2015

Procedural Modeling for Ancient Maya Cityscapes: Initial methodological challenges and solutions

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

Rachel Plessing
University of Nebraska - Lincoln, rplessing@hotmail.com

Procedural Modeling for Ancient Maya Cityscapes

Initial methodological challenges and solutions

Heather Richards-Rissetto
Department of Anthropology and Center for Digital Research in the Humanities (CDRH)
University of Nebraska-Lincoln
Lincoln, USA
richards-rissetto@unl.edu

Rachel Plessing
School of Architecture
University of Nebraska-Lincoln
Lincoln, USA
rplessing@hotmail.com

***Abstract*— Digital reconstruction of 3D cityscapes is expensive, time-consuming, and requires significant expertise. We need a 3D modeling approach that streamlines the integration of multiple data types in a time-efficient and low-cost manner. Procedural modeling—rapid proto-typing of 3D models from a set of rules—offers a potential solution to this problem because it allows scholars to create digital reconstructions that can be quickly updated and used to test and formulate alternative hypotheses that are derived from and linked to underlying archaeological data. While procedural modeling is being used to visualize ancient Roman, Etruscan, and Greek cities, in the Maya region the approach has only been applied to reconstructions of individual buildings and not an entire city. In this paper, we present initial methodological challenges and solutions to procedural modeling of ancient Maya cityscapes using the UNESCO World Heritage Site of Copan, Honduras as a case study.**

***Index Terms*—Procedural Modeling, Landscape Archaeology, Ancient Maya, 3D Visualization, Architecture**

I. INTRODUCTION

Digital representations of architectural landscapes are increasingly used in cultural heritage. To capture data on existing structures or topographies 3D surveying using, for example, laser scanning or photogrammetry, is becoming the gold standard of ground surveying. On the one hand, these technologies are rapidly altering field methods and resulting in impressive, reality-based models [1]. On the other hand, for archaeologists and others seeking to reconstruct ancient cities to investigate hypotheses and formulate interpretations, two dimensional architectural drawings, site maps, or photographs are still the main tools. This is because representing whole cities in 3D is expensive, time-consuming, and requires significant expertise. Nevertheless, because scholars are seeking ways to merge their reality-based 3D data with their interpolated data (derived from architectural plans, excavation data, etc.), projects that use 3D modeling to represent architectural landscapes are increasing and these digital representations are changing how we investigate and interpret the past. However, we still need a 3D modeling approach that streamlines the integration of multiple data types in a time-efficient and low-cost manner.

Procedural modeling—rapid proto-typing of 3D models from a set of rules—offers a solution to this problem. While various types of procedural modeling exist, we focus on using Geographic Information Systems (GIS) to transform 2D features (from multiple data sources ranging from architectural plans to laser scanning data) into 3D geometries. It is also important that the resultant 3D models are exportable into many formats for use on multiple platforms (e.g., desktop, mobile) and browsers. A major advantage of procedural modeling it that it allows scholars to create multiple virtual reconstructions that can be quickly updated and used to test and formulate alternative hypotheses. This flexibility promotes the reuse of data and stimulates ongoing discussion about reconstructions and interpretations of urban landscapes. Another key advantage is the ability for procedural models to be linked with annotations and metadata that describe modeling choices and underlying data sources [2].

II. MAYACITYBUILDER PROJECT

The MayaCityBuilder Project will be the first large-scale project to apply procedural modeling in the ancient Americas. While procedural modeling is beginning to be used to visualize ancient Roman, Etruscan, and Greek cities [3, 4, 5, 6], procedural modeling in the ancient Americas is limited to one pilot study at the ancient Maya site of Xkipché, Mexico [7]. This pilot study, while not modeling an entire cityscape, demonstrates that procedural modeling is a cost-effective approach to generate 3D models of Maya buildings [2].

