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An iterative 3D GIS analysis of the role of visibility in ancient Maya landscapes: A case study from Copan, Honduras

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Abstract
For several decades, Geographic Information Systems (GISs) have held center stage in archaeological studies of ancient landscapes. Recently, three-dimensional (3D) technologies such as airborne LiDAR and aerial photogrammetry are allowing us to acquire inordinate amounts of georeferenced 3D data to locate, map, and visualize archaeological sites within their surrounding landscapes. GIS offers locational precision, data overlay, and complex spatial analysis. Three-dimensionality adds a ground-based perspective lacking in two-dimensional GIS maps to provide archaeologists a sense of mass and space more closely attuned with human perception. This article uses comparative and iterative approaches ‘tacking back and forth’ between GIS and 3D visualization to explore the role of visibility in conveying sociopolitical and ideological messages at ancient Copan—today a UNESCO World Heritage Site in Honduras. A two-prong approach comprising computational and experiential components explores the potential role of visibility in sending messages that participate in the shaping of social interaction on a daily basis. The organization of built forms within the natural landscape created spatial configurations that sent visual messages targeting specific different groups, subsequently influencing how people negotiated their physical surroundings and the frequency and intensity of social interactions. The ancient Maya belief that sight played a key role in structuring everyday experiences because it triggered perception in the other senses thus serves to bridge the computational and experiential results in this case study.

1. Introduction
The ways in which ancient peoples arranged their physical surroundings—that is, their built environment—provide a window to the past (Ashmore, 1991; Lawrence and Low, 1990; Moore, 2005; Smith, 2007). Most studies of ancient Maya built environments view the spatial organization of site centers, houses, monuments, and even roads as a reflection of ancient Maya cosmology linked to the heavens, earth, and underworld (Ashmore and Sabloff, 2002; Houk, 1996; Maca, 2002). Recently, however, scholars have begun to explore site organization not simply as a reflection of ancient life but...
also as a mechanism that shaped it (Giddens, 1984; Moore, 2005).

In many ancient societies, cosmology, that is, the order of the cosmos, provided the template and legitimation for social structure. However, it was the daily routinization of these social categories that reinforced cosmic and social order. The organization of temples, houses, roads, and other features created spatial configurations that routinized how people negotiated their surroundings on a daily basis. People ‘read environmental cues, make judgments...and then act accordingly’ (Rapoport, 1990, p. 139), and these decisions in turn affect the frequency and intensity of interaction (Fletcher, 1981). While many factors influence interaction and experience within landscapes, this research focuses on visibility. The visibility, intervisibility, and invisibility of features communicate information that guides pedestrian movement, and consequently structures social interaction and community organization (Bernardini et al., 2013; Gillings, 2015; Kantner and Hobgood, 2016; Kosiba and Bauer, 2013; Llobera, 2003, 2006, 2007; Richards-Rissetto, 2010). Building on these ideas, this article uses Geographic Information Systems (GISs) and three-dimensional (3D) visualization, alongside epigraphic, archaeological, and ethnographic data, to explore the role of visibility in ancient Maya landscapes asking two main questions:

- How visibility might have served as a cultural mechanism to send targeted messages to influence where people went, what they did, and who interacted with whom? And
- How, in turn, did these interactions shape people’s daily experiences and possibly influence the establishment, maintenance, or transformation of social structure?

The case study is the ancient Maya polity of Copan (Fig. 1). Today a UNESCO World Heritage site located in Honduras, but from the 5th–9th centuries CE, Copan was a cultural and commercial crossroads at the southeast periphery of the Maya world. For over 400 years, a line of dynastic kings ruled Copan, but by the late 8th century, the kingdom was facing mounting sociopolitical and environmental problems (Fash, 2001). Copan’s final dynastic ruler, Yax Pasaj, like the rulers of many other Maya polities, was coping with strenuous environmental, demographic, and sociopolitical circumstances that would ultimately lead to the kingdom’s demise. Yet during this time of stress, it seems that Yax Pasaj carried out a major urban renewal project commissioning several new temples in the city center that elevated Copan’s skyline (Maca, 2002). Given the changes to Copan’s urban fabric, Yax Pasaj’s reign is an ideal case study to investigate the role visibility may have played in the (re)production of sociopolitical and ideological messages that shaped ancient Maya daily experience and potentially helped to establish, maintain, or transform social structure in a late 8th century Maya city.

