HOW-TO SERIES

Aerial, Surface, and Subsurface Multimodal Mapping in Coastal Peru

Insights from Cerro San Isidro, Moro Region, Nepeña Valley

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ABSTRACT

This article describes a series of steps to integrate multiple modes of archaeological mapping in arid and agricultural settings. We use the coastal region of Peru as a case study and share our recent field experience at Cerro San Isidro, a multicomponent hill site located in the agriculture-intensive and mid-elevation (about 500 m asl) Moro region of the Nepeña Valley. In June and July 2022, we spent eight weeks deploying a combination of drone aerial imagery, pedestrian GPS reconnaissance, and GPR survey to map the surface and subsurface features at the site and in the adjacent agricultural fields. Our efforts suggest that the ancient settlement extended over an area of at least 50 ha, well beyond the visible surface architecture. Using a multimodal approach to confirming the partial destruction of archaeological vestiges by modern agricultural encroachment is both time-effective and noninvasive. The article offers insights from our experience, including the sequence of field operations, technical troubleshooting, and the collection and integration of datasets. We discuss the methodological potential and implications of this combination of multimodal mapping and its deployment in coastal Peru, a region that, like many others in the world, is increasingly subject to rapid agricultural expansion and other anthropogenic developments.

Keywords: archaeological survey, multimodal mapping, remote sensing, ground-penetrating radar, drone imagery, Peru

Este artículo ofrece una serie de pasos sobre cómo integrar múltiples modos de mapeo arqueológico de superficie y subsuelo en entornos áridos y agrícolas. Usamos la región costera de Perú como estudio de caso y compartimos nuestra experiencia de campo reciente en el Cerro San Isidro, un sitio de colina de múltiples componentes ubicado en la región de Moro, de elevación media (~500 msnm), de agricultura intensiva en el valle medio de Nepeña. En junio y julio de 2022, pasamos ocho semanas desplegando una combinación de imágenes aéreas con drones, reconocimiento GPS de peatones y estudios GPR para mapear las características de la superficie y el subsuelo en el sitio y en los campos agrícolas y las huertas de árboles adyacentes. Nuestros esfuerzos sugieren que el antiguo asentamiento se extendía sobre un área de al menos 50 hectáreas, mucho más allá de la arquitectura superficial visible. Si bien confirma la destrucción parcial de vestigios arqueológicos por la invasión agrícola moderna, nuestro enfoque multimodal es eficaz en el tiempo y no invasivo. El artículo ofrece información sobre nuestra experiencia, incluyendo la secuencia de operaciones de campo, la resolución de problemas técnicos y la recopilación e integración de conjuntos de datos. Discutimos el potencial metodológico y las implicaciones de esta combinación de mapeo multimodal y su implementación en la costa del Perú, una región, como muchas otras en el mundo, cada vez más sujeta a una rápida expansión agrícola y otros desarrollos antropogénicos.

Palabras clave: prospección arqueológica, mapeo multimodal, teledetección, georradar, imágenes de drones, Perú

The use of remote sensing technologies, such as GPS, satellite, drone, lidar, and radar imageries, has revolutionized archaeology (Comer and Harrower 2013; Lasaponara and Masini 2012; Wiseman and El-Baz 2007). Yet, for a variety of reasons—cost, the need for technical expertise, time constraints, local topographies and ecologies, and the nature of archaeological deposits—multiple methods are rarely used in conjunction or integrated into a single research design. Individually these methods bring insights into archaeological deposits; when deployed together and integrated into a multimodal mapping strategy, their potency is multiplied, both in terms of data resolution and of logistics. Such a strategy can take advantage of the strengths of each method, balancing their weaknesses and limitations. Multimodal mapping allows researchers to combine diverse data sources and overlay them within a single map. In addition, it can reveal spatial patterns and relationships that may not be apparent when

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methods are deployed individually and datasets are kept separately.

This article makes the case for the incorporation of data across three surveys: aerial, surface, and subsurface. We argue that such a multimodal and multiscalar approach provides optimal results, producing detailed spatial representations of archaeological deposits. These data can subsequently be analyzed to document and understand various human phenomena, including settlement arrangements, the spatial patterning of activities, and people's relations to features of the surrounding landscape. Our case study presents a workflow compatible with urban-like ancient settlements embedded and encroached on by plantation and other agricultural activities. Such sites are not only key to understanding our past but are also increasingly threatened by agricultural and urban expansions worldwide.

We report here on the integrated, multimodal efforts deployed in the Moro region of the middle Nepeña Valley on the north-central coast of Peru. Our fieldwork focused on the archaeological complex Cerro San Isidro, a complex hill site interpreted as a major center of human occupation and political importance based on its size, the density of surface architectural and material remains, and its geographic centrality within the Moro region. Preservation at the site is in general excellent, making it an ideal place to integrate aerial, surface, and subsurface data. To demonstrate how our project integrated these datasets and techniques, this article describes a series of five steps: (1) aerial survey, (2) surface survey, (3) subsurface survey, (4) data processing and integration, and (5) data analysis and interpretation. It provides a "how-to" guide to integrate these techniques in the mapping of surface and subsurface archaeological vestiges in arid settings where the "natural" topography and archaeological deposits have been transformed by anthropogenic activities. These vestiges include residential terracing, architectural constructions, intense domestic activities, trash discard, and encroaching agrarian practices, including irrigation and the use of machinery. Our objective is to make it accessible for field archaeologists to implement, integrate, and refine geospatial techniques.

PROJECT BACKGROUND: CERRO SAN ISIDRO

In 2022, after several months of planning, including consulting aerial photographs from the 1940s, our team spent eight weeks deploying multiple surveying methods to document the surface and subsurface organization of Cerro San Isidro. This site is a multicomponent archaeological complex occupied mainly during the Early Horizon (about 800–200 BC) and the Late Intermediate period (about AD 1000–1500; Chicoine and Navarro 2021). The Proyecto de Investigación Arqueológica Cerro San Isidro is investigating the transformation of leadership in the Moro region as part of a broader comparative program to understand the rise of complex societies in northern Peru (Lau et al. 2023). This investigation compares settlement layouts, growth, and change through time and, as such, requires detailed maps and control over the spatial organization of ancient sites. A survey of the Moro region conducted by Hugo Ikehara (2015) indicates that Cerro San Isidro was an important population center; however, the exact extent of the settlement remained undetermined. Our project thus aimed to delimit the extent of the settlement and produce a detailed map of the occupied area.

