Survey of a Peruvian Archaeological Site Using LiDAR and Photogrammetry: A Contribution to the Study of the Chachapoya

Giovanni Righetti[1], Stefano Serafini[1], Fabian Brondi Rueda[2], Warren B. Church[3], and Gabriele Garnero[4](✉)

[1] MEDS BV, Ir. M. Schefferlaan 55, 7556 CR Hengelo, The Netherlands
[2] Instituto Geográfico Nacional, Lima, Perú
[3] Department of Earth and Space Sciences, Columbus State University, Columbus, GA, USA
[4] Interuniversity Department of Regional and Urban Studies and Planning, Politecnico e Università degli Studi di Torino, Turin, Italy
gabriele.garnero@unito.it

Abstract. In November of 2019, the company MEDS BV, based in the Netherlands but mainly active in the Americas, initiated experimental aerial remote sensing with airborne LiDAR imagery in the context of a private-public sector collaboration to enable identification of undocumented archaeological sites concealed beneath the high Andean tropical cloud forests in northern Peru's Amazonas Region. Remote sensing fieldwork and post-processing application of Deep Learning methods by MEDS BV specialists, and subsequent analysis of DTM images by archaeologists yielded a remarkably detailed picture of a forest-covered, previously unstudied sector at the extensive archaeological complex of Kuelap called Imperio. At 3000 m above sea level, the Kuelap site complex consists of at least 12 sectors and two cliff cemeteries sprawling 900 hectares along a ridge top above the western banks of the Utcubamba River valley. Kuelap's centerpiece and featured tourist attraction called "La Fortaleza" is a large settlement built atop a massive walled platform a long, prominent ridgetop. The Kuelap complex was probably the most populous locality in the Utcubamba River valley and is attributed to peoples that the Inka and Spaniards called "Chachapoya." Early Spanish settlers left no known written descriptions of the site, nor useful descriptions regarding the region's inhabitants. Consequently – and despite extensive archaeological studies – important questions concerning the political, economic, and religious roles of Kuelap in the region remain unresolved.

The project reported here has primary and secondary objectives, both resulting from multiple stages of data gathering, processing, analysis, and interpretation. The primary goal was to capture high-resolution, three-dimensional georeferenced imagery of archaeological remains hidden beneath the region's dense tropical montane forests and provide sufficient data for a rich preliminary description. This work responds to the urgent need to identify, characterize, and protect such cultural heritage from looting and destructive activities that accompany population growth and deforestation. The second objective emerged as an unexpected bonus, only because of the extraordinary success of the first. Successful imaging of surface details at Imperio provided an extraordinary opportunity to reevaluate previous interpretations of the site, and to offer an alternative novel hypothesis

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regarding Imperio's history of occupation and particularly the site's special functions. The imagery enabled identification of subtle surface features that we suggest could be overlooked and inadvertently destroyed during conventional ground-level mapping and documentation activities in such complex, overgrown terrain. Many such features are functional elements of a planned drainage system that warrants further study for long-term conservation planning.

Keywords: Kuelap · 3D model · Deep learning

1 Introduction

Aerial remote sensing with UAVs (Unmanned Aerial Vehicles) equipped with LiDAR (Light Detection and Ranging) technology has become an increasingly effective means of identifying, mapping, and analyzing surface features on archaeological sites and landscapes lying hidden beneath tropical forests in Middle America from southern Mexico through Honduras [1–4].

More recently, archaeologists have begun to deploy LiDAR aerial remote sensing in the South American tropical lowlands and Ecuadorian Andes to analyze human-modified landscapes at various scales [5–7].

Airborne LiDAR survey is still new to the Peruvian Central Andes where scientific archaeological research beginning near the end of the 19th century in unforested, and deforested regions has produced a robust archaeological record from sites near contemporary population centers. Airborne LiDAR doubtlessly has much to contribute to archaeology across the greater Andes.

However, the technology has the potential to make especially significant contributions to the archaeological record where tropical montane forests cloak undocumented and understudied sites on the eastern Andean slopes above the Amazon lowlands (Fig. 1).

Many large, abandoned settlements and monumental sites of stone masonry rarely mentioned in colonial documents remain undocumented in Peru's northern "culture area" of Chachapoyas. Kuelap's monumental core, La Fortaleza was first described in 1843 and published in 1891 [8]. This and other abandoned Chachapoya settlements and cliff tombs were familiar to local inhabitants, and subsequently visited by 19th century foreign travelers like Middendorf, Raimondi and Werthemann [9–11] a few decades earlier than more famous Inka sites such as Machu Picchu, Choquequirao, and "lost" Vilcabamba in the Andean montane forests east of Cusco.

