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What can GIS + 3D mean for landscape archaeology?

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Abstract

Until recently Geographic Information Systems (GIS) have held center stage in the archaeologist's geospatial toolkit, and there is no doubt that archaeologists have moved beyond the map – but into what? In the early years, criticisms voicing GIS as environmentally-deterministic were abundant. What methods and tool have archaeologists used to overcome these criticisms? New geospatial technologies such as airborne LiDAR and aerial photogrammetry are allowing us to acquire inordinate amounts of georeferenced 3D data – but do these 3D technologies help overcome criticisms of environmental determinism? Together – GIS + 3D – can link georeferenced 3D models to underlying data adding a ground-based humanistic perspective lacking in the bird's eye view of traditional GIS. This paper situates GIS and 3D within a semiotic framework to offer some ideas on using 3DGIS to intertwine environmental and cultural factors to work toward new approaches for landscape archaeology.

Keywords: Geographic Information Systems (GIS), 3D modeling, Landscape archaeology, Semiotics, Ancient Maya, Visibility, Accessibility

1. Introduction

Until recently, Geographic Information Systems (GIS) have held center stage in the archaeologist's geospatial toolkit, and there is no doubt that archaeologists have moved beyond the map – but into what? Old questions persist and new questions arise as we push boundaries and explore new horizons – questions such as: Is GIS more than a tool? Is GIS contributing to theoretical advancements in archaeology? These are big questions. To narrow the scope, I have set forth four objectives: (1) briefly summarize criticisms of GIS as "environmentally-deterministic", (2) provide some approaches archaeologists have used to attempt to overcome such criticisms, (3) bring 3D technologies into the discussion, and (4) finally explore what GIS + 3D can mean for landscape archaeology.

GIS allow us to capture, store, manipulate, analyze, and visualize geographic data. Since 1960 with the development of the first operational GIS, i.e., Canada Geographic Information System (Tomlinson and Toomey, 1999), people have been using GIS to integrate seemingly disparate data sets and generate new data as well as perform complex spatial analysis resulting in new knowledge. At first glance, GIS seems tailor-made for archaeology because the discipline is inherently spatial; and in fact, archaeologists were some of the earliest adopters of the technology. In the late 1980s and early 1990s, archaeologists increasingly used GIS as a part of their toolkit, not only to manage archaeological data, but also to identify spatial patterns that potentially correlate to human behavior (e.g., Allen et al., 1990; Lock and Stancic, 1995). Early analytical applications adhered to processual goals such as predictive modeling – using GIS to calculate the probability of locating archaeological sites and correlating variables to human behavior (e.g., Kvamme, 1999; Lock and Harris, 2006; Wescott and Brandon, 1999). However, soon GIS became criticized for being environmentally deterministic; predictive models were criticized because they tended to rely on environmental variables at the expense of "social" variables (Cope and Elwood, 2009; Daly and Lock, 2004; Gaffney and van Leusen, 1995; Kwan, 2002; Schuurman, 1999; Thomas, 1996). In defense of these early applications, GIS tend to preference environmental criteria for two reasons. First, GIS was developed as quantitative software; however, many of the cultural data with which archaeologists deal are qualitative in nature (e.g., Allen et al., 1990; Lock and Harris, 2000; Leszczynski, 2009). Second, GIS-ready environmental data (e.g., soil, geology, vegetation, hydrology, and terrain) are more readily available. In contrast, social data must be collected, classified, and then converted and/or linked to GIS data before it can be used – and this process is never straightforward often requiring new GIS tool development (e.g., Agugiaro et al., 2011; von Schwerin et al., 2013).

In the 1990s, post-processualism raised questions about the sterility, so to speak, of processual approaches.

Post-processualism sought to bring human agency, symbolism, cosmology, indigenous perspective, gender, cognition, and more interpretative aspects into archaeological studies (e.g., Conkey and Gero, 1991; Hodder, 1985; Trigger, 2006). Along these lines, phenomenological approaches to landscape began to take shape that contrasted first-person experience through self-reflective bodily experience to a bird's eye view so typical of GIS (Tilley, 1994); in a sense, bringing the qualitative vs. quantitative debate to the forefront. Visibility analysis in GIS proved groundbreaking to integrate computational approaches with phenomenological goals affording more reflexive and experiential methodologies (Van Leusen, 1999; Wheatley, 1993). However, GIS practitioners made obvious that GIS has its limitations in regard to human perception because it tends to create abstract realities that reduce human complexity (Gaffney and van Leusen, 1995; Gillings and Goodrick, 1996; Stead, 1995). For example, viewshed applications "critically confuse the concept of 'vision' with that of 'perception', and in so doing simplify once again the full complexity of people-place relations and dynamics" (Gillings and Goodrick, 1996). To counter such shortcomings of GIS, Gillings and Goodrick (1996) proposed integrating GIS with VRML (Virtural Reality Modeling Language) to facilitate "a sensual and experiential mode of engagement with the material remains of the past."

More recently, Marcos Llobera (2012:504–505) tackles this problem in his article "Life on a Pixel: Challenges in the Development of Digital Methods Within an "Interpretive Landscape Archaeology Framework". To overcome, or move beyond, criticisms that the quantitative nature of GIS divorces archaeology from human experience, Llobera contends that we need middle ground/ bridging concepts to: (1) situate models and methods within context-rich narratives, (2) explore how processes play out within particular contexts rather than seek universal norms of behavior, (3) shorten the gap between empirical information and narratives, and (4) generate multiple scenarios as feedback to results. In other words, as archaeologists we cannot simply use GIS as a deductive tool but rather we must also use GIS as part of an inductive PROCESS, where we tack back and forth between various data and methods to formulate new hypotheses and as a consequence provide fertile ground to drive theoretical growth (Daly and Evans, 2006; Landau et al., 2014).