2. Maya Perspectives of Vision and Visibility

For the ancient Maya, vision was multi-faceted. Research on Maya iconography indicates that the ‘senses were linked in near-synesthetic fashion, with stimulus in one modality—sight—triggering perception in the others’ (Houston et al., 2006, p. 134). Protruding eyeballs and excised eyes illustrate that sight was projective and procreative suggesting that for the Maya ‘the act of seeing’ actually affected and changed the world. People were not passive recipients—the ancient Maya believed that what they saw affected what they did, how they felt, and how they interacted with the world around them. Not surprisingly, given Maya animistic beliefs that people, animals, and things had essences, the emanating power of vision extended to human-built forms. For example, carved portraits on stelae had the ‘emanating power of vision’ serving as an extension of the actual person, thus enabling them to gaze outwardly over an audience (Houston et al., 2006).

Along these lines, epigraphic decipherments indicate that sight had an authorizing gaze and witnessing function—similar to Foucault’s (1995) panoptic gaze—where those who are all-seeing are all-knowing (Houston et al., 2006, p. 173). The preponderance of Maya sight glyphs reflects the importance of vision. The root –il refers to sight, and
the prevalence of the verb, *ila-aj* or *y-ilaji*, ‘to see’ in Maya inscriptions reinforces vision as a mechanism of agency. Epigraphers Stephen Houston, David Stuart, and Karl Taube (2006) interpret the inscription –*ichnal* in relation to the contemporary Yucatec Maya term –*iknal*, which refers to a speaker’s field of view over an audience (Hanks, 1990). Ancient inscriptions reserve the –*ichnal* for rulers and deities reflecting that the individual who ‘sees’ is always someone of high status, an overlord, who is watching over those of lesser status (Houston et al., 2006).

To be all-seeing or to give such an impression, however, Maya rulers needed to be seen, and so seemingly located themselves in physically high and easily visible places or built tall temples that dominated the landscape. At the powerful city of Tikal in Guatemala six royal temples dwarfed their surroundings and at Yaxchilan royal temples were built atop hills above the Usumacinta River; these two examples emphasize rulers gazing over, or down on, those within their *ichnal*, or field of view. At Copan, as at other Maya centers, imagery on ceramics, walls, and freestanding monuments depicted deities floating over lords who successively looked down over lower-ranking persons. Interestingly, the –*ichnal* field of view is typically ‘down’ to purposefully encompass lower-ranking persons (Houston et al., 2006). Polychrome vessels depicting the –*ichnal* in palace scenes with deities placed above a ruler seated on his throne looking down over a visiting noble exemplifies the relationship between hierarchy and verticality (K1728, Kerr, 1995).

Maya architecture replicated this vertical succession by elevating royal compounds above other architecture (Messenger, 1987), not only making rulers more visible but also bringing them closer to the heavens. This mechanism of ‘architectural vertical zonation’ employing building terraces to constitute the many tiers of the universe on earth was often coupled with cosmological imagery. For example, the imagery on Temple 22 at Copan worked in tandem with its three-story design to reflect the Maya universe—a vertical tripartite
division comprising the underworld, the earth, and the heavens. The lowest level’s flower mountain and cave imagery represent the underworld, the middle level with its portrayal of the ruler reflects the earth, and the upper story’s sky, celestial bodies, and patron deity motifs represent the heavens (von Schwerin, 2011). By linking vision and visibility to cosmological beliefs rulers reinforced the idea that they were ‘all-knowing’ not solely through their own vision but also because of their direct ties to supernatural deities and ancestors.

3. Studies of Ancient Maya Visibility

Early visibility studies in the Maya region focused on astronomical alignments between structures, freestanding monuments, and the sky (Aveni, 1980; Aveni and Hartung, 1986). While the ancient Maya typically placed their stelae in front of, on top of, or inside of buildings, at Copan and the nearby site of Quiriguá, the positioning of stelae breaks tradition in the early to mid-8th century (Baudez, 1994; Newsome, 2001; Vogrin, 1989). Many of the stelae erected between 721 and 761 CE were positioned in open plazas and appear to have been aligned to older stelae, linking these monuments not to the sky but to a historical past. However, these spatial alignments are visible only from elevated locations such as platforms or stairways reinforcing the importance of verticality (Vogrin, 1989).

Ethnographic studies showed that contemporary Maya often use sight lines to mark out spaces, inspiring researchers to investigate whether non-astronomical lines-of-sight also existed at ancient sites (Hanks, 1990). In the late 1990s, archaeologists identified sight lines between a major temple at the ancient Maya site of La Milpa, Belize and stelae located on four hilltops in satellite communities. They contend that these sight lines served as daily reminders to the inhabitants of these communities of their connection to La Milpa (Hammond and Tourtellot, 1999; Tourtellot et al., 1999), a relationship that, I would further argue, was emphasized by the constant ‘gaze’ of La Milpa’s ruler represented by the city’s highly visible central temples.