Cerro San Isidro is located less than 1 km west of the modern town of Moro, which abuts the base of the Western Andean or Cordillera Negra foothills (Figure 1). The site has a strategic location at the center of the Moro region, aka Moro Pocket (Kosok 1965:95). It is considered part of the middle Nepeña Valley (Ikehara 2008:374), squeezed between the upper reaches of the Nepeña tributaries to the north and east and the lower coastal plain and Pacific littoral some 40 km to the southwest. High water availability along with rich soils (Oficina Nacional de Evaluación de Recursos Naturales 1972: Mapa de suelos) and abundant sunshine combine to make the Moro region very attractive for agriculture. Cerro San Isidro sits at an elevation of about 500 m asl on the northern edge of a broad alluvial terrace overlooking the Nepeña River directly to the north and the Loco River less than 2 km to the south.

In this article, we focus on the multimodal mapping operations carried out during the 2022 field season. To account for the geological, ecological, and topographical complexity of the area, we offer an integrated methodology with the potential to capture archaeological information near and above the surface, as well as underground.

STEP 1: AERIAL SURVEYING

Aerial surveying documents the site's built and natural features, providing information on spatial relations between different human-made things and the surrounding landscape by identifying features and patterns that may not be visible at ground level. In addition, it documents crop and soil marks that can be used to map surface features. However, it is important to remember that pedestrian trampling or clearing efforts might compromise the compatibility and comparability of datasets. This method provides large-scale coverage and is time effective.

Today, there are multiple ways in which aerial information can be collected, with satellite imagery, uncrewed aerial vehicle (UAV) or drone surveys, and lidar survey being perhaps the most popular. Satellite imagery, including historical imagery, is rapidly becoming more available to researchers, which makes it a useful tool for providing contextual site information. Satellite imagery can also provide extensive regional coverage. A drawback is that it typically has lower resolution than other methods outlined here, so it is most suitable in areas with distinctive aboveground features and where crop and soil marks are not an important source of information. Where these conditions are not present, UAV or lidar surveys provide better resolution. In uneven or rugged topographies such as the Andean piedmonts, UAV and lidar surveys can produce more detailed elevation models.

UAV surveys are important tools for archaeologists. They provide a quick way of documenting archaeological sites with high resolution and accuracy. The downsides of implementing this method are its cost and need for technical expertise; UAVs are expensive tools that require some training to operate. Different camera options, such as those that provide multispectral and thermal imagery, create unique perspectives. Both types of imagery can be useful across many different geographic settings but have limited utility for densely covered areas such as forests. Finally, UAVs require certain weather conditions: light is required to see the surface, but too much can wash out the visibility of features. Rain, wind, snow, or cold can all impede the usefulness of UAVs.

Lidar surveys are also very useful in documenting surface features at archaeological sites (Chase et al. 2012; Evans et al. 2013; Masini et al.

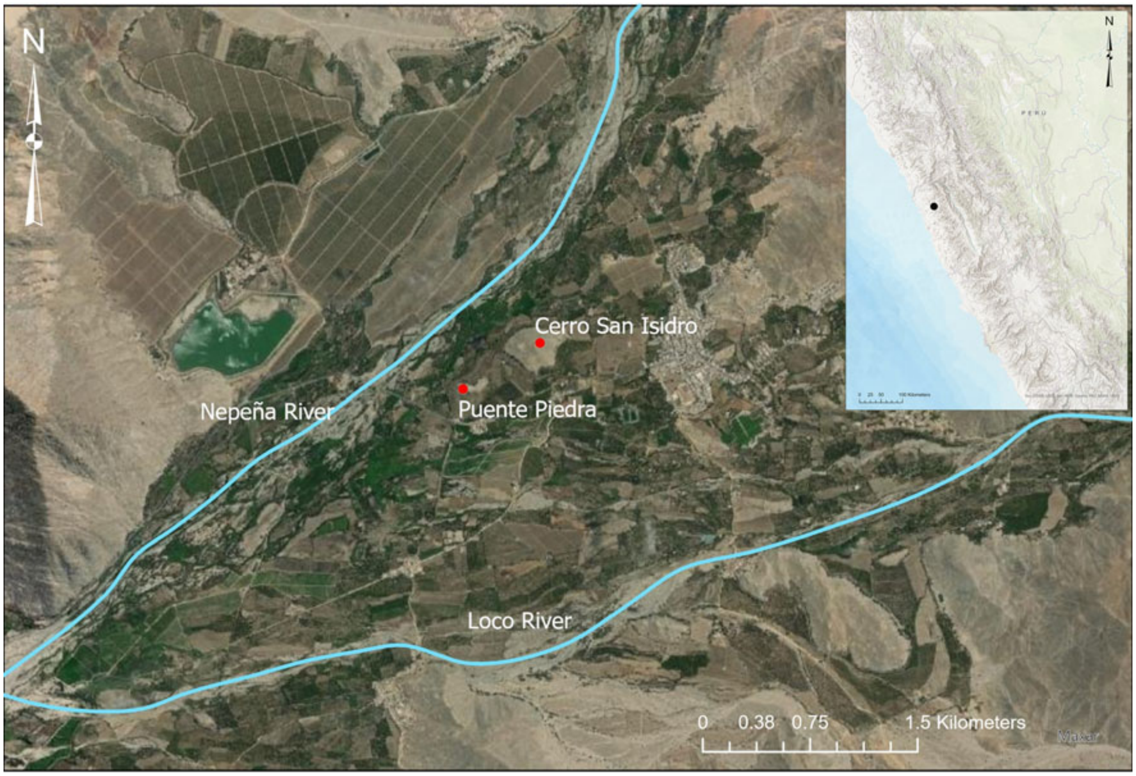

FIGURE 1. Map of the Cerro San Isidro archaeological complex and its location in the Moro region of the middle Nepeña Valley, Department of Ancash, in north-central Peru.

2011). Lidar works by sending light pulses that penetrate between foliage to reveal vertical changes, such as structures. As such, it is most useful when the survey areas have dense (about 60%) vegetation coverage. This method also produces great results on areas with uneven topography. Lidar surveys are expensive, but if a team already has in-house processing software and an expert to conduct the surveys and process the data, then its cost is significantly reduced.

For the Cerro San Isidro, for reasons discussed in the following section, we implemented UAVs mounted with optical lenses.

