Surface Architecture Scanning of Archaeological Sites with Ground Based Lidar in Southern Peru

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Abstract:

Ground based LiDAR scanning provides an innovative technique for investigating partially buried architectural structures in Southern Peru. In this paper, we evaluate the potential of ground-based LiDAR for elucidating the nature of archaeological structures with vestiges of architecture remaining on the surface. Microtopographic mapping provides evidence for subsurface architecture as well as documentation of elements of preserved standing constructions. We evaluate the potential for LiDAR to provide data on submerged structures as a complement to geophysical and excavation techniques. We also examine LiDAR's role in documenting erosional processes and in enhancing monitoring of destruction to monumental archaeological sites. Two sites are examined as case studies: the Inka (1450-1532 CE) administrative center of Sabaya and the Wari (600-1000 CE) administrative center at Cerro Baúl.

Keywords: archaeological prospection | archaeological mapping | laser scanning | Andean Prehistory

Article:

I. INTRODUCTION

Some of the most impressive and important of archaeological remains are the remnants of architectural constructions made by past civilizations. Ranging from landscapes [1] to modified caves [2,3], monumental palaces [4] to humble abodes [5,6], these constructions frame the context of human activities through the built environment. While certain well-preserved monuments capture the imagination of the public [7], the vast majority of human ingenuity in architectural construction remains obscured through the ravages of time. Vestiges of these great achievements of humankind remain preserved in the earth, yet to be documented and studied.

While ground based laser scanning has been applied successfully to standing monuments [8,9,10], we utilize the method as an addition to a remote sensing toolset in the search for the structure of buried monuments and common houses. Subtle variations in surface topography can yield clues to subterranean buildings. Here we explore the role of ground-based LiDAR in archaeological sites in far southern Peru to assess the potential for architectural analysis of buried structures.

II. PREVIOUS RESEARCH

For the past 30 years, archaeological research in the Moquegua Valley of Southern Peru has documented hundreds of archaeological sites, including extensive excavations at dozens of monuments. Yet, only a small portion of the area's buried architectural patrimony has been investigated systematically. Even sites with decades of extensive research, such as the monuments at Cerro Baul and Sabaya, have a great deal of information yet to be recovered. Previous research has involved surface architectural mapping with differential GPS and Total Station mapping [11, 12], geophysical investigations including magnetometry and ground penetrating radar [13], and wide area excavations aimed at defining architectural spaces [14]. These research agendas have been illuminating, but have not grasped the full potential of documentation.

Surface mapping is dependent on identifying the vestiges of buried architecture with the naked eye. It is often imprecise due to the vagaries of preservation of architectural remains and the inability to identify architectural compounds based on fragments of surface remnants. Geophysical investigations have limits as well. Magnetometry proves difficult to interpret in areas of volcanic formation where architectural construction is composed of the same volcanic material as the surrounding matrix. GPR is limited in the rock littered cores of monumental sites, where rubble is the predominant surface matrix and the differentiation between constructed walls and fallen debris is difficult to ascertain. Extensive excavations are costly, time intensive, and limited in area exposure.

As a complement to these other programs, we employ ground-based LiDAR to create three-dimensional representations of ground surfaces that document in high detail microtopographic variation of remnant architectural spaces. The high resolution of the laser scans allow the data to be manipulated in three dimensions and enhanced to identify detailed patterns that may not be visible via ground survey. Standing architecture can be examined in great detail to examine how stones fit together and where wall fall might be digitally reconstructed. The resulting data set can be quantitatively analyzed and incorporated into a GIS for spatial analysis with other datasets, providing a comprehensive resource for architectural analysis.

III. METHODOLOGY

We use ground based LiDAR for three-dimensional topographic documentation of architectural ruins. The method consist of point cloud rendering of ground plans of the archaeological ruins that offer a contextual incorporation of cultural patrimony and architecture associated with architectural features. We performed data collection using the Leica ScanStation 2 operating Cyclone version 7.2 with the following specifications: measurement range 1–800 m, accuracy ±10 mm (standard deviation), measurement rate up to 12,000 pts/sec, field of view 80 x 360°.

As a project standard, single scans are operated implementing a 25 cm horizontal and vertical sample spacing in the architectural environment from three different station locations. The ground based LiDAR and reflecting targets were first assembled, placed in an appropriate portion of the architectural feature in order to maximum work efficiency and facilitate the transition of each station into the next.