Recent archaeological research has moved away from lines of sight between individual objects to study the visual relationships that an object may have to the many objects or features found within a landscape. Llobera (2003) coined the term visualscape to represent this concept. In the Buenavista Valley of Guatemala, archaeologists investigated changes in the political boundaries of two powerful centers—Tikal and El Zotz—by measuring fields of view from each of the sites’ two main architectural complexes. The results indicate that the site centers had clear views of each other, and their visualscape were non-overlapping; in other words, territorial extent was marked by visual boundaries (Doyle et al., 2012).

These examples show that while line-of-sight measurements provide insight on the alignment of individual objects, we must employ a field-of-view approach to begin to understand the many relationships among built forms and bounded spaces and their broader sociopolitical implications. A field-of-view approach is critical in understanding the role of built forms and bounded spaces among the ancient Maya, who ‘contemplated vision not from a single vantage but in terms of the totality of objects within view, each as a participant in that world’ (Houston et al., 2006, p. 173). Dramatic vistas and awe-inspiring architectural views served not simply as backdrops to events, but rather they served as co-creators alongside people who used sight to interpret visual messages as part of a synesthetic experience (Houston et al., 2006).

4. GIS: Moving Beyond Sight Lines

Traditionally, archaeologists and architects measured sight lines at ancient Maya sites using mapping equipment such as a plane table and alidade, transit, or total station, which afforded only discrete, point to point, measurements—the output comprising vector files. The advent of GISs has enabled archaeologists to interpolate these discrete points into a continuous surface stored as raster (pixel) data (Lock and Harris, 2000).

A GIS is a computer system for capturing, storing, checking, integrating, manipulating, analyzing,
and visualizing data based on geographical (x, y) location. A GIS links mapped features to attributes stored in a database and overlays different data layers such as land use, elevation, archaeological sites, and hydrology to help reveal complex patterns, relationships, and trends that are not readily apparent using other tools such as non-spatial databases. Similar to a transit or total station, a GIS uses sight lines to measure intervisibility between two points; however, because a GIS uses a computer, it has affordances not offered by traditional survey equipment. First, a GIS affords high-level computational capacity to perform hundreds to thousands of line-of-sight measurements, limited only by processing power (i.e. a big data issue). Second, a GIS has analytical tools to interpolate these many points into a high-resolution raster surface that allows for fields-of-view, or viewsheds, to be calculated. Because viewsheds calculate 360° fields of view, archaeologists can use them to explore visualscapes, that is, the interrelationships of built forms and bounded spaces.

A third affordance of GIS is it contains tools to integrate built and natural environments. Among contemporary Maya, the term for large community is kahkab. Kah means ‘populated place’ and kab means ‘land’ or ‘earth’; in joining these words, the Maya integrate the built and natural environments (Marcus, 2000, p. 236). Evidence suggests that the ancient Maya practiced agrarian urbanism with urban gardens and orchards intermixed with residences (Isendahl and Smith, 2013), and melded the built and natural environments to transmit information. At Copan, the ancient Maya apparently used the natural backdrop of the hillsides to ‘heighten’ certain ceremonial and elite structures, making them appear larger than they were in reality (Leventhal, 1979).

Despite the importance of the natural environment, most visibility studies on the ancient Maya have focused solely on individual buildings or architectural complexes considering the built environment as an archive of tangible objects that provides information on the intangible ancient social world. Built forms are deemed to be ‘encoded’ with readable cultural information (Saussure, 1966), whereas natural features are not. However, Maya architecture did not haphazardly ‘pop up’ in random locations, with the natural environment simply serving as a backdrop to everyday life; instead, people constructed built forms such as temples, palaces, stelae, altars, houses, reservoirs, sacbeob (causeways), canals, and agricultural fields at specific locations in the landscape to work in concert with the natural environment to send messages that helped shape social practices (Moore, 2005; Richards-Rissetto and Landau, 2014; Whincup, 2004).