Step 1 at Cerro San Isidro

Golay Lausanne conducted the aerial survey with a DJI Inspire 1 drone mounted with a Zenmuse X3 optical camera with a 20 mm lens. This UAV has a vertical accuracy of 0.5 m and a horizontal accuracy of 2.5 m. As such, it is important to note that the coordinates of objects or points could be offset by up to 2.5 m. We chose this method because our goal was to document as many cultural surface features as possible at a high resolution, which made satellite imagery less attractive. Lidar, in addition to being costly, would not be optimal at Cerro San Isidro because the site core is devoid of vegetation. The surrounding areas, covered by tree orchards and agricultural fields, have all been plowed and leveled; most surface features were removed, further highlighting the subpar relevance of lidar. As discussed later, our solution was to deploy a combination of pedestrian and GPR in the tree orchards, which yielded important complementary material and spatial data.

Aerial photographs from the 1940s (Figure 2) indicate that the extent of agricultural encroachment was similar then it to what it was in 2022. Based on this observation, we focused on the extent of archaeological deposits visible at the surface and extended our aerial coverage to include areas topographically attractive for human settlement but that were covered since at least the 1940s by plantations.

The UAV works by taking multiple successive images of a scene that are subsequently stitched together using software—in our case, Agisoft Metashape Professional Edition. To ensure the greatest resolution and accuracy of the images, we followed UAV workflows prescribed by multiple researchers (Casana et al. 2017; Federman 2017; Nex and Remondion 2014). These include (1) UAV fly at 20 m from the highest point of the site and at a consistent elevation, (2) UAV speed should not exceed 3–4 m/s, and (3) flight paths should maintain a linear pattern with approximately 70% front lap and 60% side lap between images. By following these procedures, we were able to produce the image in Figure 3.

Because of the large size of Cerro San Isidro (about 50 ha), having multiple batteries was key in expediting the survey process. International archaeologists who travel with their equipment from abroad need to be aware airlines restrict the number of lithium batteries one can carry. In addition, it is vital to obtain the required permits for travel and use.

Several factors can affect flight logistics and battery life, including the sensor quality, weather conditions (wind, elevation, sunlight,

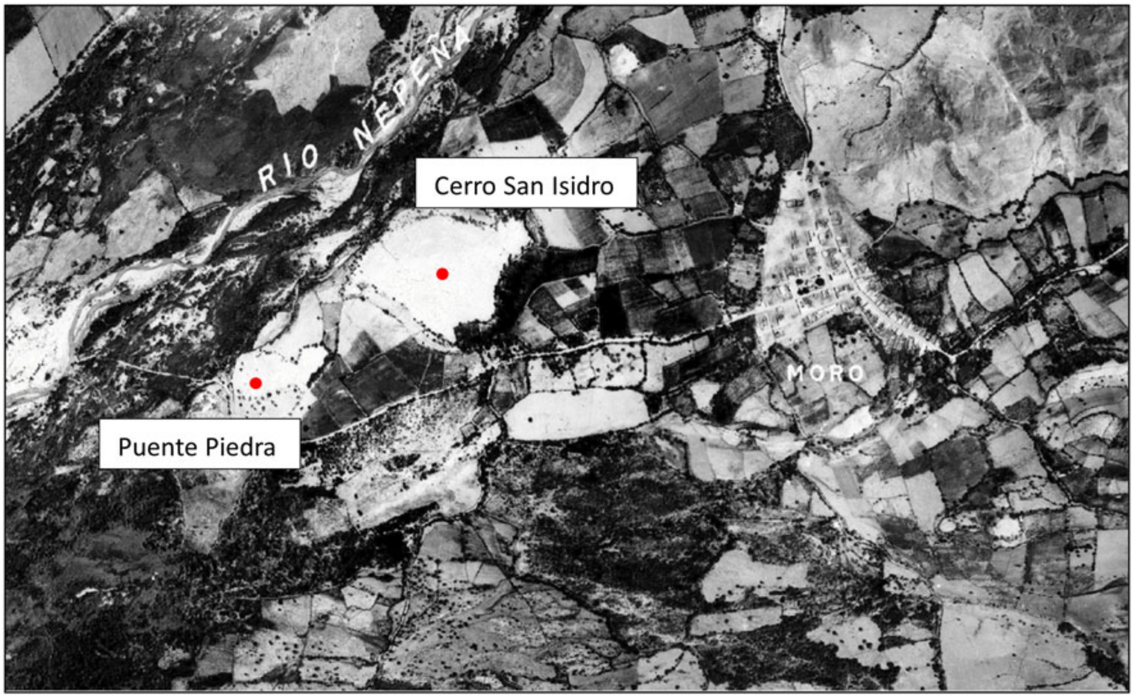

FIGURE 2. Aerial photograph of the Cerro San Isidro site and its location in the Moro region of the middle Nepeña Valley, Department of Ancash, in north-central Peru (courtesey of Servicio Nacional Aerofotográfico 1944).

