THESIS

VIEWED FROM ABOVE: EXTRACTING THE BUILT ENVIRONMENT FROM THE ANCIENT PURÉPECHA SITE OF ANGAMUCO THROUGH DEVELOPMENT OF A NEW METHODOLOGY

Submitted by

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ABSTRACT

VIEWED FROM ABOVE: EXTRACTING THE BUILT ENVIRONMENT FROM THE ANCIENT PURÉPECHA SITE OF ANGAMUCO

This thesis utilizes commonly used GIS tools to develop a methodology capable of extracting the built environment from the complex topology of the ancient Purépecha site of Angamuco located in Michoacán, Mexico. Unlike lowland areas and coastal regions Angamuco sits upon a volcanic *malpaís* consisting of rolling hills, small valleys, complex ridgelines, and a multitude of microtopographic features creating a complex physical landscape. This topographically complex landscape creates unique challenges in extracting subtle archaeological features and requires a new methodology to separate the built environment. This new methodology utilizing common GIS tools in a flexible workflow consisting of topographic manipulation, value identification, and analysis preparation.

The results of the methodology provides a data set of 87,407 possible archaeological features. These features are all greater than $5m^2$ in area and consist of a wide range of circular to rectilinear, linear, and numerous miscellaneous shaped features throughout the site. The capability of this dataset in further analysis is shown through the application of a density analysis and classification based on the Thinness Ratio to conduct OBIA at the individual feature level. Although, the dataset does require manual clean-up the application of the data to answer certain questions about the urban attributes of the site of Angamuco is valid. Further analysis of this output dataset through GIS can provide detailed answers to questions about urban design for the Purépecha prior to and during the early Empire phase.

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PREFACE

The goal of this thesis is to develop a methodology to create a dataset composed of all ancient architectural features from a topographically complex archaeological site. This dataset provides two benefits. First, it provides an initial mapping of the built environment identifying all the above ground archaeological features. Second, it provides a dataset which can be used to conduct multiple spatial analyses across the entirety of the site. The first three chapters provides the necessary background to understand the region, technology, and theory to understanding the site of Angamuco, followed by the methodology and results.

Chapter 1 provides a geographical and cultural background for the Lake Patzcuaro Basin, the imperial heartland of the Purépecha Empire during the postclassic. The Purépecha's known archaeological history is summarized in their legendary history, recorded in the Relación de Michoacán. Lastly this chapter introduces the site of Angamuco and how it creates a new history of the Purepecha's development into an empire.

Chapter 2 is a technical overview of light detection and ranging (LiDAR) for archaeological analysis. The use of LiDAR has become popular in the field of archaeology and this chapter discusses the underlying principles of how LiDAR works followed by a review of some of the most common means of data visualization currently used. The technical review is concluded by providing a few samples of how LiDAR surveys have been applied across Mesoamerica.

Chapter 3 reviews theoretical perspectives on the study of urbanism in an archaeological context followed by a summation of what is known of Purepecha urbanism and a short evaluation of Angamuco. The understanding of Purepecha urbanism is fairly limited to the site of Tzintzuntzan as the other major sites within the Lake Patzcuaro Basin have been built over by modern settlements or heavily disturbed. Finally, the importance of a site like Angamuco for the study of urbanism in the Purepecha region, cannot be overstated and will be discussed in detail.

Chapter 4 details the methodology created and how it is applied to extract the built environment from the sites underlying topography and some issues which occur. Unlike common methods used for feature extraction using LiDAR data a different approach is necessary due to the subtleness of the features and the fact this thesis relies only on the LiDAR data. The method developed combines commonly used techniques into a three step process of topographic manipulation, value identification, and analysis preparation. Overall the method is created to be flexible enough to be applied to different regions of varying landscape complexity yet still extract all the possible archaeological features.

Chapter 5 explores two possible analysis which can be conducted based on the dataset produced by the methodology. Density analysis and a classification based density analysis followed by a means of OBIA based on the geometric properties of the individual features extracted. A key feature of the analysis and classification of the possible archaeological features is the Thinness Ratio, a ratio between a features perimeter and area which is capable of providing a quantifiable means to classify all the features into meaningful and useful classes. A discussion of the variety of other analyses possible because of the dataset produced by the methodology is provided as well as a discussion of potential limitations.

CHAPTER 1

The Purépecha (Tarascan) people of western Mexico have often been overshadowed by their documented Aztec contemporaries. The second largest postclassic empire in Mesoamerica the Purépecha were never defeated by the Aztecs and instituted their own bureaucratic system along with religious practices, customs, and language. In this chapter I will introduce the Purépecha in the context of western Mexico archaeology, including the geography of the imperial heartland the Lake Patzcuaro Basin. Additionally, their cultural history and introduce the site of Angamuco will be discussed.

Western Mexico

Mesoamerica is divided into subregions based upon geography and cultural similarities, the Purépecha fall into the western Mexico region (Figure 1-1). Archaeologically speaking western Mexico includes the modern states of Nayarit, Jalisco, Colima, Michoacán, and the southern parts of Sinaloa, Zacatecas, Guanajuato and Queretaro (Beekman 2010). There are two ways to conceptualize this region the first is based on cultural continuity, the appearance of shaft and chamber tombs and Teuchitlan architecture (e.g. Kan et al. 1989, Weigand 2000). The second and more geographically focused as a result of this region not being considered unified culturally (Pollard 1997) is defining western Mexico as everything west of the Toluca Valley.

1997).

Figure 1-1. Western Mexico showing the location of the Purépecha heartland, the Lake Pátzcuaro Basin. Image produced in ESRI ArcMap.

Similar to the rest of Mesoamerica the region has a monsoonal rain pattern (June – October) and dry (November – May) cycle, an important detail as the region is home to many closed lake basins and few major river systems. Geographically the region is not uniform and includes the Pacific coastal plain to the far west, Neo-Volcanic and Sierra Madre Occidental ranges, and valleys in the Bajio region to the east. Culturally, the region is divided almost along the geographical lines, with the Coastal plain, Sierra Madre and Bajio each forming their own cultural region, and the Neo-Volcanic range being divided into a western highlands and eastern highlands due to distinct cultural and temporal traditions between Jalisco and far western Michoacán and the area which would become the Purépecha empire (Beekman 2010, Pollard 1997).

The Lake Pátzcuaro Basin

Similar to the Aztec (Triple Alliance) of central Mexico what would become the imperial heartland of the Purépecha empire formed around a lake basin. The Lake Pátzcuaro Basin (Figure 1-2), from here on referred to as LPB, is centrally located in the modern Mexican state of Michoacán at 19°37'05.1"N and 101°38'11.4"W approximately 255km from Mexico City, the former heartland of the Aztecs. The distinctive C-shaped LPB sits at an average elevation of 2036 m asl with the edges of the greater basin reaching upwards of 3400m asl (Quintas et al. 2016). The LPB is approximately 928 km^2 with the lake itself accounting for less and less of the total area, 130 km^2 (Fisher 2003) to approximately 80 km^2 today (this measurement was taken using built-in measurement tools available in Google Earth) with a depth ranging between 8-12 meters.

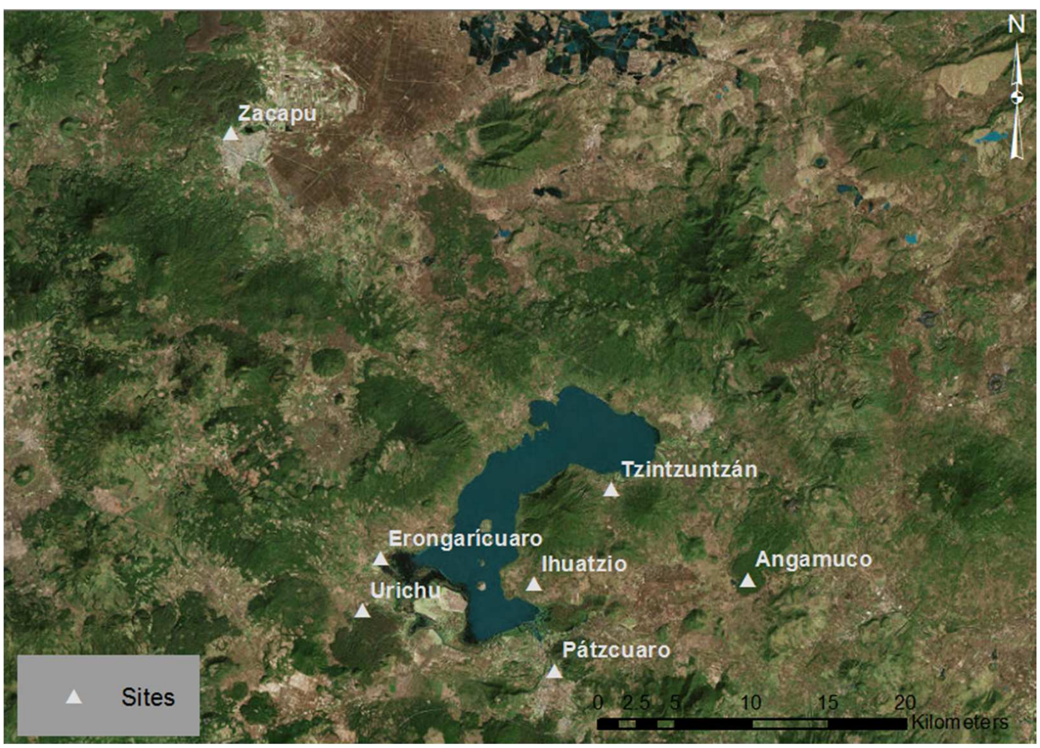


Figure 1-2. Lake Patzcuaro Basin with the major Purépecha sites mentioned in this chapter. Image produced in ESRI ArcMap.

The LPB is located within the Michoacán – Guanajuato volcanic field of the Trans Mexican volcanic belt, which stretches from the Pacific Ocean to the Gulf of Mexico and delineates the southern end of the North American tectonic plate (Ferrari 2012, Fisher 2017, Israde 1995). The tectonic activity has made the LPB a closed basin, meaning there is no inflow or outflow of water through rivers or streams making the lake entirely depending upon annual rainfall (900-1250mm per year) to maintain the water level (Chacon). Archaeologically the lake level has fluctuated between its high of >2040 m asl during the late postclassic and low of 2028 m asl during the classic period, today the lake level has steadily been decreasing towards a low equal to the classic period (XXXX). The combination of changing rainfall due to climate change, over consumption by the current basin inhabitants and naturally occurring tectonic activity underneath the LPB are all believed to be contributing to the regression of the lake (Quintas et al. 2016).

Environmentally the LPB can be separated into six distinctive ecotones (Pollard and Gorenstein 1987, Pollard 1993) defined by elevation and the available resources. 1) the open water of the lake 2) the tule-reed marshes along the shallows of the lake 3) the lakeshore (2034-2035m asl) to include the lake islands and the flood plains surrounding the lake 4) the lower sierra slopes (2100-2300m asl) 5) the upper sierra slopes (2300-2800m asl) and lastly, 6) the alpine zone (2800-3400m asl).

The Purépecha

Despite being less studied and less understood than their Aztec neighbors the Purépecha empire is considered to be the most consolidated/centralized Mesoamerican empire at the time of European contact (Beekman 2010, Pollard 2012). Lead by the *cazonci* (supreme ruler) from the imperial capital of Tzintzuntzan they were never defeated by the bordering Aztec empire. Contemporaries of the more well-known Aztecs of the Basin of Mexico, the Purépecha were a

Figure 1 3. The extent of the Purepecha Empire prior to Spanish arrival in 1522 overlaid modern day settlements. Taken after (Cohen 2016), produced in ESRI ArcMap.

culturally and linguistically distinct people who would in the years prior to Spanish contact control approximately 75,000km2 of western Mexico (Figure 1-3). Known indigenously as

Irechequa Tzintzuntzani (kingdom of the lord of Tzintzuntzan) they have often been referred to as Tarascos or Tarascan (Pollard 1993, 1997, 2008). I will be refereeing to them as Purépecha, in reference to the language they speak as Tarascos/Tarascan carries a negative connotation in the Purépecha language.

The Purépecha's 75,000 km^2 of territory incorporated majority of the modern state of Michoacán and parts of Guerrero, Jalisco, Colima and Guanajuato, making their empire the second largest, only overshadowed by the Aztecs. Geographically the empire extended northward to the Lerma River and to the south just beyond the Balsas River (Pollard 1993, 1997, 2008). To the west it extended to Lake Chapala and the surrounding Coalcoman region and the eastern boarder was marked by the settlements of Acambaro and Otzuma. The eastern boarder became a heavily fortified frontier due to continual conflict and warfare against the Aztecs, the Purépecha's military was equal if not better than the Aztecs allowing them to resist the Aztec's expansion (Beekman 2010, Pollard 1993, 1997, 2008).

Legendary History: The Relacion De Michoacán

The *Relacion de Michoacán,* abbreviated as RM, is a key historical document detailing the rise of the Purépecha and their culture around the time of Spanish contact. The RM was written by Fray Jeronimo de Acala, a Franciscan friar who live in the capital city of Tzintzuntzan. Originally written in 1541 and consisting of three parts detailing religious concepts and activities, the history of the Purépecha empire, and customs and marriages. The sections discussing the religious concepts and activities has been lost leaving this written history as the key to combine the living culture with the archaeological record. Fray Acala did write with a

European bias and may have distorted some descriptions and concepts to parallel more familiar institutions such as the European monarchy system (Haskell 2008).

The legendary history was recited yearly by the high priest during a festival known as *Equata Consquaro* (Acala 2013:13). The history begins with the immigration of the semi-nomadic Chichimecs from the arid northern frontier of Mexico (similar to the beginning of the Aztec origin myth). Originally settling in the Zacapu basin they moved to south and settled along the northern shore of Lake Pátzcuaro at a site known as Vayemo and soon forged ties with the lord of Tzintzuntzan. Within this immigrating group was the *Uacuscha* faction lead by the brothers Uapeani and Pauacume. The brothers resettled on the southern lakeshore at Pátzcuaro and built temples to Curicaueri (Acala 2013:33).

Naturally conflict developed between the brothers and neighboring polities which led to the assassination of Uapeani and Pauacume. When he was of age Tariacuri, the son of Pauacume, assumed lordship of Pátzcuaro, was defeated and subsequently exiled. Tariacuri negotiated peace with a former enemy and by marriage of his enemy's daughter was able to settle on Coringuaro's lands. Eventually Tariacuri was driven out by force when the marriage failed but was able to negotiation his return to Pátzcuaro during a time of political unrest in the basin.

Following the failure of rule by his son Curatame, Tariacuri proposed to his nephews he would eliminate all other dynasties in the basin and consolidate the basin under a single dynasty composed of three seats Patzcuaro, Ihuatzio, and Tzintzuntzan. Each city would be led by a branch of the *Uacusecha.* Though Tariacuri died his nephews carried out his will and through subsequent rulers the capital settled at Tzintzuntzan (Acala 2013).

The legendary history of the formation of the empire and the great leader Tariacuri provides a means to validate the ruling elites and solidify the monarchy. It needs to be understood under this framework and not as an entirely truthful historical account, viewing it as history can lead to false conclusions. The RM describes the why of unification of the lake basin, Tariacuri's ambition, not the how or the preceding technological and social practices which provided the groundwork for an empire to form. Per the RM small polities engaged in warfare and alliance building rapidly transformed into a structured empire, the archaeological record argues a different formation process.

Rise of an Empire

The LPB has provided little evidence of human occupation prior to the Preclassic period (1000 – 350 B.C.E) (see Table 1-1 for local sequence). Currently the only indirect evidence of occupation is domesticated maize pollen from sediment cores dating to 1500 B.C.E. (Darras 2006, Darras and Fauge`re 2005, Darras et al. 1999, Pollard 2008). The early archaeological record for the region is currently understood through excavations in the nearby Zacapu Basin, approximately 25 km north of the LPB, along with some data from other basins in area. Within the Zacapu Basin, the Los Portales cave has provided the earliest artifacts for the state of Michoacán. The cave provided a projectile point and mano dated to the archaic ceramic period (2500 – 2200 BCE) (Michelet et al. 1989). While this is the earliest evidence of human occupation it is highly likely the region was home to small groups of hunter-gatherers prior to 2500 B.C.E. (Pollard 1993).

It is during the Middle through Late Preclassic (500 BCE – 350 C.E.) evidence of occupation is strong enough throughout the region to distinguish three separate cultural groups. The Chupicuaro, Balsas/Mezcala, and Chumbicuaro (XXXX). There is no direct evidence of either group inhabiting the LPB during this time, however it is known the Chupicuaro did inhabit lacustrine environments. Evidence of Chupicurao occupation is found within the Zacapu Basin and the Cuitzeo Basin to the northeast. It can be inferred the domesticated maize pollen discovered in the LPB may belong to the Chupicuaro cultural group or their predecessors based upon the dates and the geographic location of known Chupicuaro occupation (Darras 2006, Darras and Faugere 2005, Pollard 2008). As of this writing the Chupicuaro are believed to have been the first non-hunter-gatherer occupants of the LPB.