A. Long-term Project Goals

The long-term vision of the MayaCityBuilder Project is to create a procedural modeling kit and repository that stores a digital lexicon of 2D and 3D data for ancient Maya architecture that will enable users to quickly create 3D buildings in georeferenced cityscapes. The MayaCityBuilder Project builds on data and findings from the ongoing MayaArch3D Project (www.mayaarch3.org) [8]. The 3D models will be exported into multiple formats (e.g., OBJ, FBX, and DAE) and hosted in an online repository with downloadable models. In the end, the data that are generated can be re-used for different types of analysis in multiple platforms. Specifically, the project will produce:

978-1-5090-0048-7/15/$31.00 ©2015 IEEE

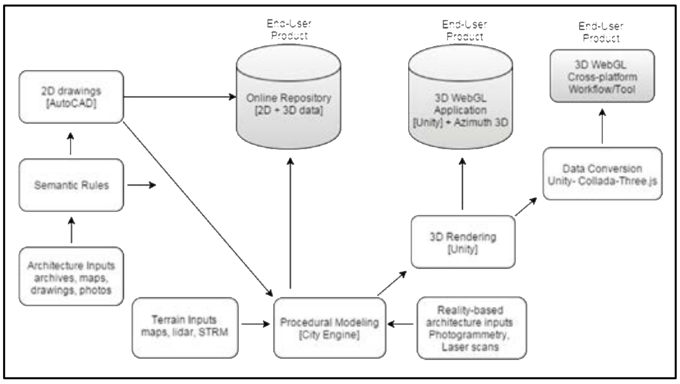

Fig. 1: Proposed Workflow for MayaCityBuilder Project

- an online repository of 2D drawings and 3D models of Maya architectural components and textures with descriptive metadata. The repository will provide downloadable 3D models of architectural elements and building composites that will enable scholars to create with alternative reconstructions of ancient Maya buildings and cities in different software (e.g., 3DStudioMax, SketchUp, Blender);
- procedural modeling kit comprising a set of architectural rules for procedural modeling that use the repository components to generate multiple versions of georeferenced 3D urban landscapes;
- 3D WebGL application that (1) allows users to interact online with alternative cityscapes (2) links descriptive metadata to 3D models, and (3) uses annotation linked to a blog that allows users to comment on specific parts of architectural reconstructions, and;
- 3D building and city models in several formats (OBJ, 3DS, DAE, KML) for cross-platform use.

Ultimately the system will be built on WebGL (Web Graphics Library)—a cross-browser and cross-platform open standard for rendering 2D and 3D graphics that does not require specialized software or plug-ins. Together these tools and datasets will comprise a tool that scholars can use to help formulate interpretations about architecture, landscape, aesthetics, and human experience in ancient cityscapes.

B. Short-term Project Goals

To begin to work toward achieving these goals, we are carrying out a pilot study to test a proposed workflow (Fig 1). The workflow has three tracts: TRACT 1- Archaeological and Archival Research, TRACT 2- Procedural Modeling, and TRACT 3- 3D Export & Rendering.

The focus of this paper is TRACT 2. The case study is a 24 km^2 area surrounding the UNESCO World Heritage Site of Copan, Honduras.

III. CASE STUDY: COPAN, HONDURAS

Copan was an important center for cultural and economic exchange on the southeastern periphery of the Maya region and one of the most thoroughly excavated Maya cities. At least by the seventh century, Copan had reached a state-level society with a heterogeneous population of Maya and non-Maya peoples composed of classes of rulers, elites, and commoners. Although the foundation of the dynasty is well understood [9, 10], there is an ongoing debate about sociopolitical organization in the last century of dynastic rulership, from the reign of the 13th ruler in AD 715 to its collapse under the leadership of the 16th ruler in AD 820. The ability to simulate several georeferenced 3D visualizations for single and multiple time periods from linked archaeological data will enable us to explore the changing roles Copan’s ancient landscape potentially played in conveying information and structuring social interaction to its inhabitants [11,12].

IV. INITIAL METHODS: CHALLENGES & SOLUTIONS

For the initial phases of the project, we are employing CityEngine—software that inputs GIS data to which users apply rules that structure how the imported data are interpreted into 3D geometries. Using procedural modeling, rules have the potential to do anything from establish the height of buildings to determining the articulation of façade features and materials. Conditional coding allows rules to have more intelligent and adaptive uses.