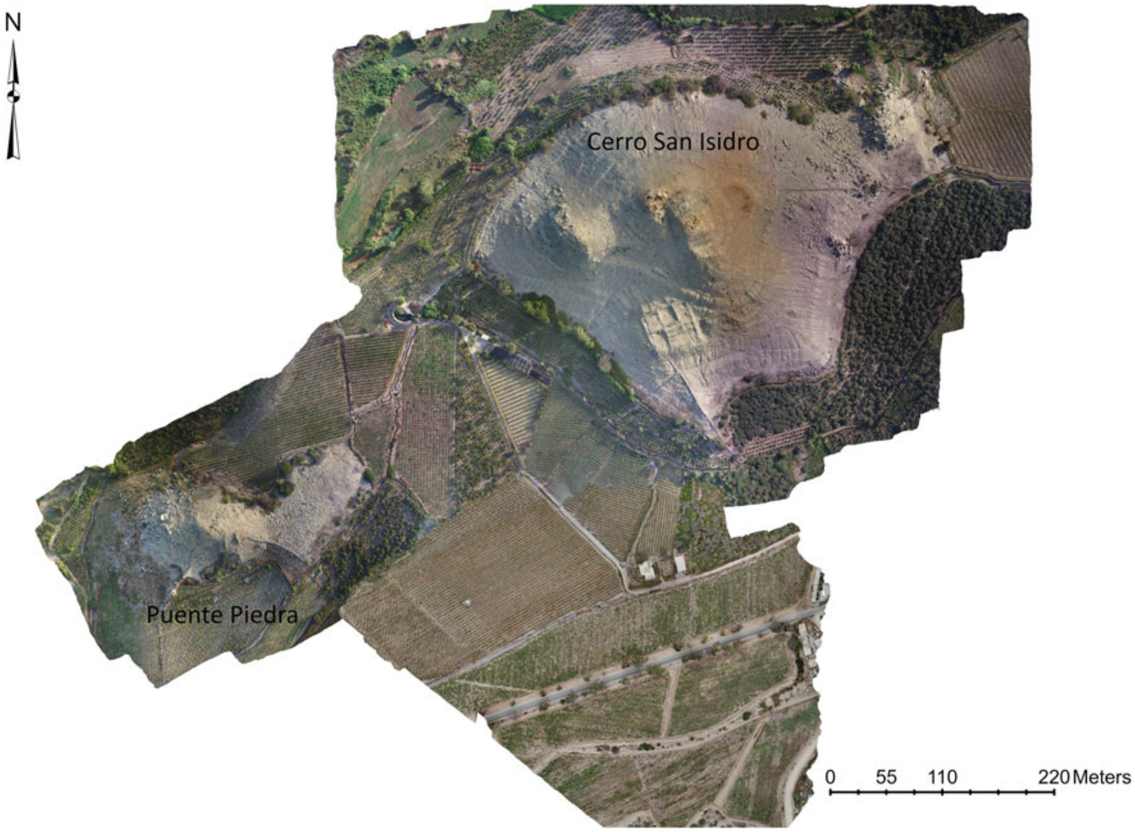

FIGURE 3. Final orthomosaic of 2022 survey at Cerro San Isidro.

heat, dust, humidity), avian fauna, terrain morphology, and UAV height relative to survey objects. Ideal weather conditions are required for image consistency and clear results, making it necessary to do multiple surveys in varying conditions. Because of the irregular and rugged topography of Cerro San Isidro, there were varying distances between the surface and camera, resulting in variable resolution across the site. To account for this, we divided the site into four sections of similar elevations and started the survey from 20 m from the highest point (Castillo et al. 2019). This yielded more consistent resolutions from 3.32 cm to 4.23 cm. The UAV survey of Cerro San Isidro recorded 0.48 km^2. Because only two batteries were available, the survey was limited to two surveys per day. Surveying each quadrant took approximately two batteries, which meant that the entire survey took four days to complete. However, if more batteries had been available, this survey could easily have been completed in just one day.

STEP 2: SURFACE SURVEY

The goal of a surface survey is to obtain finer-grain contextual details of the settlement, such as the location, distribution, and association of surface artifacts or features. A surface survey also enables a closer examination of areas otherwise hidden from an aerial survey and identifies ideal regions for the third survey type—the subsurface survey.

We claim that, for a surface survey, only one method—systematic pedestrian surveys—is needed because it is the only one that allows the researcher to view the landscape as the inhabitants would have. The surface survey should cover the same area as covered by the aerial survey: this overlap is key to providing a detailed overview of the research area. Pedestrian surveying provides greater contextual information on how the settlement fits within the greater landscape and helps highlight cultural and environmental phenomena that may not be identifiable in aerial surveying. For this step we recommend using GPS to record the coordinates of important archaeological or landscape features, such as staircases, structures, artifact clusters, irrigation canals, and outcrops. This information is critical in understanding both taphonomic and archaeological processes. Throughout this stage, the amount and extent of surface data collection depend on the goals of one's project; aspects of the site can be excluded if they do not fit the needs of the project, or more features can be included if time and goals allow for it.

Step 2 at Cerro San Isidro

Building on previous site-based (Daggett 1984; Proulx 1968, 1973) and nonsite-based pedestrian surveys (Ikehara 2015) of the area, we opted to survey an extensive area, well beyond the visible presence of surface architecture. Our survey complements the previous work by Ikehara (2015) that focused on ceramic densities as proxies for population concentrations and settlement patterns (see https://www.cadb.pitt.edu/ikehara/index.html for the Ikehara survey datasets). The goal was to walk through sectors topographically suited for human occupation. We surveyed a roughly triangular area between the merging Nepeña and Loco Rivers to the north, west, and south and the modern town of Moro to the east. The goal was to have both the UAV and pedestrian surveys cover the same, overlapping area for comparative purposes. Our team incorporated a pedestrian survey component to map the surface scatters of pottery beyond what could be said to be the site "core." In coastal Peru many archaeological sites suffer from modern agricultural encroachment and hence appear as "stranded" in the middle of arable lands. Such a situation makes it difficult to detect features through remote sensing. This is certainly the case in Cerro San Isidro, which is surrounded by fields, vineyards, and orchards.

David Chicoine carried out the pedestrian survey, asking each landowner for permission and then walking each field in a transect fashion while recording the location of each pottery sherd, quarry, canal, and water reservoir with a Garmin Montana 610 (Figure 4). The survey transects followed the furrows delineating the rows of trees. These linear, empty spaces between the rows of mango and avocado trees were parallel and approximately 3–4 m from each other. Chicoine visually examined the area immediately around the trees, thus targeting 100% of the areas walked. He was able to gain access to most, but not every, field because some owners could not be located. In total, the pedestrian survey covered an area of ~0.75 km^2 and took 15 days to complete.

During the pedestrian survey, it is important to pay attention to anthropogenic processes such as plowing and irrigation and how they might have affected the surface presence and distribution of pottery scatters. In our case, ceramics tended to accumulate in ditches and irrigation canals, but such concentrations cannot be interpreted as direct proxies for ancient distributions.

STEP 3: SUBSURFACE SURVEY

There are various options for assessing subsurface archaeology, many of which are geophysically based, such as magnetometry, magnetic susceptibility, and ground-penetrating radar (GPR). Although there are numerous other methods, we choose to focus on these options because they are the most widely used in archaeology. We also consider excavation to be a reliable subsurface survey methodology; however, our study was designed to avoid invasive methods, and so we do not discuss it here. The choice of method is determined by the characteristics of the environment and buried archaeology, as well as available time, cost, and expertise. Each geophysical method discussed here requires specialized equipment, software, and knowledge, making their use a costly endeavor.

A magnetometer measures variations in the magnetic field's strength at a specific point caused by induced and remanent magnetism (Aspinall et al. 2009). This is valuable in archaeology for detecting variations in the magnetic field caused by evidence of cultural activities like the presence of adobe bricks, ceramics, kilns, fire pits, and furnaces. It is suitable for documenting potential ceramic and food production areas and locating walls where materials such as magnetic rock, bricks, or adobes create anomalies. However, it does not provide depth information, presenting anomalies as a single image. Like other geophysical methods, magnetometer surveys can be affected by noise, which refers to false signatures in the geophysical measurements, such as pipelines, metals, or magnetic bedrock, which should be considered before conducting the survey.