Development of archaeology in Chachapoyas proceeded sporadically during the 20th century because infrastructure and services facilitating access to sites and sustained fieldwork were slow to penetrate the region [12, 13]. This is changing as a slow, seemly inexorable process of colonizing the eastern slope Montane and Premontane Life Zones [14, 15] between approximately 3,500 and 400 m continues to accelerate [16]. The demographic push has led to deforesting and increased looting of exposed sites before they can be documented and protected by authorities while many sites still lie hidden beneath forest canopies and Chachapoyas archaeology remains understudied and lagging far behind progress in other regions. Today the region's extraordinary archaeology and natural beauty make it a growing, popular adventure-tourism destination, and

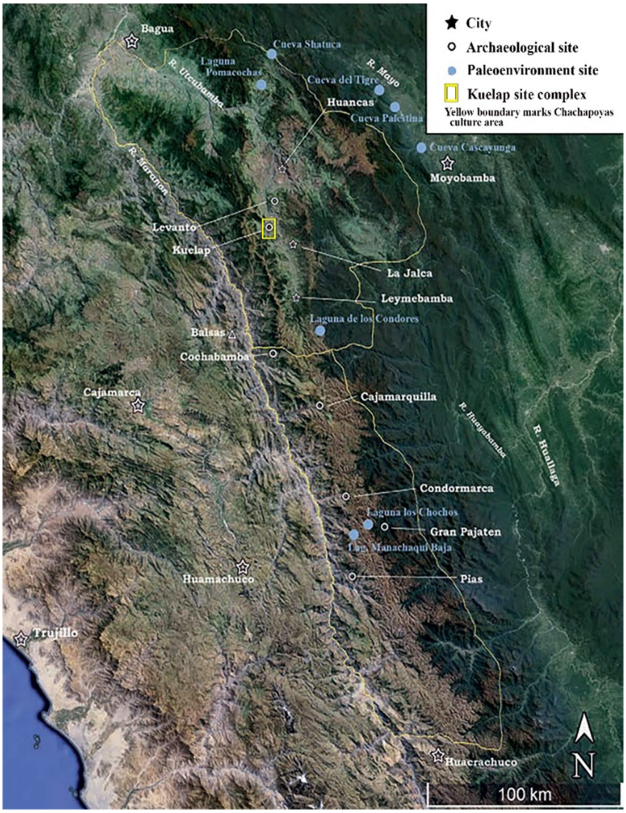

Fig. 1. Map of Chachapoyas culture area with location of Kuelap site complex.

Peru's Ministry of Culture has developed an initiative to identify, investigate, and conserve archaeological sites in and around the Chachapoyas forests. A recent evaluation by Sarmiento and colleagues [17] emphasizes the urgent need of more science-based research in the Chachapoyas cloud forests. Historical research, recent biogeographical and paleoecological studies portray a long and complex history of dynamic relationships between Tropandean forested and non-forested environments, and human inhabitants that responded to sudden and/or prolonged climate changes in interactive ways still poorly understood. Current demographic studies of populations based upon genotypes by bioarchaeologists seem likewise to reflect historical complexity. Many ancient sites and anthropic landscapes remain hidden beneath forest regrowth today. Simply put, our understanding of the Chachapoyas past is biased because of relatively frequent shifts in human demography and forest ecosystems on the Andean slopes. To locate, investigate and protect Chachapoyas cultural heritage, archaeologists have just begun using LiDAR-equipped drones to image archaeological remains. Our research represents one of Peru's first LiDAR remote sensing initiatives centered around the archaeological tourist destination of Kuelap, a sprawling site complex featuring an enormous walled settlement built on the crest of a ridgetop at 3,000 m now accessible by cable cars.

Here we proffer the results of our recent efforts to image ground surface morphology and surface architecture at Imperio, one of several smaller Chachapoya sites at Kuelap covered still by a dense remnant of humid tropical montane forest one kilometer east-southeast of Kuelap's La Fortaleza monument at 2760 m above mean sea level, UTM coordinates 18M, 177600.0 m E, 9289368.0 m S (Fig. 2). The research involved a public-private sector collaboration between Peru's Ministry of Culture and the National Geographical Institute, and MEDS BV in Amsterdam which performed the service. Two university-based archaeologists collaborated during the interpretive stage as unremunerated academic researchers.

Our presentation follows in four parts. First, we supply background information on the Kuelap archaeological complex which consists of several components or "sites" covering a large ridgetop, and specifically on the site of "Imperio" where we focused our research. We summarize previous investigations by other researchers and summarize what is known and what remains unknown about the Kuelap complex while situating it within our sketchy archaeological and ethnohistorical knowledge of the late pre-Hispanic and early Colonial Period Chachapoyas region. Second, we describe the methods and materials utilized for both the data-gathering stage, and the subsequent image analysis. Third, using the processed imagery we characterize the archaeological surface remains and their distributions in the context of Imperio's anthropogeomorphology.

The fourth stage of this presentation was not originally a part of our project prospectus. Through the course of study, it became clear that Imperio is a complex, composite "artifact," a selected landform molded and sculpted. All sites are artifacts in a manner of speaking, but Imperio experienced a use-life during which it passed through stages of remodeling and repurposing to assume symbolic functions. Subsequently, the 2019 LiDAR imagery captured one moment in a long post-abandonment stage. Numerous theoretical frameworks and methodologies may be suited to similar, site-specific imagery this kind of experimental research involves layers of interpretation that require ground-truthing. For that reason, we chose to foreground basic descriptive information that we gleaned from Imperio's imagery. However, because our initial interpretations revealed intra-site patterning that is distinctive and atypical in the Chachapoyas region, we are compelled to offer additional inferences regarding the site's chronological stages of construction and re-modeling (use-life).