Table 1-1. General Mesoamerican sequence with associated phases for Pátzcuaro (taken from Pollard 2008)

Mesoamerica	Date	Pátzcuaro
Postclassic	1500 A.D	Tariacuri
		Late Urichu
	1000	Early Urichu
Epiclassic		Lupe
Classic	500	Jaracuaro
Preclassic	0	Loma Alta
	500 B.C.	Chupicuaro

The first archaeological evidence of occupation in the LPB appears in the early classic period (150 B.C.E – 550 C.E.), known regionally as the Loma Alta phase and divided into three sub-phases. During Loma Alta 2 and 3 (150 C.E – 550 C.E) evidence is found which suggests growing social stratification such as differential burial patterns, craft specialization, settlement size hierarchy, and the beginnings of dedicated urban development (Pollard 1997, 2008). The

Loma Alta site, the type site of the phase and where its name is derived from is located in the Zacapu Basin and provides strong evidence linking the Chupicuaro as the direct predecessors to Loma Alta and eventually the Purepecha (Arnauld et al. 1993, Michelet et al. 1989, Pollard 2008). During this phase distinct architectural features appear, such as the sunken plaza which may be used as a relative means of dating for Loma Alta 2 (150 C.E. – 350 C.E.) (Pollard 2008). Within the LPB the site of Erongaricuaro, located along the western lakeshore, and Urichu an upland non-lacustrine site located on the edges of a *malpais* in the southwest of the LPB are the only confirmed site with Loma Alta materials and associated radiocarbon dates from hearths and burials (Pollard 2005, 2008, Pollard and Haskell 2006). Non-architectural landscape features such as irrigation canals near Erongaricuaro also support the dating of the site to the Loma Alta phase (Fisher et al. 1999). Recent radiocarbon dates of a bone *offrenda* from excavations at Angamuco, along the eastern edge of the basin, provide additional evidence of Loma Alta occupation within the lake basin, however more work is needed to verify (Cohen 2016, Fisher et al. 2014). The appearance of sunken plaza complexes at Angamuco also support the proposition of additional settlements during this time throughout the LPB.

The Epiclassic/Lupe phase (600- 900 C.E.) is a time of lake level fluctuations and an overall increase of population and number of settlements. Majority of what is understood about this timeframe comes from the survey work conducted in the southwestern portion of the lake basin around the sites of Erongaricuaro, Urichu, and Patzcuaro. Evidence from Urichu shows an association of elites with luxury and imported goods such as shells from the Pacific Ocean and prismatic blades made from green Pachuca obsidian from central Mexico (Pollard and Cahue 1999, Rebnegger 2013). Sediment cores from the southwest lake basin suggest an increase in soil erosion and land degradation from agricultural practices followed by an increase of terracing

(Fisher et al. 2003). Across the lake basin to the east some evidence exists of possible Lupe phase occupation at the site of Angamuco. Anthropomorphic figurines were identified which are characteristic of Lupe phase within in the greater region of Michoacán, although the possibility of reuse or use as construction fill cannot be eliminated this would expand the range of occupation of the LPB again to include the eastern portion (Cohen 2016 Fisher et al. 2014). To the north in the Zacapu Basin over ten sites have been identified with plazas and ballcourts, and in the Bajio region of northern Michoacán an increase in the number of sites suggest the population increase was a regional phenomenal and not limited to the LPB (Darras 1999; Hernández and Healan 2008).

Transitioning into the early postclassic/early Urichu phase (900 – 1000/1100 C.E.) the lake level reached its lowest level at approximately 2028m asl (Pollard 2008). This lead to an increase in the number of settlements as people took advantage of the increase in fertile land available (Fisher et al. 2003; Haskell and Stawski 2016; Stawski 2012). Towards the end of the early Urichu and into the middle postclassic/late Urichu (1100 – 1350 C.E.) populations and settlements continued to increase however the settlements location transitioned to more upland sites (Pollard 2008). These upland sites include occupation of *malpais,* ancient volcanic lava flows with poor agricultural potential. In the Zacapu Basin the transition to utilizing the *malpais* is believed to be the result of two possibilities. Consolidating settlements for defensive purposes although evidence for warfare is limited (Michelet 2008; Michelet et al. 1995). Or, a migration of new population which utilized different technologies and social practices (Jadot 2016). Within the LPB Pollard 2008 suggests either the movement to upland sites for defensive purposes or due to resource needs. Inhabiting agriculturally poor areas allows for valuable agriculturally productive areas to not be wasted on urban development. This could indicate a time of competing chiefdoms in the LPB however the evidence is inadequate.

The end of the late Urichu phase is believed to have consisted of several small chiefdoms throughout the LPB. At this time rising lake levels which flooded low lying agricultural lands and settlements possibly instigated conflict between the different chiefdoms for resources until the lake basin was unified by Taricuri ambition plan per the RM during the late postclassic/ Taricuri phase (1350 – 1520 C.E.) (Fisher et al. 1999, 2003, O'Hara 1993, Pollard 1993, 2008, 2016). How the small chiefdoms were consolidated into an empire around the transition between the late Urichu phase and Tauricuri phase is poorly understood. Pollard 2008 put forth an explanation of a "perfect storm" occurring due to population and resource pressure which lead to the development of two supra-polities in the basin, Tzintzuntzan-Uayameo and Patzcuaro-Pareo in the late Urichu before the arrival of the great leader Tauricuri. However, the site of Angamuco located at the eastern edge of the lake basin strains Pollard's theory of state/empire formation due to the anomalous size of the site prior to the development of the empire.

Angamuco

Angamuco (full name Sacapu Anagamcuo) is located along the eastern edge of the LPB and occupies a *malpais*, a badlands, formed by two major late Pleistocene lava flows approximately 27,000 years ago (Fisher personal communication) (Figure 1-4). The site covers 26km2, the entirety of the *malpais* not including the volcanic cone has been modified by humans. Today it is located approximately 8 km from the modern lake though in the past it may have been as close as 2.5 km to the active shoreline when the water level was highest during the postclassic. Compared to other sites within the basin Angamcuo is surprisingly undisturbed. This is a result of the site sitting on the *malpais* and area which is not advantageous to modern agricultural practices allowing it to be largely ignored. The northern half of the site around the volcano has been disturbed starting sometime around the 1920s from mining activity, which is still occurring and can be identified from satellite imagery (Solinis-Casparius 2015).

The site was uncovered by traditional archaeological survey methods in 2007 by the LORE-LPB project directed by Dr. Chris Fisher. In 2009 the site was formally recognized by INAH under the name of Sacapu Angamuco, however due to the similar sounding name as Zacapu, the basin to the north, the site is currently referred to simply as Angamuco. Following the initial surveys of the site its estimated size lead Dr. Fisher to search for a means to expedite the process. In 2011 the first LiDAR flight was flown over the lower half of the *malpais* covering an area of 9km2 conducted by Merrick & Company a Denver, CO based company. Analysis of the data revealed a completely modified landscape covered in archaeological features. Combining the LIDAR data and ground survey a total of 7,900 archaeological features were identified in the following field seasons which surveyed approximately 4 km^2 of the lower *malpais*. In 2015 a second LiDAR survey was flown by the National Center for Airborne and Laser Mapping (NCALM) covering a total of 35km^2 to include the *malpais* and the immediate surrounding landscape, in addition to the Itzira Ahuacuti *malpais* where the site of Urichu (Uricho Veijo) is located. Results from the second survey showed the human modified landscape encompassed the entirety of the *malpais*. Continued research at the site (Fisher 2010, Fisher and Leisz 2013, Fisher et al. 2011, 2012, 2014, 2016) has led Fisher to argue Angamuco contains over 40,000 architectural features classified into 60 architectural forms, including house mounds, plazas, roadways, reservoirs, pyramids, and ballcourts (Fisher 2017; Fisher et al. 2019).

Angamuco can be separated into two sections, lower and upper, based upon elevation and differences in topography. Lower Angamuco is defined by an elevation of 2100 – 2180m asl, while Upper Angamuco has an elevation of 2180 – 2400m asl. The lower section of the site is the most densely modified and is marked by thousands of mounds and a number of pyramids, raised roadways, reservoirs, and ballcourts. The upper section is less densely modified with majority of the architectural features situated along the edges of the *malpais* landform. However, the upper section is also the most heavily disturbed from mining operations making it difficult to parse out where archaeological features are located. Modern day vegetation has also impeded ground survey work at the site and especially the upper section.

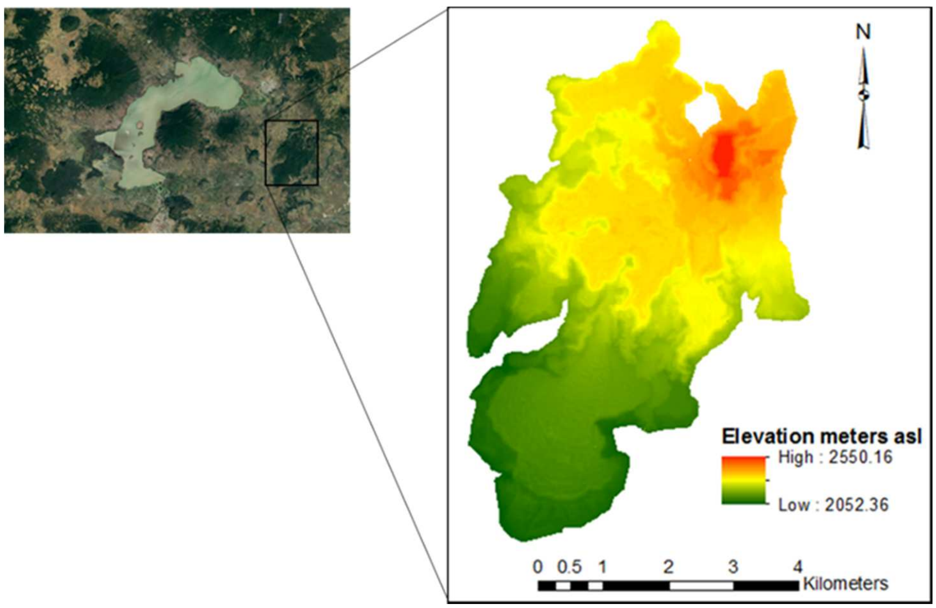


Figure. 1-4. Location of the Angamuco malpais within the LPB and associated DEM displaying elevation change on the malpais. Image produced in ESRI, ArcMap.

The current model of Purépecha state formation (Pollard 2008, 2016) becomes problematic when Angamuco is introduced into the process. The model and the RM describes a rapidly organized empire produced from a collection of chiefdoms with little to no urban tradition at the time (Urqhart 2015). Angamuco's peak predates that of the legendary history to the Urichu phase (Fisher et al. 2010, 2012, 2013). Interestingly the RM does mention a powerful polity known as Coringuaro, located in the eastern part of the basin and predates the empire (Acala 2013:25-27, Beaumont 1932). It is possible Angamuco could have been Coringuaro, or separate polity itself. If Angamuco is not Coringuaro it raises the question why a large and likely powerful settlement would be “erased” from the empires history.

Today Angamuco provides an unparalleled insight into Purépecha past. Its level of preservation, site, and status as a predominately pre-empire settlement can illuminate and answer archaeological questions about the formation of the empire, and likely lead to new questions. This chapter has provided a brief overview of the region, cultural background, and introduced the site of Angamuco and how it is situated in the overall Purépecha story. This will be accomplished by the creation of a dataset which will provide a means to analyze the spatial attributes of the site’s built environment. Before delving into how this is accomplished a discussion of LiDAR and how it is utilized in archaeology is necessary followed by a review of current approaches to defining what precisely urbanism is.

CHAPTER 2

The field of archaeology has undergone many shifts in its approach to study and understanding the past. Recently, a methodological "advancement" has occurred, comparable to the effect radiocarbon dating had on the ability to precisely date organic artifacts this "geospatial revolution" (see. Chase et al. 2012) is changing the way archaeologist approach large scale survey, conservation, and landscape level analysis. Light Detection and Ranging (LiDAR) enables researchers to survey large tracts of land and provide results in mere days. This chapter will introduce remote sensing and LiDAR and cover the products many archaeologist use in their analysis in addition to examples of how this technology is applied to answer current archaeological questions. The visualizations utilized in the analysis of Angamuco will be discussed in greater depth in chapter 4.

Remote Sensing

Remote sensing in the simplest of definitions is the ability to record data without physical contact. The earliest forms of remote sensing in archaeology were aerial photographs taken to identify soil/crop marks, changes in soil and vegetation due to sub-surface objects in cleared farmland (Crawford 1929, Leisz 2013), this method saw some success in Mesoamerica as well (Ricketson and Kidder 1930). In the 1980s following the availability of the satellite Landsat and its Thematic Mapper, capable of 30 m resolution some archaeological features could be identified from space (Sever 1990, 2000, 2008), high resolution declassified images from the cold war continued to add to researches ability to use remote sensing techniques (Lasparona and Masini 2011). While the tools available changed the process was similar the studies focused on vegetation change cause by sub-surface archaeological features. As satellite technology improves the imagery resolution available to archeologist continues to become higher, such as the GeoEye-1 with a multispectral resolution of 1.6m.

The improvements in technology allowed archaeologists to find smaller features, however the primary drawback to satellite imagery is the inability to truly see what is on the ground, i.e. beneath the vegetation and tree cover. Shuttle Radar Topographic Mission (STRM), and Advance Spaceborne Thermal Emission and Reflection Radiometer (ASTER), provided a partial answer. STRM at 90m and ASTER at 30m in resolution could now display the actual topography of the Earth's surface, however the resolutions were too low to identify anything but landscape scale features. In the early 2000s researchers began experimenting with Airborne Laser Scanning (ALS) (Challis 2006, Devereux et al. 2005, Doneus et al. 2008), also referred to as LiDAR. Following the 2010 scan of the Maya site of Caracol (Chase et al. 2012), LiDAR has become the primary means of remote sensing for regions of the world with heavy canopy coverage due to its ability to penetrate canopies and "map" the ground. This has not lead to a discontinuation of satellite imagery as multispectral and hyperspectral data sets continue to be used and experimented with (Agapiou et al. 2013, 2016 Comer 2013).

LiDAR

LiDAR, commonly referred to as airborne laser scanning (ALS) is similar to Radar and Sonar except instead of radio waves or sound waves, light is instead used. The growing number of archaeological studies incorporating LiDAR surveys is a testament to its transformative power in large scale landscape studies. Surveys conducted throughout Mesoamerica, Southeast Asia, across North America, Africa, and many Pacific islands this technology has proven itself in multiple environmental contexts. While its application is proven, it is necessary to understand the technology and how this system works as it is not a one size fits all standard in field applications (Chase et al. 2016).

Unlike the more commonly known satellite or aerial imagery products LiDAR is an active remote sensing technology. Passive systems capture the reflected light from objects produced from another source in the case of the Earth's surface the source is the sun. A LiDAR system produces the light which is reflected and measure the same way radar and sonar produce the radio/sound waves. Simply put LiDAR works by measuring the distance between the sensor and the Earth's surface based on the time it takes for a pulse of light to be emitted, reflected, and recorded by the system. This is the Time-of-Flight (ToF) ranging principle. The emitted light pulse travels at the speed of light (300,000m/s), measuring the time required to reflect back to the sensor and using a simple equation (Distance = Speed x Time) the distance from the senor is calculated. The number of light pulses emitted is determined by the system's limitations, a single light pulse may be emitted then measured, or multiple pulses can be emitted at one time of varying wavelengths and then individually measured (White 2013).

The LiDAR system measures the distance between the Earth's surface (to include, buildings, trees, vegetation, etc.) and the sensor. By itself this data is meaningless without knowing the exact location of the sensor in relation to the Earth (Figure 2-1). The sensor needs to be tied into a Global Navigation Satellite System (GNSS). This system attaches the geographic coordinates to the data providing its absolute location on the Earth's surface. Without these coordinates for each of the data points collected, it would be impossible to project the data and utilize it in any GIS program. Additionally, the Inertial Measurement Unit (IMU) tracks and adjusts for the plane's/helicopter's pitch, roll, and yaw. These minor adjustments ensure the data is as accurate and precise as possible limiting any data distortion to millimeters.

The configuration of the ALS to provide the best results in a dense tree canopy environment is a balancing act between multiple aspects. The planning process of a LiDAR survey for archaeological purposes is focused on high ground point density (number of ground returns) to produce a high resolution raster. The number of ground returns produced by a survey is often a fraction of the total number of laser pulses emitted, a higher shot density the better. The ALS system can control the Pulse Repetition Frequency (PRF), scan angle, and rarely the divergence of the laser beam which all effect the shot density (Fernandez-Diaz et al 2014). The PRF is the number of pulses emitted per second, generally the more pulses the higher the resolution of the final produced. The scan angle is related to the swath of area covered in a single pass by the aircraft, a wider angle lessens the density however in dense canopies pulses not at nadir (0) may have a high likelihood of reaching the ground and returning. The shot density and total number of returns is not a 1-1 ratio, tree canopies, and other vegetation can produce multiple returns per pulse. The number of returns measured is the result of the system configuration, and higher PRF often measure fewer multi-returns because of the lower energy of each shot, while lower PRF has more energy per shot allowing for more multi-returns to be generated. Furthermore, there are considerations related to the aircraft itself which must be included such as the altitude above ground and flight speed. The higher the altitude and faster the aircraft is traveling will result in a lower shot density. Altitude affects the scan angle widening as altitude increases and increasing the speed will disperse the pulses (Fernandez-Diaz et al. 2014).