Magnetic susceptibility measures anomalies in the Earth's magnetic field, which is valuable in archaeology to detect the changes

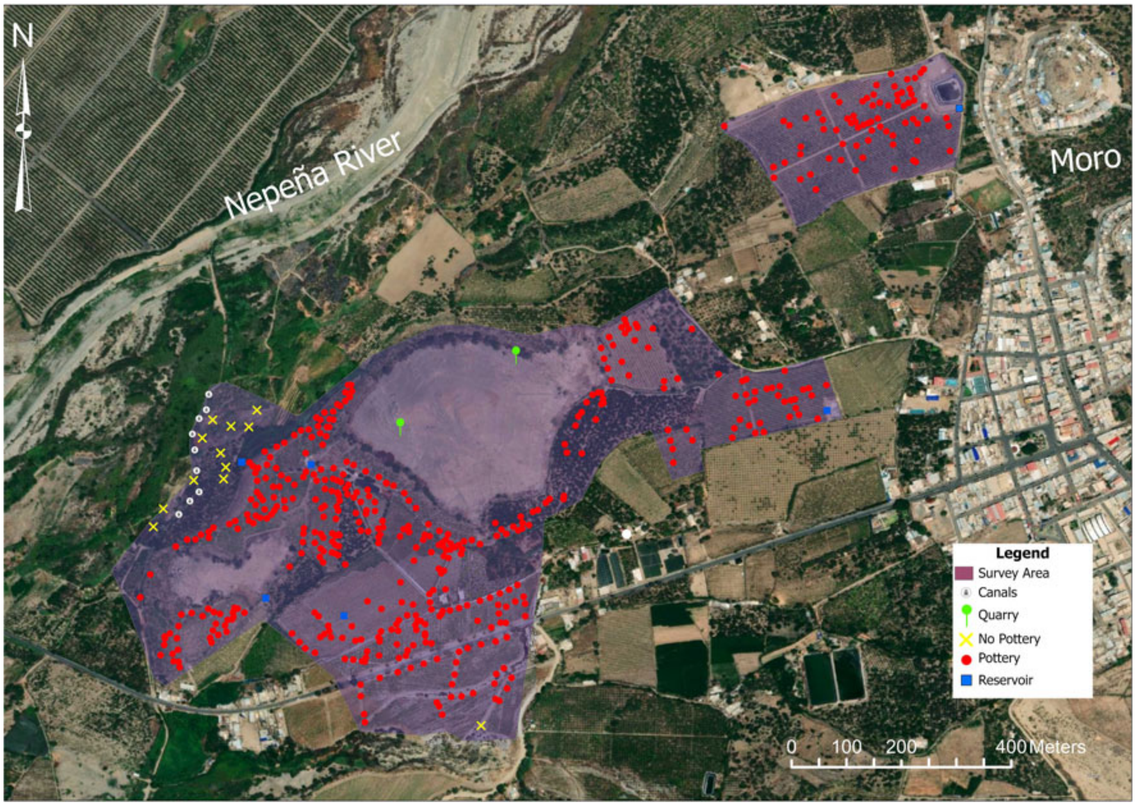

FIGURE 4. GPS points recorded during the pedestrian survey of cultivated fields. The presence of pottery suggests the extent of inhabited space.

caused by human activities (Fassbinder et al. 1990; Tite 1972; Weston 2002). It differs from magnetometry, focusing on induced magnetism (for more information, see Aspinall et al. 2009). This method is useful for detecting features like kilns, furnaces, and fireplaces with stone magnetization. Noise sources, such as surface metals, pipelines, large ceramic scatters, and magnetic bedrock, should be identified before the survey to assess its suitability. Magnetic susceptibility surveys have limited penetration, approximately 15 cm, revealing only near-surface features.

GPR is a geophysical tool that maps subsurface objects and soil/bedrock changes by using radar waves to detect differences in material dielectric constants (Conyers 2016). Its use is valuable in archaeology for distinguishing buried features with varying properties from the surrounding soil, like rock or adobe structures in sand or silt. GPR helps archaeologists pinpoint these features and can reveal variations in depth, aiding in chronology determination. However, it may be less effective when differences with the surrounding soil are minimal or when there are many materials with different dielectric constants—that is, the ability of an object to hold electrical energy, leading to noise (Conyers 2016). Ideal conditions include flat, even terrain and a research focus on documenting chronological changes in buried structures.

Step 3 at Cerro San Isidro

At Cerro San Isidro, Golay Lausanne implemented GPR surveying for the subsurface mapping phase of this project. GPR was chosen because the bedrock, which eroded and littered the surface of the site, is granite; this material tends to have a high magnetic component that would render the magnetometer and magnetic susceptibility unsuccessful. In addition, the team aimed to identify the depth of various features to aid in determining the settlement's chronology.

GPR surveys were done over a total of about 2,160 m^2 across 44 grids (Figure 5), using the Noggin 500® with a SmartTow configuration. These surveys took approximately nine workdays to complete. Flat or minimally sloped areas were cleared of loose rocks, making them ideal locations for GPR surveys. To gain a better idea of the archaeology across the site, we conducted surveys across different regions of it that were chosen because the aerial imagery had already highlighted numerous features there. By conducting GPR surveys in these regions, we hoped to create a more detailed map of the buried structures and determine the chronology of the buried architecture. The GPR survey followed the following parameters: (1) survey transects of 25 cm, (2) step size set to 0.01 m, (3) velocity of dry sand (0.12 m/s), (4) depth set to 2 m, and (5) the required use of forward parallel transects. We decided to follow these parameters because of our experience in the region, and they were the recommended parameters according to the Noggin 500 systems manual.