This fourth step in the presentation can be considered our best attempt to interpret Imperio as a whole, as more than the sum of its parts. Unless one entertains the possibility that Imperio served functions that were symbolic rather than simply quotidian, one is left to conclude that the distributions visible on the surface show little evidence of the planned organization that we believe originally underlaid its construction and continued usage. Hence, this fourth interpretive stage reinforces our most basic interpretations of some surface features. Predominant among these are traces of buildings dismantled, ostensibly to utilize scavenged construction materials for activities necessary to repurpose the site. Low walls (or "berms") and ditches that we identified are integral parts of the Imperio as a functioning whole of great symbolic significance as we will demonstrate. Accordingly, we offer preliminary interpretations of Imperio's chronology and potential function(s), both utilitarian and symbolic. We have sufficient confidence in our basic identifications of Imperio's surface features to endeavor higher levels of inference, and we did aim to stop short of unwarranted speculation. Virtually all of our interpretations can be addressed as hypotheses with fieldwork on the ground. We included this last interpretive section in our presentation because the patterning inferred from our descriptive analysis warrants a reevaluation of Imperio's functions on the landscape. A reinterpretation of Imperio as more significant than a small agrarian settlement as first thought enables a fuller understanding of the Kuelap site complex as a whole.

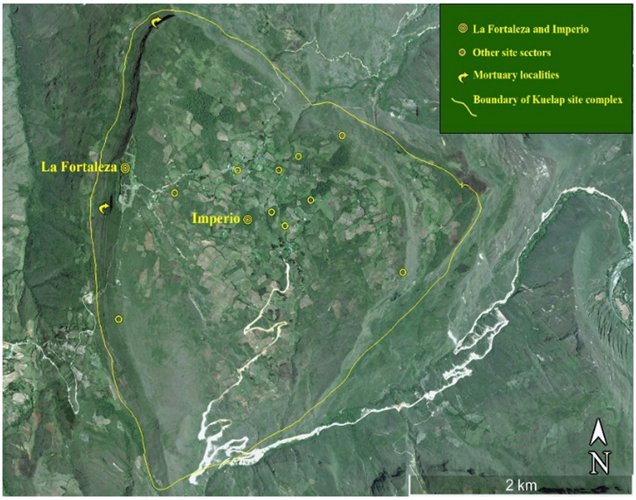

Fig. 2. Map of Kuelap site complex with locations of La Fortaleza, Imperio, and estimated boundary of site complex.

2 Materials and Methods

The research reported here was conducted with the primary objective of verifying and defining the best technology with which to identify possible settlements under the montane forest of the "Amazonas" region. For the drone flights, MEDS technicians had to size the instrumentation to be used based on:

- altitude above mean sea level,
- vegetation density,
- horological characteristics, and
- weather conditions.

To reach our goal of obtaining the highest possible number of 3D points on the ground, we planned to use:

- LiDAR instrument (accuracy 1.5 cm) equipped with high precision GNSS/IMU (planimetric positioning 5 cm, altimetric 10 cm, angular 0.015° in roll and pitch, 0.035° in the yaw).

- flight plans and acquisition parameters studied to reduce the shadow cones to a minimum.

Our parameters included:

- Flight altitude: variable from 60 to 100 m above ground level,
- Flight schedule: cross flights,
- Flight speed: 10 Knots,
- PulseRate: variable from 400 to 820 kHz based on the morphological characteristics,
- Field of View (FOV): 180°,
- Revolutions per second: 60–200 scans/s,
- Density of points detected: between 300 and 400 pt/m^2, and
- GSD photogrammetric shots: 2–5 cm.

Among the difficulties faced during the drone survey of the "Imperio" area was wind and other meteorological variability. Timing was everything, and the best time to carry out the surveys was between 11:00 AM and 2:00 PM. Due to the area's geomorphological characteristics and the altitude, the performance of the GNSS receiver was compromised, so that longer times than usual were needed for ground acquisitions.

The LIDAR data filtering and classification processes were carried out using macros in analytical software created by MEDS called ATLAS (www.theatlasgis.com). The parameters of this software development have taken into account: high humidity, dense and multilayered vegetation, and the reduced size of the objects to be searched. The data made available to the anthropological experts have been previously interpreted and extracted thanks to the use of specific developed neural networks.

Pursuing data analysis objectives, an automatic survey analysis software was implemented proceeding in four distinct phases:

- Identification of the training set,
- Learning,
- Recognition testing, and
- Application for real relief.

The selection criterion sought to include the most heterogeneous cases emphasizing visibility and the presence or absence of vegetation.

For each building identified, we determined:

- the shape (rectangular or circular),
- the centroid, and
- the approximate size (larger diameter/smaller diameter for circular or elliptical buildings, length of sides for rectangular buildings).

All of the selected buildings have a diameter less than 15 m, and this measure has been used as a sample size for software together with a search area of 30 × 30 m. Then the software started looking for buildings of the aforementioned size, and the overlap used was 50% to ensure the entirety of the sample. For each building (either for training or verification), the software generated:

- LiDAR sections centered on the building, and
- Alternated the data model, by inserting spatial transactions and rotations and altered the set of points with random noise.

Such alterations amplified to a total of 125 variants for each building, bringing the total set of samples to 10500.

The buildings identified were divided into two groups:

- the first (70%) for training neural networks, and
- the second (remaining 30%) for the verification.

