash 2011a, 2012), the MayaArch3D Project summarized here (see also Remondino *et al.*, 2009), and the Mesoamerican Three-Dimensional Imaging Database (Doering and Collins, 2009) (http://www.famsi.org). Other web-based applications, like CyArk, use Google Earth and make point clouds available of whole Maya structures (http://archive.cyark.org). Meanwhile, some archaeological projects in the Maya area have published static maps on the web with links to still views of 3D reconstructions (http://www.papacweb.org/copan.html), whereas other projects such as the Palenque Map provide interactive maps with Quick Time VR panoramas as well as fly-throughs of 3D buildings (http://learningobjects.wesleyan.edu/palenque/explore/). The Maya Skies project has gone further to link 3D reconstructions and animations of buildings not only to a map but also to an archaeological database (http://Mayaskies.net). The La Blanca Project in Petén, Guatemala, an archaeological project carried out by the University of València, the Polytechnical University of València and the University of San Carlos in Guatemala since 2004 (http://www.uv.es/arsMaya), also has linked scanned data with simulated models of ancient buildings created in CAD programs such as 3DStudioMax or SketchUp and has built prototypes of online tools to analyze the 3D data and to display the results of excavations and hypothetical reconstructions. Such 3D visualizations obviously are effective ways to educate the public about Mayan cultural heritage. One can even now download apps of reconstructions of Maya temples (http://www.Maya-3d.com) for use on mobile devices. In sum, 3D documentation is becoming a new standard for accurate, reality-based archaeological documentation, research, and visualization of results in Maya archaeology.
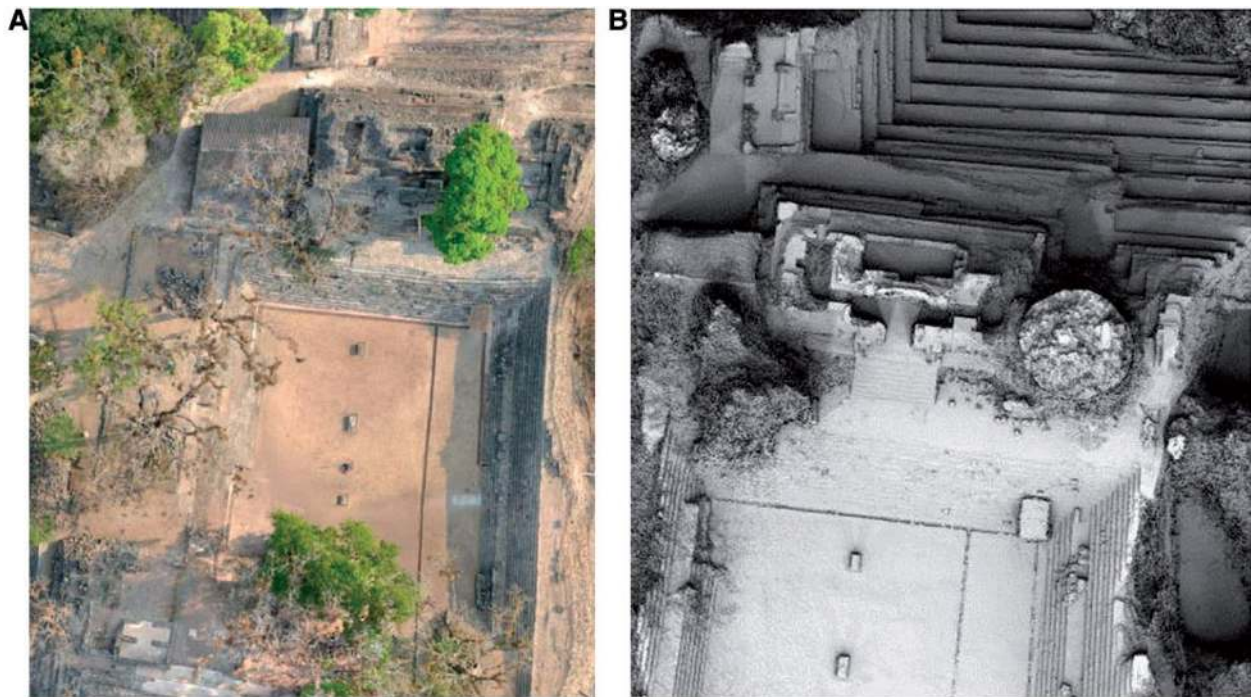
Figure 4. Results from unmanned helicopter flights over the East Court of Copan and Temple 22 to capture images for aerial photogrammetry. Right: Surface model with 5 cm resolution. Left: Orthophoto with 1 cm resolution. (Graphic: H. Eisenbeiss)

1.3 Limitations of 3D models for archaeological and art historical inquiry

The dissemination of these 3D data or products, however, still is limited due to developing countries' limited access to hardware, software, and sufficient band-width. The 3D models therefore present challenges for enabling public access and longer term digital use/preservation (e.g. copyright issues or large files sizes that make them difficult to visualize via the web), and as a result they often only are published via 2D images in printed journals. Thus, most 3D models cannot be measured or compared with each other in any way, and it is difficult to share source models between users. Moreover, although powerful 3D visualization tools do exist, they implement either no or only limited query functionalities for data retrieval. Additionally, most 3D models themselves are not digitally linked to scientific data and not contextualized in their broader spatial and/or temporal context.