The survey grids were marked with orange flags at each corner. To record the coordinates of each flag, we flew the UAV over the survey area following the overlap parameters previously noted but at about

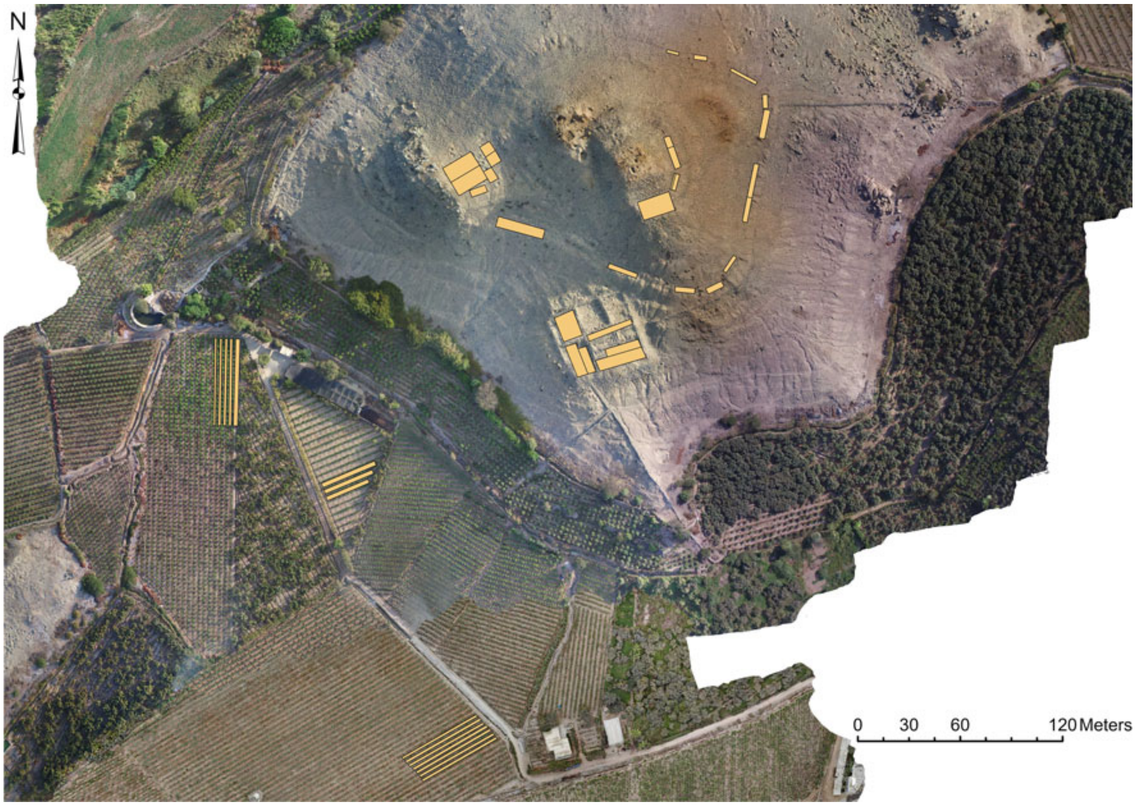

FIGURE 5. Locations of GPR survey grids at Cerro San Isidro.

10 m above the surface. The UAV automatically records the GPS location of the images, giving us the coordinates of the flags. These images were processed and overlaid on the base map in ArcGIS, and each flag was marked with a point. This procedure allowed for rapid surveying of the coordinates and ensured that the coordinates of the grid were relational to the original drone map of the settlement. There are other ways in which this can be done, such as using a GPS and total station, but we chose the UAV method because it was faster, maintained the same coordinate systems, and included the same potential inaccuracy as the UAV imagery. As such, both would be offset by the same or similar amount. Figure 6 shows the results of the GPR surveys overlayed on their grid areas.

STEP 4: DATA PROCESSING AND INTEGRATION

Although each data type requires a different set of protocols and processes to create meaningful results, we recommend following these same steps for all the methods. The first step of data processing is to align the data collected from the different sensors or at different times to a common coordinate system. This is vital to ensuring accurate integration. While processing the data, all noise should be reduced from the datasets to enhance the quality of the information. Data quality of the data should also be enhanced through techniques such as filtering and interpolation, which can improve the clarity of the archaeological features.

To effectively combine datasets, it is essential to follow the previous steps and use geographic information systems (GIS). After processing the datasets, they should be added to a GIS project to create advanced spatial analysis and visualizations. Aerial surveying provides the ideal base map to integrate all other datasets because it typically covers a larger area that encompasses the other two survey stages. The data must be georeferenced to the base map; in this step the researcher associates each dataset with a map, which in this case is the base map collected during aerial surveying.

The pedestrian survey data take the form of coordinates outputted from GPS, which automatically overlay on the base map after being imported. However, the survey locations for the subsurface survey must be georeferenced to the base map. This can be done by taking GPS coordinates of the survey grid and uploading them to GIS or by using the UAV to record the grid locations, as noted in our subsurface survey. Flags or markers of some form are placed at the corners of each grid unit, and the drone is flown over. If using the UAV survey for step 1, this is a useful practice because it ensures the same coordinate system and accuracy as in the first step, making the integration of the datasets more accurate.

When integrating datasets, it is important to consider temporal integration. Certain subsurface methods, such as the GPR, document potential features at different depths. To ensure a relatively consistent temporal frame, the uppermost results from the subsurface data should be included.

FIGURE 6. GPR results across surveys on the core of Cerro San Isidro.

After this stage, the archaeological features within each dataset need to be digitized. There are three ways this can be done: either a polyline is drawn down the center of every wall, a polyline is used to outline walls, or a polygon is used to outline the shape of the wall. The choice is based on the user's preference. Additional features, such as the location of ceramic scatters, channels, and staircases, should be marked as a separate point file based on types. All wall features can be digitized with all features in a single file, or the features can be digitized based on the survey type—for example, one layer for GPR and one layer for UAV—and then merged into a single additional layer. Both methods have their benefits and drawbacks. The first method would enable consistency across all datasets, allowing the features to flow continuously between the datasets. However, then the different layers cannot be teased apart to see where each data type was from or what each survey brought to the table. In addition, when merging the finals, more work needs to be done to ensure that features flow continuously. For example, if part of a wall appears in one dataset and another part of the same wall in another, it would be necessary to manually create one single wall, so they do not appear as two separate walls. The second method also allows one to see what each survey step brought to the table.

