3D Tool Evaluation and Workflow for an Ecological Approach to Visualizing Ancient Socio-environmental Landscapes: A Case Study from Copan, Honduras

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3D Tool Evaluation and Workflow for an Ecological Approach to Visualizing Ancient Socioenvironmental Landscapes

A Case Study from Copan, Honduras

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Abstract
Architectural reconstructions are the centerpieces of ancient landscape visualization. When present, vegetation is relegated to the background, resulting in an underutilization of plant data—an integral data source for archaeological interpretation—thus limiting the capacity to take advantage of 3D visualization for studying ancient socioenvironmental dynamics. Our long-term objective is to develop methods of 3D landscape visualization that have value for examining changes in land use and settlement patterns. To begin to work toward this objective, we have (1) identified 3D tools and techniques for vegetation modeling and landscape visualization, (2) evaluated the pros and cons of these tools, (3) investigated biological and ecological approaches to simulate plant habitats, the data requirements of these approaches, and the pros and cons of these approaches for reconstructing archaeological landscapes, and (4) then built on these findings to propose a workflow to integrate archaeological, paleoenvironmental, and ethnobotanical into Geographic Information Systems (GIS) for export into a virtual landscape for investigations of ancient socioenvironmental interaction. To identify possible 3D digital tools and workflows to visualize plant distribution models alongside archaeological settlement, we keep in mind several key issues: capacity to handle georeferenced data, levels of detail, multiscalar analysis, and availability of quantitative and qualitative data.
Introduction

Vegetation is a key source of data for investigating archaeological landscapes; however, in 3D visualization they often serve as a backdrop to architectural reconstructions rather than as an integral component of ancient landscapes. Our project’s long-term vision is to develop methods of 3D landscape visualization that have value for examining changes in land use and settlement patterns in archaeological landscapes. We employ an ecological perspective that enables scholars to integrate cultural and environmental data in landscape reconstructions in order to facilitate a more holistic and active engagement with and exploration of ancient socioenvironmental dynamics.

To begin to work towards this long-term goal, we have (1) identified 3D tools and techniques for vegetation modeling and landscape visualization, (2) evaluated the pros and cons of these tools, (3) investigated ecological approaches to simulate plant habitats, the data requirements of these approaches, and the pros and cons of these approaches for reconstructing archaeological landscapes, and (4) then built on these findings to propose a workflow to integrate archaeological, paleoenvironmental, and ethnobotanical data into Geographic Information Systems (GIS) for export into 3D virtual environments. The case study is the UNESCO World Heritage Site of Copan, Honduras and 24 km surrounding the site’s main civic-ceremonial core. The workflow brings together 2D and 3D data with archaeological, environmental, ethnographic, and ethnobotanical data sets into a georeferenced 3D virtual environment for visual, spatial, and temporal analysis of ancient socioenvironmental dynamics.

Case Study: Copan, Honduras

Located on the southeast periphery of the ancient Maya world, Copan’s multiethnic history offers a unique perspective on social and environmental interaction (Figure 1). For much of the Preclassic period (1300 BCE–CE 100/250), Copan’s population was Non-Maya. Ceramics indicate that populations from El Salvador, the Pacific Coast, and eastern Honduras occupied the valley (Canuto 2002; McNeil 2009, 2010, 2012; Viel 1993). Sometime between CE 100–250, Maya populations immigrated to Copan (McNeil 2009, 2012). While ceramic evidence suggests that proto-Chorti (ancestors of present-day Chorti Maya) settled at Copan ca. CE 100 (Sharer 2009), recent pollen data support also a later immigration ca. CE 250 (McNeil 2009).

In CE 426 (the Early Classic period), Copan’s 1st dynastic ruler, a foreign-born Maya noble, was seated (Bell et al. 2004; Stuart 2007). Until relatively recently, it was assumed that with the establishment of Copan’s dynasty (which was to last nearly 400 years) Copan “becomes” Maya; however, new evidence continues to come to light to question this assumption. For example, El Salvadoran migrants, who were displaced due to the eruption of Ilopango Volcano, settle in the valley ca. CE 430 (McNeil 2009). This line of evidence along with ceramic, bioarchaeological, and settlement pattern data suggest that Copan contained a multiethnic population throughout the Late Classic period (CE 250–850) (e.g., Canuto and Bell 2008, 2013; Gerstle 1987; Maca and Miller 2009; Price et al. 2008; Richards-Rissetto 2010) (Table 1).
While evidence of Copan’s multiethnic polity is increasing, the scope of ethnic heterogeneity and its impact on cultural practices and interaction at particular time periods remains unclear. In other words, archaeologists know little about how the polity’s multiethnic history may have impacted interaction with(in) the physical and social landscape. To address this issue from a unique perspective, we propose to explore the pros and cons of 3D visualizations (derived from paleoenvironmental, ethnographic,
archaeological, and other data sources) and how these visualizations can be used to investigate changes through time in land use, particularly in relation to changing ethnic populations.