These limitations become problematic when an art historian or archaeologist, for example, wants to
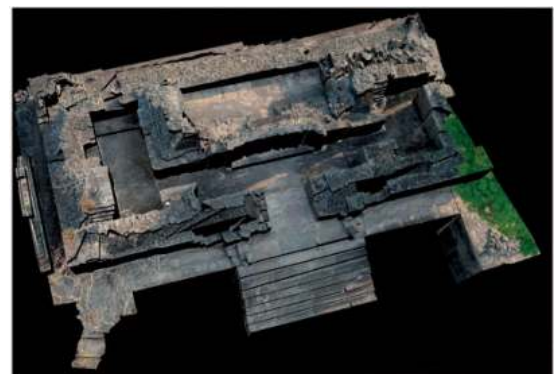
Figure 5. Reality-based 3D model of Temple 22 generated from laserscan data. (Graphic: F. Remondino)

analyze a temple within its urban context to understand its relationship to other temples, and changes in temple and urban design through time. To reveal spatial and temporal patterns, scholars need to be able to compare structures in both quantitative and qualitative ways and to analyze them within their larger spatial and temporal context, and along with their associated archaeological data (Robertson
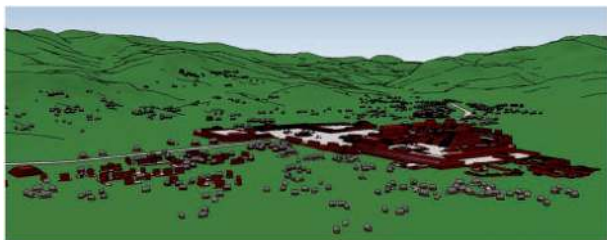
Figure 6. VR Environment—created using georeferenced building footprints in SketchUp—View facing northeast and overlooking Principal Group (SketchUp model by H. Richards-Rissetto)

et al., 2006). For example, a research project comparing temples built >100 years at Copan and commissioned by three different rulers. These temples were part of an urban context, and surely their messages were intended to convey to a larger audience throughout the city; therefore, we need a tool that will examine the temples at multiple scales and perspectives and allow us to address questions such as: how did the messages change, or the intended audiences change, between the reigns' of different rulers? How were temples, similar or different in their relationship to the natural landscape, or to the urban settlement at large? Specific methods of inquiry that such a tool could assist with would be:

1. *Distribution* (Figure 7): How did the distribution of freestanding monuments such as stelae in space and time between the reigns' of different rulers? What were the spatial and temporal distribution of forms, symbolism, and texts? Do patterns exist between the content and spatial location (interior, exterior, lower story/upper stories, etc.) of motifs/glyphs on the temples that inform on message and audience?
2. *Accessibility* (Figure 8): Which residential groups had the easiest access to the temples? What were possible ritual procession routes between ceremonial sites, and what was their relationship to natural features in the landscape such as mountains or springs? What was the accessibility of ceremonial sites in comparison with residential sites and in relation to temples in the civic-ceremonial center as well as the natural landscape?
3. *Visibility* (Figure 9): What was the overall visibility of hypothesized civic-ceremonial sites (e.g. Group 8L-10), visual connections between civic-ceremonial sites as well as to which social groups they were most visible? Which temples were more visible from the elite residences to the East? How could visibility inform us about possible boundaries for ritual activities?
4. *Orientation to the urban and natural landscape* (Figure 10): What was the spatial alignment of temples in relation to (1) other ceremonial structures in the urban landscape and (2) mountain peaks and horizon markers in the natural landscape and what might this tell us about cosmological associations of space and place in ancient Copan?

1.4 Geographic information systems

For these types of approaches, Geographic Information Systems (GIS)—linking map features to searchable databases—currently are better suited because they include queries as standard functions and allow for spatial and temporal analyses of relationships, patterns, and trends that are not evident when using traditional, non-spatial, databases (Lock 2000; Wheatley and Gillings, 2002; Conolly and Lake, 2006; Bodenhamer *et al.*, 2010; Zerneke *et al.*, 2006). Archaeologists began to use GIS in the 1980s to create, manage, and analyze geographically referenced information. For example, early archaeological research applications analyzed artifact distributions or predicted site locations. More recently, archaeologists have begun to perform visibility, accessibility, and network analyses in GIS to quantitatively explore the structure of ancient societies and the relationships between anthropogenic and natural phenomena.