Some GIS approaches can be rightly criticized for being environmentally deterministic and overly quantitative due to both practical issues involving data and software availability, and the underlying theoretical assumptions driving research objectives. Some of these limitations, however, can be overcome and cultural information can be integrated into GIS analyses if they are explicitly grounded in archaeological and/or social theory and interpreted within a society's particular historical, sociopolitical, and ideological circumstances (Llobera, 1996; Lock, 2000; Lock and Harris, 2006). To overcome these shortcomings, archaeologists cannot employ GIS as an unbiased tool. Instead, they need to think of GIS as a form of practice that must be situated within archaeological theory; they need to use theory-inspired cultural variables in GIS – realizing that places are socially created as well as linked to both space and time (Tschan et al., 2000).

2. Semiotics: a bridging concept for landscape archaeology

Space is often defined as locations with no social connections; in contrast, places are imbued with human meaning(s) (Relph, 1976; Tuan, 1977). However, space is not a blank canvas serving as a neutral backdrop for human action (Tilley, 1994), we all transform spaces into places in relation to physical surroundings and cultural/ personal experience (Hu, 2012; Wheatley and Gillings, 2000). Early social theorists such as Morgan, Durkheim, and Mauss posited evolutionary and functional theories

to explain the roles of bounded spaces and built forms (i.e., built environment) in social life (Durkheim and Mauss, 1963; Morgan, 1965). In reaction to these theories, symbolic approaches such as structuralism emerged that understood architecture and space as reflecting cultural rules (Lawrence and Low, 1990; Lévi-Strauss, 1963). Pierre Bourdieu (1977) and Giddens (1979, 1984), posited practice-oriented perspectives to insert human agency into the production and reproduction of social meaning and relations; however, such approaches continue to treat spaces as neutral backdrops for social practice (A. Smith, 2003). Semiotics – a theoretical framework that views cultural phenomena (including built forms and bounded spaces) as systems of signs or social configurations that convey culturally constructed meaning (Burks 1949) – seeks to make space an active agent in cultural re(production).

In this article, I explore the potential of semiotics, as one way, to explicitly link GIS data and methods to social actions. Semiotics is grounded in the belief that to understand the *what*, it is necessary to understand the *how*. This means that archaeologists must investigate the mechanisms that were used to send specific messages – whether ideological, political, economic, etc. – and GIS provides some of the tools for such analysis. According to Charles Sanders Peirce (Buchler, 1978), a triadic relation exists among signs, objects, and interpretant. In this relationship objects become signs when, and only when, individuals assign meaning to them. This means that for archaeologists to reconstruct the meanings of ancient signs, they must take into account who is creating these signs and whom these signs are targeting. Senders, or addressers, send messages via signs to receivers, or addressees (Goffman, 1983; Jakobson, 1980; Parmentier, 1987; Silverstein, 1976). Archaeological remains provide evidence to help identify the identity of both senders and receivers; however, identifying senders is often more straightforward than identifying receivers, particularly across vast landscapes. GIS provides tools to identify receivers and ultimately to better understand how people communicate with one another.

Furthermore, semiotics asserts that people have interactive relationships with the built environment – comprised of building forms and bounded spaces – both creating their surroundings and simultaneously finding their behavior influenced by them; the ways in which different groups of people respond to these "signs" influences how they interact in a landscape. Along these lines, semiotics provides two fundamental concepts – audience and indexicality that can be used to bridge GIS and social theory. The concept of audience is important because culturally constructed messages are created with a particular audience in mind, which means that people are targeted. One way this can be accomplished and identified in the archaeological record, for example, is via architecture in the form of barriers and facilitators that either inhibit or facilitate social interaction among different social groups.

The concept of indexicality is relevant because it provides an ideal perspective for investigating how architectural arrangements worked together to convey messages and direct sociopolitical interaction. Indexicality is based on the concept that adjacency and spatiotemporal context are critical elements in communication. Architectural indexes are signs that help to structure how people negotiate their physical surroundings (Buchler, 1978; Gardin and Peebles, 1992; Jakobson, 1980; Parmentier, 1987; Preucel and Bauer, 2001). Components of the built environment such as buildings, roads, walls, and stairs are often aggregated and organized into spatial configurations (indexes) that convey meaning. These components can be arranged in different ways; however, their meanings change depending on what is placed next to what and on their larger spatial context.

These ideas strongly relate to a structuration approach (Llobera, 1996, 2001; Daly and Lock, 2004) focused on *how*

landscapes can structure and characterize cultural practices, and using GIS to analyze social spaces on the landscape to study past human meanings and practices. By examining how messages were being communicated, we can better understand what messages were being sent, to whom they were being sent, and why they were being sent. Using this knowledge, we can identify patterns of communication between social groups (Rapoport, 1969, 1988, 1990), which will in turn help us to study how groups of people interacted and how social roles might have been defined. Ultimately, connections can be made between communicative patterns and the roles landscapes played in structuring human interaction, and in turn linked to the different social, political, ideological, etc. roles played by ancient inhabitants. Thus, semiotics can serve as a framework in which to study sociopolitical interaction and the transmission of culturally meaningful messages to particular social groups; in Llobera (2012) terms it can serve as a bridging or middle ground approach to begin to overcome criticisms that the quantitative nature of GIS divorces archaeology from human experience.

3. Grounding GIS in semiotics

How does the organization of the landscape influence where people go, what they do, whom interacts with whom, and how does this shape their experiences? While many factors influence interaction and experience within a landscape, this research employs semiotics and GIS to investigate how the visibility and accessibility of buildings, roads, and other features function as signs that influence how people move about, interact in, and experience landscapes.

While the distribution and arrangement of architecture leaves a spatial imprint that archaeologists can use to reconstruct cultural processes, for past peoples the spatial layout of their communities contained both tangible constructions such as roads, houses, or temples as well as intangible information on cosmological beliefs and social norms that guided their daily interactions and experiences (Fig. 1).

Much of my work has been strongly influenced by other archaeologists exploring accessibility and visibility – not only from a GIS perspective but also from a culture-specific perspective in regard to ancient Maya studies.