While CityEngine is designed for contemporary urban planning, it has been effective for 3D reconstructions of ancient Roman, Greek, and Etruscan cities [3, 4, 5, 6]. These cities typically have orthogonal city plans with defined streets making the application of standard rule files and tools relatively straightforward; however, ancient Maya cities are not orthogonally planned [13]. The absence of a gridded layout defined by streets (or paths) means that we cannot always apply standard rule files in CityEngine; instead, we must derive alternative solutions.

In the case of Copan, a shapefile of building footprints (interpolated from mounds and mapped from excavations) and their associated attributes (height, building type, identification, etc.) was imported and a rule was assigned to each footprint. While the rule file automatically applies coded actions to a building footprint, assigning height, building size, and orientation based on object attributes coded in the attribute table, we have coded new parameters and procedural rules allowing users to manually override the generated building results as needed.

We present three challenges and their potential solutions that we have encountered in our initial research on using procedural modeling to generate 3D reconstructions of ancient Maya architecture.

A. Building Generation

After importing a GIS shapefile of Copan’s building footprints into CityEngine, the first challenge is to develop accurate building forms from the footprints. Many footprints are irregular in shape (because they were interpolated from unexcavated mounds) and must be regularized in order to more accurately depict the original form of the building. For this, we employ the shape operation *innerRect*, which inscribes a rectangle within the footprint. CityEngine automatically orients the rectangle in the direction maximizing its size. However, this parameter sometimes results in the building being skewed Fig. 2). It became necessary to build in a parameter named "*building_rotation*" into the rule file to allow users to rotate the rectangular footprint if needed.

```
Footprint-->
    rotate(rel, world, 0, building_rotation, 0)
    innerRect extrude(platform_height) center(xz)
```

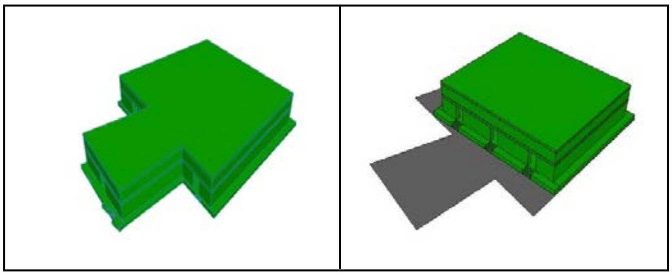

Fig 2: skewed building generation using standard (left); regularized building generation using customized parameter (right)

B. Roofs

Ancient Maya architecture comprises building forms with flat and pitched roofs. At Copan, we have four site types (1-4) that contain architecture with mixed roof types. The creation of a sloped roof was a challenge. The roof needed to offer more flexibility than the standard contemporary roof types found in CityEngine. While we added a conditional code to the rule file to select the appropriate roof for a building based on the site type (1-4) data imported from GIS, to generate a flexible roof to accommodate Maya architectural style, we needed to offset the surface from which the roof is generated to form a small roof top and four sides (instead of a single surface) (Fig. 3). Moreover, we added a component index to allow the *roofShed* operation to be individually applied and modified to each side so the roof was oriented in the correct direction and angle. Without the indexing, all sides sloped in the same direction.

```
Roof-->
    case type== 4: NIL
    else:
    s(scope.sx+roof_overhang,scope.sy+roof_overhang,'
    1) center(xyz) SlopedRoof
offset_dist=topheight/tan(roof_angle)
SlopedRoof-->
    offset(-offset_dist) comp(f){inside: RoofTop | border:
    RoofSides}
RoofTop-->
    t(0,0,topheight)
RoofSides-->
    case comp.index==0:  RoofSide1
    case comp.index==1:  RoofSide2
    case comp.index==2:  RoofSide3
    case comp.index==3:  RoofSide4
    else: NIL
RoofSide1-->
    roofShed(roof_angle,4)
```