**Advantages and Challenges to 3D Visualization for Landscape Archaeology**

There are both advantages and challenges to using 3D visualization for archaeological research. While 3D data acquisition and 3D visualization varies in technology (e.g., terrestrial laser scanning, airborne LiDAR, photogrammetry, Computer Aided Design) and scale (ranging from artifacts to individual buildings to entire cities) there is a common thread—most 3D visualization focuses on artifacts and architecture. While the advantages and challenges of 3D modeling and visualization of artifacts and built environments are critical to archaeological practice (e.g., Barcelo et al. 2000; Dell’Unto et al. 2015; Frischer et al. 2008; Forte et al. 2003; Forte 2005; Richards-Rissetto 2013); our focus is on 3D visualization of vegetation in association with archaeological settlement data in georeferenced virtual environments because vegetation data (e.g., palynological, ethnobotanical) are an integral data source for archaeological interpretation and critical for understanding past land use, environmental impact and cultural adaptation (e.g., Fedick 1996; McNeil 2012).

Some advantages of 3DGIS for landscape archaeology include: 3D models that provide a sense of ancient places to foster public appreciation and facilitate scholarly interpretation, clicking on plants to access information about plant communities (e.g., potential use, time range, habitat characteristics) in context of archaeological settlement patterns, ability to perform 3D analysis in a landscape context, for example, to calculate visibility or travel costs based on both ecological and settlement data in a 3D environment, and interaction with alternative 3D reconstructions of how individual buildings, architectural complexes, and entire cities may have a looked in their environmental contexts.

Some disadvantages of 3DGIS include: incomplete data sets requires “filling in the blanks” to create realistic models that are not necessarily “accurate”, difficult to convey uncertainty in 3D reconstructions, realistic models are often time-consuming and require expertise to build, current navigation tools are very basic, 3D plant modeling is typically limited to point data and models tend to be crude and unrealistic, GIS environments tend to exclude important qualitative data essential for understanding cultural complexities, and importantly modeling capabilities in GIS are limited potentially leading to reductive reconstructions (e.g. Forte et al. 2005a, b; Forte 2014; Pescarin et al. 2005).

Generally speaking 3DGIS has the potential to bring together experiential, quantitative and qualitative approaches into a single tool for comprehensive, holistic, and unique analysis; however, current 3DGIS systems still lack key functionality particularly in regard to capturing aesthetics and a realistic sense of movement within ancient landscapes. To address these concerns, several archaeological projects are working to develop 3DGIS tools such as the MayaArch3D Project (www.mayaarch3d.org/,
von Schwerin et al. 2013) and Gabii Goes Digital (http://gabiiserver.adsroot.itcs.umich.edu/gabiigoesdigital/index.html); other projects use combinations of existing software for 3DGIS visualizations (e.g., Dell’Unto et al. 2015; Dylla et al. 2009; Opitz and Nowlin 2012; Saldana and Johanson 2013); however, currently these projects are not developing tools to incorporate ecological data.

To begin to move toward the development of a 3DGIS tool that integrates and analyzes georeferenced ecological and archaeological data, we devised a preliminary workflow (Figure 2). The workflow allows us to simultaneously work linearly and iteratively. We adopt a linear—step-by-step—approach to identify the requirements for each component. However, we iteratively work back and forth among components to modify requirements and update steps as we learn and discover new issues, alternative tools, etc. in other components. Our goal is to use the workflow to identify required tasks, and then to evaluate existing 3D tools (particularly free and/or open source) that can fulfill these tasks.

**Workflow: An Ecological Approach**

The workflow has three main parts: (I) Data Acquisition, (II) Data Processing, and (III) 3DGIS Data Visualization and Analysis.

![Figure 2. Workflow for ecological approach to 3DGIS visualization.](image-url)
Data Acquisition

Data acquisition comprises four components: (1) Plants, (2) Terrain, (3) Settlement, and (4) Land Use.

Plants
Plant data serve two broad uses: identification and visualization. Identification: Palynological data (e.g., soil cores) and modern plant communities are two data sets that can be used to model plant species within a specified spatial extent (i.e., landscape). Visualization: Photos, airborne LiDAR (Light Detection and Ranging), and 3D model libraries can be used to generate 3D individual plant models and populate 3D landscape visualizations from those data sets.

Terrain
Terrain comprises vector (shapefiles) and raster data. GIS vector data for soils and geology provides attributes to describe terrain characteristics for discrete areas that influence the growth of plant communities. Elevation data from, for example, airborne LiDAR or rasterized contours (as continuous data), provides a Digital Terrain Model (DTM) that combined with hydrology and geomorphology data reconstructs the bare earth surface.

Settlement/Architecture
Archaeological settlement data come from excavations, pedestrian surveys, aerial and satellite imagery, and airborne LiDAR. Excavations provide temporal data for diachronic visualizations.

Land Use
Ethnographic, ethnobotanical, and archaeological studies on land use provide context for interpreting and integrating plant, terrain, and settlement data for analysis and 3D visualization.