From multiple scans in dense canopy environments there is guidance to achieve the highest number of ground returns. The entire surface area needs to be surveyed, to include from multiple scan angles and the pulses need to have enough energy to penetrate the canopy and make the return trip. A higher PRF does not equal a higher ground point density, and flight plans which cover the same area from different angles are more likely to find gaps in the canopy and reach the ground (see Fernandez-Diaz et al. 2014 for more details).

LiDAR records each return pulse with, at a minimum, x,y,z coordinates and an intensity value. From this a point cloud (PC) is created and for all intents is the final produce produced without more intensive data manipulation. Some of the more common means of viewing the data will be discussed next, none of them are capable of answering all the questions a research may have and often custom algorithms are created to answer very specific questions (Chase et al. 2017).

Data Visualizations

The PC LiDAR produces is not in and of itself useful for archaeologists, the data needs to be processed to reveal any archaeological features in the data. Through a multitude of software systems available (e.g. MARS) the individual points are classified according to their elevation and the most likely object they belong to (ground, tree canopy, low vegetation, etc.). For common analysis archaeologists all points except points classified as ground returns are unnecessary and are subsequently removed. The points are not deleted from the dataset, but are masked so as to not be visible or utilized when the software program produces end products.

A Digital Elevation Model (DEM) (Figure 2-1a) is a raster, a grid of squares/pixels which contain unique values related to some kind of measurement, in LiDAR the main measurement is elevation. Each cell is of equal size used to determine the resolution of the dataset, e.g. a DEM with a pixel 50cm x 50cm would have a resolution of 50cm. the resolution a DEM is capable of displaying is limited by the sensor used to collect the data, however high resolution sensors can produced low resolution rasters through certain software tools. The resolution needed is dependent upon the analysis being conducted, if the research question involved was looking at large geographical features such as hills and valleys a resolution of 50cm would be unnecessary, whereas 50cm is ideal for archaeological architectural features.

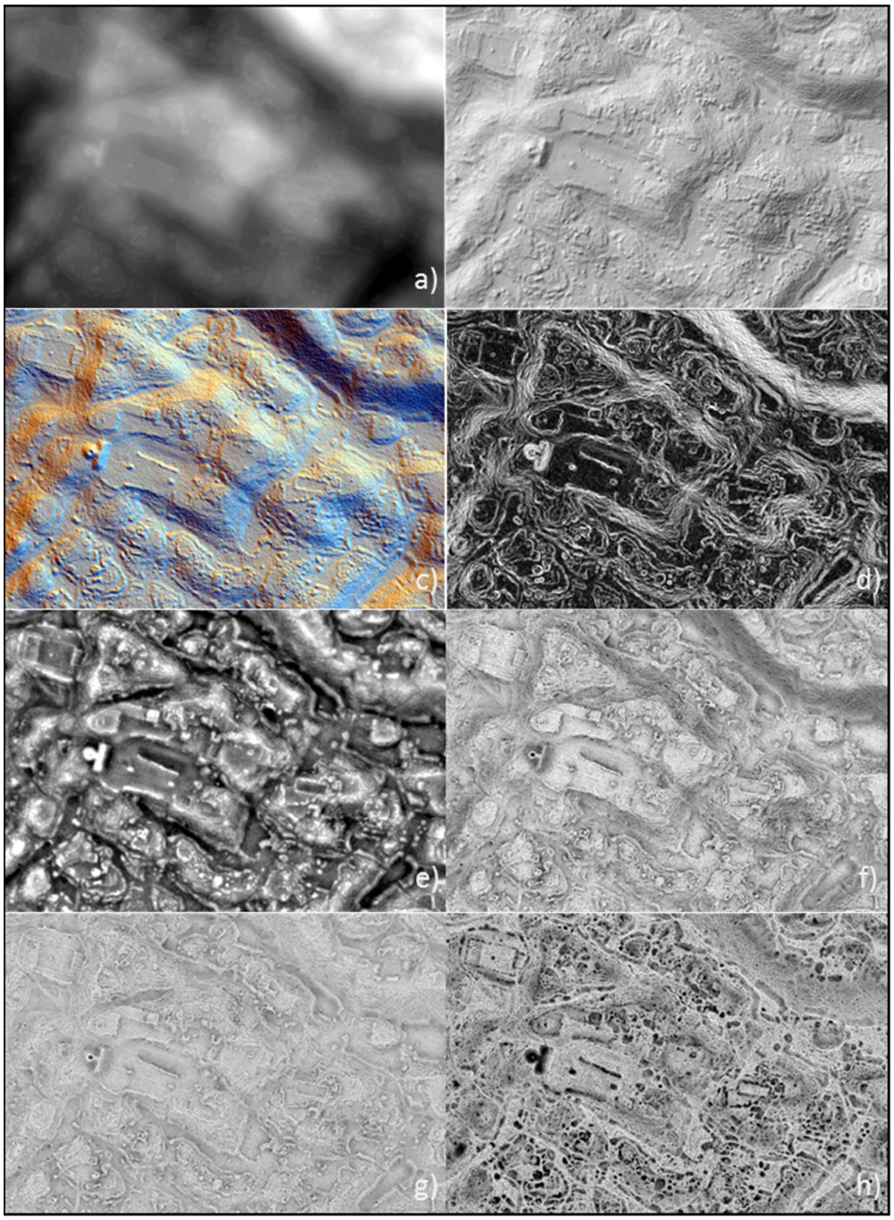


Figure 2-1. Visualizations of LiDAR data of a civic-ceremonial zone at Anagamuco. a) DEM, b) hillshade, c) multidirectional hillshade, d) slope, e) local relief model, f) Sky View Factor, g) positive openness, h) negative openness. Images produced in RVT (Zaksek et al. 2011) and ESRI ArcMap.

Hillshade

A hillshade (Figure 2-1b), also known as an analytical hillshade, is the most commonly used visualization as it is the most intuitive to understand when being viewed. Additionally, a hillshade is a basic tool in any GIS software program and thus requires a minimal amount of technical skill to utilize. A hillshade is produced by assuming the DEM is a Lambertian surface (a rough surface which reflects all light equally) with a singular light source set at a defined elevation angle and defined azimuth, the default in ESRI ArcMap is consider an elevation angle of 45 and azimuth of 315. This singular light source illuminates areas and produces “shadows” across the DEM creating a sense of depth (Kokalj et al. 2013, Kokalj and Hesse 2017). This depth in turn produces a pseudo 3D image where concave and convex features are fairly easy to distinguish. While hillshades are a quick and easy means to visualize LiDAR data they do have limitations, as all the different visualizations do.

The primary limitation is of the hillshade due to the illumination azimuth. Any linear feature which runs in alignment with the illumination azimuth on the DEM will be obscured because the feature will be completely illuminated with minimal to no shadows produced making it difficult to discern by the human eye (Devereux et al. 2008). The angle and azimuth of illumination may result in concave features visually appear convex and visa-versa. Additionally, the pixel values of the raster become terrain/directionally dependent which is disadvantageous for any advanced automated/semi-automated feature extraction or Object-based image analysis (OBIA).

Two further types of hillshades are commonly used by archaeologists the multidirectional hillshade (Figure 2-1c) and principle component analysis (PCA) hillshade (Devereux et al. 2008, Kokalj et al. 2013, Kokalj and Hesse 2017). The multidirectional hillshade, as its name implies, is a combination of illumination from different azimuths and elevation angles. A PCA hillshade is a summation of a multidirectional hillshade. A PCA is a statistical analysis which identifies the highest percentage of variability in a data set, usually the first three PCA components provide ~99% of the variability. Due to the typical limit of three components the PCA hillshade simplifies the interpretation of a multidirectional hillshade (Kokalj and Hesse 2017).

Slope

The second most commonly used visualization is transforming the DEM's elevation value into a measure of the slope between pixels (Figure 2-1d). This is also a tool included in GIS programs similar to the hillshade. The slope is calculated by measuring the change in elevation over distance between pixels, e.g. if a pixel is at an elevation of 1 m and an adjacent pixel is at 2 m, and the resolution is 1 m, the slope difference would be 45. This tool is very useful in identifying possible archaeological features such as walls and mounds, due to the usual sharp increase in slope compared to the surrounding topography. Challis et al. (2011) argued slope was the best technique for most situations due to the lack of bias, unlike a hillshade. A slope raster will contain values between 0 and 90 and while not as intuitive to view as a hillshade it is more advantageous to identifying possible archaeological features. A drawback to this technique is because there is no other information provided beside the slope factor concave and convex features can be ambiguous and easily confusing depending on the color scheme used.

Local Relief Model

Proposed by Hesse (2010) the local relief model (LRM) is a more labor intensive visualization requiring a series of steps to produce the final visualization. The goal of the LRM is to differentiate between large topographical features on the landscape and smaller archaeological features (Figure 2-1e). In short the LRM is a trend removal technique used to increase the visibility of features which might be obscured by the landscape they site upon. In Hesse's original publication of this visualization (LRM) he described a six-step process using ArcMap and ENVI. Novak (2014) simplified the process of producing the LRM by creating an opensource toolbox compatible with ArcMap, including the workflow so any problems can be troubleshooted.

There are two versions of the LRM, the main LRM and a quicker simple local relief model (SLRM). The difference between the two is the time it takes due to the workflow, a SLRM is a subtraction of a smoothed DEM from the original, and small differences in the end product. The SLRM is biased towards smaller features which may or may not be beneficial depending on the size of the archaeological feature being analyzed (Hesse 2010). Due to the removal of larger topographical features the "zero" contour line is redefined. This allows for better identification of subtle built and depressed features throughout the studied area which may have been obscured previously. With the addition of an intuitive color scheme this subtle features become readily identifiable.

Sky View Factor

Sky View Factor (SVF) (Kokalj et al. 2011, Zaksek et al. 2011), is a widely used visualization primarily due to the visual effect it has on a DEM. SVF is based on the percentage of the sky viewable from an individual pixel with a defined viewing radius and selected number of viewing angles, usually eight or sixteen (Figure 2-1f). The algorithm calculates the viewable sky and assigns a value between 0 and 1 to the pixel. A value of 1 indicates, from that pixel based upon the viewing radius there are no obstructions and the horizon is visible from all angles. Hilltops and edges on walls are prime examples of features which would have a value of 1. A value of 0 is impossible as it would imply the pixel cannot "see" or be viewed from the sky. This algorithm makes SVF proficient at locating small depressions and highlighting the edges of walls, terraces, and other architectural features. Since the viewable radius can be modified micro features can be identified which may be overlooked by other visualizations.

The disadvantage to this visualization is twofold. First, the features on the ground will become abstract looking due to the high contrast between edge pixels (values near 1) and non-edge pixels (values near 0) this may lead to some features becoming visually distorted. The second disadvantage is a hilltop and a flat plaza or plain can both have a value of 1 since the algorithm "looks up" from a defined horizon.

Openness Factor

Openness, or sometimes referred to as Openness factor consists of a Positive and Negative application (Yokoyama et al. 2002). The difference is whether the focus is on concave or convex features on the landscape. Popularized by Doneus (2013) for use in archaeological studies the process is similar to that of SVF, expect there is no "horizon" limiting the algorithm. Openness is calculated based upon the total radius so the angle of view can exceed 180. Due to the similarity with SVF Positive Openness is almost identical visually to SVF, except a flat plain and hilltop would have different values because of the lack of a horizon for the algorithm (Figure 2-1g). While there are two types of Openness the values produced do not correspond directly as the inverse of the other, e.g. a high value for Positive does not necessarily equal a low value for Negative (Doneus 2013, Kokalj and Hesse 2017).

Openness is not used as widely as SVF, this may be because it is slightly less intuitive as the general topography is masked more by Openness (Zaksek et al. 2011). However, this fact the general topography is masked, especially with Negative Openness (Figure 2-2h) does give it an advantage over some of the other visualization techniques, the ability to extract features based upon value.

Additional Visualizations

Above are some of the most commonly used visualization for analyzing LiDAR, see Kokalj and Hesse (2017) for additional methods of visualization. A common approach is to combine multiple visualizations, exploiting the different strengths and combing it into one image. This is completed in GIS software such as ArcMap or QGIS, by controlling the transparency, brightness, contract, and other visual effects multiple visualizations can be layered on top of one another. Other composites require more mathematical workflows to produce a new image, these include I-Factor (IFACT) a combination of both Positive and Negative Openness, Highest Gradient Model (Mayoral 2017), and Red Relief Image Map (RRIM) an image produced when slope factor is overlaid an IFACT image (Chiba et al. 2007, 2008).

Current Applications in Archaeology

The “geospatial revolution” (Chase et al. 2012) popularized the usage of LiDAR although it had previously been used in Mesoamerica at the site of Copan, Honduras (Gutierrez et al. 2001). The capture of Copan with LiDAR was incidental and not the main focus, however it did serve as a proof of concept. Perhaps the reason this did not start widespread usage of LiDAR for archaeological purposes is due to the relatively poor resolution systems were capable of at the time. The initial surveys of Caracol and Angamuco producing high resolution images has led to numerous more surveys within Mesoamerica and outside. As of Chase and others (2017) 2,500 km2 has been surveyed throughout Mesoamerica, recent publication by Canuto and others (2018) has in effect doubled that number to close to 5,000 km^2. Many other LiDAR surveys have been conducted yet haven't been published so the overall area surveyed to date is likely much higher. The following are a few surveys conducted throughout Mesoamerica highlighted the current state of LiDAR analysis.

A 2014 survey of 48km2 in the Yucatan Peninsula of Mexico including the sites of Chichén Itzá and Yaxuná was used as a technical of the effectiveness of LiDAR in varying vegetation coverages. The survey area included milpas, areas cleared on vegetation for farming purposes which provided a "true" bare earth DEM as there was no vegetation to obscure any features. What Magnoni and others (2016) found was two major issues which can arise with LiDAR data. The first being a bias in the identification of archaeological features by individuals, including false positives and omissions. The second being the failure of LiDAR to detect features, due to its process of sampling and not contiguous measurements of the ground. An interplay of local topography, LiDAR's system setup, and researcher identification bias can limit the effectiveness of analysis.

The discovery of archaeological features in the Misquitia region of Honduras, is a unique case of the application of LiDAR as it was conducted privately to locate any evidence of human activity in a remote region of the world. The survey was flown without any pre-existing knowledge of possible archaeological sites in the survey area. Once researchers were brought onto the project to analyze the data evidence of human occupation became apparent, through usage of contour mapping which identified earthen mounds, plazas, terraces and possible canal systems (Fisher et al. 2016). Following ground-truthing in 2015 and verification of the features identified were archaeological a total of 19 settlement were identified, with the largest estimated at 146 hectare in size, classifying it as a city. This survey, started as merely prospective and was able to show evidence of human occupation in one of the most remote regions of the world.

In 2015 470km2 were surveyed around the Maya site of Ceibal, Guatemala, the largest site in the Pasion River region, followed by two field seasons of ground-truthing with test excavations (Inomata et al. 2018). In this case LiDAR is not used as the sole means of analysis, it is used in conjunction with previous data as a means of validation and enhancement. Using the E-group, a distinctive collection of structures who's configuration can distinguish certain timeframes, and other pyramid and platform complexes as the foci for LiDAR identification alongside excavations allowed Inomata and other (2018) to develop a landscape scale settlement timeline. The LiDAR data allowed the researchers to pinpoint where labor intensive work needed to be conducted. Combining the architectural morphologies with test excavation, ground-truthing, and surface collection provided stronger evidence to support the landscape settlement chronology.

Chase and Weishampel (2016) is a different usage of LiDAR data compared to the above examples. Relying on 2009 survey of Caracol, Belize, here the authors approach the data not from a mapping perspective, but rather a terrain analysis of the modified landscape. The ability of LiDAR to map the ground in great detail allows researchers to see how human modification affects certain natural processes such as flow and subsequent management of water. Through hydrological analysis Chase and Weishampel, detail how the terracing of the landscape around

Caracol increased the water retention for agricultural purposes and managed the soil erosion. The availability of analysis through GIS tools can quantify the effects of human modification of the landscape providing an explanation of why certain behaviors developed.

The above examples highlight some general trends which are slowly becoming de-facto standards for LiDAR surveys and inclusions into research designs. These include the necessity of ground-truthing and not dismissing traditional survey techniques, understanding the effect of the vegetation types in the study area and how it effects the LiDAR system's ability to sample and map the ground, and lastly ability of LiDAR data to be analyzed in a way through GIS to tackle complex questions in quantifiable ways. Additional surveys across the world detail the wide variety of applications: North America (Davis et al. 2018, Friedman et al. 2017, Krasinki 2016), Europe (Fernandez-Lozano et al. 2014, Cerrillo-Cuenca 2017, Mayoral 2017), Africa (Freeland 2016), Pacific Islands (McCoy 2018, Jackmond et al. 2018), Mesoamerica (Venter et al. 2018, Rosenwig 2012, Macrae and Ionnona 2016, Loughlin et al. 2016, Ebert et al. 2016, Brewer et al. 2017), Caribbean (Opitz 2015).

Noticeable in the current literature is the reliance on manual identification of archaeological features in the data with some exceptions e.g. (Davis et al. 2018, Ebert et al. 2016). This is likely due to the fact majority of archaeologists are not GIS specialists, while the application of GIS has become widespread throughout the field of archaeology the applications are fairly limited to the available tools which are included in GIS programs. This issue will likely disappear overtime as GIS and remote sensing technical skills are becoming more refined for archaeological purposes. As these skills continue to be developed and LiDAR becomes more integrated in research designs the questions being asked and answered will continue to expand.