1.5 GIS in Maya archaeology

Maya archaeologists are using GIS in diverse ways. For example, to understand sites in a landscape context, archaeologists are combining remote sensing technologies (such as satellite imagery and airborne LIDAR) with GIS to discover new sites and offer new understandings of ancient Maya kingdoms such as at Caracol (Chase *et al.* 2011) and
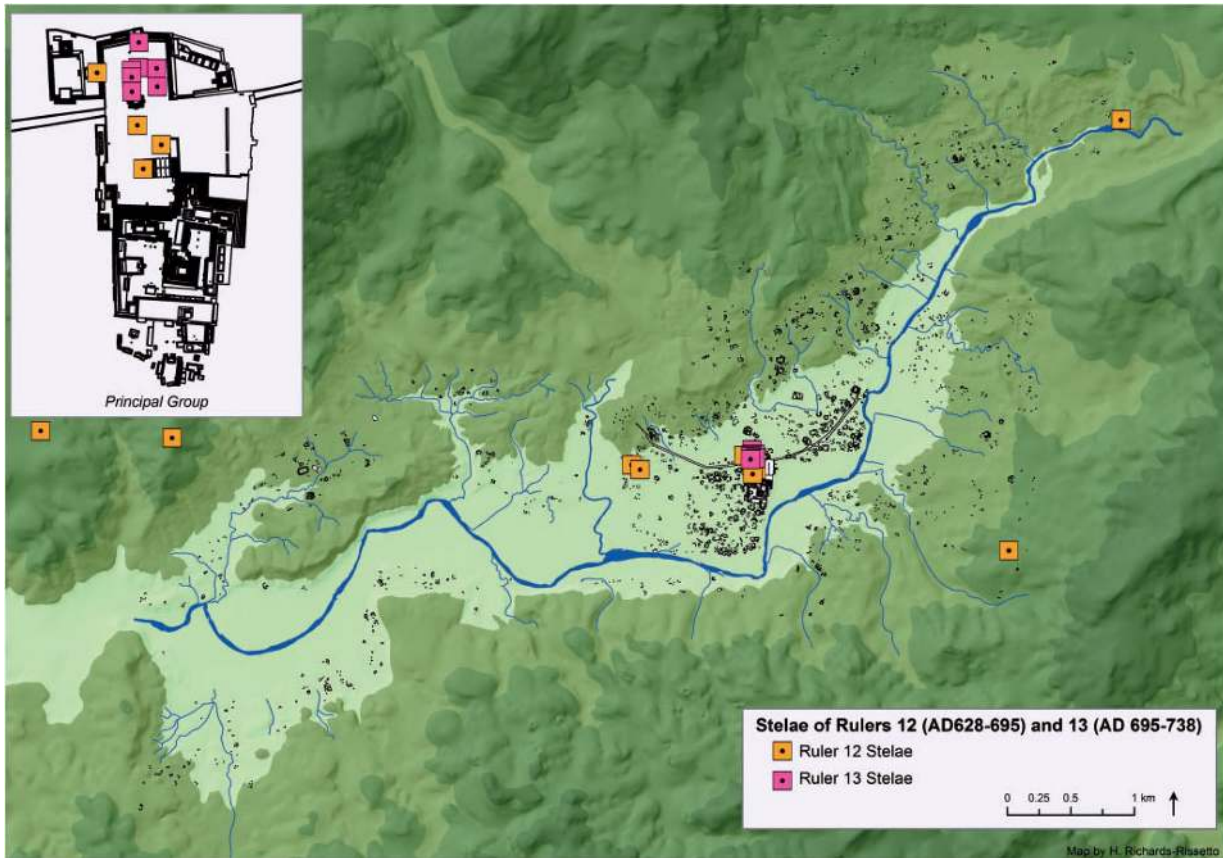
Figure 7. Distribution of Stelae for Rulers 12 and 13- Copan GIS (Map by Heather Richards-Rissetto 2011)
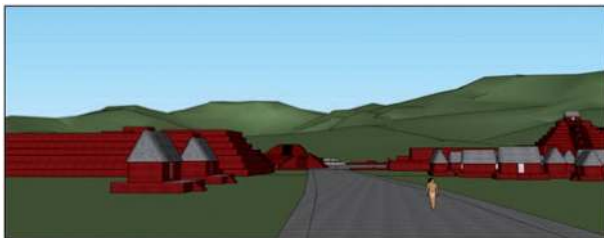

Figure 8. Accessibility: Western *sacbe* leading to Copan's main civic-ceremonial complex (SketchUp model by H. Richards-Rissetto)

San Bartolo (Saturno *et al.* 2007). Researchers have applied GIS and aerial photos to predict site locations in the Yucatan peninsula (Podobnikar and Sprajc 2010). GIS also has been used for visibility studies to reconstruct site lines and identify intergroup connections and ancient political boundaries (Hammond and Tourtellot 1999; Richards-Rissetto 2010; Doyle *et al.* 2012). The only project that

makes GIS data on Maya archaeology available online for research, however, is the Electronic Atlas on Ancient Maya Sites. This project uses GIS as a repository to store the locations of Maya archaeological sites and to create maps that overlay these sites on terrain, hydrology, or other features to illustrate polity size or political boundaries (http://Maya-gis.smv.org/). One issue of concern is to what extent GIS data should be made available to the public, given the endemic looting that is significant at archaeological sites in Latin America. User management systems are useful in this way and can allow for password-protected access to sensitive data, particularly real-world coordinates or overlaying satellite imagery. The MayaArch3D Project has planned to institute five levels of user access ranging from most restricted access for the public to open access for internal researchers, and in this way can address concerns about looting.
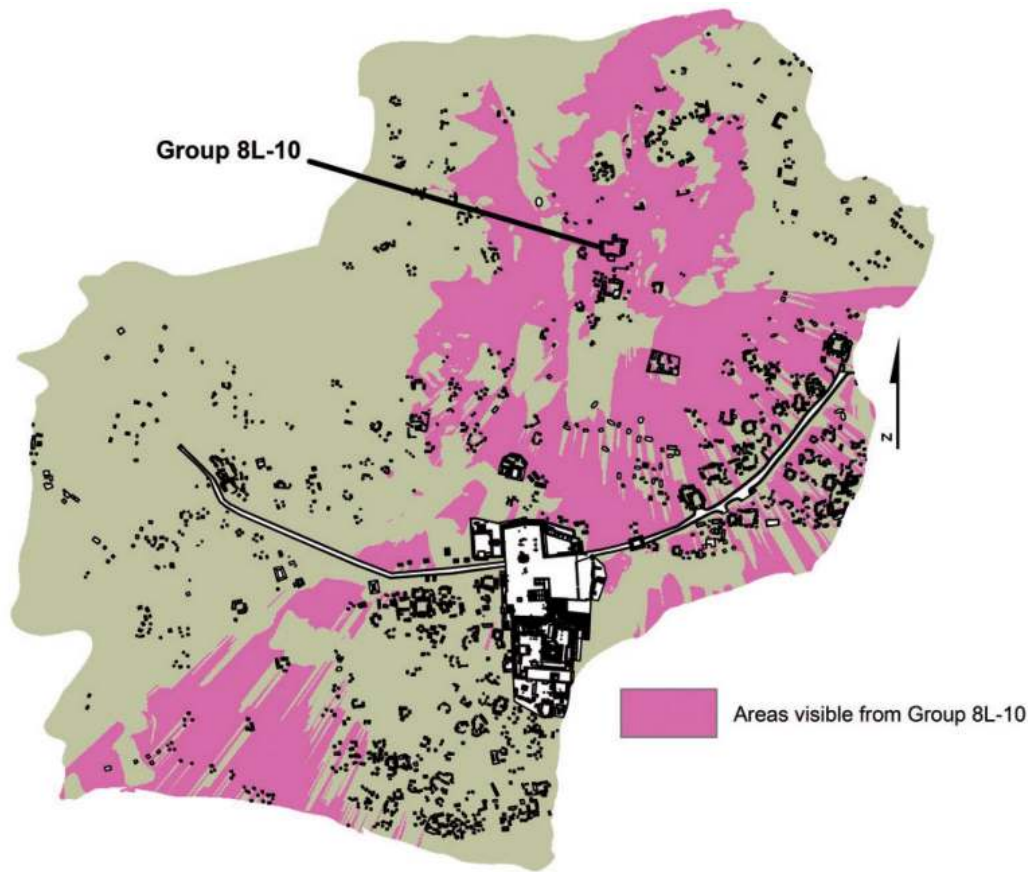
Figure 9. Visibility: Viewshed of hypothesized civic-ceremonial group (8L-10) in Copan's urban core, derived using GIS (Map by H. Richards-Rissetto)