Step 4 at Cerro San Isidro

Each dataset was processed according to recommended procedures (Agisoft 2023; Sensors and Software 2018) before being added to ArcGIS. The UAV imagery served as the project's base map, supplemented by the world base map available in ArcGIS. Because the pedestrian survey area extended beyond the UAV imagery, the imagery was included. Ideally, more UAV imagery would have been useful, but time constraints prevented more surveys. However, the pedestrian survey covers all areas where UAV imagery was captured. The GPR data from step 3 was georeferenced to align with the UAV imagery. It is important to note that the UAV and GPR (the coordinates captured with UAV) have a 2.5 m accuracy, whereas the GPS for pedestrian survey is accurate between 10 to 15 m. As such, points taken with the GPS may not be in exact relative position to materials captured with the UAV. Subsequently, the walls within each dataset were digitized as separate shape files (Figures 7–9). This was done by outlining each wall feature with polylines. The drawings were then merged into a single polyline file. Once completed, the polylines were edited to create a clean, cohesive dataset. All additional features, such as staircases, ceramic scatters, and the like, documented in Step 1 and Step 2 were similarly merged into the same map (Figure 10).

STEP 5: DATA ANALYSIS AND INTERPRETATION

Once a single, comprehensive representation of your archaeological site is created, you can analyze and interpret the results to make inferences regarding the historical, architectural, and cultural context of the settlement and its occupation through time and space.

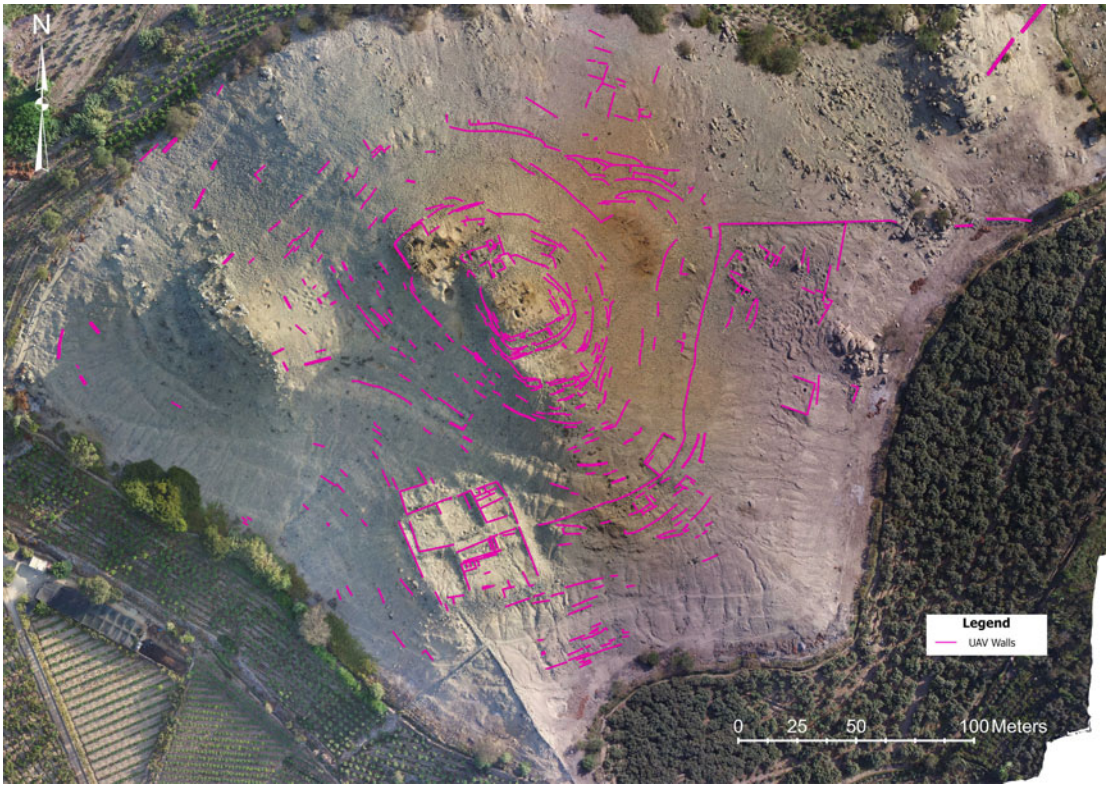

FIGURE 7. Digitized results from a UAV survey of Cerro San Isidro identifying surface walls across the site.

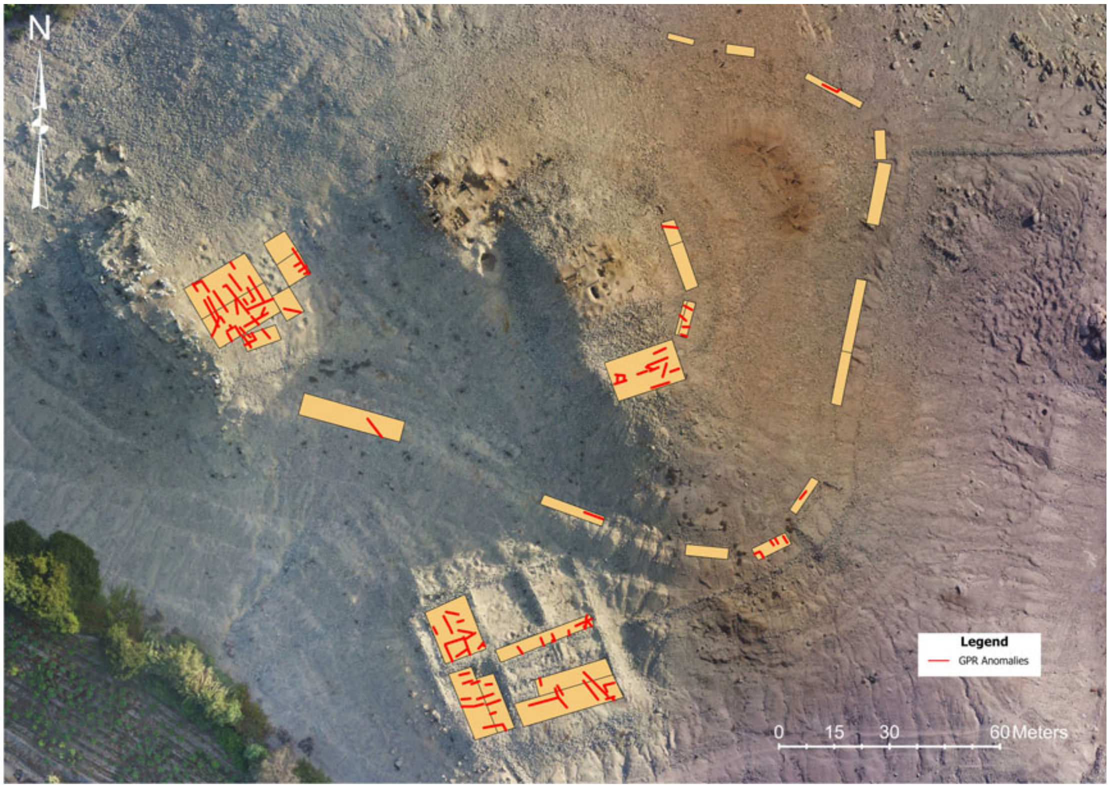

FIGURE 8. Results of a GPR survey on Cerro San Isidro core, showing the digitization of potential anomalies. These results provide a detailed map of potential architecture.