The case study is the archaeological "site" of Copan – what is today a UNESCO World Heritage site but from the fifth to ninth centuries CE, was an important cultural and commercial center at the southeast periphery of the Maya world (Bell et al., 2004; Fash, 2001). At Copan, as at other Maya sites, architecture and space conveyed information directly through inscriptions and imagery, building form, building function, and quality of materials, and more abstractly through location, access, and visibility (Fig. 2). But what role did this architecture and its position play in the daily lives of people living at Copan? While there are of course various ways to address this question, I want to understand experience from the perspective of visibility and accessibility in order to get at "*how*" messages/information was sent and "*to whom*" they were sent as an approach to ultimately better understand the "*what*" of the messages themselves.

Previous research indicates that access and visibility help to structure human interaction by channeling pedestrian movement and sending messages to particular audiences (e.g., Hillier and Hanson, 1984; Hillier et al., 1993; Llobera, 2003, 2006), and thus are part of a suite of site-planning principles used in the organization of architecture and space (Ashmore and Sabloff, 2002, 2003; Smith, 2007). Since the nineteenth century, people have contended that Maya architecture channeled people through spaces (Stephens, 1969; Houston, 1998). And recently, archaeologists, employing space syntax, found quantitative evidence that movement was channeled within ancient Maya palaces with differences in access patterns through time reflecting distinct sociopolitical systems. Classic period palaces had few entrance points and complex floor plans to tightly control access into and within palaces. However, in the Postclassic period people could enter palaces from several entrances and simple floor plans allowed for less restricted movement (Stuardo, 2003). These different access patterns reflect a shift from centralized
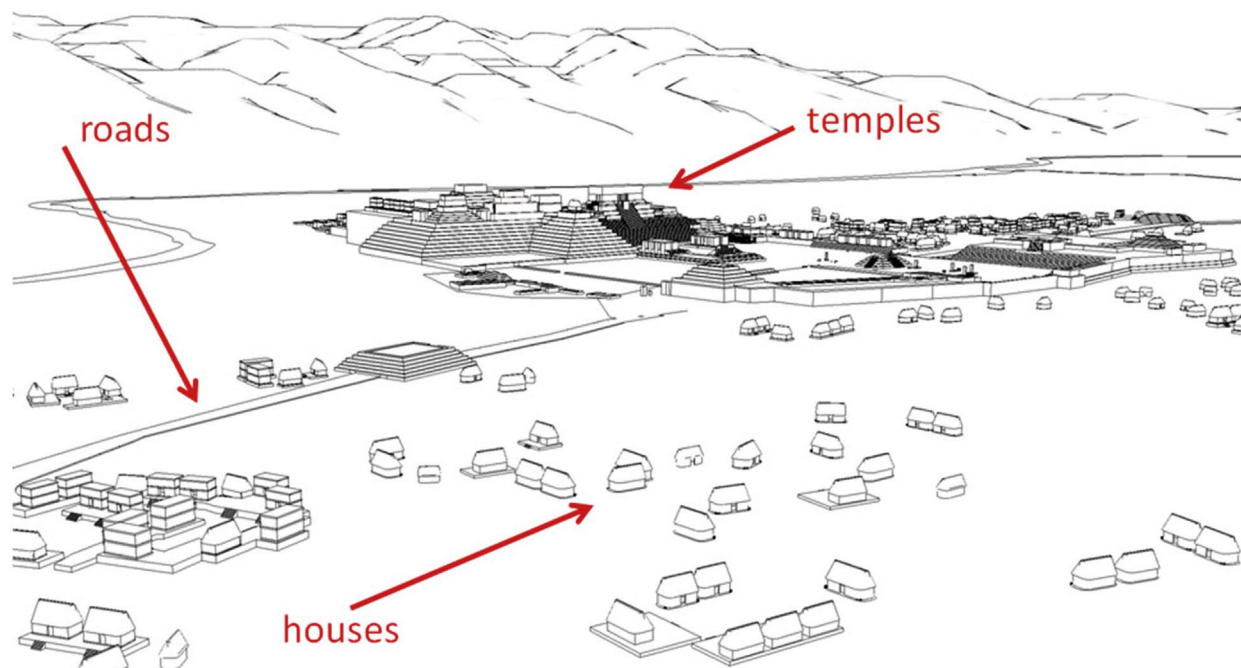