The deep learning software, based on TensorFlow, was implemented in C++. The LiDAR sections were used by the recognition algorithm that provided the dimensions and orientation for each sample; based on the identification of the section with longer and shorter length for each building under study. All the data has been uploaded to the MEDS' AtlasGIS, to verify the truthfulness of obtained results through an "images comparison" technique (Fig. 3).

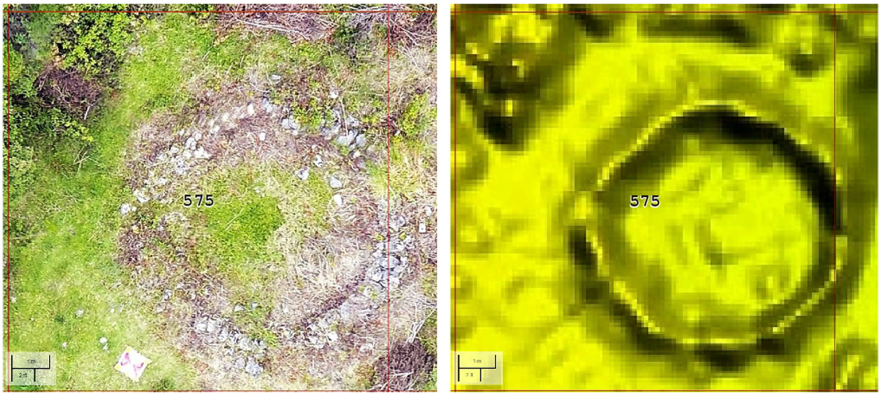

Fig. 3. Circular stone building viewed in orthophoto and DTM

3 Methodology of Image Analysis

Our methodology for experimental descriptive analysis of Imperio relied on identically georeferenced orthophotographic and Digital Terrain Model (DTM) imagery with 2 cm and 15 cm resolution, respectively. The bulk of the imagery analysis conducted by the team utilized The AtlasGIS software program which features multiple tools for visualizing and measuring site features in three dimensions yet is easier to use for relatively simple analysis than ESRI's ArcGIS.

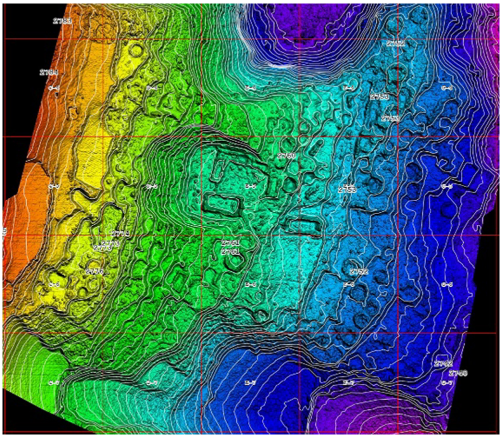

Fig. 4. Contour line overlays at 5 m and 1 m intervals shown with 50 m-grid

A color ramp overlay was created for the DTM to highlight topography and changes in elevation. Three sets of contour lines were generated as layers using 5 m, 1 m, and 0.5 m intervals (Fig. 4). The 0.5 m contour interval was useful for quickly identifying low walls that we refer to as "berms," as well as low or poorly preserved wall foundations. The MEDS team easily identified surface building structures and utilized these for the Deep Learning process.

Additional analysis enabled unusually good recognition of surface drainage patterns and more subtle features that will await ground-truthing. This process facilitated subsequent archaeological identification of buildings, free-standing walls, ditches, and berms in three-dimensions.

This is experimental research rather than one of the many kinds of archaeological projects listed in the legal document Decreto Supremo N° 003–2014-MC that provides guidelines for more conventional cultural resource documentation. Our research, and hence our report, is a non-invasive view of Imperio created to sketch general characteristics of the site's surface morphology, especially landform, cultural remains on the surface, and their relationships to one another as one small but complex component of a very large Kuelap "cultural landscape."

4 Results

The configuration of the site's constructed area is constrained by basin-shaped, eroded sinkholes, that are typical of the region's karst bedrock geology. Such concavities pock the otherwise smooth surface of the eastern slope of La Barreta, and are generally not visible with Google Earth satellite imagery, or even at ground-level where forest patches may conceal the depth of some sinks. The characteristics of karst geomorphology played a significant role in determining locations for pre-Hispanic settlements, tombs, and shrines. The configuration of the natural landform upon which Imperio was constructed undoubtedly met specific criteria identified by its builders as we hope to demonstrate in paragraphs to follow. Our LiDAR imagery facilitated creation of a polygon with an area of 3.62 hectares conforming to both the constructed area and the complex terrain. The landform viewed beneath the forest vaguely approximates symmetry along an axis trending WNW and ESE. Although we offer detailed measurements at the 10-cm level (and occasionally at the one-centimeter level) in the following paragraphs with care, readers should keep in mind that no LiDAR sensor will produce a point cloud of sufficient density and homogeneity to replicate ground topography in a forested landscape with impeccable precision, although we can expect methodological improvements after additional ground-truthing.