Conclusion

Remote sensing, both satellite and LiDAR has provided archaeologists with the means of landscape level analysis, however with the application of any technology issues and obstacles are constant in how best to utilize a certain methodology. Researchers are not shy about confronting these issues. Within Mesoamerica the difficulties of fully utilizing and managing LiDAR is well know (Chase et al. 2016), as mentioned above ground truthing is a necessity as anomalous features, and missing features are not uncommon (Canuto et al. 2018, Magnoni et al. 2016). The usage of advance algorithms to identify and extract features from the data may not be as beneficial as wanted due to a lack of technical knowledge in creating and modifying algorithms (Quintes et al. 2016). Acknowledging these obstacles has seen the development of best practices and the continued focused on new means of collecting, managing, and analyzing these large data sets has motivated researchers to delve into new fields such as machine learning (Opitz and Herrman 2018). As with all methodologies and technologies continual refinement is needed as the technology itself advances, and new questions are attempted to be answered.

CHAPTER 3

The study of Mesoamerican urbanism is overwhelmingly focused on the urban practices by the ancient Maya with a second and much smaller focus on the Aztecs, Mixtec and others. This is not surprising as the ancient Maya spanned the majority of what is considered Mesoamerica with architectural differences spread throughout the Guatemala highlands, northern and central lowlands. In the following chapter the theoretical approach to understanding urbanism will be reviewed as well as the known urbanism of Mesoamerica and what little is known of the Purépecha form of urbanism.

Approaches to Urbanism

To study urbanism, it must first be defined. This has proven to be a difficult task for archaeologists throughout the world especially when approaching Mesoamerican complex societies (Blanton 1976, Cowgill 2004, Smith 2007, 2010). The difficulty in defining urbanism stems from what constitutes a city, Child (1950) and Weber (1958) biased the study of urbanism by limiting what could be considered urban through a list of characteristics which are predominately western-centric. This bias approach naturally eliminated majority of New World settlements from the urban class. Today the question of urbanism centers on demographics or function (Cowgill 2004, Smith 2007). The demographic definition is described by Sanders and Weber (1988) who based their understanding of urbanism from Wirth's (1938) three main factors (1) large population size, (2) dense population nucleation, and (3) high internal heterogeneity (Sanders and Weber 1988: 522). Functional interpretations are more recent (Blanton 1976, Fox 1977, Marcus 1983, Smith 1989, 2005, 2007) and are based on the social functions which occur in cities and their affluence over a larger hinterland (Marcus 1983, Smith 2005).

Following the demographic definition, very few Mesoamerican sites would qualify as urban. Sanders and Weber (1988) qualify classic period (200-600 A.D.) Teotihuacan and post classic (1350-1520 A.D.) Tenochtitlan as the ideal Mesoamerican urban forms, relegating majority of the classic Maya centers as nonurban settlements. Smith (1989:454) argues:

"In this approach, Teotihuacan and Tenochtitlan are seen as the archetypical Mesoamerica cities, while other less densely populated centers (including those of the Classic Maya) are viewed as something less than urban." Smith continues to critique, "While it is true that functional approaches to urbanism will result in smaller centers being classified as urban Sanders and Webster are not prepared to go very far…Smaller centers which may have a variety of central place functions (economic and other), are not cities in this view, and are left out of discussions of urbanism." (1989:455).

Sander and Weber's bias in defining urbanism is quite evident, "Over the years we have resisted, in our own work, a broad definition of the city, reserving that term for the largest and most complex Mesoamerican communities" (1988:527). The problems with this approach are quite apparent, most noticeably it is a very rigid approach and is not capable of being modified to different cultural traditions. It assumes what is urban is universal without individual cultural inputs.

A more flexible though less precise definition has developed to challenge the static demographic approach (Joyce 2009). This functional interpretation views urbanism as a process, if a settlement fulfills urban functions then it is urban (Smith 1989). Unlike the other approach this allows for a hierarchy of urban settlements and an understanding certain functions are limited to specific urban settlements but the lack of one of these certain functions does not exclude a settlement from being urban, additionally it become culturally relative and can be molded to different cultures throughout the world.

Fox (1977) separated urbanism into three major categories, regal-ritual cities, administrative cities, and mercantile cities. Marcus (1983) expands the different functions of cities to include other socioeconomic factors. Expanding what could be urban does not remedy where cities can be found, as Cowgill (2004:526) noted Fox asserts that cities are found only in state level societies, and by extension no state existed without cities, naturally this is a debated topic. The key defining feature in identify what can be considered a city is a relationship between the city and its hinterlands. “All settlements have catchment areas, but only cities have hinterlands” (Cowgill 2004:527). This extends to defining societies themselves. A society without cities is nonurban, as rural only has meaning within a society with an urban sector (Cowgill 2004). Under this framework a city is an urban center with a larger geographic sphere of influence, and a town is an urban center which performs certain urban functions yet has a very limited extended influence. The use of city and town to describe different levels of urbanism does have precedence in other disciplines (Smith 1989).

Becoming Urban

There are two primary means for a settlement to become urban, a “natural” congregation of people and social functions to a centralized location either through the pull of the settlement itself or the push of outside factors such as warfare or environmental change; “growing from earlier villages as centripetal forces attracted people to growing centers of prosperity and safety..”(Pugh and Rice 2017:576). Or a city was deliberately created to serve some purpose or the interests of powerful elites (Cowgill 2004). Evidence for the planned creation of a city does exist within Mesoamerica, within the valley of Oaxaca the early urban site of Huamelulpan. The city was founded on a previously unoccupied hilltop away from the best agricultural lands primarily for defensive purposes (Balkansky 1998). The settlement developed rapidly in a similar fashion to the better known site from Oaxaca, Monte Alban (Blanton 1976).

How a city developed is tied to its purpose, capital cities were often “invented” to signify a new social organization (Yoffee 2005), or they could solve current issues. An intermediate city could be founded to strengthen the communication and connectedness of outlying settlements (Blanton and Fargher 2011), or garrisons for military purposes, ports for trading or settlements for colonies. Cowgill (2004) refers to these types of cities as “planted”, created by those with previous urban experience, unlike pristine or Primate Cities like Teotihuacan which arose from a regional tradition without previous urbanism.

Variety of Urban Form

Defining Mesoamerican urbanism is not easy, even after considering the above. The variety of forms are often divided between planned and unplanned (organic) (Smith 2007) with all points of the spectrum displayed throughout the Mesoamerican world. Many of Mesoamerican archaeologist subscribe to some form of the functional definition, to include Joyce (2009) discussion on action theory the inclusion of social agency and a bottom up approach instead of high-level social functions dictating the development. The reason for greater adherence to a functional definition over a demographic approach is a result of the “typical” ancient Maya urban form, a civic-ceremonial center surrounded by a low-density built environment. Fletcher (2009) defines this type of urbanism in the tropical regions of the world to include the class period Maya as "low-density agrarian-based urbanism". This definition was expanded upon by Isendahl and Smith (2013) to include majority of ancient Maya and Aztec cities based upon the urban agriculture prevalent throughout the two cultures. Recent LiDAR surveys have shown how pervasive this urban agricultural practice was throughout the Maya world and even at the site of Angamuco.

This approach, viewing urbanism along a scale from low-density agrarian-based to the "formalized" layout of Teotihuacan and Tenochtitlan, leads to the question of how the urban form can be studied when there is a range of what can now be considered urban is so vast. Smith (2007) constructed a new approach based on a series of scales, not a presence/absence, yes/no, means of measuring. He focuses on two components, coordination among the building and spaces in a city, divided into five sub-components and standardization among cities in terms of architectural inventories, layouts, orientation, and metrology. From this approach there is a very wide degree of planning which can be used to describe a city, while complicated it fully accepts the multifaceted nature of urbanism unlike earlier approaches which sought to simplify this complex social phenomenon, for example (Smith 2007:7):

> "*More planned* can refer to the degree of coordination or standardization. Orthogonal layouts, for example, suggest more involvement in planning than simple coordination among buildings. *More planned* can also refer to the effort involved in planning. Formally placed large monumental buildings require greater energy investment than simple coordination of alignments among houses. *More planned* can also refer to the extent of a city that exhibits planning (in both absolute and relative terms)."

This greater freedom allocated by this approach towards studying urbanism has one major drawback, it becomes difficult to quantify. This difficulty makes this approach more human and underscores the idea not everything can be molded to fit into neat categories when dealing with processes which result from innumerable factors and highlights the complexity of human interactions and choices in increasing larger groups.

Purépecha Urbanism

The study of Purépecha urbanism is quite limited. The primary sites which constitute the empire's heartland Tzintzuntzan, Ihuatzio, and Patzcuaro as named by the RM are currently covered by modern settlements or have been nearly cleared of any architectural features e.g. Ihuatzio. This has led to a poor understanding of what Purépecha urbanism constitutes and how it is similar and/or different to neighboring polities like the Aztec to the east. What research has been conducted into urbanism primary comes from Pollard's work at Tzintzuntzan and the RM's ethnohistorical accounts. The following is what little is known about Purépecha urbanism and is based heavily from Pollard's work (1972, 1977, 1980, 1993, 2003a, 2003b).

Tzintzuntzan

Tzintzuntzan (Figure 3-1) was the Purépecha imperial capital during the late post classic period located along the eastern shore of Lake Patzcuaro between Cerros Tariacuri and Cerros Yaguarto, two hills/extinct volcanos. At the time of European conquest in 1525 the size of the city was approximately 6.74 km2, Pollard estimated the population of the capital to range between 25,000 and 35,000 people (Pollard 1993). Through her work Pollard divided the city into five zones: residential, manufacturing, public, commercial, and agricultural, with sub categories for more specific organization. Minimal excavation was conducted in her research of the imperial capital her data and categorization are based heavily on surface collection of artifacts.

Residential zones were divided into four subcategories based on the artifacts distributed throughout each zone. Type i residential zones are considered to low status areas. The prevalence of courseware ceramics generally mono/bichrome with few decorative motives and per the survey conducted constitute the largest, in area, of all the residential zones. Type ii zones are believed to belong to the highest of the social classes, as more decorative ceramics and other wealth objects are found within these zones. To include, red and green obsidian, ear/lip plugs, pipes, and unusual ceramics with fairly unusual motifs. The RM supports the archaeological evidence for these zones being of higher class as lip and ear plugs are specifically mentioned to be associated with high-status. Within zone two are variations in the type and amount of wealth objects, which is believed to be related to the location of the zones to other features of the city. Type iii zones can be considered “middle” status, there are some but not all of the artifacts associated with type ii zones and should more accurately be referred to low high-status as the RM does mention stratification within the high-status class. Type iv is unique as it is defined specifically by the occurrence of Querenda ware ceramics, which likely indicates an ethnic *barrio* as Querneda ware is also found at imperial frontier sites to the northeast.

Manufacturing zones consist of three lithic workshop types and a forth “other” workshop. Lithic workshop type i, with five sites identified are composed of high proportions of unretouched prismatic blades and polyhedral blade cores and blades. The lithic workshop type ii is defined by a “pavement” of chipping debris, red and green obsidian, crude blades and flakes. The third lithic workshop type is primarily identified by large scrappers, and the lack of chipping debris suggest the two sites within this category were use sites and not manufacturing sites. The "other" workshop is a catch-all for the 28 other specialists mentioned in the RM, however none of the specialized workshops were identified based upon the survey conducted.

Public zones are broken down into three primary: primary religious, secondary religious, political-administrative and six "other" sub zones. The primary religious zone is the main platform (Tz-25) 450 x 250 meters with five yacatas located along the eastern side. The platform and yacatas are constructed using rubble fill and faced with stacked basalt slabs. Several burial chambers are located in the platform across from the yacatas, the RM described the five yacatas as being dedicated to the god Curicaueri and his four brothers. The secondary religious zones consist of four sites which are either rubble filled structures and/or have a high concentration of pipes/pipe fragments. The political-administrative zones do not exist. Little evidence was recorded of any site having this primary function, it is likely other zones were used as secondary political/administrative locations such as the kings palace. The "other" zones are *Casa de las aguiles*, a Jail, a Zoo, storehouses, ballcourt, and baths.

There is no evidence of a commercial zone based on the survey conducted by Pollard, with the assumption a market existed outside of the city limits. The agricultural zone is assumed to have been lake shore milpas as there are mentions in the RM but no mention of the location beside lake shore.

Ihuatzio

Ihuatzio (Figure 3-1) is the only other major site mentioned in the RM to have received major archaeological investigation. Sadly, that investigation is very limited. The site is located 7 km southwest of Tzintzuntzan along the lake shore of Lake Patzcuaro, with an estimated size of

125 hectares and a population of 3,000-5,000. For its smaller size compared to Tzintzuntzan the area dedicated to religious/ceremonial actives/political activities constituted approximately 40% (50 ha) of its size, with three yacatas as the center piece. Unlike Tzintzuntzan the RM describes Ihuatzio as being "founded" as part of a military buildup, and its unusual structural alignments supports a central plan for this settlement. Evidence suggest there were residential zones around the ceremonial center associated with different classes/occupations. Following the unification of the Purépecha state Ihuatizo is only mentioned in ceremonial contexts.

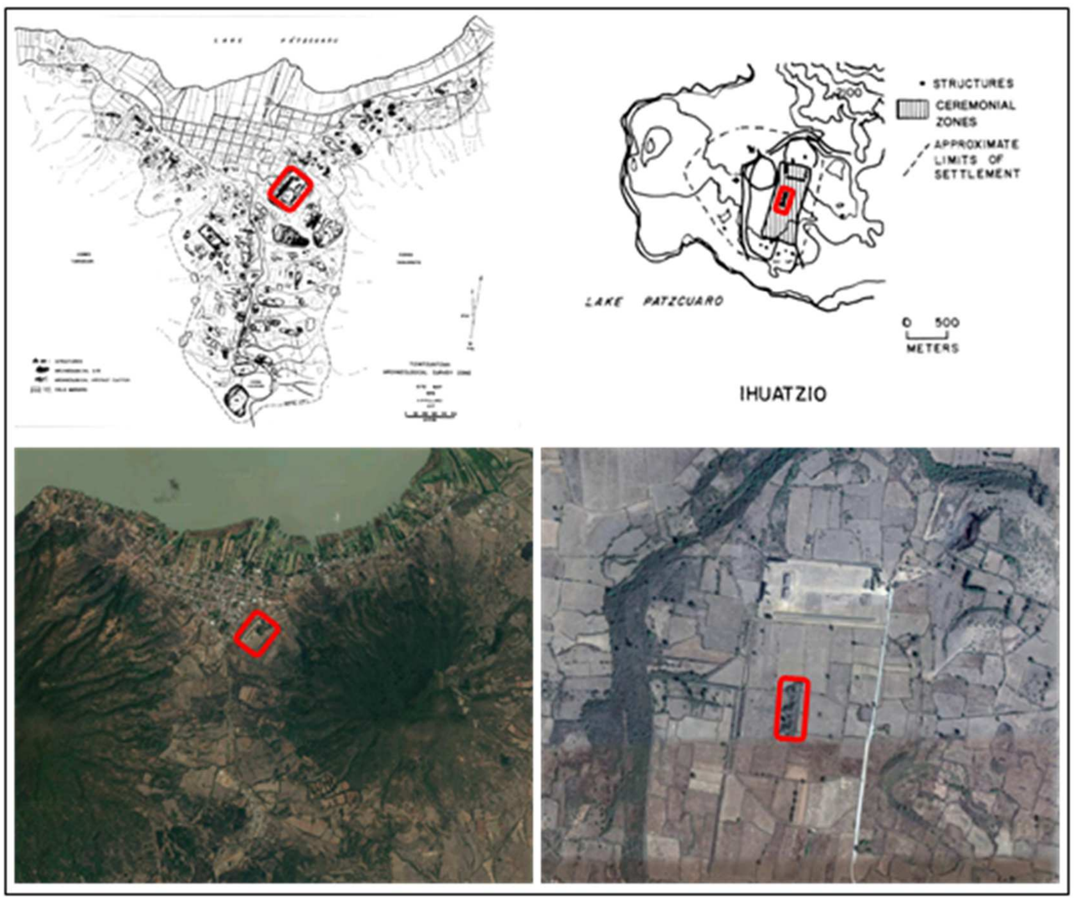


Figure 3-1. Comparison of the maps created of Tzintzuntzan(left) and Ihautizo(right) and their current appearance on Google Earth.

Pátzcuaro

Pátzcuaro, the home of the legendary hero Taricuri, is mentioned frequently in the RM but almost nothing is known about it archaeologically due to the modern settlement of Pátzcuaro covering the pre-hispanic settlement. Unlike the other two major sites above, Pátzcuaro is not located along the lake shore, it is 3 km south and 100-150 m above the contemporary lakeshore estimated to have covered 100 hectares with a population of 5,000 or less. Based on the RM the site consisted of two public zones, a central residence zone and several surrounding smaller settlements or hamlets. It is unclear if Pátzcuaro existed before the events of the RM.

Erongaricuaro

Referenced in the RM (Acala 2013:96) the site of Erongaricuaro is estimated to be at least 250-300 hectares, with a possible population between 5,000 and 10,000. The function of the city is known through historical documents although its physical layout is barely understood, and it was only known at the time of Pollard's writing through aerial photographs and ground surveys.