Dual axis compensation was employed to eliminate error from settling due to the motion of the scanner during survey. By extracting a minimum of three known georeferenced reflecting targets at each station, scan position of delimited areas can be registered one to another with an average error of about 5–6 mm (standard deviation).

In addition to geometric measuring, colored textures are also recorded using the onboard camera that incorporates the surroundings into a photographic overlay of the point cloud data using Cyclone post-processing software. Images are mapped onto the geometry by using the registrations tools of Leica’s processing software.

In order to avoid the accumulation of registration errors inherent in laser scanning, traverses with wide baselines were performed in order to form a distortion-free triangulation net of control points. Simultaneously, reflecting targets were measured along the traverse, constituting the global coordinate system of each terrace. The registration tool within Cyclone 7.2 allowed the automatic transformation of measured point clouds into that global coordinate system. After cleaning up the raw point clouds of delimited spatial units and gathering them in a modelspace view, geometric 3D data is exported in various file formats that can be used in further CAD-based design and GIS-based analysis tools.

IV. CASE STUDY: SABAYA

Sabaya was the Inca administrative center for the Torata Valley. Established around 1450 CE, it was organized around a large central plaza. A great hall, or *kallanka*, flanks one edge of the plaza. On the opposite side of the plaza, an *usnu*, or royal viewing platform, oversees the site. Elite residences flank the far side of the plaza and surrounding areas (Fig. 1).

After the Spanish conquest in 1532 CE, Sabaya continued to be occupied. A colonial cemetery was placed at the foot of the usnu. Excavations in 1990 revealed one corner of the wall that surrounded the cemetery [12], but only fragments of the wall are visible on the surface (Fig. 1B). Ground based LiDAR reveals new perspectives on microtopographic variation of the 16th century cemetery. These variations illustrate the size and shape of the colonial compound built at the foot of the *usnu* that is only partially visible on the surface (Fig. 1C). The compound measures approximately fifteen by twelve meters. Definition of the compound wall focuses ongoing excavations within the colonial cemetery.