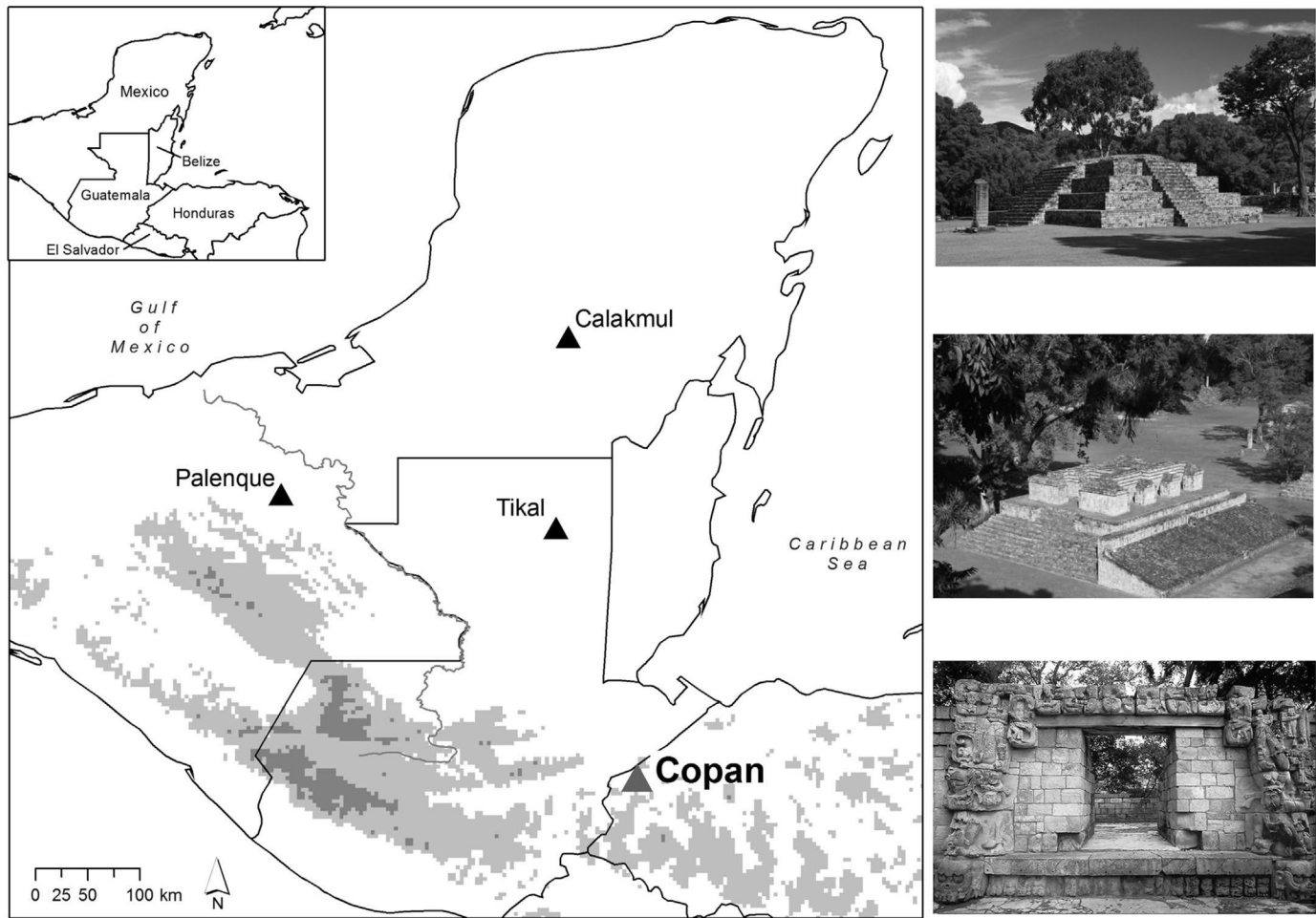**Fig. 1.** 3D reconstruction of Copan's urban core.

Fig. 2. Map of Copan's location.

rule under divine kingship to a more decentralized rule under a council of nobles. Other research – both qualitative and quantitative – has shown that sculptural motifs differed based on accessibility (Sanchez, 1997). For example, at Palenque in Mexico, rulers placed public imagery portraying rulers as authoritative in spaces where access was less controlled; in contrast, private portraiture depicted rulers dressed in simple costume and subordinate to deities (Parmington, 2011).

Iconographic studies indicate that for the ancient Maya sight was multi-faceted. Protruding eyeballs indicate that sight was projective and procreative suggesting that for the Maya "the act of seeing" actually affected and changed the world. In other words, 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 (Houston et al., 2006). In terms of visibility, deciphered hieroglyphs indicate that "seeing" afforded high status, and sight had an authorizing gaze and witnessing function (similar to Foucault's Panoptic gaze) where those who were all-seeing in a sense were all-knowing (Foucault, 1979). In order to be all-seeing or to give such an impression, however, Maya rulers needed to be seen, and so often located themselves in physically high and easily visible places or built tall temples that dominated the landscape as can be seen at the ancient Maya site of Tikal in Guatemala.

If we look at how visibility is materialized in the landscape, at the Late Classic site of La Milp in Belize, archaeologists Hammond and Tourtellot (1999), identified lines-of-sight between stelae located on hilltops in the periphery and a large temple in the city's center. They argue that these lines-of-sight served as visual reminders to people living in the periphery of the ruler's power as well as their ties and obligations to the city center. More recent research by Doyle et al. (2011) suggests that visibility played an important role in establishing territorial boundaries between the Classic Maya sites of El Zotz and Tikal. Visual boundaries seem to correlate to territorial boundaries and the two sites' main temples were in view of one another–patterns reflecting the Maya notion that all-seeing is all-knowing. This information about ancient Maya concepts of accessibility and visibility provides cultural context to develop, apply, and appropriately interpret GIS methods.

4. GIS methods

4.1. Measuring accessibility

To measure accessibility, I grounded my analysis in the notion of movement in contrast to access points, which prior to GIS was a more common approach, e.g. space syntax (Hillier and Hanson, 1984; Parmington, 2011; Stuardo, 2003). To do this, I used GIS
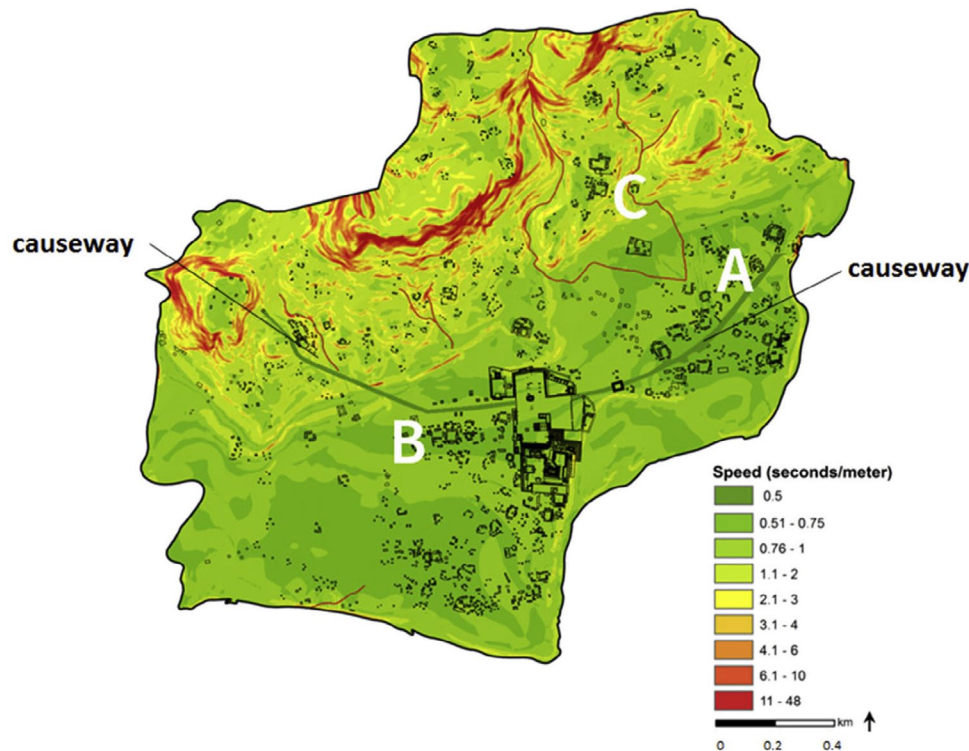
Fig. 3. Example of Least Cost Analysis (LCA) Surface for Copan's urban core.