While Maya archaeologists currently use GIS, the ability to link GIS data to 3D models online would expand research possibilities dramatically. For example, Heather Richards-Rissetto created a GIS for Copan to study the visual and spatial relationships between built forms and natural landscape features (Figure 11). The GIS of Copan's archaeological and topographical features covering over 24 km^2 (Richards-Rissetto 2010, 2012) provides the data required to investigate the accessibility and visibility of different types of architecture at Copan and then relate these findings to possible levels of social interaction. Soon however, Richards-Rissetto realized that the 2D perspective of GIS maps limited her interpretations. For example, viewsheds calculated in GIS identified what could be seen from fixed vantage points at Copan,

but it is not possible to 'get on the ground' to view the results from a pedestrian perspective (see Figure 8). Because GIS software was created to handle mainly terrain models (i.e. 2.5D data), it falls short when dealing with real 3D models (e.g. a building with interior).

1.6 State of the field in linking GIS and 3D models

In the humanities, Geo-browsers, or 'virtual globes' (such as Google Earth, NASA's World Wind, and ESRI's ArcGIS Explorer) are the most common solution to 'link' GIS to 3D models. For example, the Digital Karnak Project, which traces the development of a temple precinct in Egypt from its origins as a local shrine to a powerful center, has a time slider that enables users to visualize changes (using 2D site plans) in the temple precinct through-
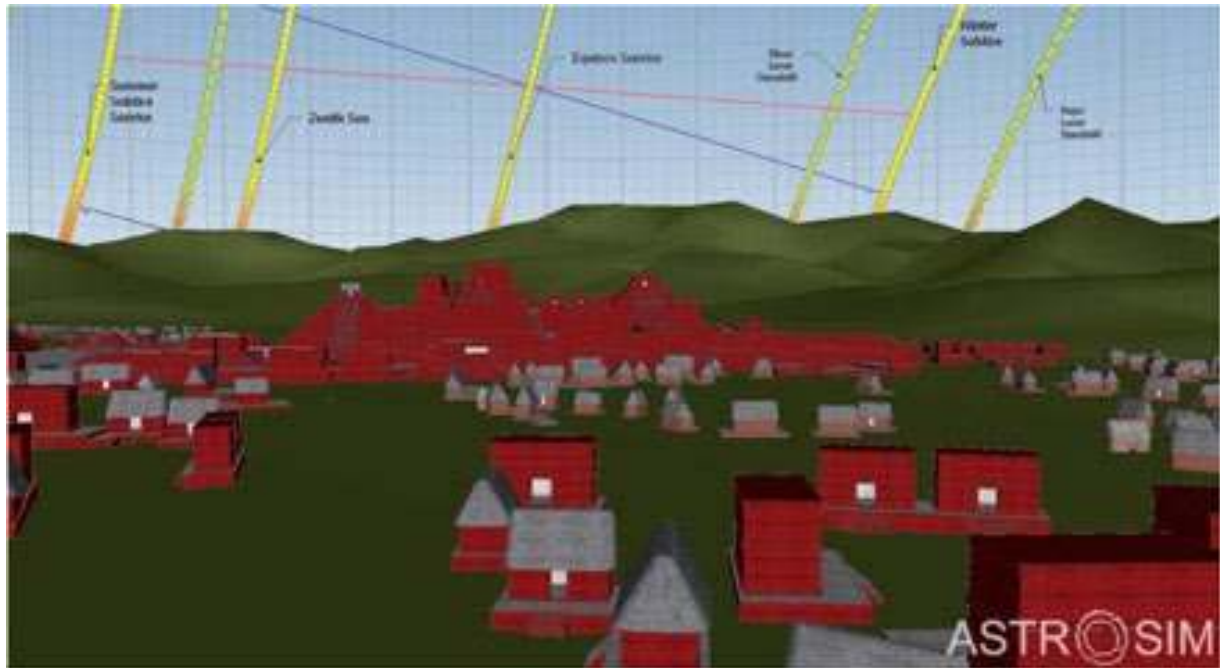
Figure 10. Orientation: View of eastern sky solar alignments in 8th Century, Copan—visualized using Stellarium Scenary3D Plugin and SketchUp (3D SketchUp model by H. Richards-Rissetto and G. Zotti)

out its 3,000 year history (http://dlib.etc.ucla.edu/projects/Karnak/google_earth). For users to track in 3D the construction phases of the Temple of Karnak through time, the system uses Google Earth's time slider. However, more complex interactive queries are not implemented in Google Earth because this and other existing geo-browsers cannot query the 3D models against a database. It is not possible, for instance, to select all 3D models of structures in a city/site built between a certain time intervals, or planned by a certain architect/ruler. Finally, geo-browsers cannot visualize big and complex polygonal models. Because of these limitations, GIS and geo-browsers are not ideally suited to more recent approaches in archaeology and art history that are concerned with 3D space, such as performance studies, phenomenology and aesthetics, the relationship of architecture to the landscape, and archaeoastronomy.