Pollard limited the urban tradition of the Purépecha to only the capital city of Tzintzuntzan while acknowledging Erongaricuaro did have some "urban character" (Pollard 2003:380). For her, Purépecha urbanism was synonymous with the state, the formation of the empire and prior to the state's formation the settlements were ceremonial centers. Some archaeological evidence supports her conclusion, her work at Urichu identified three civic-ceremonial compounds with little residential architecture (Pollard 2003b). When viewed from the functional definition considering the new ways of defining Mesoamerican urbanism

Patzcuaro and Ihautzio should likely also be considered on the urban spectrum. These sites to have performed some urban functions even lacking a discernable hinterland.

Angamuco

The limited understanding of Purépecha urbanism highlights how important the site of Angamuco is and the need for in-depth analysis of its physical layout. Perhaps the most beneficial aspect of the site is it has not been built over by modern settlements or heavily impacted as Tzintzutzan and Pátzcuaro. As discussed previously Angamuco experienced its zenith pre-empire, what is known of the Purépecha Empire urban form will likely be restricted to our understanding of Tzintzuntzan's urban zoning. Angamuco has the potential represents the pre-empire Purépecha urban form, while it is likely pre-empire urban form influenced the empire urban form particularly due to the location of Angamuco in relation to the imperial capital, caution is necessary is drawing definitive conclusions.

To date there have been three main publications attempting to analyze Angamuco's urbanism from different approaches; Bush (2012) studying the architectural layout and planning at the local plaza group level, Fisher and Leisz (2013) introduce the complejo concept, in short defining neighborhoods spatially at the site, and Urqhart (2015) expands upon the complejo concept by applying the altepetl model to Angamuco and attempts to automate the identification of complejos through object based imagery analysis (OBIA). These studies were the first approaches to studying urbanism with the additional benefit of LiDAR data in the LPB. Continuing in a similar methodology as the previous theses the means for understanding Angamuco's urbanism will rely on GIS applications to the LiDAR data, to extract the urban environment from the underlying topography to be used for spatial analyses. The methodological approach is described in detail in chapter four.

The Palimpsest of Angamuco

Developing a theoretical approach to understanding the development of urbanism for the Purépecha in the LPB based on the current literature and the Angamuco LiDAR data runs into one major roadblock, the palimpsest theory. A palimpsest originally was a manuscript in which the original writing was erased to be written on again, however traces of the original writing remained resulting in a messy manuscript which could be read in possibly many ways. Within the study of landscapes and in this case a city, a palimpsest has taken on a broader definition to summarize the ever changing and complex interaction between natural and human processes which leave traces years after the event (Johnson and Ouimet 2018). In short "the traces of multiple, overlapping activities over variable periods of time and the variable erasing of earlier traces" (Lucas 2005:37). Archaeologically this is easy to see, throughout the world peoples have built and lived upon the land their ancestors lived. Recognizing the complex and layered landscap of Angamuco as a palimpsest highlights the importance of understanding the temporal aspect and the challenge without the addition of non-LiDAR based evidence to provide the context necessary to objectively study the data (Risbol 2013, Johnson and Ouimet 2018).

Currently there are 15 calibrated radiocarbon dates from the 2014 excavation, 10 are related to burials removed from the cemetery located at the foot of the main *yacata* (Cohen 2016 Fisher et al. 2014, 2013, 2012). The time depth is understood to extend to the pre-classic with confirmed carbon dates to 795-547 B.C.E however the time breadth across the site is near non-existent. The 15 calibrated dates are from 5 of the only 7 excavated locals at Angamuco. Cohen does utilize architectural and ceramic data to relatively date the excavation sites and support the radiocarbon dates, however extrapolating this data to date the full site is irresponsible as so little is known about the urban tradition.

LiDAR data is in a sense timeless, a brief image of the landscape as it is at the exact time of survey, we are seeing the site as it is today and inferring its past. We may infer time by the superposition or structure of certain features (e.g. use of sunken plazas to date to the Loma Alta phase, and *yacatas* for the empire phase) from LiDAR products, however the means of inference is from outside data and not the LiDAR itself. The problem is exacerbated at sites which have been disturbed, while Angamuco appears to be fairly unscathed by post-European contact processes, excluding the aforementioned mining which occurred (chapter 1), the palimpsest visible in the data makes any approach to determining the development and growth of the site extremely difficult.

Conclusion

Taking into account the palimpsest, limited excavation at the site, and minimal understanding of the Purépecha urban tradition the data produced is this thesis is analyzed at face value with conservative interpretations made. Heavily applying a theory of urbanism to the site at this early stage analyzing the site is irresponsible due to the limited ground surveys and excavations at the site. This does not mean some decisions can be made about the site in the context of the discussed approaches and our current view of Mesoamerican urbanism. 1) the site is urban, 2) a degree of community planning can be identified by the construction of raised roadways, and the water management features, 3) there is an inventory of consistent architectural forms which occur throughout the site, 4) the density, minimal number of agricultural terraces, and scale of the site would require a large catchment area to support the population which may be classifiable as a hinterland. While, beyond the primary scope of this thesis the exploratory analysis of the dataset produced from the methodology to be discussed in the following chapter provides an avenue of approach to tackling the Palimpsest obstacle using excavation data and some assumptions related to the sites architectural inventory.

CHAPTER 4

The methodology (Figure 4.1) presented here was developed with two primary purposes. First, a methodology which does not require advance knowledge of GIS/programming to use. Second, a method which can be applied to multiple geographic areas without adjusting the general framework of the method. The result is a methodology which consists of combining multiple means of LiDAR analysis into a general workflow capable of extracting all built up possible archaeological features located at the site of Angamuco. The method relies upon ArcGIS 10.5 and an open-source toolbox to manipulate the DEM (Jenness et al. 2013)

Overview

Currently, there are numerous methods to extract buildings and other features from LiDAR data in the literature, however these methods rely upon the combination of LiDAR data and additional multispectral imagery. The general method utilizes the sharp elevation increase buildings and other structures have in relation to the surrounding landscape along with their unique spectral signature to distinguish features from the surrounding environs (Sohn and Dowman 2003, 2007, Lee et al. 2008, Awrangjeb et al. 2010). It can be considered a two-step verification methodology. This poses an issue when trying to apply current methods to an archaeological LiDAR dataset. Primarily the subtleness of elevation change between a possible feature and the surrounding topography, and the lack of multispectral imagery due to features being under canopy cover, and the variety of possible irregular, circular, and rectilinear shapes found at a single site. Thus, this methodology is designed around utilizing only the LiDAR data.

The methodology created here (Figure 4-1) can be divided into three sections, topographic manipulation, identification and extraction, and analysis preparation. Within the three major sections are multiple steps many with options which are decided by the user, i.e. selecting the search radius for the SLRM or the Topographical Position Index (TPI). The number of steps which require user selection allows for this method to be applied to a variety of topographical landscapes, however this freedom of variable input does eliminate the possibility of any one set of variable inputs being the best for any one situation.

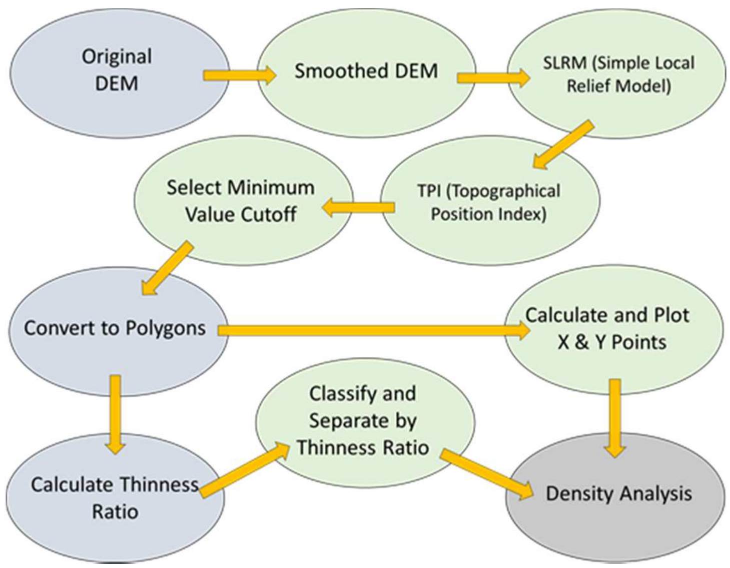


Figure 4-1. Generalized workflow for the identification and extraction of the possible built-up features. Blue ovals indicate steps with minimal user input, while the green ovals indicate steps with necessary user input.

Topographical Manipulation

The complex topography of the *malpais* provides a unique challenge in extracting the possible archaeological features from the landscape. Unlike areas of the Maya region which have been surveyed with LiDAR which consist of mostly rolling hills and floodplains (there are exceptions e.g. Caracol), the Angamuco *malpais* is disadvantageous to feature extraction due to the geological features which share certain attributes similar to built features. The first part of this methodology is to minimize the effect of the underlying topography on the analysis.

First, the DEM, the basis for nearly all analysis of LiDAR data, needs to be “cleaned” of noise in the data. An issue which arose when designing this methodology was the roughness of the DEM, the small bumps which can be visually see in FIGURE 2, resulted in a messy and crowded final product with thousands of extracted features unlikely to be of any archaeological importance. To minimize the bumps and de-noise the image a smoothing technique was applied to the original DEM.

In ArcMap 10.5 the focal statistic tool was used, a circular kernel of 3 cells was passed over the entire DEM which removes extreme outlying values, this is akin to smoothing a wood plank with sandpaper. By smoothing the data (Figure 4-2)   the number of small features less than a meter squared in area are removed from analysis without needing any additional steps. Secondly larger and likely archaeological features can now visually be clearly identified. The shape and size of the kernel used will produce different outputs from the same DEM input. It would be advised not to extent the size of the kernel past 2 meters (4 cells based on this DEM’s pixel resolution) as small features may be smoothed to such an extent defining elevation changes and markers of possible human influence may be erased. Additionally, smoothing the edges of possible features may preclude them from being identified as they may be classified as the underlying topography.

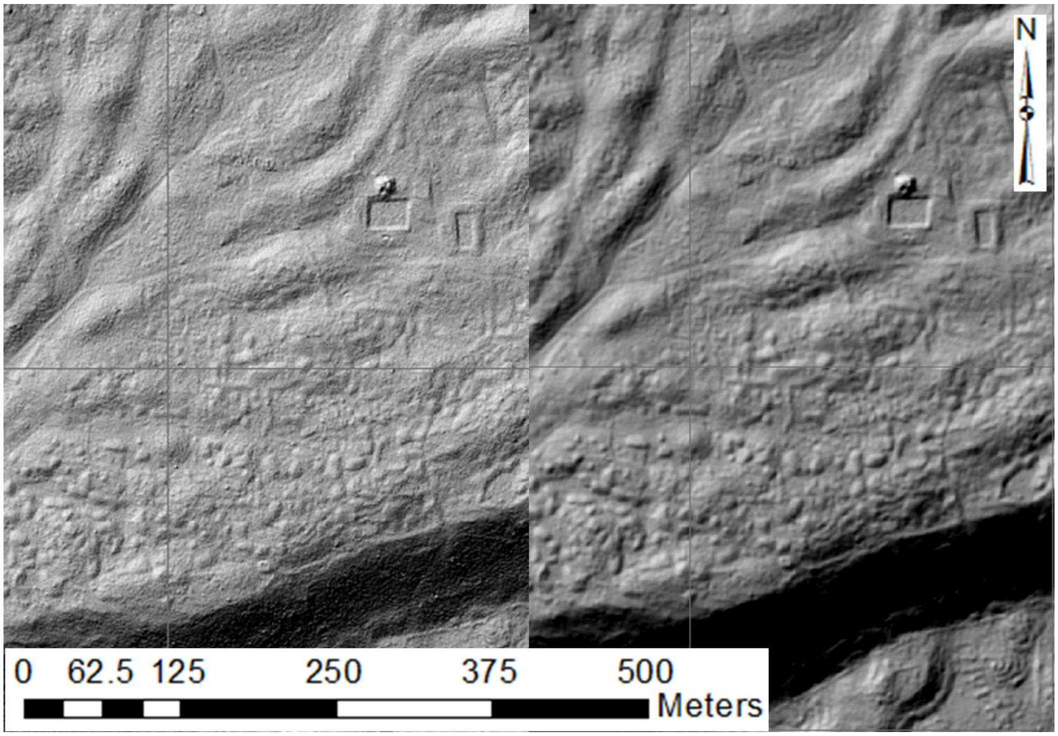


Figure 4-2. DEM Hillshade visualizing the effect of smoothing the original DEM to "de-noise" the DEM. Left is processed from original DEM, Right is after a 3x3 kernel was applied.

Following the smoothing of the DEM, the first step of topographical manipulation is applied, the SLRM. The details of an SLRM has been previously discussed (chapter 2) and won't be restated here. The SLRM was set at a circular kernel size of 20 cell radius, for the size of the known and possible archaeological features and due to the topography of the malpais a 20 cell radius produced the most advantageous output. A different cell radius could have been chosen if the goal of this methodology was focused on different sized features, or if the underlying topography was of a different nature. Application of smaller kernel sizes will maintain smaller features better but will not reduce the underlying topography to a great extent. While a larger kernel size will reduce the number of small features and greatly reduce the effect of the underlying topology. The decision of the kernel size is a trade-off between maintaining small features or reducing the underlying topography. The output from this step (Figure 4-3) has removed majority of the underlying topographical features allowing for more accurate and precise identification and extraction of smaller archaeological features.

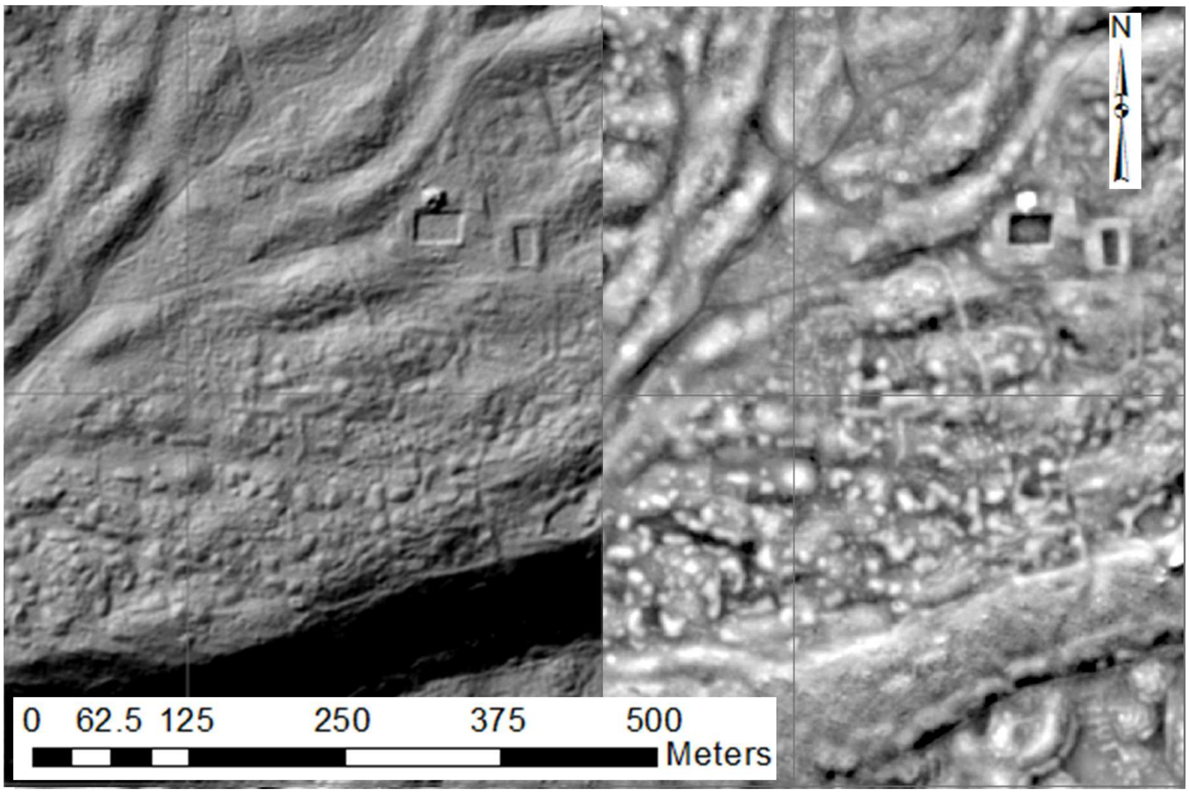


Figure 4-3. SLRM of the DEM. The lighter the pixel the higher the relative elevation. Notice the lack of an apparent hillside in the lower right of the image compared to Figure 4-2.

Identification and Extraction

The key to identifying and extracting archaeological features is the the Topographical Position Index (TPI). The TPI is a means of classifying the landscape (DEM) pixel by pixel by their relative position to other pixels, unlike other processes which only produce new pixel values, the TPI can also classify the values into previously designated landscape features. The original usage of TPI included six topographical feature classes consisting of Hilltop, Upper Slope, Middle Slope, Flat Slope, Lower Slope, and Valley derived by Standard Deviations from Elevation and slope percentage (Jenness 2006, Jenness et al. 2013, Weiss 2001). The application of this for archaeological purposes in the Maya region (Ebert et al. 2016) used the same classification scheme originally proposed. While effective for that specific application, using the original scheme did not work for the site of Angamuco. The resulting output consisted of overwhelmingly of two main classes Upper Slope, and Lower Slope, small features were not included and majority of possible features were conjoined with each other or with topographical features. In short the complex nature of the site precludes basic landscape feature classification which could identify archaeological features from the landscape, manual classification/identification is needed. For the purposes of this project the algorithm was applied using the standard TPI value output produced by the toolbox.