to calculate travel costs between sites with different socioeconomic status. At Copan, there are five site types that have been correlated to socioeconomic class (Willey and Leventhal, 1978; Willey et al., 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. The method uses Least Cost Analysis (LCA) to measure mobility as the *potential* for movement rather than modeling actual paths of movement. The underlying assumption is that people are more likely to travel to and *interact with* people living at places they can more easily, or quickly, reach, because such places are more accessible (See Richards-Rissetto and Landau, 2014 for methodological details).

Fig. 3 provides an example. If a person were to travel from site A to site B, she would travel along the causeway across relatively flat terrain and the only barriers she would encounter would be buildings. To travel from site A to C she would not have to travel as far, but she would be walking upslope potentially skirting areas that were too steep, and need to ford or walk around several streams so her journey would take longer, not to mention be more strenuous (Kantner, 2004; Llobera et al., 2011; White and Surface-Evans, 2012). LCA is employed also because ancient Maya cities practiced urban agrarianism, lacked formal street networks, and viewed cities as *kahkab* – *kah* as "populated" and *kab* as "land" or "earth" (Marcus 2000) – making topography integral to movement within ancient Maya cities (Ashmore, 2004; Isendahl and Smith, 2013).

A Digital Terrain Model (DTM) with a 1-meter resolution and generated from airborne LiDAR data was used for least-cost calculations (von Schwerin et al., 2016). Archaeological mounds were replaced with reconstructed archaeological structures using a trigonometric approach in GIS (See Richards-Rissetto, 2013 for specifics of method) to generate an Urban DEM to better simulate the ancient landscape. While geomorphological changes are not modeled for the Urban DEM, the accessibility methodology uses an aggregated approach that measures

group connectivity rather than seeking to identify individual travel routes likely mitigating the effects of minor landscape changes (see Richards-Rissetto and Landau, 2014 for Urban DEM methodology).

4.2. Measuring visibility

To measure visibility, I employed viewshed analysis using Arc-GIS 10.3 and IDRISI (GIS and Image Processing software), which estimates the visible and non-visible areas from specific locations in a landscape. In this process, I measure both *topographic prominence* and *intervisibility*. The differences between intervisibility and topographic prominence is critical to getting at audience and indexicality – two key concepts of semiotics. Topographic prominence refers to an object's overall visibility in a landscape and *intervisibility* investigates the visual relationships between objects – together they offer data to reconstruct ancient visualscapes (Llobera, 2001, 2007; Wheatley, 1995).

First, I calculated the topographic prominence of each of Copan's site types (1–5), i.e., overall visibility of each site type within Copan's landscape, to determine if specific site types were more visible in the landscape than others. Second, I calculated intervisibility between these five site types to acquire information on the visual spaces of communication between different socioeconomic groups. Fig. 4 illustrates the concepts of topographic prominence and intervisibility. While the two source sites, A and B, 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 is overlapped with ancient settlement we see that people living site A had few visual connections with other sites in the valley. In contrast, people living at site B had a viewshed that overlapped with many other sites indicating its residents had strong visual ties to Copan's other inhabitants and thus, were less isolated than site A residents.
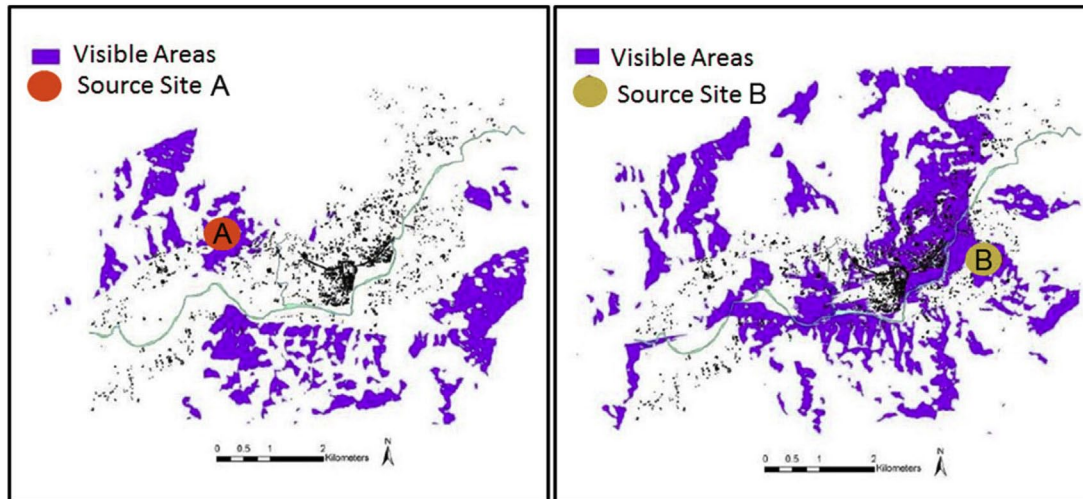
Fig. 4. Viewsheds from Copan illustrating Topographic Prominence and Intervisibility.

5. GIS results

5.1. Accessibility results

The valley-wide (24 km2) accessibility results have been published elsewhere (Richards-Rissetto, 2010) and the urban core accessibility results were published in the Journal of Archaeological Science (Richards-Rissetto and Landau 2014). The results mirror social order at Copan. The royal precinct, comprising all of Copan's type 5 sites, was located in the most accessible location in the city. People from all socio-economic classes were channeled to the city center to witness the king's power – further evidenced by the city's only two *sacbeob* (causeways) leading into the open Great Plaza that housed bleachers for over a thousand spectators.