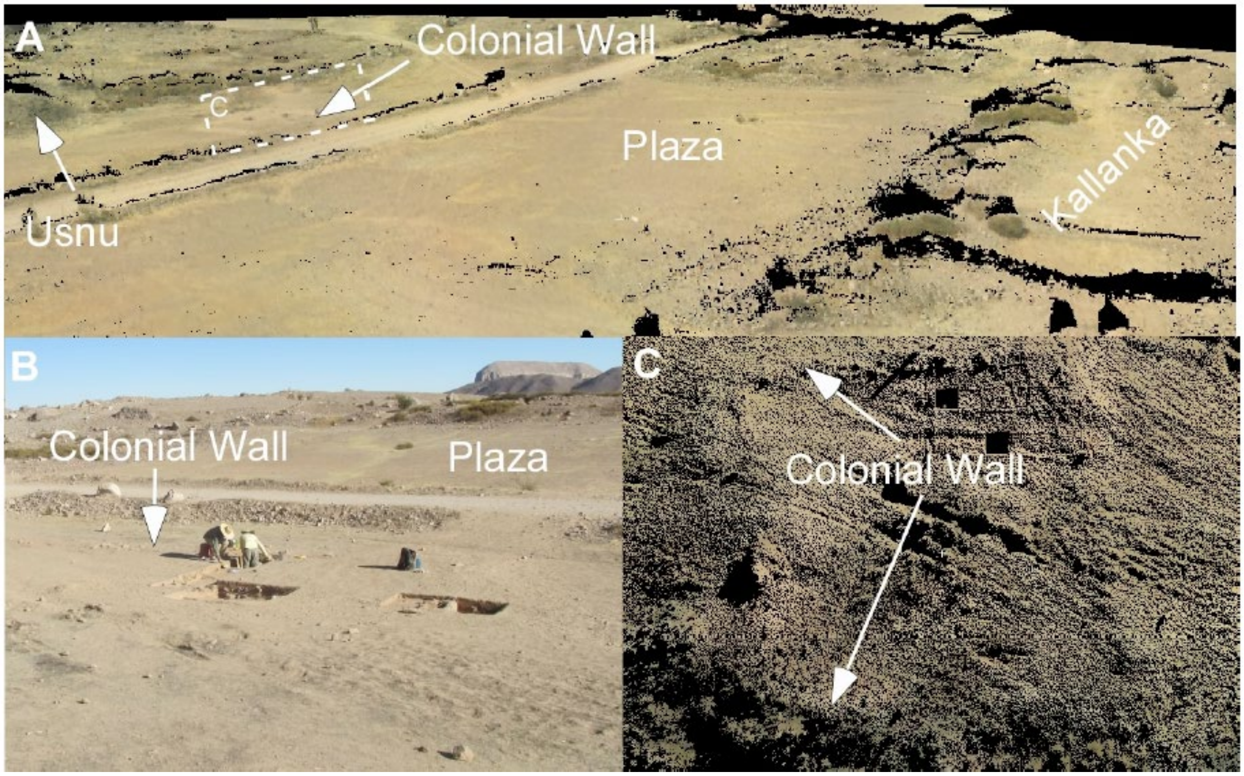

Fig. 1. LiDAR scan of Sabaya (A) with details of excavations in the Plaza (B) and LiDAR detail of colonial cemetery wall (C).

V. CASE STUDY: CERRO BAÚL

The site of Cerro Baúl represents a huge investment of human labor and creative engineering savvy. The kilometer-long mesa top citadel towers some 600 meters above the valley floor with no natural water source [14, 15, 16]. Far from a practical location, the monumental structures demonstrate wealth and power and their inhabitants enjoyed a unique vista of the surrounding snow-capped peaks. This visual connection with sacred mountains appears to be the impetus for the site's placement and the architecture's orientation [17].

Surface remains are difficult to interpret because many of the structures were more than one storey and a millennium of tectonic activity has taken its toll. The main cluster of buildings is approximately 300 by 500 meters, a scatter of fallen rubble with the footings of walls hidden between loose rock. Nevertheless, more than ten years of excavations and debris clearance reveals that the site is organized into more than ten walled compounds, which are apparent because their outer walls are the thickest on site and average a meter wide. From the surface many of the structures appears to have rounded corners, however the pattern results from the manner of building collapse and excavation shows that structures replicate imperial Wari canons of elite architecture present at the capital and other administrative centers [11]. This pattern consists of long rectangular rooms (i.e. Room 9A) which frame nearly square or trapezoidal central patios (i.e. Patio 9B), one or more of these units appears along with open plazas in walled compounds (Figs. 2-4) [18, 19, 20].

Fig. 2. Cerro Baúl Unit 9B in initial stages of excavation

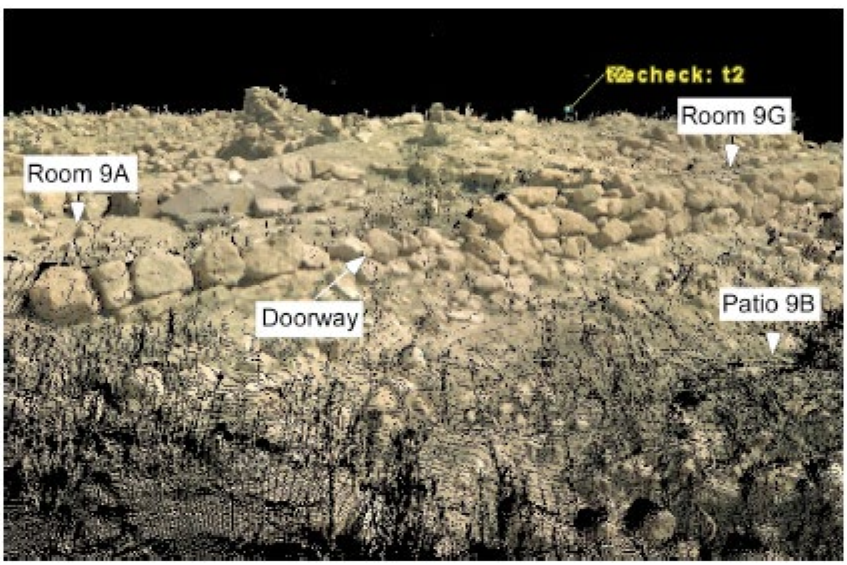

Fig. 3. LiDAR scan of Unit 9 after reinterment showing architectural details

Unfortunately, in some cases the walls surrounding plazas collapsed in mass and can mimic the appearance of rooms surrounding a patio. On several occasions excavation has proven surface observations of architecture to be incorrect. Surface observations often depend on the angle of light available and the relative elevation or perspective of the observer. The more systematic microtopographic data that three dimensional scanning can offer greatly improves an archaeologist's ability to recognize patterns and differentiate between the remnants of a standing wall and phantom walls created by simultaneous collapse at Cerro Baúl (Figs. 3-4).