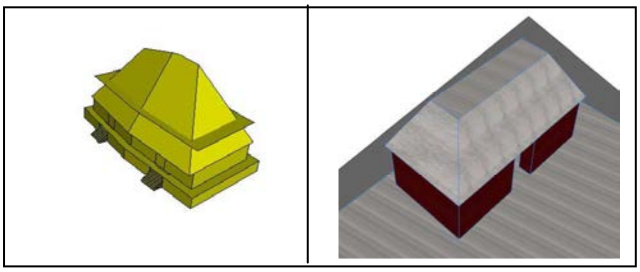

Fig 3: unsuccessful attempt to modify hip roof with trim plane (left); successful sloped roof using split surface and component index (right)

C. Orientation

Following the basic generation of building form and sloped roofs, one of the greatest challenges to using CityEngine for ancient Maya architecture is developing code allowing the rule file to accurately identify the front façade of buildings to which doors and platform steps are assigned. CityEngine normally uses a building's relationship to streets to determine the façade. The standard operation splits a building footprint into components (equivalent to sides) where the building-side closest to a street is automatically designated as the front. However, at ancient Maya sites front facades are generally positioned inward to courtyards and relative to doorways rather than outward to streets. At Copan, there are only two streets (an eastern and western causeway extending about 0.5km from the city's main civic-ceremonial complex).

Currently there is no clean solution for automatically assigning the orientation of the front façade. Initially we attempted to use courtyard centroids in lieu of streets. While this method works in most cases, (due to GIS coding) sites with multiple courtyards receive multiple centroids resulting in a few incorrectly oriented doors. However, we have written code within the rule file to allow users to select the orientation of the front façade based on world orientation (Fig.4).

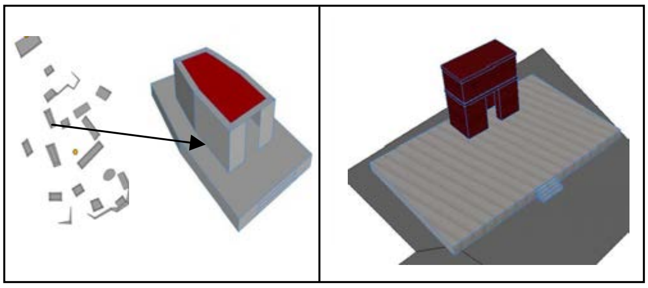

Fig. 4: incorrect façade orientation using centroids (left); door and stairs oriented to front facade using world orientation (right)

This solution requires the direction of the front facades to be manually assigned, but does give the rule versatility by allowing the front to be adapted to different situations. Another solution is to assign orientation as an attribute of the shapefile.

```
case building_orientation == "north":
comp(f) {world.south: EntryWall | world.west: Wall |…
case building_orientation == "west":
comp(f) {world.west: EntryWall | world.north: Wall |…
```

V. CONCLUSIONS & FUTURE DIRECTION

In modeling ancient Maya cityscapes we confront challenges not encountered in modeling orthogonally-planned cities. We have presented three initial challenges and potential solutions encountered as we begin to apply procedural modeling to ancient Maya architecture. While we are in the early stages of the project, in the end, we have three goals: (1) foster discourse about non-western architecture and cityscapes, (2) present new challenges and solutions for 3D modeling that can support the development of more comprehensive 3D data standards, and (3) contribute to landscape archaeology.

The MayaCityBuilder project is pursuing procedural modeling because it allows us to generate buildings directly from archaeological data stored in a spatial database (Fig. 5), integrate reality-based models (e.g., photogrammetry, laser scanning) with the automated models, test hypothetical reconstructions, and investigate ancient Maya architecture from multiple perspectives and scales in a landscape context. Using the data and tools being developed in the MayaCityBuilder Project, researchers will ultimately be able to approach questions such as—how are urban environments similar or different? And, what can these similarities or differences tell us about local and regional social and environmental processes?—in a variety of innovative and insightful ways.