Some of the first experiments in 3D WebGIS include the Via Appia Antica Project—which developed a specific tool in Open Scene Graph (Forte *et al.*, 2005) that integrated topographic landscapes with 3D architectural models in a VR environment to offer interactive virtual exploration and multi-perspective experiences. There are some '3D GIS' software products (such as ESRI's CityEngine) that can rapidly build virtual cities, but they have two shortcomings: (1) they are based on procedural modeling; in other words, they create buildings with standard geometries and textures (not useful for studying aesthetics) (taking accurate measurements) and (2) they do not perform complex 3D spatial analyses. These systems cannot be used, for example, to model the aesthetic experience of ritual processions while simultaneously quantifying how far away a certain sculpture on a temple could be seen as people walked in this procession. This type of analysis still has to be done using separate GIS and 3D modeling systems.

Given the state of the field summarized earlier in the text, our goal for the QueryArch3D tool is to combine the benefits of 3D visualizations with the analytical capabilities of a GIS to enable online real-time comparisons and analyses of multiple types of data. In other words, as one reviewer elegantly put it: "If these two distinct approaches to modeling reality could 'talk to each other,' one could do
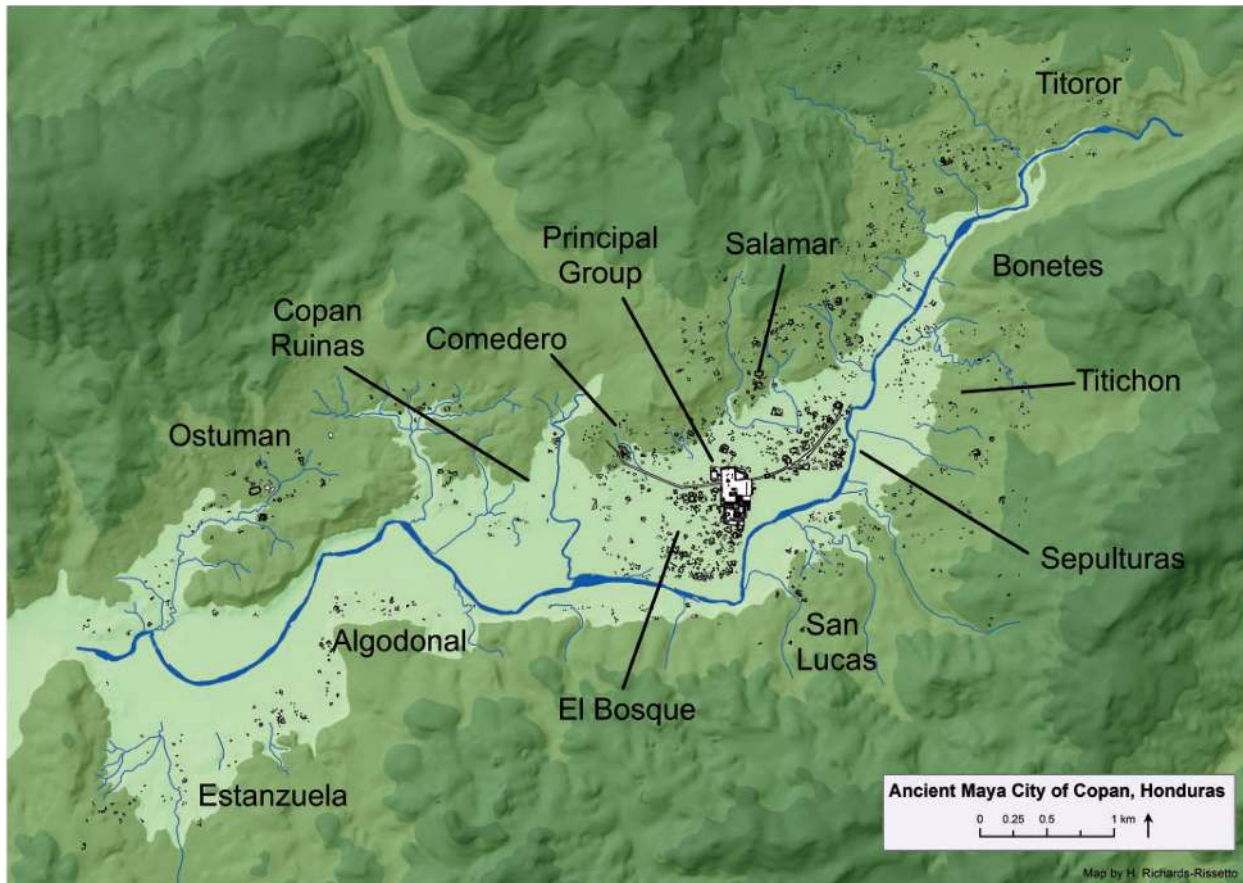
Figure 11. Copan GIS. Vector data (archaeological structures and hydrology) on Digital Elevation Model (DEM) (Map by H. Richards-Rissetto)

research inside the 3D model (or its hosting environment)." To be able to perform interactive queries on high-resolution models and change parameters "on the fly" (e.g. restrict access to spaces based on gender or class) would significantly enhance research and education on ancient architecture and landscapes.