For Angamuco the TPI was selected with a kernel search radius of 20 pixels and a circular kernel (Figure 4-4). The radius sized selected visually appeared to be the “best-fit” in capturing majority of the features apparent area. The kernel shapes (Circular, Rectilinear, Annulus) did not appear to have a significant impact on the classification of the landscape. There were minor changes in some features rectilinear features did appear “cleaner” using a rectilinear kernel. However, the decision was to keep the kernel shape circular as it was for the SLRM for uniformity. Similar to deciding on the size of the kernel for the SLRM a larger or smaller radius for the TPI did effect the classification of features. The trade-off was similar to the SLRM a smaller radius identified smaller features but in this case also reduced the area of larger features, while a larger radius eliminated many smaller features.

After the TPI has be processed, a visual comparison is conducted between the TPI raster and a multitude of different visualizations to determine the minimum value which will be selected for. This involves side by side comparisons of the TPI raster and other visualizations, as well as overlays. The basis for the minimum value is to include the greatest area per possible feature while also still being precise enough so two features which are close together can be separated. Once the minimum value is decided through basic tools (right click identify in) in ArcMap all values above the decided value are extracted from the TPI raster, reclassified so the values are equalized and converted to a single polygon shape file. During the conversion to a polygon shapefile the option of simplifying the polygons can be selected (this smooths the edges of the polygons), the result is a shapefile (Fugure 4-4) which contains all the possible archaeological features.

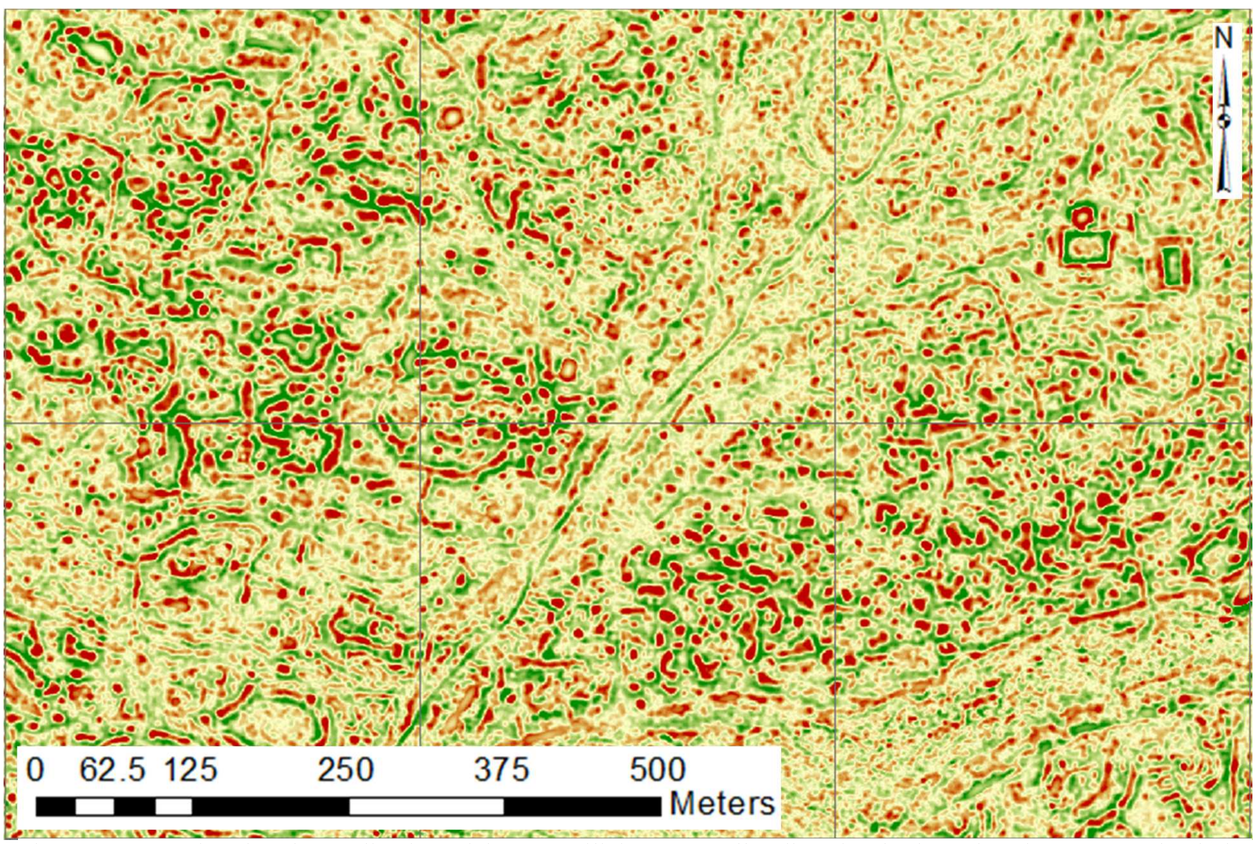
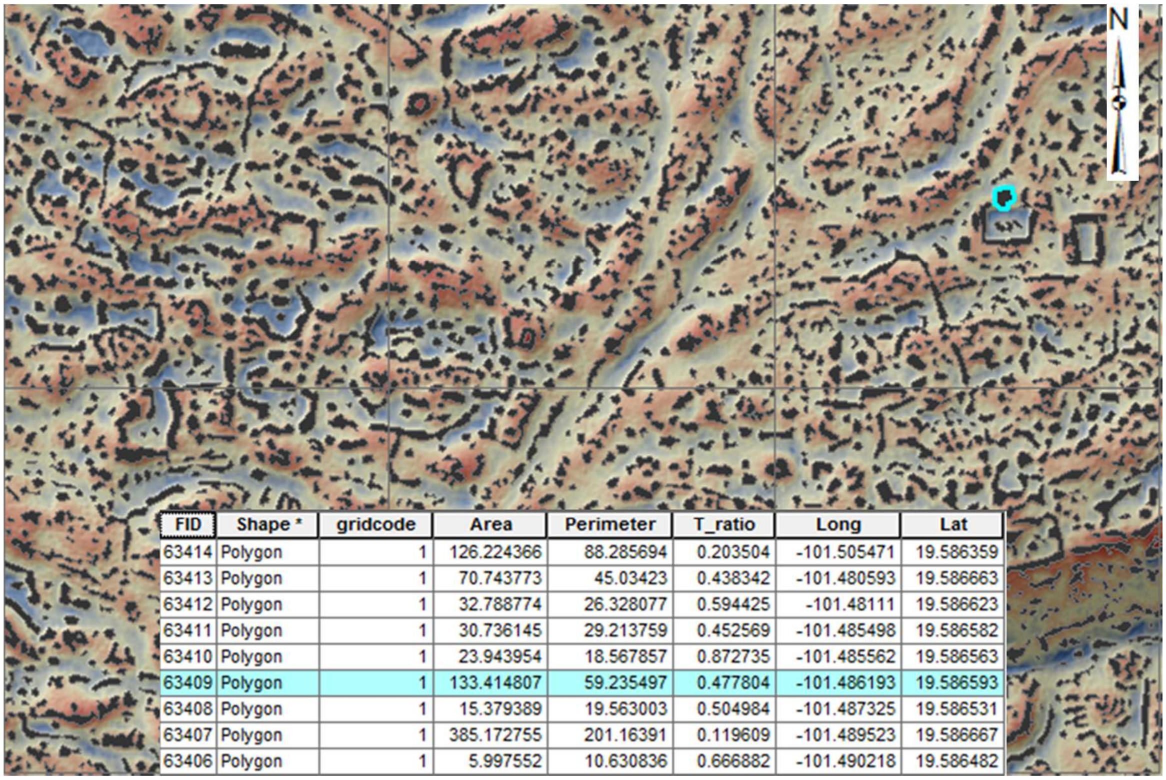


Figure 4-4. Results after the application of the TPI utilizing a 20 cell radius circular kernel to the SLRM. The dark red features represent all possible archaeological features.

Analysis preparation

At this point the polygons do not consist of any analytically useful data besides visually identify the possible features and the number of features. This in and of itself can be useful as it can also serve as an initial mapping of the site minimizing the time to manual digitize individual features across the site. To improve the usefulness of the data, the central latitude and longitude of each polygon, its area, and perimeter are calculated in the attribute table. The latitude and longitude can be plotted in a separate shapefile to produce points for each individual possible feature. With a point shapefile spatial analysis such as density analysis (chapter 5) as well as other methods to study density, distribution, and clustering patterns can be applied to answer spatial questions. The area and perimeter of each polygon are calculated to provide basic geometric values to each possible features and to calculate the Thinness Ratio, the key attribute in classifying the polygons in chapter 5.

The Thinness Ratio is a means to determine how close an object is to be a perfect circle, the closer an object's Thinness Ratio is to 1 the more circular it is. Using the formula (ratio = $4pi(A/P^2)$) as a quantitative means to separate the total number of polygons into smaller to handle and more precise classes for analysis will increase the level of detailed analysis. For example, combining the Thinness Ratio and other geometric attributes such as the features' polygon perimeter a means of OBIA can be conducted to classify features into specific architectural classes. This ratio can quantify the shape of the archaeological features and replace a qualitative means of identify features.



FID	Shape *	gridcode	Area	Perimeter	T_ratio	Long	Lat
63414	Polygon	1	126.224366	88.285694	0.203504	-101.505471	19.586359
63413	Polygon	1	70.743773	45.03423	0.438342	-101.480593	19.586663
63412	Polygon	1	32.788774	26.328077	0.594425	-101.48111	19.586623
63411	Polygon	1	30.736145	29.213759	0.452569	-101.485498	19.586582
63410	Polygon	1	23.943954	18.567857	0.872735	-101.485562	19.586563
63409	Polygon	1	133.414807	59.235497	0.477804	-101.486193	19.586593
63408	Polygon	1	15.379389	19.563003	0.504984	-101.487325	19.586531
63407	Polygon	1	385.172755	201.16391	0.119609	-101.489523	19.586667
63406	Polygon	1	5.997552	10.630836	0.666882	-101.490218	19.586482

Figure 4-5. The extracted possible built-up archaeological features overlaid onto a colored SLRM/hillshade composite visualization, with a selection of attributes used in analysis. Polygon 63409 relates to the highlighted pyramid in the upper right of the image.

Accuracy Assessment

Two accuracy assessments were conducted on the extracted dataset of the possible archaeological features. The first was an assessment of the accuracy of the overall feature extraction results while the second assessment was focused on the accuracy of a means of classifying the possible archaeological features based on the features geometric properties, specifically the thinness ratio. The features were classified based on the thinness ratio into three broad categories to begin organizing the numerous features into manageable datasets. The classes consist of circular features with a thinness ratio of 1-0.7, miscellaneous/rectangular 0.7-0.4, and linear 0.4-0.0. The decision on the break lines between the class is related to the shapes each thinness ratio value represents. A thinness ratio of 0.68 can but not always represent a ten by twenty pixel rectangle, while a ratio around 0.4 represents features which are no longer generally rectilinear, the application of the thinness ratio is discussed further in chapter 5. Approximately each feature has its own unique thinness ratio value, and with the possibility of similar thinness ratios representing different physical shapes there is difficulty in creating definitive classes.

The accuracy assessment was conducted by creating a shapefile and manually identifying all visible features (circular, misc/rectangular, and linear) and comparing these features to the ones extracted by the methodology. The features were compared by manually counting and using the ArcMap tool spatial join to identify features manually identified and those extracted. The assessment was conducted on a 250 by 250 meter section of Angamuco highlighted in Figure 4-6.

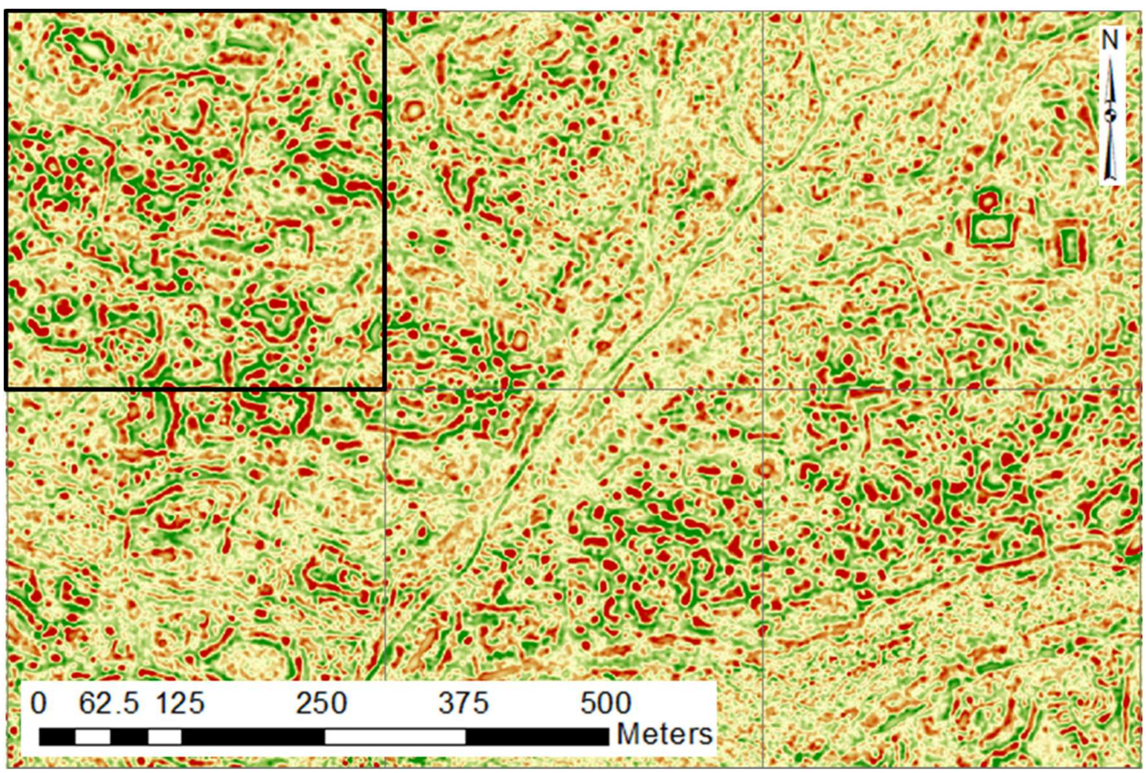


Figure 4-6. Section of Angamuco used to conduct the accuracy assessment.

The first accuracy assessment, comparing the total number of features manually identified to those extracted through this methodology was promising. The total number of possible archaeological features manually identified was 346, the number of features extracted equaled 372, with a total of 295 features matched between the two datasets. The difference between the two attempts at identifying features can be due to numerous reasons, such as bias when manually identifying and the extraction of topographically features from the methodology. Accepting the 295 features as archaeological features provides a manual accuracy of 85.26% and the extraction methodology with an accuracy of 79.30%.

The second accuracy assessment related to the thinness ratio classes assigned to each individual feature relies on using a confusion matrix (Table. 4-1), a common tool to assess accuracy in remote sensing research (Jensen 2005). A confusion matrix is used to assess overall classification accuracy, and the accuracy of the individual classes from a producer's and users point of view. The difference is related to what a pixel, or in this case feature, was classified as by the analyst (producer) of the data compared to what the data actually represents on the ground (user) (Jensen 2005, Lillesand et al 2015).Additionally, a confusion matrix can be used to produce an overall accuracy measurement of the different classes known as $K_{hat.}$ This is an estimate of Kappa which is often used in statistics to determine if the results of the matrix are better than a random sampling (Jensen 2005).

Table4-1. Confusion matrix of the classification accuracy of the three broad categories of the 295 features within the sample area.

Confusion Matrix Assessment					
	Circular	Misc.	Linear		User Accuracy
Circular	108	32	15	155	0.69
Misc.	32	45	23	100	0.45
Linear	2	9	29	40	0.72
	142	86	67	295	
Producer Accuracy	0.76	0.52	0.43		K hat = .37

The results of the accuracy assessment answers how trustworthy this method is for identifying and extracting possible archaeological features. Compared to manually identifying any possible features this methodology nearly as capable, 85.26% for manual compared to 79.30% from the methodology. It is likely applying this methodology to less topographically complex landscape would result in better accuracy. When the data is separated into classes based on the thinness ratio, the circular classification is fairly accurate while the other two classes are more difficult to confidently classify. This is probably due to a bias in it is easier to manually identify more circular like features and harder to determine how to classify certain feature shapes when the thinness ration is between 0.7 and 0.4. In addition to the increase probability topographical features are more likely to reside within the misc/rectangular classification range.