4.1 Infrastructure and Structures

Here we offer a list of surface elements, features, and structures that we have identified up to the present before we enter into subsequent, more complex levels of description. These were in turn divided into two categories. We have termed the smallest objects of our attention identified in the imagery as "elements" that may or may not be parts of "features" that we tentatively assigned to the first of the two major catteries, "infrastructure." These tend to be constructions on the surface including terraces, berms, drains, borrow pits, and so forth. The term "structure" is reserved for features interpreted as above-ground buildings. These three terms are used heuristically and were chosen only because they were useful to us for analysis and are useful for the description to follow. Problems with such terms arise when one risks identifying a ditch that appears to be a built drainage channel constrained by a terrace or building wall on one side and a berm on the other, and a channel eroded by surface runoff that can be traced across the site.

We identified three categories of "structures" at Imperio, but only after thorough analysis of the constructed area did we feel confident in our identifications which were usually distinguished as circular buildings and their foundations that represent the most common late pre-Hispanic form of house, or family dwelling in the Chachapoyas region. We also easily identified rectangular buildings that were uncommon in the region until the Inka conquest sometime after 1470 CE (Christian Era). Inka attribution of five of these structures can be offered with confidence because they articulate with one another to form a patio group seen frequently across the Inka empire and called a kancha in the Inka Quechua language. More puzzling at first were surface cuts, and flat circular "footprints" where we conclude that circular stone buildings (and at least one rectangular structure) were dismantled to repurpose construction materials. In sum, the three-dimensional LiDAR imagery of Imperio's constructed area allowed us to identify the remains of eight rectangular buildings and 82 circular constructions with confidence. This alone is a remarkable achievement given the dense forest cover and more than doubles the number of 40 circular constructions previously counted at the site.

Using the LiDAR imagery and the general arrangement of terraces, we determined that Imperio can be visually divided into Upper, Middle and Lower Zones for descriptive purposes. Within each of the three zones, one or more terraces extends roughly north-south across the promontory, but the central sinkhole occupies much of the Middle Zone. To distinguish each of the three zones at a more demonstrably objective level, we conducted a cursory search for meaningful statistical evidence with which to isolate and evaluate surface features. The site's small size, evidence of periodic reorganization, renovation, and the lack of better chronological control undermines our confidence in such efforts. Nevertheless, we felt that the tripartite division was visually distinctive. We hesitate to offer infer a great deal of chronological significance to the zones, although the Upper Zone shows more evidence of building dismantling. This is indicative of a relative chronology. Numerous avenues for additional research can be pursued using the LiDAR imagery, but these remain beyond the purview of this presentation.

A detailed hydrological study of Imperio's water management system and dendritic drainage pattern can begin with the three-dimensional LiDAR imagery before undertaking more extensive ground-level fieldwork. Because we are dealing with an aspect of the site's development that was crucial for habitation and use, we offer preliminary observations pertinent to the terraced system by referring to the whole as "surface infrastructure," before describing the remains of architectural living spaces built atop the surface.

4.2 Site Anthropogeomorphology

At the top of the landform visible near the WNW edge of our image (in the Upper Zone), an actively cultivated area at 2780 m elevation can be identified on both the orthophoto and the DTM image. From there, Imperio extends 220 m down a peninsular ridge trending east-southeast. Eroded sinkholes flanking the ridge on both north and south sides narrow the landform, thus rendering its prominent ridge-like appearance.

The constructed area within the image drops 40 vertical meters with an averaged gradient of 18%.

The awkward term "anthropogeomorphological" aptly describes the landform because the entire ridge surface was modified. Artificial terraces create an irregular series of "steps" descending eastward, and most or all of these are sufficiently intact to detect with our LiDAR and over one meter-high. Stone terrace facades are mentioned in all site descriptions. Space constraints would have precluded use of these terraces for cultivation on a significant scale (Fig. 5).

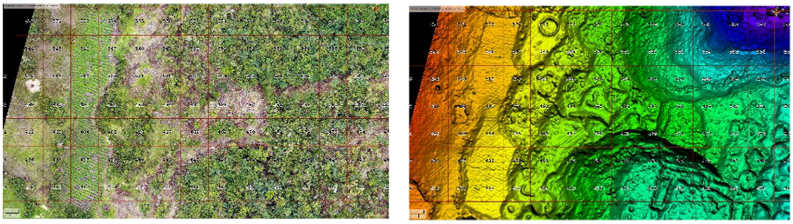

Fig. 5. Cultivated area at west edge of site imaged as orthophoto and DTM.

The sinkhole concavities on the promontory flanks cut deeply into the northern and southern sides nearly halfway down, constricting the site surface to 115 m at its narrowest point. The corresponding slopes on the north and south sides fall away precipitously 21 m on the north side with a 60% gradient, and 11m on the south with a gradient of 50%. Below the midsection, the promontory expands to 189 m at its widest point 55 m above the bottom which roughly corresponds to the eastern edge of the image.

Situated slightly north of the narrow midsection, the dominant and most visually striking feature on the ramp-like promontory is a wide, flat-bottomed sinkhole. This

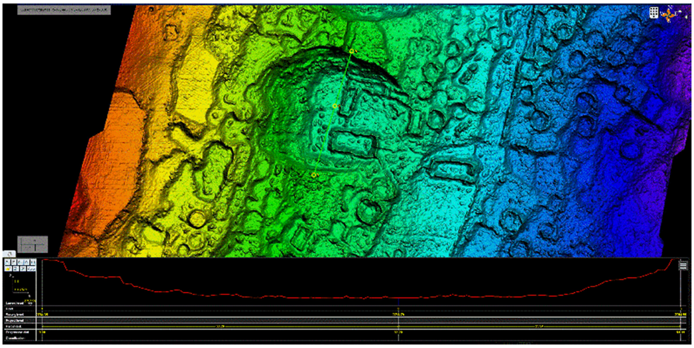

Fig. 6. The Central Sinkhole.