GIS allows archaeologists to convert built forms from vector (points, lines, polygons) to raster data, and apply map algebra (cell-by-cell combination of raster data layers) to integrate rasterized built forms with a digital terrain model (DTM) to generate an urban digital elevation model (DEM) (Fig. 2) (Ratti, 2005; Richards-Rissetto, 2010, 2012; Richards-Rissetto and Landau, 2014). The urban DEM allows archaeologists to move beyond line-of-sight analysis to field-of-view (viewshed) analysis that takes into account the built and natural environments—essential for understanding the role of visibility among the ancient Maya. Moreover, because the basic binary schema of viewsheds (non-visible cells = 0 and all visible cells = 1) allows for complex mathematical calculations to calculate topographic prominence (overall visibility) of individual features (or classes of features) and percentage of intervisibility among features—the two key calculations used in this research.

While this computational capacity provides quantitative data that are critical to visibility analysis, ‘viewsheds depicted in a GIS map bear little resemblance to what people experience on the ground’ (Conolly and Lake, 2006, p. 233). This limitation occurs because viewshed data are 2.5D. In other words, viewsheds store heights/elevation, but they are not actually 3D models. For digital humanists, bird’s eye view maps lack a sense of mass, scale, and aesthetics integral to human perception and experience, and the numerical outputs fail to differentiate visibility of a building’s façade versus its sides or back—essential for close reading interpretation. While GIS results provide data on, for example, who could see whom and who might be sending targeted messages to whom, the bird’s
eye perspective offered by these flat two-dimensional (2D) viewsheds makes it difficult to investigate everyday experience. In other words, GIS analyses are missing a sense of mass and scale that is a key element to human perception and how people actually move about and interact in a landscape—they offer a computational approach but lack the experiential. For the experiential approach, we move into 3D.

5. 3D: Moving Beyond the Bird’s Eye View

While most visibility analyses of archaeological landscapes use traditional 2.5D GIS, recently archaeologists have been exploring the potential of 3D approaches for visibility analysis in archaeology. 3D technologies offer an alternative to GIS. 3D data acquisition (e.g. airborne LiDAR, terrestrial laser scanning, and photogrammetry), 3D modeling (e.g. SketchUp, 3D Studio Max, Agisoft), and interactive/immersive 3D visualization (e.g. Unity and Oculus Rift) are transforming archaeological practice. But what impact are such 3D technologies having on visibility analysis across ancient landscapes? Airborne LiDAR, for example, rapidly collects 3D data for archaeological sites across vast areas (Chase et al., 2012; Prufer et al., 2015; von Schwerin, 2016). However, most LiDAR data are of unexcavated mounds requiring subsequent 3D modeling of architecture and proper alignment within terrains to perform visibility analysis—traditionally time-consuming tasks (Richards-Rissetto, 2013). To overcome some of these challenges, a few archaeologists have begun to develop new approaches that combine GIS and 3D.

Paliou (2014) developed a computational visibility approach to analyze the visual range of Tehran murals of Late Bronze Age Akrotiri. She first uses
3D modeling programs (3D Studio Max and AutoCAD) and then converts the results into raster maps to be analyzed in a GIS. Dell’ Unto et al., 2015 bring georeferenced 3D architectural models (using laser scanning and photogrammetry) into a GIS to calculate visibility of building interiors at Pompeii. While Saldan˜a and Johanson (2013) also use 3D GIS, they employ procedural modeling to rapidly generate alternative 3D building reconstructions based on a set of architectural rules and attributes stored in a GIS to explore visibility in Ancient Rome (Saldaña, 2015).

Building on this scholarship and my involvement with two projects, MayaArch3D (www.mayaarch3d.org) and MayaCityBuilder, that seek to integrate GIS and 3D to study ancient Maya landscapes, I employ an iterative 3D GIS approach to explore the role of visibility at the ancient Maya site of Copan. The approach is two-fold: computational and experimental. In the computational approach, I employ traditional 2.5D viewshed analysis in GIS to establish a baseline for a comparative experiential analysis in 3D.

6. Methodology: GIS ± 3D

6.1 Computational component

The computational component involves three main steps: (1) creating the Urban DEM, (2) generating viewsheds, and (3) calculating topographic prominence and intervisibility values.

Step 1: Creating the urban DEM: An urban DEM is a raster map that stores elevations and building heights in a matrix of pixels (Fig. 3). In 2013, the MayaArch3D project commissioned airborne LiDAR data for 25 km² surrounding the UNESCO World Heritage Property of Copan. A 1 m resolution digital surface model (DSM) of the modern surface was generated; however, the DSM had to be post-processed to remove archaeological mounds that are filtered as bare-earth by most algorithms. Additional post-processing of the LiDAR data removed the archaeological mounds to create a DTM (bare-earth minus archaeological mounds) that provided terrain elevation (Fig. 3) (von Schwerin et al., 2016). Elevations for ancient structures were derived using archaeological maps, architectural drawings, photogrammetric data, and a trigonometric function for unexcavated mounds (Fash and Long, 1983; Hohmann, 1995; Hohmann and Vogrin, 1982; Richards-Rissetto, 2013). Vector data (as GIS shapefiles) were converted to a raster format, and map algebra was used to ‘add’ the DTM and rasterized buildings together to create a single raster surface—the urban DEM.