Type 4 elite sites were located at highly accessible locations; in contrast, type 1 non-elite sites were often situated in less accessible places. For example, in the urban core travel it took on average seven minutes less for the elite (type 4) to walk to another elite site (type 4) than for people living at type 1 sites to walk to other type 1 sites. Within a semiotic framework, these results may reflect intentional intragroup segregation of Copan's lower status residents as well as and channeling of lower status residents to type 4 complexes; thus, providing data to support the hypothesis that accessibility helped to establish and reinforce differences between ancient Maya social groups.

5.2. Visibility results

The visibility data reinforce the accessibility results indicating a visual hierarchy at Copan where higher status sites are generally more visible than lower status sites. The topographic prominence results indicate that from 76% of Copan's sites people could see the royal precinct. The residences of the wealthiest elites, living at type 4 sites, could be seen from 48% of sites, whereas, in contrast, the houses of the city's poorest inhabitants could be seen by less than 35% of sites. As for the intervisibility results, they indicate that 88% of the city's elite lived in sight of the royal precinct, whereas only 60% of non-elite could see the ruler's domain from their homes. Other intervisibility results provide quantitative data reflecting communication ties between specific groups and social segregation between others. For example, higher status residents had stronger visual ties to other high status households than did lower status residents

who experienced greater visual segregation from other low status households. 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. These visual data indicate a greater sense of social segregation and isolation among lower status "communities" as well as a sense that they were being "watched over" by the occupants of higher status sites; like the accessibility results helping to establish and reinforce differences between ancient Maya social groups (Richards-Rissetto, 2017).

Together, the accessibility and visibility data indicate that the elite of highest socioeconomic status, constructed their houses in the most accessible and visible locations. Interpreting these results within our understanding of ancient Maya ideology and a semiotic framework, the channeling of people past their elaborate complexes and constructing taller houses, in highly visible places enabled the elite to target specific *audiences*. Through the concept of *indexicality*, we can argue that the elite situated themselves adjacent to and in proximity of particular built forms and bounded spaces with the topographic landscape to send messages of status, wealth, and power as well as let the non-elite know that they were they were being 'watched over' linking back to ancient Maya core beliefs about vision. In contrast, while people of the lowest socioeconomic status were the most numerous, they were in some sense the most isolated because were they situated in places of low accessibility and had fewer visual ties to the city's other residents of a similar socioeconomic class (Richards-Rissetto and Landau, 2014; Richards-Rissetto, 2010, 2012).

While GIS analyses of accessibility and visibility offer quantitative data illustrating that visibility and accessibility played fundamental roles in the daily lives of the ancient Maya by not simply expressing royal power but also indicating that lesser elite also employed accessibility and visibility to send messages of power, wealth, and authority – thus linking daily experience to the ancient Maya belief that to be "all seeing" is to be "all-knowing". But are these GIS data sufficient for examining accessibility and visibility in ancient Maya landscape? How well can we truly embed these GIS results within a semiotic framework?

While the concept of audience is brought to the foreground from the GIS data, the concept of indexicality remains in the background. Yes, we can use the GIS data to identify "what is next to what", or in this case, how "close in proximity" things are to each other; however, we are missing a critical component

– what did these "things" look like? Viewshed analyses measure objects (represented as pixels) as visible or non-visible and while we can employ, for example, Higuchi viewsheds (Higuichi, 1983; Richards-Rissetto, 2010; Wheatley and Gillings, 2000), to account for diminishing vision over distance, other factors affecting visual acuity such as background clarity and color are absent (Bernardini et al., 2013; Wheatley and Gillings, 2000). Yes, we can use a database to code the presence/absence or types of, for example, iconography or hieroglyphs, but the concept of indexicality extends to the third dimension. Where on a wall was a glyph inscribed? Was it next to another glyph or some other motif? And, who could see them, for example, if attending a ritual event? To answer these questions and many more, we must turn to 3D or rather we should use an iterative process that brings together GIS and 3D.

6. Potentiality of 3D technologies

GIS offers locational precision that allows us to use maps to examine relationships between buildings, or between buildings and landscape features, and thus more accurately carry out spatial analysis. In contrast to GIS, 3D models allow us to create complex architectural visualizations and explore, for example, building interiors. They give us a sense of mass and space more closely attuned with human perception and this allows us to more intuitively interact with our data. New 3D geospatial technologies such as airborne LiDAR and aerial photogrammetry are allowing us to acquire inordinate amounts of georeferenced 3D data of what exists today, but do such 3D technologies help overcome criticisms of GIS – do they help us link GIS to theory and narratives. While they allow us to do fantastic things like reveal sites beneath dense canopy, such as you see here from the airborne LiDAR data commissioned by the MayaArch3D Project at Copan, 3D technologies offer much more (von Schwerin et al., 2016) (Fig. 5).

We are not limited to reality-based 3D data acquisition but as archaeologists we can also employ 3D modeling and visualization to find new ways to simulate and explore our data. I have argued elsewhere in a paper on "From mounds to maps to models" that a key part to archaeological inquiry is the actual modeling process from GIS to 3D, where we acquire knowledge and formulate new questions that we can then go back to GIS to re(test), and ideally link these 3D models/visualizations to associated archaeological data via 3D GIS or other approaches (Richards-Rissetto, 2013; von Schwerin et al., 2013, 2016). For example, Fig. 6 shows GIS data from Copan converted into 3D models and situated in a georeferenced terrain derived from airborne LiDAR with a virtual reality environment (i.e. Unity – a 3D gaming platform). Using, in particular, recent immersive technologies such as the Oculus Rift, we are exploring the potential of immersive VR for visibility analysis using GIS-based data (Richards-Rissetto et al., 2016a,b). For example, using eye-tracking we can measure what objects within a landscape – based on distance, background, and color – draw the eye, or not. However, the quantitative phase of our VR research is in its formative stages.