Data Processing

Geographic Information Systems (GIS)
GIS is a mainstay of archaeology for data management, creation, analysis, and visualization. Most importantly it affords archaeologists the tools to reveal and analyze complex patterns and trends in spatial data through an interactive mapping interface (Chapman 2006; Conolly and Lake 2006; Wheatley and Gillings 2002). In the workflow, GIS serves two main purposes: (1) integrate the settlement (building footprints) and environmental data including 2D (e.g., soils shapefile) and 2.5D (e.g., DTM) data sets into a common coordinate system (e.g., Universal Transverse Mercator) and (2) analyze spatial relationships among settlement/archaeological and environment variables to output new “analytical/interpretative” GIS data sets about ancient land use and settlement patterns. These GIS data also serve as inputs for 3D visualizations.
3D Modeling
3D modeling is rapidly becoming more commonplace in archaeology. 3D reconstructions are multipurposed offering data preservation, public outreach, scholarly research and much more (Barcelo et al. 2000; Fisher 2012; Forte and Kay 2001; Forte et al. 2005a, b; Frischer and Dakouri-Hild 2008; Richards-Rissetto et al. 2013). The workflow converts photos, airborne LiDAR, and shapefiles into 3D models of plants, terrain, and hydrology. Billboards (to decrease data size and modeling time/cost) for plants are generated for Level of Detail (LOD) management and display to facilitate real-time visualization for faraway objects in a 3D scene (Kim et al. 2011). Excavation, settlement, and ethnographic data are integrated to generate 3D architectural models of buildings. GIS footprints (shapefiles) provide building locations for 3D architectural models.

A major challenge to 3D landscape visualization is the tools that best let researchers visualize architecture in 3D are not well-suited for visualizing vegetation in 3D, and even when they do a decent job of visualizing vegetation they are typically not good for landscape analysis. This challenge arises in great part because scholars have diverse research interests. As previously stated, we contend that to ensure appropriate 3DGIS data visualization and analysis, researchers must first define their goals and objectives. The second step is to devise specific methods to achieve those goals and objectives based on available data.

3DGIS Data Visualization and Analysis

Ecological Framework

Populating ancient landscapes with plant communities is not straightforward. The vast majority of sites are unexcavated, potentially leading to “biased” samples (from excavated sites), the preservation (quantity and quality) of paleoenvironmental data vary regionally and by type (species), and diversity in species pollen dispersal (e.g. range and amount) makes it challenging to “translate” paleoenvironmental data into discrete areas that can be mapped on the landscape, particularly at intermediate-level scales ranging (e.g., 20–50 km) (e.g., Franklin 2010; Franklin et al. 2015). The problems arises that if we cannot map ancient plant communities, then we cannot “accurately” visualize them in three dimensions. To overcome some of these limitations, we propose an ecological model that uses proxies derived from modern and paleoenvironmental data to estimate the spatial extent of ancient plant communities. To properly derive proxies, it is necessary to step back and ask an initial set of questions to frame the ecological approach.

Initial Questions
We pose the following four questions:

1. What approaches do biologists and ecologists use to simulate plant habitats in landscapes?
2. What types of data do they use? How do they use these data?
3. Which of these approaches can we use given our data set for Copan, e.g., palynological, hydrological, soil, geological, and ethnobotanical?
4. What other data might we need? Can we get these data?

Based on our findings (and available data sets), we identified two, but not mutually exclusive, approaches to simulate plant communities at ancient Copan. These two approaches are combined to create a model that employs data from the past and present to provide more holistic reconstructions of Copan’s ancient landscape(s).

Approach #1
This approach employs ordination analysis of modern plant communities in order to determine plant communities that are most likely to occur in specific areas. Ordination analysis is a way to determine whether particular plant communities tend to be found in a consistent habitat type, and which communities are most similar to each other. This approach records attributes such as plant species, soil type, elevation, and water availability along transects in a study area and subsequently uses ordination analysis to develop a list of plant communities that tend to occur and the characteristics (e.g., soil type, elevation) of where they tend to occur. We can then assign plant communities to particular habitats if such patterns become apparent. While this method allows us to develop broader models of plant distribution throughout the site and understand potential interactions between different plant species, the downside is that it assumes that modern communities have not changed from the communities that existed during the period of study.

Approach #2
This approach uses pollen data from soil cores to estimate the proportion of different plant species and functional groups within the landscape. The process involves five broad steps: (1) identifying ideal locations for sediment cores, (2) grouping the pollen data from cores into species as aquatic, terrestrial, or arboreal, to provide an initial sense of the proportions of each species and general potential for dispersal, (3) correct for amount of pollen produced by species, i.e., gymnosperms versus angiosperms, (4) establish ratios of each plant as part of the whole community, based on pollen core, and (5) model habitat preference categories, i.e., most likely locations of those plants based on habitat characteristics such as soil and elevation (factor in pollen dispersal distance, here or during analysis of ratios) (Fisher-Meerow and Judd 1989; Judd 1987; Higuera-Gundy et al. 1999; Holdridge 1945).