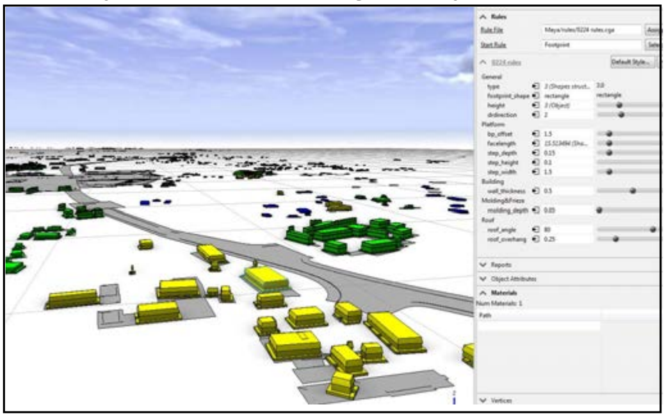

Fig. 5: Procedurally-generated buildings based on GIS footprints and site type coded in spatial database

ACKNOWLEDGMENT

The Layman Award, University of Nebraska-Lincoln provided a seed grant to carry out initial tests. We are grateful to the Honduran Institute of Anthropology and History (IHAH) for permission to work at Copan. The MayaArch3D Project is generously providing some data for the project. We thank UNL students Stephanie Sterling and Michael Seager.

REFERENCES

[1] Remondino, F. and A. Rizzi. 2010. Reality-based 3D documentation of natural and cultural heritage sites – Techniques, problems and examples. Applied Geomatics, Vol.2(3), pp. 85-100

[2] Haegler, S., P. Mueller and L. Van Gool. 2009. Procedural modeling for digital cultural heritage. EURASIP Journal on Image and Video Processing. Vol. 2009, November 2009.

[3] Dylla, K, B Frischer, P Mueller, A. Ulmer, and S Haegler. 2009. Rome Reborn 2.0: A case study of virtual city reconstruction using procedural modeling techniques. 37th Proceedings of the CAA Conference 2009, Williamsburg, Virginia (Archaeopress: Oxford, 2010) 62-66.

[4] Fanini, B and D Ferdani. 2011. A new approach from 3D modelling and scanning of archaeological data to realtime online exploration. CAA2011 - Revive the Past: Proceedings of the 39th Conference in Computer Applications and Quantitative Methods in Archaeology, Beijing, China.

[5] Piccoli, C. 2014. 3D Reconstruction techniques as research tools in archaeology: the case study of Koroneia, Greece. TMA 25 (52):1-6.

[6] Saldana, M and C Johanson. 2013. Procedural modeling for rapid-prototyping of multiple building phases. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. XL-5/W1.

[7] Muller, P, T. Vereenooghe, P. Wonka, I. Papp, and L. van Gool. 2006. Procedural 3D reconstruction of Puuc buildings in Xkipché. The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage, VAST (2006). M Ioannides, D Arnold, F Niccolucci, K Mania (Editors)

[8] von Schwerin, J. , H. Richards-Rissetto, F. Remondino, and G. Agugiaro. 2013. The MayaArch3D Project: A 3D WebGIS for analyzing ancient Maya architecture and landscapes at Copan, Honduras. Literary and Linguistic Computing 2013.

[9] Andrews, E. Wyllys and William Fash. 2005. Copán: The History of an Ancient Maya Kingdom. School of American Research Advanced Seminar Series: Santa Fe, NM.

[10] Bell, E., M. Canuto, and R. Sharer (editors). 2004. Understanding Early Classic Copan. University of Pennsylvania Museum of Archaeology and Anthropology, Philadelphia.

[11] Richards-Rissetto, H. 2013. From mounds to maps to models: visualizing ancient architecture across landscapes. Proceedings of Digital Heritage International Congress, Marseille, France.

[12] Richards-Rissetto, H. and K. Landau. 2014. Movement as a means of social re(production): Using GIS to measure social integration in urban landscapes. Journal of Archaeological Science 41: 365-375.

[13] Smith, M. 2007. Form and Meaning in the Earliest Cities: A New Approach to Ancient Urban Planning. Journal of Planning History 6: 3-47.