These 3D data offer a different perspective than traditional 2D or 2.5D maps. 2.5D maps extrude objects as pixels based on a height attribute field leading to two problems. First, large pixel sizes lead to data loss, for example, if our pixel size (spatial resolution) is greater than one meter, important architectural features such as individual steps are often lost. Second, 2.5D creates blocky, schematic objects because they are limited to pixels, and therefore, architectural details such as sculpture and molding are not represented leading to a loss of aesthetic details that are critical to human perception and experience. Moreover, with 3D we can see the mass and scale as well as the relationships

(indexicality) of buildings to each other and the landscape. We can also integrate more refined 3D models produced in, for example, 3D Studio Max or SketchUp, and link these models to descriptive and/or paradata to inform users about not only what they are looking at but also how modeling decisions were made and the data sources used to make those decisions.

7. 3D + GIS – from ground to sky and back again

3D modeling and visualization offer a ground-based perspective with a sense of mass and scale as well as aesthetic details such as sculptured facades or painted doorways. However, 3D archaeological reconstructions often forgo the natural environment. Hills, streams, and plants, when present, often serve as a backdrop rather than active agents in cultural transformation – the antithesis to semiotics where space is not a neutral backdrop and plants, water, and other environmental features are integral to anthropomorphic landscapes because they reflect not only cultural "land-use" practices but also in a more technical way – our GIS analyses. The debate about the impact of vegetation, landform, etc. on visibility and accessibility is not new by any means (Wheatley and Gillings, 2000); however, the focus here is cultural interpretation rather than methodology.

To counter these shortcomings, the MayaCityBuilder Project – a project using 3D + GIS to develop a library of 3D models and new tools to study ancient Maya landscapes – is using late eighth century Copan as a case study. In working toward the project's long-term goals, we have developed an interactive 3D visualization of Copan's ancient buildings that is situated within georeferenced terrain. This 3D environment enables students and scholars to explore Copan from a ground-based perspective – moving us beyond traditional 2.5D GIS; however, 3D architecture and terrain are not sufficient. Therefore, we are also working with paleoenvironmental and ethnobotanical data to create a database of images and 3D models linked to descriptive attributes that inform on plant habitat, for example, elevation range, cultural affiliation, time period, etc. (Fig. 7). The objective is to create GIS and 3D data that allow scholars to interchange not only georeferenced architectural models but also environmental models within a 3D environment. Georeferenced 3D architectural, vegetation, hydrological, and topographic data bring together the locational precision of GIS with the human perception of 3D allowing researchers to explore archaeological and other data from the ground to the sky and back again. In this way, GIS becomes less "environmentally-deterministic" and we continue to move towards the development of new GIS methods in landscape archaeology (Richards-Rissetto et al., 2016a,b).

8. Conclusions and looking forward

Is GIS more than a tool? Is GIS contributing to theoretical advancements in archaeology? In reality, GIS can be more than a tool and it can contribute to theory depending on how it is applied. If GIS is considered a form of practice that is situated in archaeological theory, then theory-inspired cultural variables can be employed to bridge quantitative and qualitative data. Semiotics with its concepts of audience and indexicality offers a potential theoretical framework to directly situate accessibility and visibility – proxy measurements in GIS – to acquire quantitative data that can be interpreted within specific cultural circumstances. However, GIS alone is not enough to bridge the gap between processual and postprocessual approaches.

In the 1990s, archaeologists were quite hopeful about the potential for GIS to help us understand ancient perception and cognition, but in reality GIS approaches by themselves tend to fall short – in part because we unavoidably ignore human perception with our flat, bird's eye view maps (Gaffney et al., 1996;
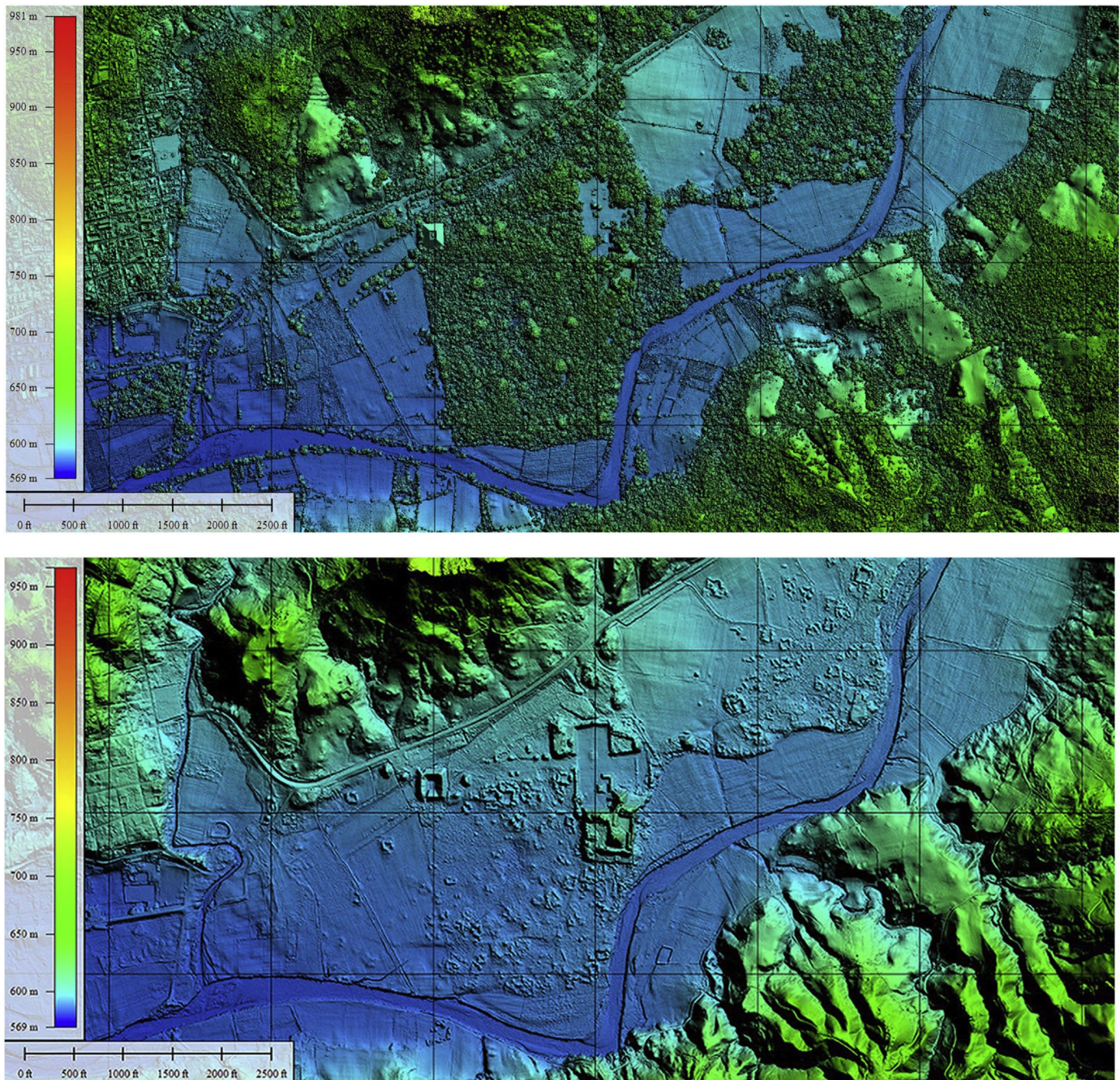
Fig. 5. Airborne LiDAR from Copan: First Return showing canopy (top), Post-processed bare-ground with archaeological structures (bottom) [Courtesy MayaArch3D Project].