While this approach provides hard evidence of the existence of species dated to the time being studied, not all pollen has equal dispersal or durability and this method may lead to a model biased towards particular species. Additionally, potential locations for collection of pollen cores may be limited, increasing the bias towards plants near those locations.

To help counter some of the shortcomings of these two approaches, our methodology combines these two approaches into a single ecological framework to integrate
data from the past and present in order to fill gaps in paleoenvironmental data and contextualize modern data (to the fullest extent possible given a particular data set) in prehistory. Archaeological, ethnographic, and ethnobotanical data (when available) are also incorporated into the model. Data integration occurs in a GIS to model potential plant distributions for specific time periods and then these georeferenced data are used to populate 3D visualizations with plant models in accordance with settlement data. We turn now to the case study at Copan, Honduras.

Case Study: Copan Honduras

The long-term goal of our project is to develop an innovative approach to investigate socioenvironmental dynamics in ancient landscapes. The case study focuses on investigating how Copan’s multiethnic history (900 BCE–CE 1100/1250) may have impacted interaction with(in) the physical and social landscape. Our main objective is to employ 3D visualizations (derived from paleoenvironmental, ethnographic, archaeological, and other data sources) to investigate this line of inquiry. To work towards achieving this objective, we have begun to test the workflow for Copan including evaluating potential 3D tools for plant modeling and landscape visualization.

Data Acquisition

The data for Copan are being acquired from a variety of sources and used for GIS and 3D modeling.

Plants

Photos

- Digital photos acquired from online databases (very few host data for Mesoamerica, particularly with high-resolution images necessary to generate 3D plant models or billboards)
- Digital photos acquired from field work. [When possible it is best to acquire photos of individual plants without background vegetation to facilitate subsequent 3D modeling (Figure 3).]

Airborne LiDAR

- LiDAR data, acquired in May 2013 by the MayaArch3D Project, provides 3D point clouds of vegetation
- Forestry algorithms can be employed to generate 3D models of plants (Figure 4) (Hu et al. 2014; Li et al. 2012).

3D Models

- Few 3D plant models for the semitropical environment of Central America are available from plant libraries or 3D warehouses.
Pollen (Soil Cores)
- Pollen and spore raw data from Petapilla pond sediment core, Copan Valley provide (when possible) species classifications from 46 levels (McNeil 2012)
- Percentages of pollen and spores classified as arboreal, herb, aquatic, or unknown from 46 levels (derived from raw data) (McNeil 2012).

Plant Communities
- Maya Ethnobotanical Report—a quantitative ecological study for Copan Archaeological Park describes main ecosystems with data on species density, frequency, and dominance (House 2007).

Terrain

LiDAR
- Digital Terrain Model (DTM), 0.5 m resolution, generated from LiDAR.

Shapefiles (Vector Data)
- Soil
- Hydrology (Copan River, quebradas, ancient reservoirs)
- Geology

Settlement
- LiDAR provides georeferenced mound and building locations
- Pedestrian survey maps provide building footprints and type (Fash and Long 1983)
- Excavations provide attribute information for 3D reconstruction of buildings and additional social, political, ideological, and economic data.
Land Use

- Ethnographic data (e.g. Wisdom 1940)
- Ethnobotanical data (House 2007)
- Archaeological data (e.g., Baudez 1983; Webster 2005).

Data Processing

Data Processing is divided into two components, GIS and 3D Modelling. These two components overlap—GIS data are used to generate some 3D models and to spatially reference non-GIS derived 3D models such as individual 3D plant models—and the process is iterative, working back and forth between GIS and 3D modeling software. This is a critical phase in the workflow because it is in this phase that the ecological approach is applied to determine potential plant communities and their spatial locations within Copan’s landscape.

GIS

**Determining Potential Plant Community Locations**

**Step 1.** Plant Classification: It is necessary to classify the plant data into broad types and then determine percentages of these types for specific time periods for analysis and visualization purposes. To begin this process, we are using McNeil’s data (2012) pollen data derived from soil cores.
Step 1a. We identified time periods (n = 7) that combine key cultural events with ecological trends at Copan in order to better understand the general trends and changes in specific plant species (Table 2).

Step 1b. We compiled tables (n = 7) with percentage per species of total for the seven time periods listed in Table 2. Table 3 illustrates an example from the Early Classic Period (CE400–600).

Step 1c. Using McNeil’s (2012) data, we identified traits and trends in plant data for each time period by comparing to previous time period (e.g., comparing Early Classic Period data to ProtoClassic Period data).

Trees and Shrubs
- Diversity of tree species continues to increase, e.g., pine trees increase ~8%; Oak stable; Urticales and Piperaceae stable

Aquatic Plants
- Typha stable, Osmunda increase from ~3.5 to 12%, Cyperaceae decrease from 26 to 22%, Pterid... increase from 6 to 11%

Upland Herbs
- Zea mays slightly increases; daisies decrease from 37 to 17%; Chenopodiaceae/Amaranthaceae increase from 6 to 10%; grasses stable

Step 1d. We subdivided each time period into two categories “trees and shrubs” and “upland herbs” based on McNeil (2012) (Table 4 illustrates the Early Classic Period).