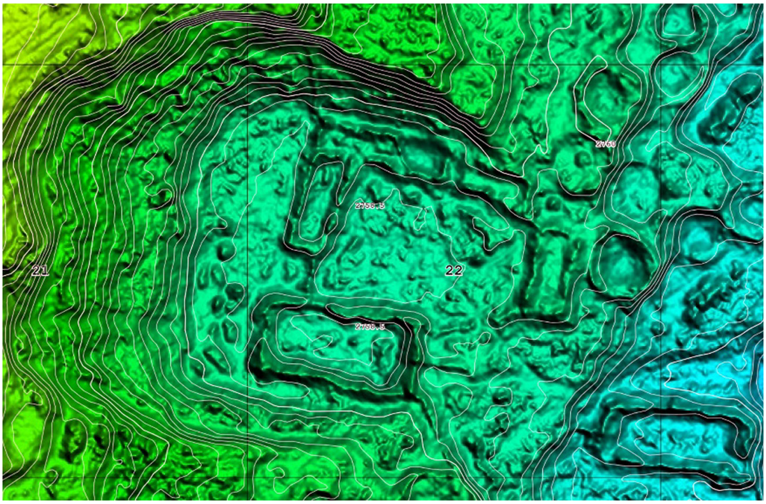

Fig. 7. Patio group or rectangular buildings within sink.

feature here referred to simply as the “central sinkhole” clearly served as the focal point of Imperio’s constructed area. On the promontory surface, the concavity’s diameter stretches 54 m, and the steepest wall at the northern rim falls 8.4 m with a gradient of 60%. At the cavity’s western edge, the wall slopes more gently with a gradient of 22%. Arrayed on the “floor” of the sinkhole sits an orthogonal group of five rectangular buildings surrounding a patio and connected to one another by low walls (Figs. 6, 7). Because the central sinkhole appears as a “notch” in the hillside, it is crescent-shaped and open to the east where the walls of the sink meet the slope.

The appearance also recalls the shape of an amphitheater, but we eschew this descriptive term to avoid unintended interpretation of the landform’s function(s).

The patio group does not occupy the entire bottom but was constructed at the sinkhole’s opening and protrudes eastward onto a narrow terrace. The eastern side of the crescent formation is 31 m wide but for the purpose of access, the northern half of this width is blocked by one of the buildings. The narrow terrace extending beyond the access supports several circular buildings to the north and south. The maximum diameter of the level bottom measures north-south reaches 35 m. The entire oblong bottom of the central sink, including the constructed area, spreads over 1,677 m^2 and would have been intentionally leveled and the narrow terrace constructed, prior to erecting the patio group. The narrow terrace at the sinkhole opening ends 1.5 m above a broad terrace large enough to have functioned as a plaza for gatherings of people. The largest rectangular structure at Imperio labeled Building A sits in front of the access to the central sinkhole and the patio group. This terrace extends nearly 35 m south of Building A but narrows where constructions cluster toward the northern end. Below this terrace, and in front of the sinkhole, a large recessed, terraced corridor splits the sequence of descending terraces into northern and southern parts that can be roughly matched using bands of the color ramp, the 1-m contour lines, and surface elevation points.

4.3 Additional Aspects

Further in-depth analyses are underway which will develop aspects relating to the following

- Infrastructure: terraces, berms, and drains
- Circular constructions and indigenous community
- Rectangular constructions and the patio group

The limitations of the present document do not allow these arguments to be explored in depth.

5 Discussion: Interpreting Imperio Through Time

We are inclined to conclude that the patterning just described and visible on the surface of Imperio represents a conflation of Imperio's two most substantial occupations prior to abandonment, beginning with the Inka occupation at Kuelap and ending after a period of Spanish colonial occupation of unknown duration. The landform was also likely inhabited long before the Inka conquest. However, isolating evidence pre-dating major landscape modifications attributable to the Inka as attested by large stone terraces was not possible with our imagery, and may be difficult with ground-level investigations. The location was probably chosen as a construction site for the same compelling reasons related to its geomorphology and utility as a source of water during three successive occupations by three cultures arriving in succession.

In terms of Imperio's chronology, we hypothesize that the location was gradually, perhaps sporadically, occupied prior to Inka conquest. Presuming that the central sinkhole had always disgorged and perhaps pooled large quantities of water, the high ground of the Upper Zone would have been a preferred location to camp or reside. Earliest habitations may be among those cannibalized, but without visual evidence from the LiDAR imagery our suggestions are speculative. Some residents of a rustic hamlet may have managed access to water for irrigation on behalf of kin groups. Some may have cared for a shrine that might have existed and required maintenance. The earliest dated evidence for settlement on La Barreta by approximately AD 400 are reported from excavations at La Fortaleza, and the monument's stone walls may have been under construction by AD 900. We suggest that occupation and some construction at Imperio may have begun at about the same time, but we have no data to support the hypothesis.