Step 2: Generating viewsheds: Esri’s ArcGIS 10.3 (standard GIS software) was used to run viewsheds to calculate (1) topographic prominence of temples and Copan’s site types and (2) intervisibility between site types. Viewsheds are binary—non-visible pixels are assigned a value = 0 and visible pixels are assigned a value = 1. The total number of visible or non-visible pixels from a location, or set of locations, in a landscape was calculated and converted to a percentage visibility for those locations. For example, from a specific location where 300 of 1,000 pixel values = 1, then 30% of the ‘landscape’ is visible and 70% is non-visible.

Copan has five site types, each hypothesized to represent a different socioeconomic class (Willey and Leventhal, 1978; Willey and Leventhal, 1978). Types 1 and 2 represent non-elite households, Types 3 and 4 indicate elite households, and the only Type 5 site is the city’s main civic–ceremonial complex—the Principal Group. Thus, at Copan, I first calculated the topographic prominence of each site type (1–5), i.e. overall visibility of each site type within Copan’s landscape, to determine if specific site types were more visible than others. Second, I calculated intervisibility between these five site types to acquire information on the visual spaces of communication between different socioeconomic groups.

Figure 4 illustrates the concepts of topographic prominence and intervisibility. While the two source sites, A and B, in these two maps have similar topographic prominence, that is, similar percentages of overall visibility, they have markedly different intervisibility values. When the viewshed of the source site A, on the left, is overlapped with ancient settlement, we see that people living at this site had few visual connections with other sites in the valley. In contrast, the people living at source site B, on right, had a viewshed that overlapped with many other sites. We can ‘read’ these results as indicating
that source site B had strong visual ties to other inhabitants of Copan, and in a sense were less isolated, or less segregated than those living at source site A.

Step 3: Calculating topographic and intervisibility values: Visual messages are often sent via topographic prominence, that is an object’s overall visibility within a landscape. Attraction theory states that highly visible objects attract the eye and thus have the potential to send messages to a greater number of people (Llobera, 2001, 2003, 2006). For example, the human eye is typically drawn to the highest peak or the tallest building. Intervisibility provides data on ‘lines’ of communication between people and places, and importantly also information on senders (transmitters) and receivers (audience) of visual messages (Jakobson, 1980).

A stratified random sampling strategy (based on site type and physiographic zone) was employed to select a sample of 82 (of 594) archaeological sites for the visibility analysis. Points were placed on the
corners of each structure within a site to perform site-level analysis. Thus, even if only one structure was visible at a site comprising, for example, seven structures, the site was considered visible.

Topographic prominence, or a site’s overall visibility, was calculated by dividing the number of visible pixels from each viewshed by the total number of pixels in the viewshed (i.e. non-visible and visible pixels). Using this number, I calculated the percentage representing each sample site’s overall visibility in the Copán Valley.

Calculating intervisibility between different site types required more processing steps. For example, the total number of pixels for Temple 22’s viewshed is 22,933. The non-visible areas make up 10,753 pixels, and the visible areas make up the remaining 12,180 pixels. To calculate percentage visibility for Structure 10L-22 (Type 5) to all Type 1 sites, it is necessary to divide 12,180 by 22,933, yielding a visibility of 53.11%. The results indicate that 76% of people could see Copan’s main civic-ceremonial group (a Type 5 site), i.e. the ruler’s domain, from their homes. The residences of the wealthiest elites, living at Type 4 sites, could be seen by 48% of sites, whereas, in contrast, the houses of the non-elite, Type 1 sites (lowest socioeconomic status) could be seen by less than 35% of households (Fig. 5). These results are intriguing because there are 443 Type 1 sites compared to only eighteen Type 4 sites. It was expected that when scanning Copan’s horizon, people would be more likely to see a Type 1 site, simply because there are so many of them, however, in reality, people were more likely to see a Type 4 site, despite there being so few of them. The results indicate a visual hierarchy at Copan where higher socioeconomic sites are generally more visible than lower socioeconomic sites.