Step 2. Compare all identified plant species (derived from sediment cores) to ecosystem shapefiles (generated from House 2007) to assign preliminary spatial locations to specific plant species

Step 3. Use GIS to generate “ecosystem” shapefiles for each time period (n = 7) based on total percentage of trees and shrubs and upland herbs

Table 2. Time periods for the 3D visualization and analysis case study of Copan’s socioenvironmental dynamics

<table>
<thead>
<tr>
<th>Period</th>
<th>Date range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preclassic</td>
<td>900 BCE–CE 100</td>
</tr>
<tr>
<td>Protoclassic</td>
<td>CE 100–400</td>
</tr>
<tr>
<td>Early classic</td>
<td>CE 400–600</td>
</tr>
<tr>
<td>Late classic</td>
<td>CE 600–780</td>
</tr>
<tr>
<td>Terminal classic</td>
<td>CE 780–980</td>
</tr>
<tr>
<td>Protopostclassic</td>
<td>CE 980–1100</td>
</tr>
<tr>
<td>PostClassic</td>
<td>CE 1100–1220/1300</td>
</tr>
</tbody>
</table>
### Table 3. Illustrates species percentages classified by time period (e.g., Early Classic) [based on McNeil 2012]

<table>
<thead>
<tr>
<th>Genus/Family</th>
<th>CE 400–600</th>
<th>Total%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acalypha (a) (Genus)</td>
<td></td>
<td>0.68</td>
</tr>
<tr>
<td>Acrocomia (a) coyol palm</td>
<td>0.40</td>
<td>0.40</td>
</tr>
<tr>
<td>Alchornea (a)</td>
<td>0.48</td>
<td>0.48</td>
</tr>
<tr>
<td>Alnus (a)</td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>Arecaceae (a) palms</td>
<td>0.35</td>
<td>0.35</td>
</tr>
<tr>
<td>Chamaedorea-type (a) palms</td>
<td>7.08</td>
<td>7.08</td>
</tr>
<tr>
<td>Hedyosmum mexicanum (a)</td>
<td>0.35</td>
<td>0.35</td>
</tr>
<tr>
<td>Ilex (a)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Mimosa (type A) (a)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Mimosa pigra (type B) (a)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Pinus (a)</td>
<td>25.88</td>
<td>25.88</td>
</tr>
<tr>
<td>Quercus (a)</td>
<td>8.22</td>
<td>8.22</td>
</tr>
<tr>
<td>Urticales (a)</td>
<td>3.48</td>
<td>3.48</td>
</tr>
<tr>
<td>Piperaceae (a)</td>
<td>5.12</td>
<td>5.12</td>
</tr>
<tr>
<td>Liquidambar (a)</td>
<td>0.68</td>
<td>0.68</td>
</tr>
<tr>
<td>Burseraceae (a)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Myrtaceae (a)</td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>Rhamnaceae (a)</td>
<td>0.13</td>
<td>0.13</td>
</tr>
<tr>
<td>Sapindaceae (a)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Osmundata-type (aq)</td>
<td>12.10</td>
<td>12.10</td>
</tr>
<tr>
<td>Typha (aq)</td>
<td>0.75</td>
<td>0.75</td>
</tr>
<tr>
<td>Cyperaceae (aq)</td>
<td>21.98</td>
<td>21.98</td>
</tr>
<tr>
<td>Pterid., monolete and psilate (aq)</td>
<td>11.15</td>
<td>11.15</td>
</tr>
<tr>
<td>Croton (aq)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Begoniaceae (aq)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zea mays (h)</td>
<td>0.27</td>
<td>0.27</td>
</tr>
<tr>
<td>Asteraceae (h)</td>
<td>16.90</td>
<td>16.90</td>
</tr>
<tr>
<td>Chenopodiaceae/Amaranthaceae (h)</td>
<td>10.08</td>
<td>10.08</td>
</tr>
<tr>
<td>Poaceae (h)</td>
<td>18.97</td>
<td>18.97</td>
</tr>
</tbody>
</table>

### Table 4. Table comparing percentage of trees and shrubs to upland herbs: example from Early Classic Period (derived from McNeil 2012 pollen data)

<table>
<thead>
<tr>
<th></th>
<th>Early classic (CE 400–600)</th>
<th>Total%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trees and shrubs</td>
<td>53.5</td>
<td></td>
</tr>
<tr>
<td>Upland herbs</td>
<td>46.5</td>
<td></td>
</tr>
</tbody>
</table>
Step 4. Use GIS to calculate “potential” total area for each species within an ecosystem based on environmental variables such as soil and hydrology combined with percentages of individual plant species categorized as trees and shrubs, upland herbs, or aquatic; calculations stored as attribute of ecosystem (spatial location within each ecosystem assigned stochastically based on estimated area/plant species (stored as attribute) in 3D visualization).