Wheatley, 1993; Whitley, 2004; Zubrow, 1994). While 3D modeling and visualization help us to obtain a sense of mass and space and arguably then a sense of place (Forte and Siliotti, 1997; Forte and Kurillo, 2010; Forte and Bonini, 2010; Frischer and Dakouri-Hild, 2008; Paliou, 2013, 2014; Dell Unto et al., 2015), newer technologies such as Oculus Rift – an immersive headset – and gesture-based technologies such as LEAP Motion and Microsoft Kinect – are allowing us to experience these ancient places in potentially ground-breaking new ways (Fig. 8) (Richards-Rissetto et al., 2013).

And if we continue to tack back and forth between GIS + 3D as we move forward also into the immersive with gesture, touch, sound, and smell, we can begin to interact with these georeferenced data in new synesthetic ways. We can begin to record eye movement and brain reaction to specific "experiences" that have potential to further unlock GIS for cognition studies, albeit by tacking back and forth – iteratively moving from GIS to 3D to 3D GIS, back to GIS and so on... to continue to move GIS beyond the map and to contribute to theoretical advancements as archaeologists applying and developing GIS have been doing for the past several decades. GIS doesn't give us answers per se, but enables us to see" links among our data that provide footing to ask even more questions, and that in and of itself advances archaeology.

Fig. 6. Georeferenced 3D Architectural Models in LiDAR landscape, Copan.

Fig. 7. Example Photos and 3D Models (generated using SpreedTree) of Copan's Plants.
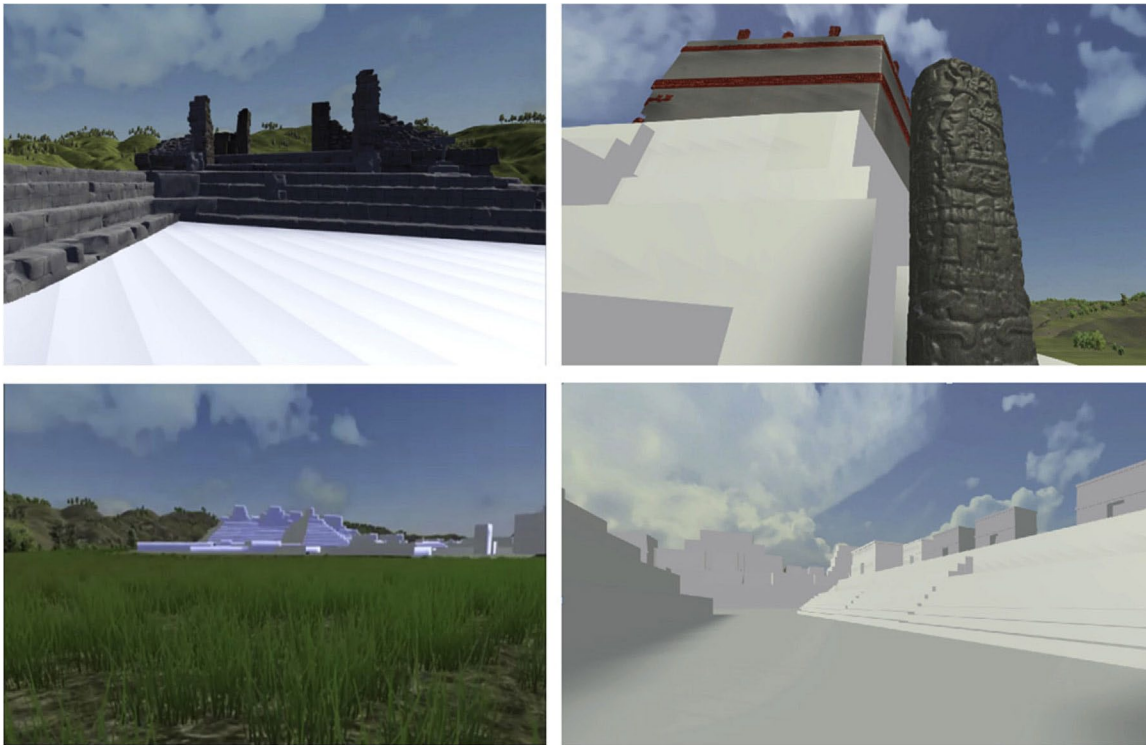
Fig. 8. Illustrating use of Oculus Rift and LEAP Motion to explore ancient Copan.

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