Overall Review of Methodology

This methodology is flexible enough to be applied to multiple regions with varying underlying topography and archaeological features. The number of steps which do require some form of user input can be detrimental, as the possibility of a "more perfect" output may seem likely. However, due to applying this methodology to the site as it is after centuries of site formation processes have taken their toll accepting a "good enough" output is necessary. Unlike modern buildings, structures, even settlements which are distinct from the landscape due to modern building methods and architectural leanings a perfect extraction of possible archaeological features is impossible, due to the difficulty of completely eliminate all the natural underlying topography from the final output (e.g. hilltops and ridgelines). This difficulty also impacts the accuracy of the methodology, while some feature types such as the circular features were fairly accurate when compared to a manual identification due to their noticeable difference from the landscape. Other feature shapes which more closely resemble nature topographical features do not stand out enough to not be confused with possible non archaeological features.

Additionally, due to large portions of the site awaiting traditional survey verification the veracity of what is a definitive archaeological feature is not possible. Even so, a total of 87,407 possible features greater than $5m^2$ were extracted from the dataset. How to approach studying these features and means to divide and manage the date will be discussed in the following chapter.

CHAPTER 5

This chapter will describe the analysis of the data produced from the methodology outlined in the preceding chapter. First, an analysis of the overall spatial distribution of the possible archaeological features by density. Followed by a density analysis based on an application of the Thinness Ratio. Second, an in-depth analysis of utilizing the Thinness Ratio and other geometric properties of the individual polygon, in conjunction with known excavation data to assign polygons an architectural form. Further possible applications of the methodology will also be discussed.

The number of possible archaeological features at the site of Angamuco greater than $5m^2$ total 87,407. All features which were less than $5m^2$ were removed as it is difficult to determine without large scale ground survey if these features would have been archaeological. Those greater than $5m^2$ include archaeological features as well as, hilltops, ridgelines, modern features, conjoined features, and divided features. It excludes any features less than $5m^2$, depressed features, or large scale landscape features. Taking into account the non-archaeological included features and excluded archaeological features it is likely the *malpais* contains between 70,000 and 80,000 features total, an exact number of features would require time intensive manual data cleanup and information from ground surveys.

Density Analysis

Analyzing 87,407 features in an area of approximately $26km^2$ is feasible through specific spatial analysis tools in ArcMap 10.5 and additional GIS software programs. A common spatial analysis is a density map, sometimes referred to as a heat map. The basis of this analysis is simply counting the number of features within a defined spatial area to visually show how the features are dispersed across the landscape and the regions in which the features are highly concentrated. Figure 5-1 shows the density of all features per hectare (10,000m^2), while Figure 5-2 shows the density of features after they have been classified and separated based upon their Thinness Ratio, respectfully into classes of 1-0.7, 0.7-0.4, and 0.4-0.0.

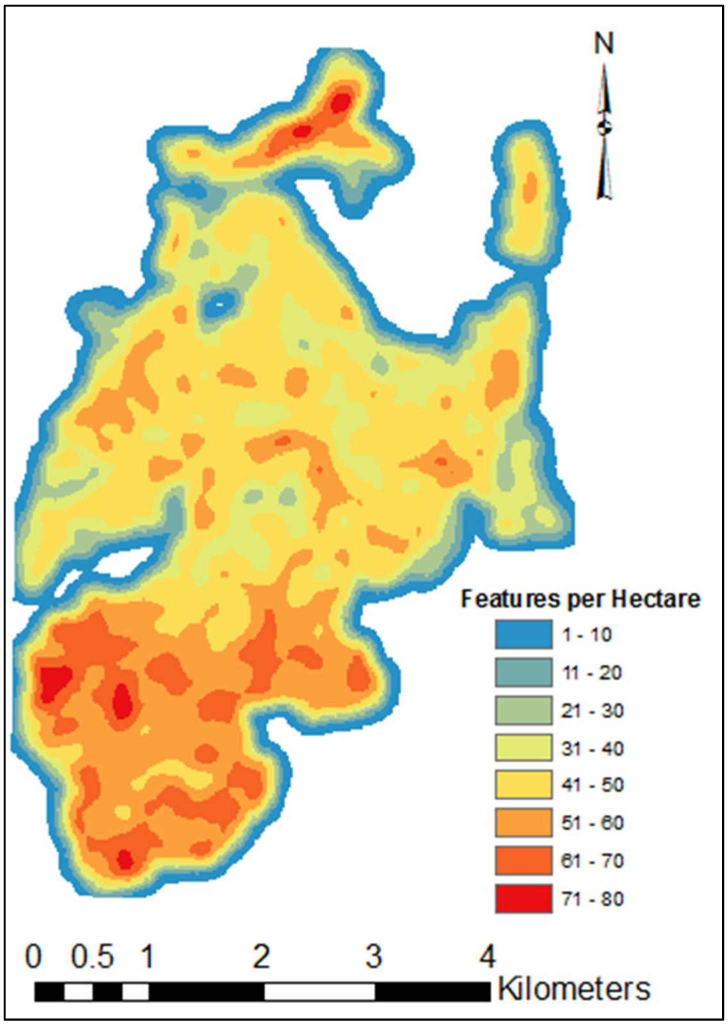


Figure 5-1. Density analysis of all possible archaeological features across the site of Angamuco calculated points per hectare.

After analyzing the density of all possible features (Figure 5-1) a handful of observations can be made about the distribution of the built environment at the site of Angamuco. First, the concentration of features is bi-modal with the greatest densities at the very northern tip of and the lower half of the malpais. The most likely explanation for this at the lower end of the malpais is the topography of this area compared to the central area of the malpais, with elevations greater than 2150m asl, contains less complex/rugged topography reducing the limitations of what could be constructed. The northern density is likely due to the age of the archaeological features, as mentioned in the first chapter the northern edge of the malpais likely was the Empire era site of Coringuaruo as it appears on maps included in Pollard (1993). Additionally the portion of this malpais while greater than 2150m asl is more like the general topography of the lower malpais. Or, an explanation for the bi-modal density distribution may be a result of the mining which has occurred over the past hundred years resulting in possible archaeological features being destroyed in the central region. Second, the distribution of the high and low density regions of the site may also indicate on a broad scale the intensity of occupation, and hint and the land usage based on the number of archaeology features, e.g. it can be predicted less features would be located in an area dedicated to agricultural usage while more features would be located in a residential district.

Dividing all the points into three broad categories based on the geometric properties of each points corresponding polygon provides a more nuanced approach to the density of features at Angamuco. The broad classifications based on the Thinness Ratio correspond to circular to circular like (1.0-0.7), rectilinear to miscellaneous (0.7-0.4), and linear to extreme linear features (0.4-0.0) (Figure 5-3). Naturally, these classes are fairly arbitrary and the break lines of the classes can be changed based upon the analysis being taken however from comparing various Thinness Ratios a classification based on these break lines can guide further analysis. The broad classification is used primarily as a general breakdown of the dataset to better handle the 87,407 possible features and to begin to identify different architectural forms which are consistent throughout the site. Though broad the features included in the 1-0.7, and 0.4-0.0 classes do correlate to known features across the Angamuco landscape.

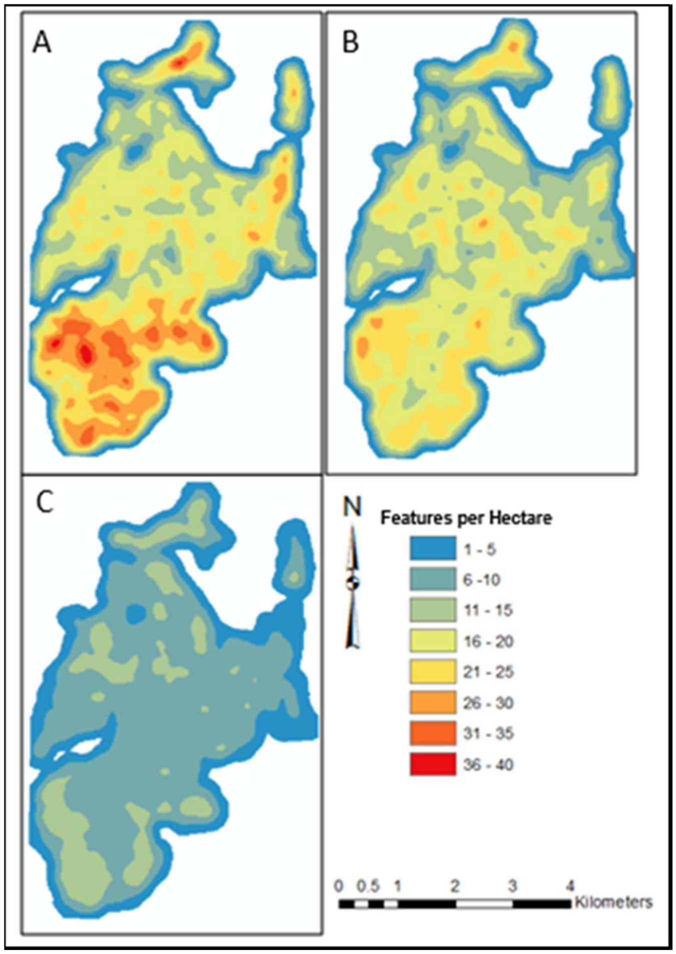


Figure 5-2. Density analysis based on the separation of the total features. A is calculated using points with a Thinness Ratio between 1.0-0.7. B is calculated with a Thinness Ratio of 0.7-0.4. C is calculated with a Thinness Ratio of 0.4-0.0.

Compared to the all points density output the 1.0-0.7 Thinness Ratio is relatively similar in the spatial distribution of the denser areas. This could be due to the number of features (37,495), accounting for 43% of the total. It is likely this distribution is due to the observation Thinness Ratios greater than 0.7 appear to correlate highly to probable archaeological features. Due to the site formation processes of how built-up features become “buried” unless the original feature was of an unique shape the resulting feature we would see today would be an ambiguously circular like mound. Running with this assumption it can be proposed this output could be the most accurate means of identifying the population foci of the site, excluding ground excavations.

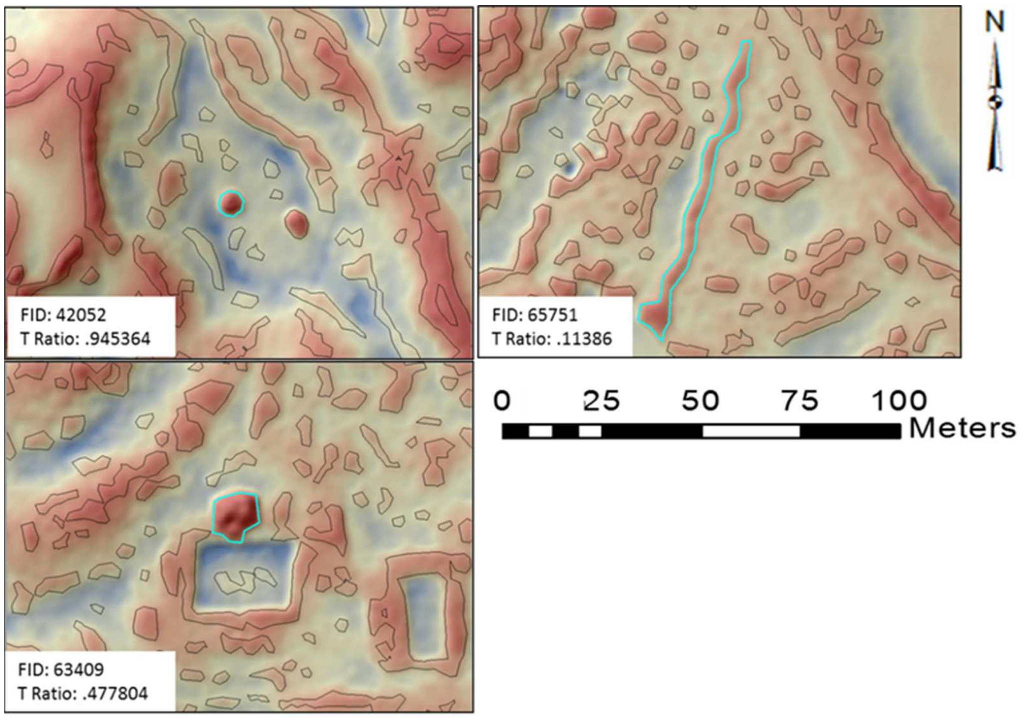


Figure 5-3.Visualization of the different Thinness ratios associated with the three classes used in figure 5-2.

The point density of 0.4-0.0, 17,697 total points approximately 20%, can also be used to identify certain foci of the site related to a unique urban feature, the raised roadways. Identifying the concentrations of these features can be used as a means to date large areas of the site to approximately just before the Empire stage in the late Urichu phase. The only other site within the LPB to be associated with these raised roadways, *huatziri,* is Ihuatzio the founded ceremonial city before the consolidation of the basin. Similar to the circular point density the concentration of these points is primarily bi-modal with a larger area concentrated in the south along the edges of the lower *malpais.* This provides more evidence to the likelihood the central area of the *malpais* was not heavily occupied. An issue with this class is the appearance many of these features are likely the result of topographical features such as ridge lines, or conglomerations of likely multiple features. It is interesting to note the main *yacata* of the lower *malpais* falls into this class with a Thinness ratio of .22.

The third class 0.7-0.4 and second in size at 32,215 features and 37% of the total, constitutes a mixed group of rectilinear and miscellaneous features. These features are irregular in their shape either by their design, site formation processes, or two features were combined during the workflow (see discussion in chapter 4). Beyond the density distribution of these features it is difficult to extrapolate more due to the varied shapes included in this class, however visual comparison of this class to the topography of the site appears to indicate majority of these features are possibly archaeological. Of the three broad categories this one contains the greatest amount of variability in the features' geometry and needs a greater amount of sub-classification.

Thinness Ratio OBIA

Beyond basic density outputs of the possible archaeological features and breaking the features into smaller and easier to handle classes based upon the Thinness Ratio, this attribute can be applied to specific feature classification. Using the T Ratio and the perimeter of individual features it is possible to fairly confidently classify certain features as specific architectural forms. An example of this application will use Mound 9858 (Figure 5-4) possibly a proto-*yacata.* Exploratory excavations in front of the mound were conducted in 2014 with charcoal providing a date to the preclassic, however the charcoal is unlikely to be directly associated with the mound.

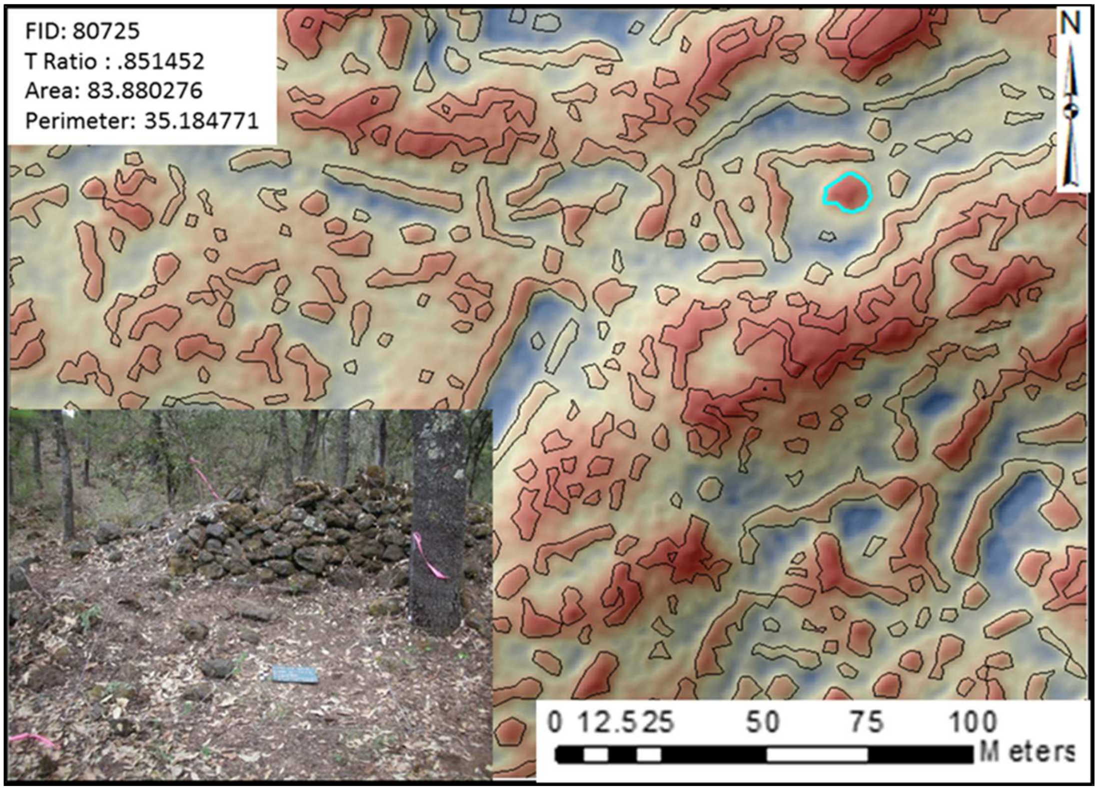


Figure 5-4. Mound 9858 (highlighted) in relation to its surrounding features. Inset picture is of the mound during excavations in 2014.

This method using the T Ratio is a manual means of object based image analysis (OBIA), a focus on the properties of the shape and not necessarily what the shape actually represents. In the language of OBIA the topographical manipulation and identification and extraction steps segmented the data and produced a layer which represents what is actually on the ground followed by the classification which was done at a basic level with the three major classifications used in the density analysis of the site. The greatest advantage to this application of the geometric properties is the detailed breakdown of the data allowing for specific questions to ask. In understanding the urbanism of the site this OBIA by using a known tackles the Palimpsest obstacle discussed in Chapter 3 if an associated time period can also be determined.