Determining Archaeological Settlement Locations

LiDAR data combined with pedestrian survey maps provide settlement data (i.e. mound locations and building footprints) spanning the Late Classic and Terminal Classic Periods (ca. CE 700–820). However, mapping settlement data for earlier time periods is not straightforward because the majority of Copan’s nearly 3600 buildings remain unexcavated (Figure 5 compares Preclassic to Classic Period settlement patterns).

To begin to generate building footprints for earlier time periods we turn to three data sources: (1) extensive excavations, (2) test excavations, and (3) settlement patterns derived from excavation and survey data at Copan and nearby valleys (e.g., Canuto and Bell 2008; Manahan and Canuto 2010).

Archaeologists have also identified four key indicators that differentiate Non-Maya and Maya settlements: (1) settlement pattern, (2) spatial organization, (3) architecture, (4) and use of space (e.g., Canuto 2002; Canuto and Bell 2008).

Non-Maya Patterns

Settlement Pattern:
- Hilltops overlooking floodplain
- Sites located approximately 30 m above agricultural fields

Spatial Organization:
- Standalone range structures
- Positioned along edge of hilltop
- Large, open, and accessible interior plazas

Architecture:
- Earthen platforms
- Pole-and-thatch superstructures
- Lower Buildings (<2 m)
- Residential platforms wider/longer than Maya
- Little intracommunity variation

Use of Space:
- Higher P-accumulations in plazas
- Small refuse and garden areas
- Intensive infield agricultural system
- Minimal household horticulture
Figure 5. Preclassic settlement pattern, Copan Honduras illustrating dispersed, low density settlement on hilltops prior to valley bottom settlement (top); Late Classic settlement pattern, Copan, Honduras illustrating high density settlement in urban core and into foothills (bottom)
Maya Patterns

Settlement Pattern:
- Settlement on/adjacent floodplains
- Not on hilltops

Spatial Organization:
- Clear boundaries defined by architecture
- Smaller and more tightly packed buildings
- Residences w/smaller plazas
- Restricted access ceremonial structures

Architecture:
- Cobblestone platforms
- Taller buildings
- Large intracommunity variation
- Superstructures (wattle-and-daub, cut-masonry)

Use of Space:
- Lower P-accumulations in plazas
- Large refuse and garden areas
- Fields distant from households
- Exclusive land tenure pattern
- Intensive horticulture

We propose an approach that integrates these generalized Non-Maya and Maya settlement patterns and site organization plans, arguably representative of distinct cultural groups, with paleoenvironmental data that McNeil (2009, 2012) has correlated to specific cultural groups in order to reconstruct land use, plant communities, and settlement patterns for each of the key time periods at Copan (n = 7). This strategy aligns with the ecological approach described above.

Admittedly, any spatial data sets derived for early settlement at Copan are approximations; however, we see this as a first but necessary step to begin to generate GIS data that can be ingested in a 3DGIS. Subsequently, these data are explored from a three-dimensional perspective that links underlying archaeological and ecological data to the 3D models to generate preliminary settlement and land use models for earlier time periods and importantly to initiate scholarly discourse within a collaborative, dynamic, and iterative framework about changing ancient socioenvironmental at Copan that can ultimately be investigate in regard to ethnicity.

3D Models

The 3D models component of the workflow is divided into two parts: (1) identify options for modeling individual plant species and (2) evaluate existing software to visualize and interact with 3D landscapes that can integrate georeferenced architecture and vegetation data.
Generating Individual 3D Plant Models

Given that our case study is in Central America, existing 3D plant models, particularly free models, are limited to say the least. This circumstance requires that we devise a workflow to efficiently generate plant models. To this end, we have investigated and evaluated several data types and software to generate 3D plant models. Table 5 lists the evaluated software, primary function, pros, cons, and comments. From our investigations, we have identified three general approaches to visualize plants in a 3D landscape context.

Table 5. Summary table of 3D tools and data for generating individual 3D plant models