6.2 Computational results

Topographic Prominence: The topographic prominence results offer a distant reading of the overall visibility of site types at Copan. The results indicate that 76% of people could see Copan’s main civic-ceremonial group (a Type 5 site), i.e. the ruler’s domain, from their homes. The residences of the wealthiest elites, living at Type 4 sites, could be seen by 48% of sites, whereas, in contrast, the houses of the non-elite, Type 1 sites (lowest socioeconomic status) could be seen by less than 35% of households (Fig. 5). These results are intriguing because there are 443 Type 1 sites compared to only eighteen Type 4 sites. It was expected that when scanning Copan’s horizon, people would be more likely to see a Type 1 site, simply because there are so many of them, however, in reality, people were more likely to see a Type 4 site, despite there being so few of them. The results indicate a visual hierarchy at Copan where higher socioeconomic sites are generally more visible than lower socioeconomic sites.

6.2.1 Intervisibility

The intervisibility results offer a closer reading of visibility at Copan because they identify visual connections between specific site types, and not simply overall visibility. For example, a close reading of Copan’s only Type 5 site—the Principal Group—shows that 88% of the elite (people living at Type 3 and Type 4 sites) lived in view of Copan’s royal architecture, whereas only 60% of non-elite (people living at Type 1 and Type 2 sites) could see the ruler’s domain from their homes.

Fig. 4 Viewsheds illustrating topographic prominence and intervisibility
can also be done for Copan’s other site types. The visibility values of Type 1 sites indicate that 25.6% of the people living at Type 1 sites could see at least one other Type 1 site, 28.2% could see one or more Type 2 sites, 32% could see at least one Type 3 site, and 33.3% could see one or more Type 4 sites. In contrast, the visibility values of Type 4 sites indicate that 39.2% of the people living at Type 4 sites could see at least one Type 1 site, 53.1% could see one or more Type 2 sites, 52% could see at least one Type 3 site, and 50% could see one or more Type 4 sites. Understood alongside epigraphic data, these results might suggest a greater sense of social segregation and isolation among lower-status ‘communities’ as well as a sense of being ‘watched over’ by the occupants of higher-status sites. Moreover, the intervisibility results reinforce the presence of a visual hierarchy at Copan. People living at sites of higher socioeconomic status had greater visual connectivity to the city’s inhabitants than people living at sites of lower socioeconomic status.

The computational component provides quantitative data to discern visibility patterns for Copan’s site types. Examining these results in their cultural context, that is what we already know about ancient Maya vision, we can confirm that Copan’s rulers constructed higher temples. Most likely to legitimize power in varied ways—by placing themselves closer to the heavens to emphasize connections with deities, and by conveying, on a daily basis to many of Copan’s inhabitants, who only had to cast their gaze in the direction of one of these royal temples, that the rulers were ‘all-seeing’ and hence ‘all-knowing’. While access studies have shown that Maya rulers placed imagery in public versus private spaces to target specific audiences (Parmington, 2011; Sanchez, 1997; Stuardo, 2003), the quantitative data on visibility from Copan provide new insight into royal Maya use of visibility to target specific audiences.

The fact that a larger percentage of elite sites than non-elite sites were located in the gaze of royal monuments suggests that rulers targeted elites with greater frequency to remind them that their actions were being witnessed and they were being watched over. Moreover, these GIS results offer data leading to new interpretations about the hierarchical nature of vision and visibility among the ancient Maya. These findings extend the purview of the ichnal from rulers and deities to other non-royal elite, who seemed to have adopted the witnessing power of vision to visually target people of lesser
status. Elites—replicating royal strategy—typically constructed taller houses in highly visible locations enabling them to send messages of status, wealth, and power, and let the non-elite know that they were being ‘watched over’.

While the quantitative data from the computational component provide new insights into ancient Maya visibility, viewsheds are flat, static 2D maps offering a bird’s eye view to ancient life. One way to move beyond this bird’s eye perspective is to bring in the third dimension, however, not simply as static 3D models but rather as an experiential component with dynamic, interactive, and interchangeable 3D visualizations.

6.3 Experiential component

The MayaCityBuilder project (http://mayacity-builder.org/)—begun in 2015—is researching the potential of procedural modeling for 3D visualization of ancient Maya landscapes. The project’s long-term vision is to create a procedural modeling kit and repository that stores a digital lexicon of 2D and 3D data for ancient Maya architecture to allow users to create 3D buildings in georeferenced cityscapes using a WebGL (online, open-source) application.