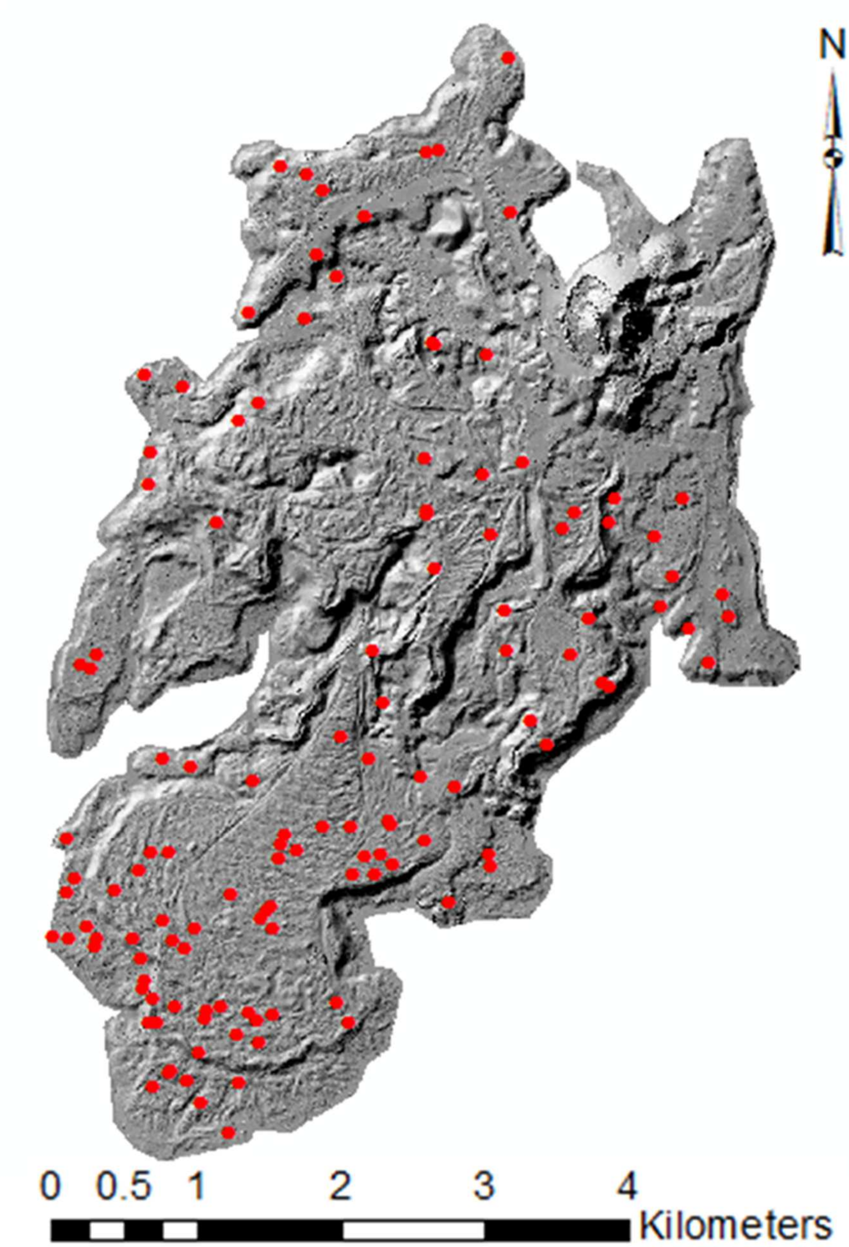


Figure 5-5. Location of all possible proto-yacatas identified using the OBIA technique based on Mound 9858.

Mound 9858 geometric properties are pulled from the data layers attribute table and a range is decided on to the left and right of its T Ratio, Perimeter, and Area. The range of the value selection was .11 for the T Ratio (.79 - .90), and applied first, followed by the Perimeter set at 10m (30-40). The values needed to be inclusive enough to take into account site formation processes which effect the shape of mounds based on how the structures decayed over time. The results from the application of these value ranges resulted in 150 (including Mound 9858) possible proto-yacatas across the *malpais* (Figure 5-5). Naturally, not every single possible feature identified by the application of the above values will be a proto-yacata, expertise of the local region and site is necessary to narrow down the 150 based on their visual aspects and context with the site.

After quick visual analysis of the 150 identified features, four warrant further investigation into the likelihood of being proto-yacatas or other possible forms of public architecture (Figure 5-6). Approximately ten features were considered however four showed the strongest likelihood. The features not requiring further investigation were eliminated based on their context in comparison to other features, their shape, and if they could be explained by being a part of the underlying topography. A main attribute to the context of these features in relation to other features was the appearance of an open area in the immediate vicinity of the identified features. This open area may have served as a plaza and if so would strengthen the argument for the likelihood of the identified features being either a proto-yacata or other form of public architecture. FID 4541 (Figure 5-6) is a feature which is likely not a proto-yacata but another form of public architecture based on its visual geometric shape. While its geometric attributes align closely with the other three likely features, visually it is an outlier and would probably be better suited in a classification of rectilinear pyramids. This feature was included to show a limitation of this analysis and why manual verification is necessary. Additionally, FID 4541 appears to have a defined plaza space whereas Mound 9856 and the FID 70520 and 71966 open areas are less definitive. FID 55262 is interesting because of its similarity to both the other proto-*yacatas* and the rectilinear feature.

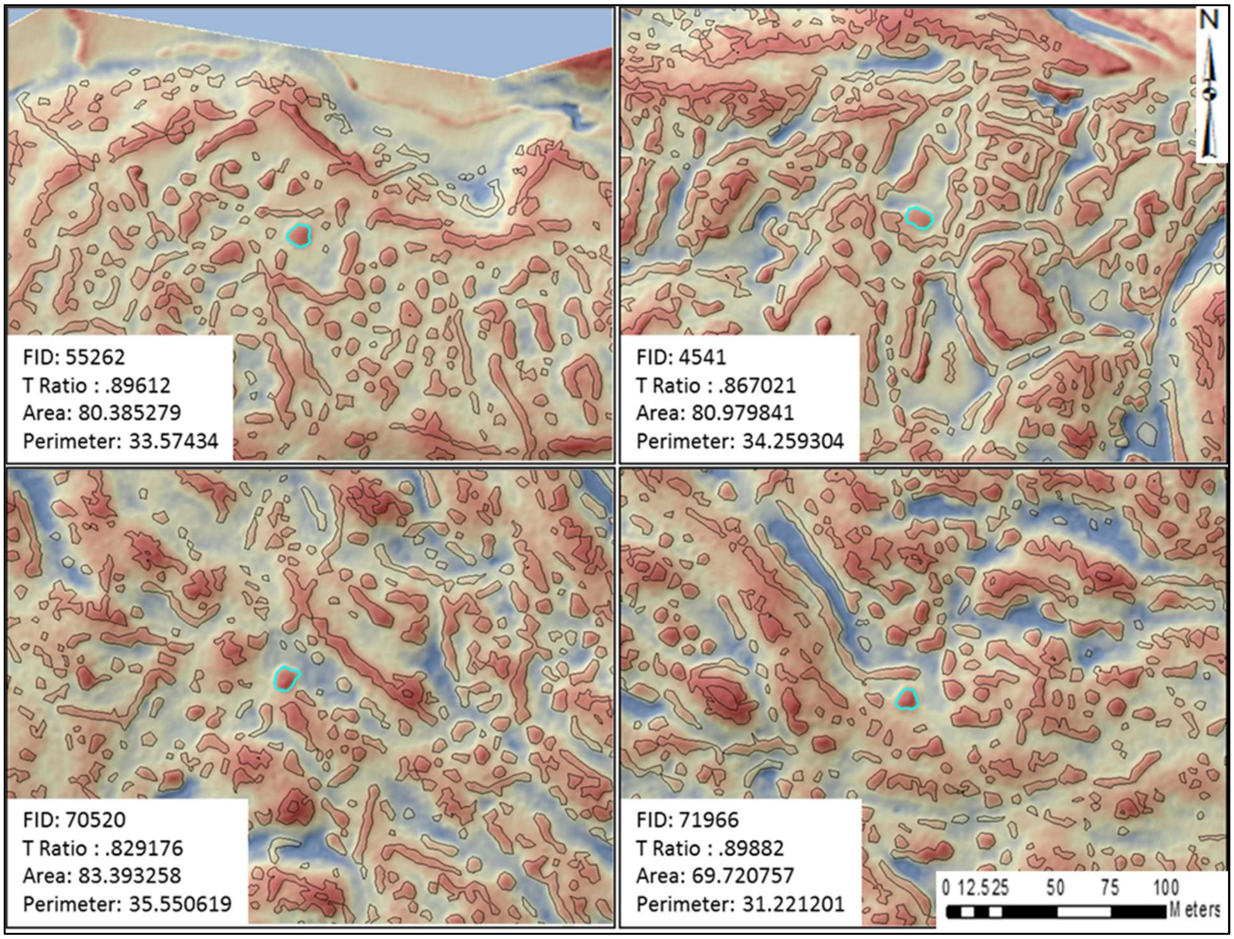


Figure 5-6. Visualization of the three possible proto-yacatas and the one rectilnear feature with similar attributes.

Using the four features identified for more investigation and specifically the three likely proto-yactas along with the known Mound 9858 we can begin to tackle the palimpsest obstacle in understanding this site with only the information we currently have using Mound 9848 and the three features with the highest probability of being a proto-yacata, and the included outlier (Figure 5-7). Accepting the assumption similar form and context to other features in the landscape represent an ideological and likely temporal relationship between the features it is likely the four identified possible proto-*yacatas* were constructed around the same time. This can provide a quantifiable basis to add support to means of using architectural forms to relatively date sites. Applying this approach to multiple know features can provide greater fidelity in the temporality of the site through the use of multiple lines of evidence.

The assumptions made in the attempt to expand the known geographic-temporal data does have precedent as certain architectural forms are commonly used as benchmarks to identify time periods in archeology and the modern era as well. The issue with the assumptions made here is the lack of knowledge of what modifications/construction phases may have been built upon older features of the site which through site formation processes could be mistaken as a proto-yacata based on only the LiDAR data and this methodology. Using the LIDAR data in conjunction with limited data from ground-truthing and excavation can start to tease apart the palimpsest of the site, however it is necessary for these assumptions to guide further excavations to validate or disprove conclusions made using only the data produced from this methodology. This can be a hard limitation as parts of the site are difficult to reach due to the topography and vegetation as well as access to the site in general due to geopolitical issues.

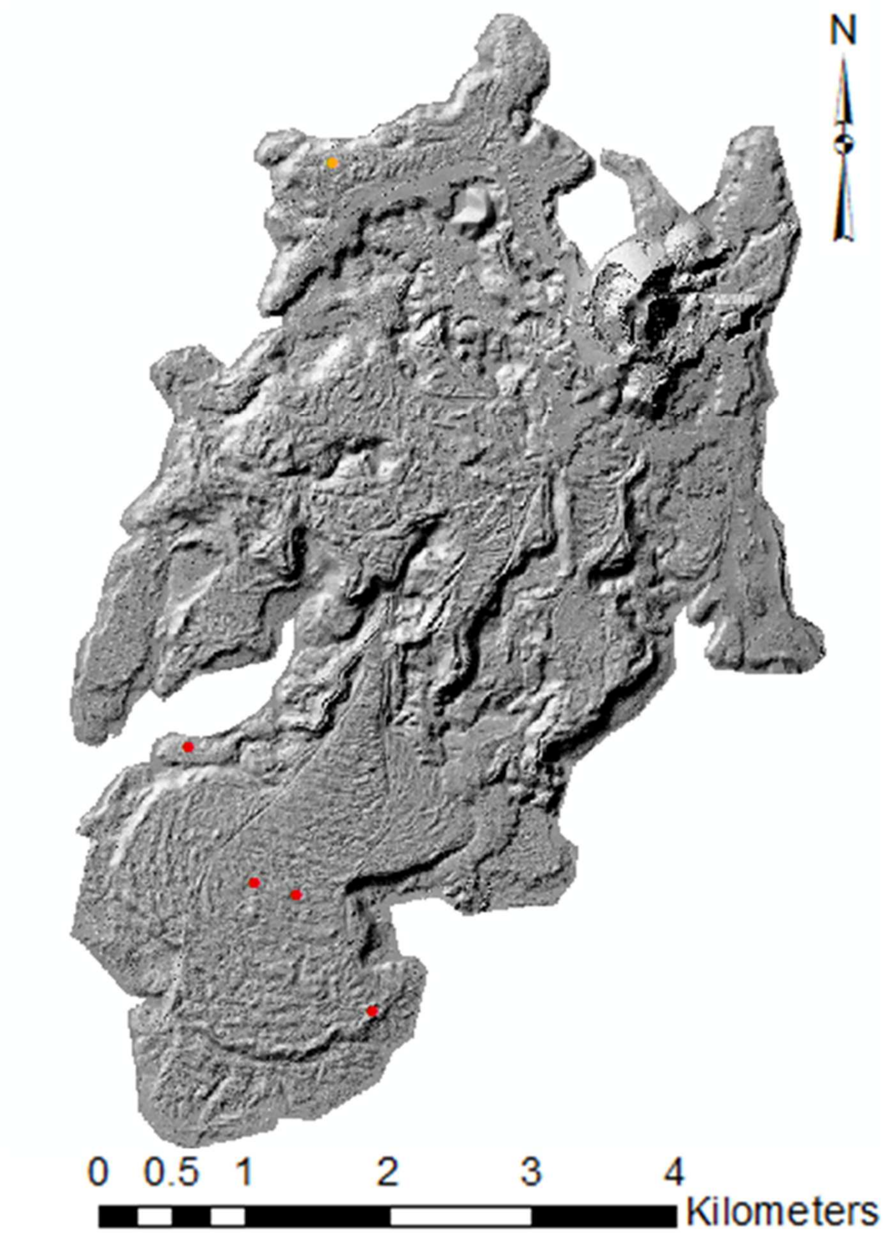


Figure 5-7. Location of the four possible proto-yacatas (including Mound 9858) and the outlier rectilinear feature at the site of Angamuco.

The results discussed in this chapter are an examples of possible means of analysis which may be utilized based on the output of the methodology. A quick density analysis can provided information on the distribution of feature types and may provide information on population distribution, and the output of the methodology can be a great tool in basic OBIA. It is beyond the scope of this thesis to delve into all the possible ways to analyze the data produced, however other possible means of analysis and ways to apply the identification of all these possible archaeological features will be discussed in the following chapter.

Future Analyses and Conclusion

This purpose of this thesis was to develop a methodology capable of extracting the all the possible archaeological features from a topographically complex landscape and conduct some initial analysis into the site in an attempt to being to understand the urban structure of Angamuco. Due to the focus on developing a methodology and producing a data set which could be usable for spatial analysis the analyses provided in the previous chapter are light and capable of being developed upon further than described.

Including the point density analysis and application of the Thinness Ratio for OBIA there are other ways this dataset can be used to analysis the site of Angamuco. The OBIA method can be applied to multiple other features to identify them throughout the site and can be used to provide a more nuanced classification scheme beyond the three broad categories used in the density analysis. Inclusion of other environmental variables such as elevation, relationships to other landscape features such as reservoir and terraces, clustering and dispersion analysis such as Ripley's K-function and a host of other applications is now possible due to the dataset and the attributes associated with each feature. Additional attributes can also easily be added to each feature to consolidate data into a single geospatial database, this includes brief descriptions from excavations and other aspects which can provided additional variables to be included into any spatial analysis.

Additionally, the dataset itself can be modified and individual features can be manipulated to separate conjoined features or to combine features which may have been divided into multiple pieces such as raised roads. The creation of this dataset has provided the first initial mapping of the built up archaeological features and includes a number of topographical features. Due to the number of features which have been extracted and the number of topological features also included in the data set it is necessary to go through and manually eliminate features which are likely topographical and not archaeological in nature. This is a time intensive processes and would benefit greatly from information collected from ground surveys.

The primary limitation of this methodology and resulting dataset is its regional specificity. While the method itself can be applied to a variety of different topographical environments due to the number of adjustable steps the outputs wills be geographically limited in their applications. Attempting to use the polygon dataset and Thinness Ratio to classify features located outside of the Purepecha region would be irresponsible. A lesser limitation but an important on in the verification and replication of specific data sets is the number of variables which can be adjusted to produce a final produce. Majority of the steps which require the use of a kernel can be subject to user preference with the outputs being selected based upon the visual appearance. This does bring into question how to develop a best practice for the methodology. It is difficult to argue for a way to quantify the best fit kernel shape or size, or the value cutoff due to the variety of archaeological features and the variation between different regions. Explicitly stating the variables selected so they may be recreated is perhaps the best options as it ensures the flexibility of the application of this methodology.

In conclusion, this thesis demonstrates it is possible to extract archaeological features from the underlying landscape from a LiDAR derived DEM to produce a dataset which can be used to conduct spatial analysis of a site. The methodology presented here could be considered a form of OBIA, a means of analysis which is being attempted by various means and at various locations (Davis 2019). A flexible methodology like this one can alleviate the initial time and effort necessary to analyze large scale LiDAR dataset however, manual identification of archaeological features is and likely will always be necessary due to the variety of shape and architectural form of archaeological ruins throughout the world.

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