2 QueryArch3D — A 3D Web GIS for Maya Archaeology

To address these interdisciplinary needs, the MayaArch3D Project developed a new computing pipeline and built a prototype tool for an online, searchable repository — called *QueryArch3D* — that brings together GIS, 3D models, and virtual environments for teaching and research on ancient ar-

chitecture and landscapes. Developed in 2010 in collaboration with Fabio Remondino and Giorgio Agugiaro at the Bruno Kessler Foundation (FBK) in Trento, Italy, and Gabrio Girardi at Graphitech, in Trento, Italy, the QueryArch3D tool stores CAD, reality-based and hybrid models and attribute data in an open source spatial database and then makes them queryable via a VR environment. What is unique and technologically cutting-edge about QueryArch3D is that it enables users to:

1. Integrate and visualize 2D and 3D data at "multiple resolutions"

2. Link 3D models to archaeological data and perform attribute and "spatial" queries

3. Visualize, compare, and analyze 3D buildings and artifacts — all in a single "online" navigable VR landscape

2.1 Technical features

The development pipeline for QueryArch3D has been described in detail elsewhere (Agugiaro *et al.*, 2011) but to summarize — the tool has two main components: (1) data modeling and storage in a database management system and (2) 3D visualization. The database management system uses the free and open source software PostgreSQL with the PostGIS extension. Dr Agugiaro determined a pipeline for importing and exporting standard GIS formats from/to PostgreSQL (i.e. using ArcGIS and its Data Interoperability extension or, alternatively, by means of the open-source GDAL library) and a way to import/export the *.obj file format for triangulated 3D geometries. Structural hierarchies and ontologies (i.e. what is a wall, roof, etc., and how do they relate to each other) were created. Normally, direct access to 'standard' attribute tables can be implemented using forms embedded into HTML; however, a suitable interface (i.e. QueryArch3D) needed to be developed for graphical access from a 3D viewer.

For the interactive navigation and 3D visualization, the tool uses Unity, a game engine development tool (Figure 12). A PHP interface links Unity and PostgreSQL allowing the data retrieval from the database and the (on-line) visualization. Users can download a free web player plugin for Unity to use the tool online or offline. The system is organized into four LoD for the different geometric structures (Figure 13).

The prototype tool currently contains data from the archaeological site of Copan. In terms of 3D models/visualizations, the tool contains:

1. A virtual landscape of Copan site that covers 24 km^2

2. 3D schematic models of over 3,800 ancient structures

3. A 3D Studio Max model of an 8th century temple

4. Reality-based 3D models of sculptures and stelae

As users virtually navigate through Copan's ancient landscape, they can click on structures, stelae, and even architectural features within a structure to query a small set of test data from the database. The prototype includes only a few attributes: structure names, group names, site type, and in which ruler's reign a structure was dedicated. In the current phase of the project (introduced later in the text), we are linking the 3D models to many more attributes including archaeological data as well as photos, and drawings and their metadata.

2.2 Analyses currently possible

Currently, users of the tool can visualize and query a limited set of 2D and 3D archaeological data of different types and resolutions and perform simple spatial and attribute queries of data in a virtual landscape context. For example, users can view high-resolution 3D models of sculpture and architecture, rotate and click on the models for attribute information and additional images. Users can perform line-of-sight analysis. They can also query the database to highlight, for example, all stelae erected by Ruler x or all structures belonging to a particular neighborhood. To segmented structures, we have linked photographs and text. Another tool in the system is a basic measurement tool that allows users to measure architectural elements and distances between features (Figure 14). For permitted users, the database can be edited online using a Graphical User Interface.

2.3 Beta -testing results

Beta-testing of this prototype was carried out in Fall 2011 with 100 researchers, students, and educators in the humanities at five universities in Europe and the United States[2]. Most participants were anthropology and art history students (graduates and undergraduates) aged between 15 and 35 years, who had little experience with 3D models and were interested in the tool from an educational standpoint. Five anthropology and archaeology professors 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 ~30 min 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. plat-

Figure 12. QueryArch3D tool showing different data visualization modes and query functions

form (MAC or PC), browser, RAM], most and least popular features, and most important features for immediate development.

Testers unanimously were enthused about the tool, particularly at having the ability to:

1. enter and manage information online and to work in real-time using the online query and analysis capabilities
2. navigate online through a virtual model of an ancient Maya city
3. access higher resolution models of objects in context (of building/landscape)
4. query the archaeological database via 3Dmodels and vice versa

Suggestions for improvement to the tool centered on:

1. initial download time
2. improving user interface (changes to navigation commands, adding 2D navigation map and a text search box)
3. adding more data to the database
4. adding textures and transparency to models
5. implementing a broader range of spatial queries
6. allowing more complex queries of the database
7. adding a time-slider