<table>
<thead>
<tr>
<th>Software</th>
<th>Function</th>
<th>Pros</th>
<th>Cons</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>XFrog</td>
<td>Create 3D plant models</td>
<td>Full-featured plan modeling @$200–400</td>
<td>Steep learning curve; nongenerative</td>
<td>Good option for creating models for GIS-based visualization</td>
</tr>
<tr>
<td>3D ArcStudio 3D TreeMaker</td>
<td>3D plant modeling</td>
<td>Easy to learn; inexpensive; customizable; parameters</td>
<td>Proprietary; tailored to work with SketchUp</td>
<td>Quick, easy, change tree templates</td>
</tr>
<tr>
<td>TreeGen</td>
<td>Procedural plant modeling</td>
<td>Open source, free; adaptable, e.g., to Blender</td>
<td>Python Script (requires coding to adapt; creates random trees)</td>
<td>Possible modify to generate nonrandom trees and generate other plants; designed for 3D StudioMax</td>
</tr>
<tr>
<td>Abaro</td>
<td>3D tree modeling</td>
<td>Implements tree generating algorithm; import into Blender; open source (Java)</td>
<td>Few trees in library</td>
<td>Open source; complicated; steep learning curve; time-consuming</td>
</tr>
<tr>
<td>SpeedTree</td>
<td>Middleware solution for modeling and real time rendering of plants</td>
<td>Procedural approach to modeling</td>
<td>Proprietary; expensive @ $895.00 ($19 monthly option)</td>
<td>Procedural approach with data interoperability compensates for its existing libraries having few Mesoamerican plants</td>
</tr>
<tr>
<td>SketchUp</td>
<td>3D modeling</td>
<td>Easy to learn; inexpensive; exports multiple formats</td>
<td>Proprietary; can create plugins but difficult to customize; manual process</td>
<td>Time-consuming to create models (existing libraries have few Mesoamerican plants)</td>
</tr>
<tr>
<td>LIAR</td>
<td>Use 3D points to generate 3D plant models</td>
<td>Useful for present-day plants</td>
<td>Data acquisition and post-processing expensive; requires expertise, proper algorithms; data for species not in coverage not collected</td>
<td>Apply forestry algorithms to model tree species</td>
</tr>
</tbody>
</table>
• “True” 3D models with x, y, and z coordinates—these have the advantage of being useful for analytical purposes but are rather large to store and visualize
• Billboards—2D object always oriented to face object—decreases data size and modeling time/cost and is particularly valuable for online visualization; however, not useful for 3D analysis
• Procedural Models—ultimately we prefer a procedural approach where the plants can be generated from a set of rules.

While all three options require researching plant species and collecting digital photos and/or drawings prior to 3D visualization, from our software evaluations we prefer software that employs procedural modeling such as TreeGen or SpeedTree because it permits flexibility in modeling that facilitates the generation of multiple 3D reconstructions, and hence an interactive, dynamic, and iterative exploration of socioenvironmental simulations.

3D Settlement Data

While the focus of this chapter is not 3D modeling of architecture, it is important to provide an overview of the subject because the ultimate goal of the proposed workflow is to integrate 3D settlement and environmental data. Three methods of 3D modeling of architecture are briefly described.

• Extruding GIS footprints—streamlined, quick process using height attribute but results in blocky unrealistic representations that would hinder analysis, e.g., visibility analysis—an example is flat versus pitched roofs
• Manual Modeling—using software such as 3D Studio Max or SketchUp to model buildings—this process is useful for modeling individual buildings or small spatial extents; however, it is time-consuming to model vast landscapes
• Procedural Modeling—use a set of rules to generate and texture 3D buildings based on GIS attributes and automatically situate buildings to their spatially referenced locations in a landscape.

Software for 3DGIS Landscape Visualization

Increasingly, more software for 3D landscape visualization are available. These software programs range in functionality (visualization vs. analysis), platform (desktop, web-based, mobile application), data interoperability, rendering capabilities, and ability to integrate and link to georeferenced data. Table 6 lists nine software programs along with their main function as well as pros and cons and comments relevant to an ecological approach for 3D visualization of plants and architecture in virtual landscapes. Initial tests were carried out using VNS3 (Visual Nature Studio 3). VNS3 performs 3D rendering of georeferenced data sets (raster and vector) taking advantage of GIS’ ability to deal with locational data and overlay settlement and vegetation data.
### Table 6. 3DGIS Visualization Software evaluated for utility in ecological workflow