To realize this vision, we have developed a research design with five tracts: Tract 1: Archaeological Research/Data Collection, Tract 2: Procedural Modeling, Tract 3: Import/Export Workflows, Tract 4: Database Development, and Tract 5: Implementation (Fig. 6).

The experiential component currently involves Tracts 1–3 and has three main steps pertinent to exploring visibility among the ancient Maya. They are (1) generating 3D terrain, (2) generating 3D architectural models, and (3) 3D visualization of terrain + architecture.

Step 1: Generating 3D terrain: The 1-meter resolution DTM generated from the post-processed airborne LiDAR is used to create the 3D terrain. The process involves converting a 2.5D raster DTM into a 3D polygon mesh terrain. To efficiently and accurately carry out this process, we iteratively developed workflows starting with a manual approach to acquire knowledge to transition to semi-manual and automatic workflows. In each workflow, the objective is to maintain maximum data integrity in the file format conversion to ensure accurate elevations and georeferencing for the 3D terrain—criteria that are essential for visibility.
analysis—and still minimize expertise and labor/time costs.

Step 2: Generating 3D architectural models: We employ 3D architectural models that are derived from different acquisition and modeling techniques. Terrestrial laser scanning and photogrammetry are used to create examples of extant architecture (Remondino et al., 2009; von Schwerin et al., 2013). Partially complete buildings or structures that exist as remnant mounds require 3D modeling, that is using available data sources such as maps, drawings, photographs, and excavation notes to create hypothetical 3D models. Because the majority of ancient Maya buildings exist as remnant mounds, we use the software CityEngine to carry out procedural modeling to rapidly generate 3D models based on a set of rules about Maya architecture in conjunction with the attributes in a spatial database (i.e. GIS). This approach allows us to efficiently and accurately turn architectural footprints (GIS shapefiles) into georeferenced 3D buildings, i.e. buildings with spatial reference—we must know how things spatially relate to one another to carry out visibility analysis (Muller et al., 2006; Richards-Rissetto and Plessing, 2015). Heights of still-standing or excavated structures are assigned as an attribute in the spatial database. However, because most archaeological structures remain unexcavated, we have implemented a trigonometric function based on building footprints, survey and data, and ethnographic sources to interpolate building heights using a standardized procedure. The method integrates variables affecting overall structure height including platform height, wall height, roof pitch, wall thickness, site type, and building dimensions, and employs GIS to rapidly calculate potential building heights (Richards-Rissetto, 2013). In the end, we have several different file types generated using different software and at varying levels of detail that we bring into a 3D visualization environment; however, because all of these data are georeferenced, this data integration is possible (Fig. 7).

Step 3: 3D visualization of terrain + architecture: While procedural modeling makes the generation of 3D buildings quite rapid, the 3D visualization environment in which they are visualized, in this case, CityEngine, is limited in regard to lighting, texturing, and vegetation; in other words, the aesthetic elements of the landscape seem rigid, cold, or unnatural. To overcome this shortcoming, our workflows also export, import, and then integrate the georeferenced 3D terrain and 3D architectural models into a different 3D visualization environment. Currently, we are experimenting with Unity5—a gaming platform; however, our end goal is to develop workflows that bring these 3D data into WebGL—an open-source JavaScript Application Program Interface (API) for rendering interactive 2D and 3D computer graphics in browsers without plugins—to facilitate open access and data reuse for scholarly and education purposes.

In Unity5, we are able to bring together the georeferenced 3D architectural models and situate them directly on the 3D terrain in their precise locations. Additionally, we are working with another procedural modeling software—SpeedTree—to create 3D models of plants using GIS (hydrology, terrain, soil, etc.), ethnographic, ethnobotanical, and paleoenvironmental data (McNeil et al., 2010). Given the ancient Maya significance of the kahkab—intimate intermingling of the built and natural environments—as well as the potential impact of vegetation on visibility, adding plants to the 3D visualizations has technical and interpretative significance. These 3D plant models can be easily visualized in Unity5 and assigned location based on a set of rules. For example, the terrain can be ‘coded’ to represent specific plant types or communities, and Unity5 will ‘grow’ them based on the coded terrain.

Importantly for visibility, the high-quality 3D rendering capabilities of Unity5 allow us to adjust global and local lighting illumination and atmospheric conditions. Unity5 also allows users to navigate the 3D environment in first-person point of view—moving us away from the bird’s eye perspective into the human arena. In this way, users can explore the landscape not from the air but on the ground—as did the ancient Maya—and at multiple scales and from multiple perspectives, for example, they can walk along an ancient road looking at the details of elaborate architectural sculpture on individual buildings and then look up to scan the horizon to see the city’s skyline framed by hilltops.
These human-scale perspectives are absent in traditional GIS.