Some archaeologists have posed water supply as a significant unanswered problem when considering the substantial needs of an estimated 3,000 inhabitants in La Fortaleza, the needs for agriculture, and for watering camelid herds. In reply to such questions, Ruiz has described the abundance of springs and seeps on and around La Barreta. Some seeps and springs known today by area residents would have functioned in the past. We think it likely that Imperio was already in use as a source of water for agriculture and drinking, and the bottom surface of the central sinkhole was conditioned to retain and impound water as local needs increased. Another peripheral archaeological site at Kuelap known as El Lirio also reportedly has a spring. Such places where water emanated from the ground were and often still are considered sacred by Andean peoples. On the sacred landscape of La Barreta, the water source within the central sinkhole was probably considered a pakarina, a sacred place of origin or emergence for one or more of the local kin groups, and as a source of life in the most universal sense.

6 Conclusion: LiDAR in Tropandean Cloudforests

We have squeezed many inferences from the LiDAR imagery at our disposal for this study… some critics may say too many. To generate our interpretations, we used the few descriptions of Imperio at our disposal, most of which were understandably cursory given the thick vegetation. Our experimentation with airborne LiDAR imagery convinced us that the resulting imagery is extremely valuable, especially for aerial prospecting when long-distance flights become feasible with technological advances. Perhaps the greatest value of this LiDAR technology is its ability to penetrate dense tropical forest to identify the presence or absence of archaeological settlements. We also see great value in the use of LiDAR for research conducted to support conservation planning where site locations are known. Furthermore, we propose that LiDAR imagery is capable of providing an excellent tool to aid preliminary analysis of forested sites like Imperio, and to venture hypotheses regarding complex architecture when is unexpectedly encountered as it was in this case. Without full imagery of the broader landscape including the site's cultural and environmental contexts, it is obvious that our interpretations await evaluation through appropriate ground-level fieldwork.

The use of LiDAR technology is hardly necessary in all terrains and environments to identify or analyze every kind of small or large archaeological site. Tropical montane forests of in the Andes, and especially on the eastern slopes pose special challenges for archaeological reconnaissance, and the presence of stone architecture constructed on monumental scales provide an extraordinary "testing ground" appropriate to truly challenge and evaluate LiDAR's capabilities. What we presently understand of site densities on the eastern slopes indicates that the Vilcabamba region east of Cusco, and the forested stretches of territory within the more biogeographically diverse areas of Amazonas, San Martin, and La Libertad Regions contain many monumental archaeological sites in areas remaining to be examined by archaeologists. These sites are threatened by farming and herding societies pushing eastward in search of unclaimed land parcels and perhaps more humid climates. These are not the only eastern slope regions with stone settlements beneath forests, but to all indications, their site densities are unmatched. Logically, the forested landscapes of eastern Cusco and the northeastern Peruvian Andes are ideal proving grounds for the development of LiDAR technology in Peru.

While the use of LiDAR imagery at a site like Imperio has advantages over ground survey to quickly observe spatial relationships, and to estimate structural dimensions, architectural and masonry details, and most preservation issues should be assessed by ground survey and ground-level visual observations. Using the LiDAR imagery, we found at first that the spatial organization of constructions appeared to be extremely complex but the site structure became easier to comprehend after we began to recognize the berms and channels serving as drainage infrastructure. While conducting ground-level fieldwork within tangled forests, one becomes quickly disoriented. Simply orienting oneself to conduct ground-level mapping requires cutting of vegetation, and potentially destructive "cleaning" of architectural features may follow. Furthermore, archaeologists and support crews wielding machetes and piling brush may fail to recognize relatively subtle spatial patterns before detailed three-dimensional surface mapping is completed. The activities involved in the arduous process of creating such a detailed map might inadvertently trample and further erode traces of drainage systems like Imperio's which appears to have been carefully planned by the site's builders. For these reasons, we conclude that this LiDAR imagery was an invaluable tool with which to begin study of Imperio.

We are in complete agreement with the consensus among archaeologists that the methodologies of LiDAR imaging and surface documentation complement one another, and together enable more robust descriptions needed to study and protect ancient sites and landscapes… especially in such terrain. In fact, the archaeological ground reconnaissance organized and led by archaeologist Lic. Constante Luján Bazan enabled verification of the image findings that gave us sufficient confidence to proceed. The archaeological team on the ground was also able to document such details as the traces of plaster and decorations on the church wall surfaces.

It was never the goal of this project, or even this publication, to answer the question, "What was Imperio?" Further inquiry is needed to provide plausible answers. However, we retrieved imagery attesting to the complexity of Imperio's chronology of construction, and the site's functions. We do propose that the site was more socially, economically, and politically significant than a rural agricultural hamlet as previously suggested. Somewhat miraculously, we feel that we say this with confidence although we have not touched the site surface, but present only hypotheses for others to pursue or ignore. We hope that our preliminary interpretations serve to provoke additional investigations at other archaeological sites on La Barreta and elsewhere. Perhaps this work will help confirm Ruiz's observation that the entire Kuelap settlement complex has almost twice as many habitations as we have been led to believe in literature, and on guided tours. Reevaluating La Fortaleza within an enlarged context will certainly enhance our understanding of Kuelap as a multi-functional site complex, and not just a fortress as was once commonly believed. Hopefully, a fuller analysis of the complex, combined with surface archaeological procedures, will provide a sorely needed step towards resolving controversies surrounding the site's ancient functions and meanings within the greater Chachapoyas region.