<table>
<thead>
<tr>
<th>Software</th>
<th>Function</th>
<th>Pros</th>
<th>Cons</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESRI ArcScene</td>
<td>Visualizing 2.5/3D georeferenced data</td>
<td>Easy to use interface, file Compatibility (DWG, DXF, DGN), Interfaces with ArcGIS Desktop</td>
<td>Limited in use of full geometry for 3D Analysis and visualization; proprietary</td>
<td>Limited 3D rendering and analysis capabilities for web-based visualization</td>
</tr>
<tr>
<td>ERDAS Imagine Virtual GIS</td>
<td>Geological remote sensing, Image processing</td>
<td>Uses image data to create 3D representations; focus on visualization, rapid rendering and fly-throughs</td>
<td>Proprietary, expensive, and limited ability to include modeled 3D imagery. No ability for 3D analysis</td>
<td>Appropriate for quick visualization of existing landscapes, not ideally suited to integrating 3D plant models</td>
</tr>
<tr>
<td>GeoMedia Terrain</td>
<td>3D representation of 2D GIS</td>
<td>Visualizes 2D maps and runs fly-throughs of GIS data in GeoMedia platforms</td>
<td>Expensive, limited analysis and visualization capabilities</td>
<td>Intended for visualizing terrain, and expensive</td>
</tr>
<tr>
<td>GRASS GIS</td>
<td>3D representation of 2D GIS</td>
<td>Open Source, free, works with Quantum GIS; ALIDAR tools, Adaptable.</td>
<td>Limited in use of full geometry for 3D Analysis and visualization</td>
<td>Provides basic open source and free platform; however, for intensive visualization and integration of 3D vegetation models, additional plugins and adaptations required</td>
</tr>
<tr>
<td>Demeter Terrain Engine</td>
<td>Renders 3D Terrain using OpenGL</td>
<td>Open Source, free; uses OpenGL; adaptable; fast performance; integrate with Open Scene Graph to populate with objects, such as trees; adaptive mesh</td>
<td>Limited 3D analysis, needs to integrate Demeter into application to add 3D models (i.e., using Open Scene Graph)</td>
<td>Option as a basic platform, however, it is essentially only a visualization program, and would not be able to perform analysis</td>
</tr>
<tr>
<td>Virtual Terrain Project</td>
<td>Project linking a suite of software to create 3D simulations of real world</td>
<td>Interfaces with Xfrog (Plant Modeler), Open source, free, has library of 94 species and 409 instances (as billboards)</td>
<td>Limited capacity for analysis, not well linked with common GIS platforms</td>
<td>Good potential, existing (limited) plant library; infrastructure for adding plants based on ecological classification</td>
</tr>
<tr>
<td>ESRI CityEngine</td>
<td>Procedural modeling of GIS data for architecture/plants</td>
<td>Rule-based (generative); exports to multiple formats; exports to WebGL; plant libraries; plants visualized based on probabilities</td>
<td>Proprietary, expensive; requires learning CGA Shape Grammar—steep learning curve</td>
<td>Procedural approach allows for flexibility and testing of visualizations; GIS platform enables vegetation placement based on ruler linked to attributes in geodatabase; permits subsequent GIS analysis</td>
</tr>
<tr>
<td>BioSphere 3D</td>
<td>Modeling and 3D visualization of real world on virtual globe</td>
<td>High visual quality, streamlined rendering, uses Xfrog; used in visualization of landscape change; open source</td>
<td>Little analytical capability</td>
<td>Good potential for development; supports shapefile, satellite/aerial imagery, open source allows for modification to add analytical functionality</td>
</tr>
<tr>
<td>Visual Nature Studio 3</td>
<td>3D Visualization of architecture and plants using GIS data</td>
<td>Imports GIS (vector/raster) data; models ecotypes and foliage; dynamic modeling</td>
<td>Midrange price (dungeon); steep learning curve; exports do not store full scenes; no analysis</td>
<td>“Quick” option to model 3D landscape from GIS data but not a long-term solution for development</td>
</tr>
</tbody>
</table>
Moreover, because VNS3 was originally designed for forestry applications it enables users to set parameters for rendering vegetation data, for example, to set minimum and maximum size and density for ecosystems and foliage types in relation to underlying GIS data. This ability to integrate georeferenced settlement data as 2D vector and/or 3D architecture models (e.g., as OBJ) and render in conjunction with 3D plant models based on ecosystems defined by underlying GIS data enables users to test alternative landscape simulations (Figures 6, 7, and 8).

Following these initial test simulations, we have also begun a procedural modeling approach using CityEngine in order to overcome the limitations of VNS3 including lack of flexibility in modeling to rapidly test alternative simulations, limited data interoperability for export, lack of interactive interface for rendered scenes, and steep learning curve (Richards-Rissetto and Plessing 2015).

**Future Direction: 3DGIS Data Visualization and Analysis**

Implementation of the complete ecological workflow at Copan requires further collection of data on current plant communities, and possibly further assessment of paleoecological soils and microclimates. However, from these preliminary visualizations,

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**Figure 6.** GIS versus 3D Views of soil data (left) and geological data (right)—overlaid with Late Classic settlement data from Copan, Honduras in Visual Nature Studio 3.
Figure 7. A 3D simulation of Cerro Chino—a Non-Maya Preclassic Period Site at Copan, Honduras illustrating hilltop settlement with downslope maize production using VNS3 in landscape.

Figure 8. A 3D simulation of Late Classic Period Sites at Copan, Honduras illustrating shift from hilltops to valley bottom with garden orchards using VNS3 in landscape.
we highlight some general advantages of visualizing archaeological and environmental data together in a three-dimensional environment including:

- Depth perception
- Explore multiple perspectives
- Visualize multiple variables
- Ability to portray movement
- Explore interrelationships between archaeological and environmental features

Future research applications at Copan include:

- Visualize in 3D paleoenvironmental changes through time to understand processes of change in land use as different cultural groups immigrate to and emigrate from Copan
- Visualize in 3D ratio of trees to herbs through time to investigate (a) de(forestation) rates and their impact on human behavior and (b) contrasting hypotheses about the nature of collapse at Copan

We close with the question: Is there a future for 3D landscape visualization in archaeological research? While this question is open-ended, we conclude from our initial investigations that 3D landscape visualization is a good way to bring different lines of evidence together—archaeological, geomorphological, paleoenvironmental, etc.—in order to investigate processes of past human behavior from nontraditional and alternative perspectives. We propose an iterative workflow that works back and forth between GIS and 3D visualization tools to come to see new and different things in a 3D environment that were not apparent in the GIS and vice versa—ultimately making past landscapes tangible objects of study.

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