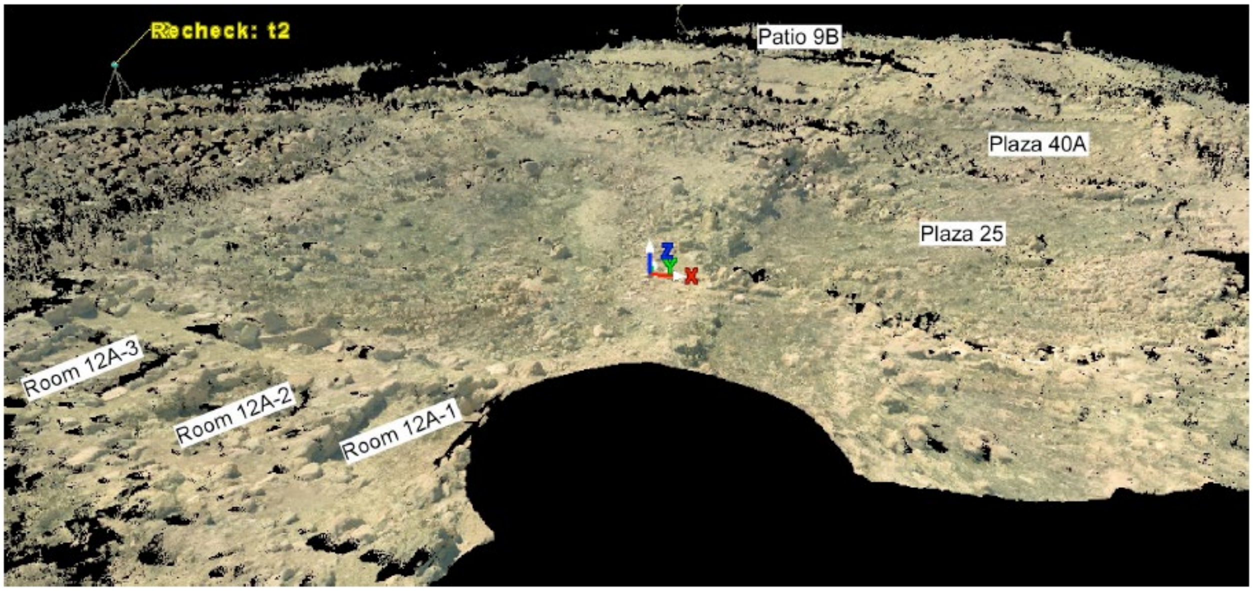

Fig. 4. LiDAR scan of the walled compounds of the palace at Cerro Baúl. Excavated rooms are named.

VI. DISCUSSION

Ground based LiDAR documents small topographic changes in the surface of unvegetated sandy soils that excavations at Sabaya have revealed reflect an early Spanish colonial wall enclosing a cemetery at the base of the *usnu* at Sabaya. Likewise, large compound walls at Cerro Baúl have been detected in topographic variation of wall rubble between remnant walls and open spaces. Smaller internal walls proved more difficult to detect in topographic variation in wall rubble, though in some cases doorways and other architectural details were discernable from surface scans, even if not obvious to the naked eye.

Irregular surface vegetation presented challenges to identifying ground surfaces and thus hindered interpretation. Variation in more regular surface vegetation may be reflective of subsurface architecture, but that is not the case in the desert Peruvian South in the sites investigated here.

Ground based laser scanning has proven to be a valuable tool in assessing subterranean architectural features, even when the tops of walls are barely visible on the surface. The subtle variations in surface topography reflective of subsurface architectural variation are effectively measured by high resolution digital surface models, for which ground based laser scanning provides an operational methodology. Lidar may be an effective complement to geophysical techniques that penetrate the surface, for microtopographic variation coupled with color variation may prove to be a good predictor of subsurface anthropogenic variation.

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