As LiDAR technology shows increasing potential for effective remote sensing, concerns regarding ethics and data access are moving to the foreground. We also regard these as very important concerns. On La Barreta, competing land claims create social friction. However, this publication was designed as a report on research and development of a particular technology. Clearly there will be questions about who should have access to the data, and we imagine that the Ministry of Culture will initiate these kinds of conversations along with other Peruvian institutions and stakeholders such as local communities. The use of LiDAR imagery can also contribute to ethical and sustainable tourism development by supporting design of scientifically correct 3D reconstructions that may be displayed on immersive Virtual, Augmented and Mixed Reality tools. Depending upon future development planning, Kuelap could be toured virtually by individuals with physical disabilities, or by others unable to undertake the rigorous trip to this high-altitude site, a visit that does require some physical stamina. As we prepared this publication during a global pandemic crisis, the advantages of such technologies became immediately obvious.

More information on the use of deep learning to discover lost cities can be found on https://www.youtube.com/watch?v=aCZwM-9nE_4&ab_channel=MEDSAMSTERDAM.

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References

1. Chase, A.F., Chase, D.Z.: Detection of Maya ruins by LiDAR: applications, case study, and issues. In: Masini, N., Soldovieri, F. (eds.) Sensing the Past. GE, vol. 16, pp. 455–468. Springer, Cham (2017). https://doi.org/10.1007/978-3-319-50518-3_22
2. Fisher, C.T., Cohen, A.S., Fernández-Diaz, J.C., Leisz, S.J.: The application of airborne mapping LiDAR for the documentation of ancient cities and regions in tropical regions. Quatern. Int. **448**, 129–138 (2017)
3. Inomata, T., Pinzón, F., Ranchos, J.L., Haraguchi, T., Nasu, H., Fernandez-Diaz, J.C., et al.: Archaeological application of airborne LiDAR with Object-Based vegetation classification and visualization techniques at the Lowland Maya site of Ceibal, Guatemala. Remote Sens. **9**(6), 563 (2017)
4. McAnany, P.A.: Large-scale early Maya sites in Mexico revealed by lidar mapping technology. Nature **582**(7813), 490–492 (2020)
5. Iriarte, J., et al.: Geometry by design: contribution of lidar to the understanding of settlement patterns of the mound villages in SW Amazonia. J. Comput. Appl. Archaeol. **3**(1), 151–169 (2020). https://doi.org/10.5334/jcaa.45
6. Castro-Priego, M., Olmo-Enciso, L., Labrada-Ochoa, M.O., Jijón-Porras, J.A., García-Campoverde, J.A.: Agrarian spaces, pre-Hispanic settlement and LiDAR technology in the central coast of Ecuador. Virtual Archaeology Review (2021)

7. Khan, S., Aragão, L., Iriarte, J.: A UAV–lidar system to map Amazonian rainforest and its ancient landscape transformations. Int. J. Remote Sens. **38**(8–10), 2313–2330 (2017)
8. Nieto JCaMB: Torre de Babel en el Perú. Boletín de la Sociedad Geográfica de Lima. 1891 [1843] **1**(10–12), 440–448 (1891)
9. Raimondi, A.: Imprenta Nacional, El Peru. Lima (1874)
10. Middendorf, E.W.: Peru Beobachtungen und Studien über das Land und seine Bewohner. Berlin (1895)
11. Werthemannn, A.: Ruinas de la fortaleza de Cuelap. Boletín de la Sociedad Geográfica de Lima. **2**(4–6), 147–158 (1892)
12. Church, W., Guengerich, A.: Introducción: La (re) construcción de Chachapoyas a través de la historia y la historiografía. In: Guengerich, A., Church, W., (eds.) ¿Qué fue Chachapoyas? Aproximaciones interdisciplinarias en el estudio de los Andes Nororientales del Perú Boletín de Arqueología PUCP. 23, p. 5-38. PUCP, Lima (2018)
13. Schjellerup, I.R.: Incas and Spaniards in the Conquest of the Chachapoyas. Archaeological and Ethnohistorical Research in the North-eastern Andes of Peru [Ph.D.]. Gothenburg (1997)
14. Naturales) PONdEdR. Mapa ecológico del Perú: guía explicativa. Lima: Republica del Peru, Oficina Nacional de Evaluación de Recursos Naturales (ONERN) (1976)
15. Young, K.R., León, B.: Peru's humid eastern montane forests: An overview of their physical settings, biological diversity, human use and settlement, and conservation needs: Centre for Research on the Cultural and Biological Diversity of Andean Rainforests (DIVA) (1999)
16. Schjellerup, I., La Ceja de Montaña, a disappearing landscape: interdisciplinary studies from North-eastern Peru, Aarhus Universitetsforlag (2009)
17. Sarmiento, F.O., Bush, M., Church, W., VanValkenburgh, P., Oliva, M., Delgado, E., et al.: Mountain science poised to help ecotourism in Peruvian cloud forests. Past Global Changes Magazine. **28**(1), 22–23 (2020)