6.4 Experiential results

We are in the early stages of the experiential component. We have begun to explore specific computational results from the GIS visibility analysis in the 3D environment. Figure 8 shows the ‘view’ the king would have seen as he looked out from his elevated acropolis out over the city of Copan. It illustrates that the many people living below the showdown of the royal Acropolis felt the king’s gaze on them and also forced them to look up on a daily basis at the glory and power of the king, who, in his elevated courtyards, was closer to the heavens. However, in the 3D environment, we are not limited to static, 2D snapshots of the past, but rather we can walk along hypothesized procession routes through the royal precinct to get a sense of the mass and space of the Acropolis.

We can also experiment with painting surfaces with different colors or interchanging construction materials (by applying different textures) to delve into the aesthetic aspects of past landscapes. With detailed 3D reconstructions, we can encounter the glyphs and imagery on the buildings offering deeper insight into the meaning(s) of these places. We can bring in the GIS viewshed results to find out who could see what from where in three dimensions, getting a better sense of the experience of past audiences—a perspective that is not possible from the bird’s eye perspective of viewsheds. After moving through these virtual spaces, we can tack back to GIS to ‘simultaneously’ calculate the potential number of spectators for a courtyard for comparative data to bring back into the 3D environment.

However, because we have generated also 3D terrain, we can move away from the royal perspective and the main civic–ceremonial precinct to explore daily experiences—in terms of what people living at Copan’s different site types saw across the vast...
By iteratively moving back and forth between GIS + 3D, in other words, using an iterative 3D GIS approach, we can combine the computational and experiential components to move toward new knowledge and developing innovative methods to study visibility in ancient Maya landscapes.

7. Conclusions and Looking Forward

Anthropologists were early adopters of computers (Hymes, 1962), and archaeologists were among some of the first scholars to employ GIS to investigate cultural phenomena (Allen et al., 1990). While we know that Maya kings typically constructed highly visible temples, we actually knew very little about the role visibility may have played in sending targeted messages that influenced daily interactions and structured social connections among different social groups. To begin to investigate the role of visibility in everyday life across societal scales, I broadened the view from civic–ceremonial precincts to encapsulate the broader landscape—both built and natural (Doyle et al., 2012; King et al., 2015; Landau, 2015; Richards-Rissetto, 2010, 2013).

The results show that GIS is a valuable tool to quantitatively measure visibility within ancient landscapes. GIS provides locational precision to data that allows relations between overlapping data layers to be explored in ways not possible without computers. 3D technologies give us a sense of mass and space and offer hands-on, personal interaction with archaeological information to help experience ancient landscapes in innovative ways that can lead to new discoveries and new ways of doing research. Recent advances in virtual reality (VR) are beginning also to offer tools to create a more synesthetic, or multi-sensory, experience of ancient landscapes—not only of vision but also of sound, smell, and touch and look forward to iteratively working among these various technologies.

As we look forward, we see rapidly changing technologies and the rapid adoption of 3D tools and techniques from discovering new archaeological sites using airborne LiDAR to hands-on engagement inaccessible ancient artifacts using 3D printing. In regard to experiential research, we are using the Oculus Rift—a head-mounted VR display—to create an immersive experience of ancient Copan and testing gesture-based interaction, as two approaches to more intuitively interact with archaeological data (Barcelo et al., 2000; Forte and Bonini, 2010; Forte and Siliotti, 1997; Frisher and Dakouri-Hild, 2008; Richards-Rissetto et al., 2012, 2013). Future research plans to track eye movements using Oculus Rift to identify whether certain objects or views attract the human eye to further investigate the power of vision and visibility in the ancient Maya world. The MayaCityBuilder project is also using 3D modeling and VR to generate quantitative (computational) data on acoustics and translating these data into the immersive 3D world using the spatial sound capabilities of the Oculus Rift.

Fig. 8 3D visualization in Unity5 of the field of view of Copan’s ruler from Temple 11 over Great Plaza
In the end, it is not one technology or approach that is better than another, rather as we continue to move iteratively between GIS and 3D, we strive to develop new methods and interpretations for visibility analysis of ancient landscapes—analyses that would not be possible without taking advantage of the digital and the humanities to cross-cut the computational and experiential. Together 3D + GIS offers ways to go from tangible material remains to begin to explore some intangible aspects of ancient landscapes.

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