The aforementioned features are useful for public education—in that the 3D virtual environment
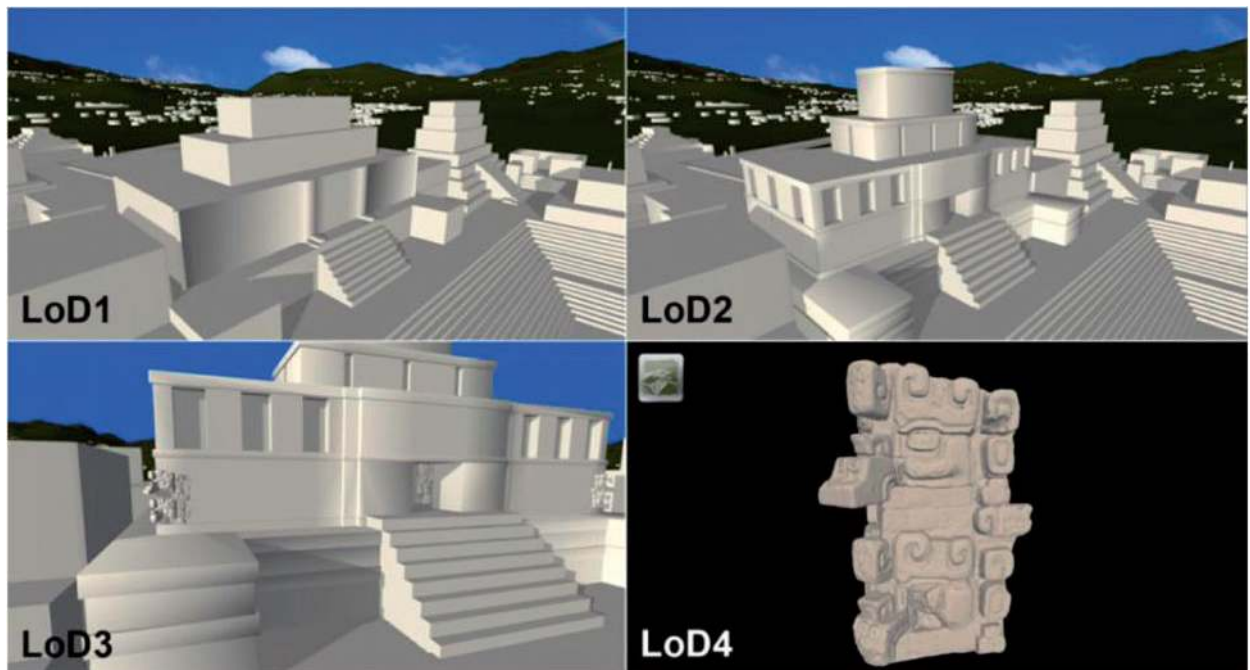
Figure 13. Different LoD in the QueryArch3D tool, Temple 22 models. Clockwise from top-left: LoD1 with prismatic geometries, LoD2 with more detailed models (only exterior walls), LoD3 with interior walls/rooms and some simplified reality-based elements, LoD4 with high-resolution reality-based models. (Graphic: Giorgio Agugiaro)
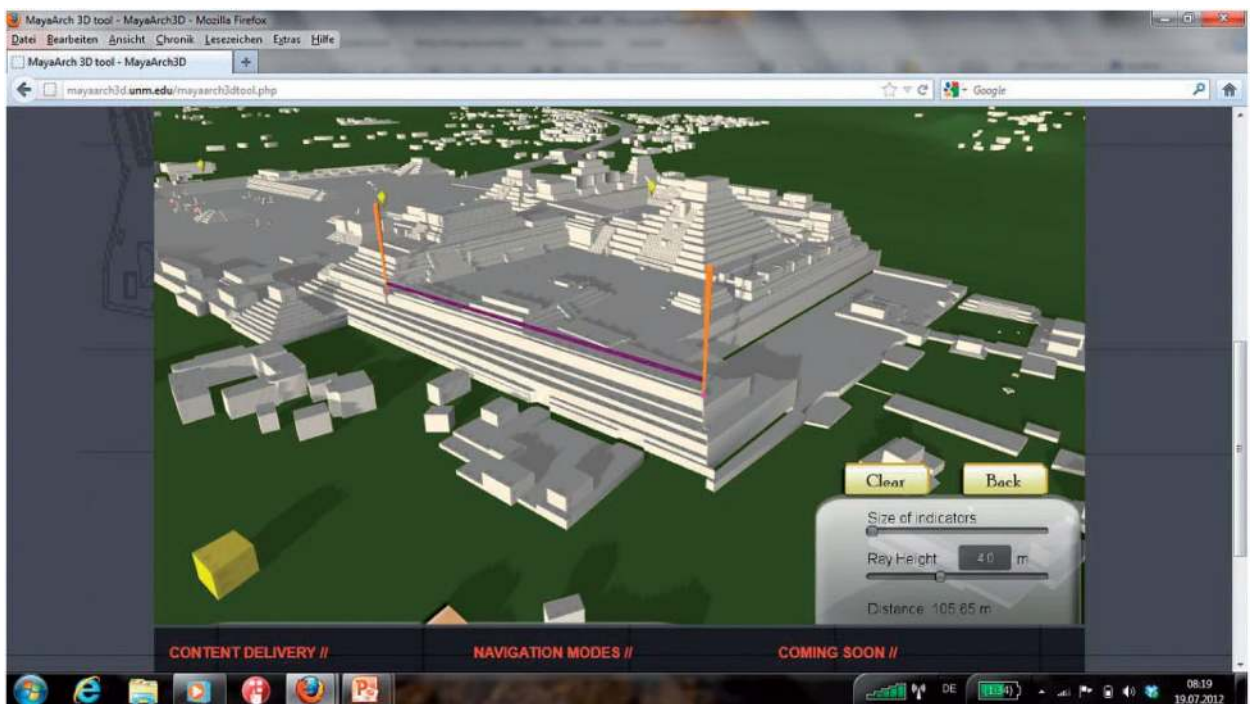
Figure 14. Measurement Tool in QueryArch3D

stimulates student interest and enthusiasm by bringing complex sets of data together in a visual and tangible way and allows for interactive exploration. This tool is ideal for interactive museum installations and initial tests have been made into applications of QueryArch3D using Microsoft's Kinect for gesture-based interaction (Richards-Rissetto *et al.*, 2012, 2013).

The research utility of the tool is focused at this point on visual analysis and database queries; that is, bringing together various 3D and GIS data of different types and resolutions in a single virtual environment where researchers can query the 3D models against the database as well as execute line of sight queries and distance measurements.

2.4 Discussion, current research topics, and next steps

What we currently have is a prototype and various limitations and difficulties came to light during its development and testing. The project's next stage will focus on data collection and tool development to permit more complex analytical functions and test the tool's utility for applied research. We are considering new software and navigation tools, modifying and expanding the database and user-interface, implementing database storage procedures for the textures contained in the *.obj files, and expanding the GIS functionality of the tool. For example, in addition to line of sight, which already exists in the tool, it should calculate visibility (field-of-view). It should also be possible to calculate azimuth (based on 360 degree compass) and perform complex SQL queries (e.g. Ruler x OR Ruler y AND elevation z). It also is crucial to have the ability to visualize and analyze temporal data to investigate change through time, which is not currently in place.

Finally, a transparency function that allows the viewer to compare architectural reconstructions with reality-based models is also necessary. To be transparent about the certainty of reconstructions, the system currently shows a photograph of the building when a user clicks on a model. In a future version of QueryArch3D, we intend to have the ability to move back and forth between reality-based models and CAD reconstructions as in the Via Flaminia project (Forte *et al.*, 2006) as well as

to allow users to review the data that were used for the reconstructions (e.g. plan views, drawings, etc.) that are stored in the archaeological database. We have selected these particular functions to add to QueryArch3D because they will allow for a multi-scalar, visual, and spatial study of Copan's urban landscape, which in turn will demonstrate what kinds of empirical research can result from using 3D GIS for art historical and archaeological research.

In addition, we must address some technological problems associated with using Unity for the visualization component of QueryArch3D. Because Unity is a game engine, it was not conceived to handle spatial and reality-based data, and thus works best with relatively low-resolution data. As a result, it was designed to load all data at start-up (i.e. a videogame level). This results in two key technological problems. First, high-resolution 3D models must be split into sub-models and optimized into less detailed polygonal models — this is both time-consuming and results in data loss. To overcome this limitation, we need interactive streaming of data, depending on the position and field of view of the user. Second, there is some waiting-time when the tool is started. This can be problematic when using the tool online because load time depends on internet speed — an issue that is relevant to users in some countries, we have tested like Honduras with slower broadband connections.

Fortunately, because this pilot project has demonstrated great potential, a research project to develop a new tool in light of the prototype's limitations began in August 2012 with support from the eHumanities program of the German Ministry for Education and Research. This is a collaboration with the German Archaeological Institute's Department for the Archaeology of Non-European Cultures in Bonn and the Chair of Geoinformatics at the Institute of Geography at the University of Heidelberg, as well as the existing partners of the University of New Mexico and FBK, Trento. The work will focus both on data collection and on re-designing the tool in light of the beta-testing results to allow scholars to analyze architecture and landscape within an integrated system to discover relationships that otherwise would not be apparent. We expect that tra-

ditional research questions and methods will be enhanced, and that the tool will enable new ways for scholars to study ancient urban environments using 3D WebGIS.

3 Conclusions

Based on our experience in this project, we summarize a few critical issues with regard to the possibilities of 3D WebGIS for humanities research:

1. Building a 3D WebGIS relevant for research requires a team that includes humanities scholars and experts in geo-informatics, database systems, remote sensing, and 3D modeling. We found that because project members came from diverse fields they had different interests, goals, and needs (e.g. research, funding, and publication). For these reasons, it is important that the project be a stimulating research effort for all, and everyone must keep in close contact throughout the project.

2. Another challenge is that 3D technologies are typically expensive, but this is changing quickly with the development of WebGL. Everybody's concern is, of course, how 'future-proof' the tool might be. QueryArch3D uses the Unity game engine, which is not open source, and thus we cannot rely on the continuance of the free plugin. To address this risk, we are considering open source software options and are using standards for data collection and storage so that the data can be imported to the next tool.

3. To develop such a tool certainly requires considerable funding, but we intend to build an open-source tool that will be useful, with some adjustments, for other archaeological projects around the world that work with both 3D models and GIS. In this way, we can help to lower future costs for archaeological projects, as they seek tools for working online with their complex archaeological data.

4. Of course, the analysis of spatio-temporal artifact distribution on an urban scale requires massive amounts of data collection and stan-dardization by trained researchers. This requires a multi-year data entry project, ideally done by students entering data that are related to their individual research projects. The educational, research, and financial benefits of structuring data entry to overlap with student research projects is not to be underestimated and the next phase of the MayaArch3D project will follow this strategy.

In conclusion, the good news is that 3D WebGIS has significant implications for all kinds of Digital Humanities work that requires visualizing and analyzing 2D and 3D data in a geo-referenced spatio-temporal context. By combining the strengths of GIS and 3D models, QueryArch3D brings together strengths of both the humanities and the sciences, for we gain the ability both to quantitatively measure and to perform aesthetic and experiential analysis. The tool's ability to visualize and analyze models of different types and resolutions ranging from reality-based to 3D Studio Max and SketchUp reconstructions offers models of buildings as they look today situated within a simulated landscape to convey a sense of space (as it 'existed' in the past) that fosters visual learning. Such a tool will challenge researchers to develop new space-based research questions and methods for studying ancient urban environments. As one Maya archaeologist said, 'just being able to walk around in ancient Copan and see things I had not seen before elicited new ideas and questions.' In sum, tools like QueryArch3D can provide users with a VR experience on their laptop computers that links queryable 3D models to underlying archaeological data, thus enhancing art historical and archaeological analysis and fostering the circulation and comparison of ideas. This leads to the most important conclusion of this start-up project—that 3D WebGIS is poised to offer a new level of international, collaborative work in the humanities and social sciences.

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Notes

1. The virtual reconstruction of Temple 22 from Copan (A.D. 715) was elaborated by the Virtual Heritage Lab at UC Merced, under the supervision of Maurizio Forte and Jennifer von Schwerin. The models were made by students Fabrizio Galeazzi and Raul Maqueda based upon a previous wireframe model made by Laura Ackley for the project in 2001. Following this, Forte, Kurillo (UC Berkeley) and Maqueda worked on optimizing the new models for a Teleimmersive System created at UC Berkeley and UC Merced thanks to a grant sponsored by CITRIS. The Teleimmersive System for Archaeology was created to enable researchers at different locations to collaboratively, simultaneously and virtually work with 3D models.

2. University of New Mexico (USA), University of Merced California (USA), California State University Stanislaus (USA), University of Bonn (Germany), and Umeå University (Sweden).