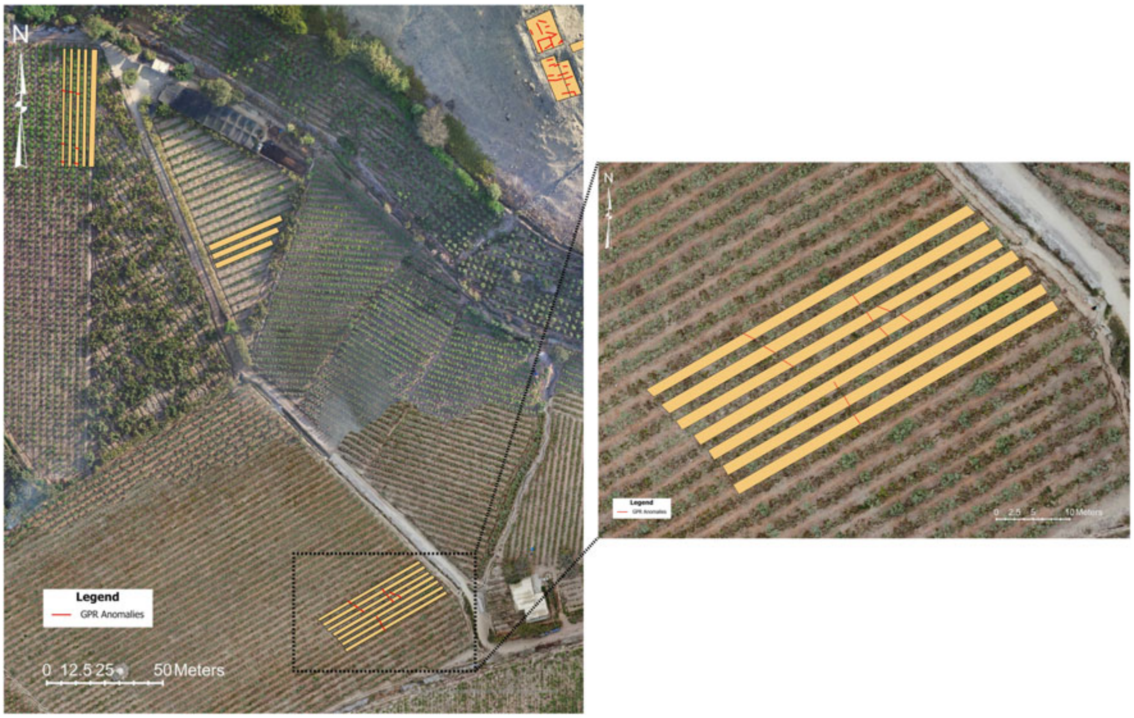

FIGURE 9. Results of GPR survey in agricultural fields surrounding Cerro San Isidro. The zoomed-in section highlights the presence of linear anomalies, suggesting potential walls in the fields.

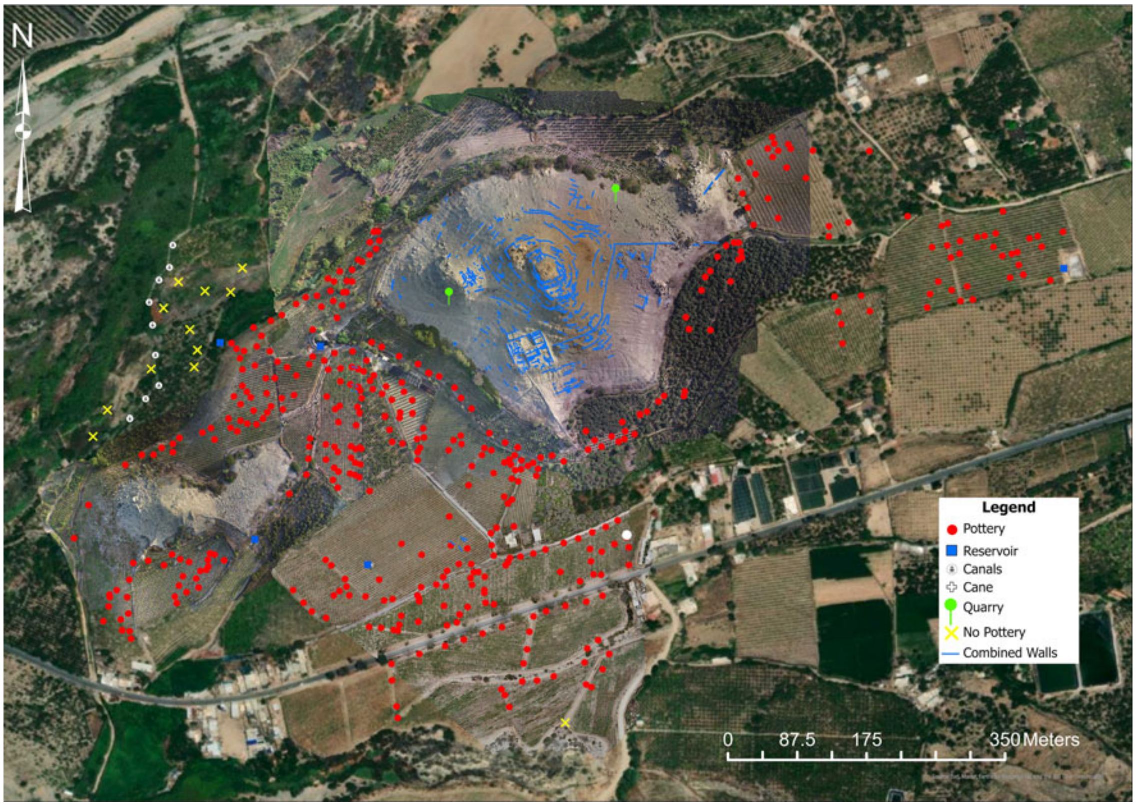

FIGURE 10. Integrated UAV, GPR, and pedestrian survey results.

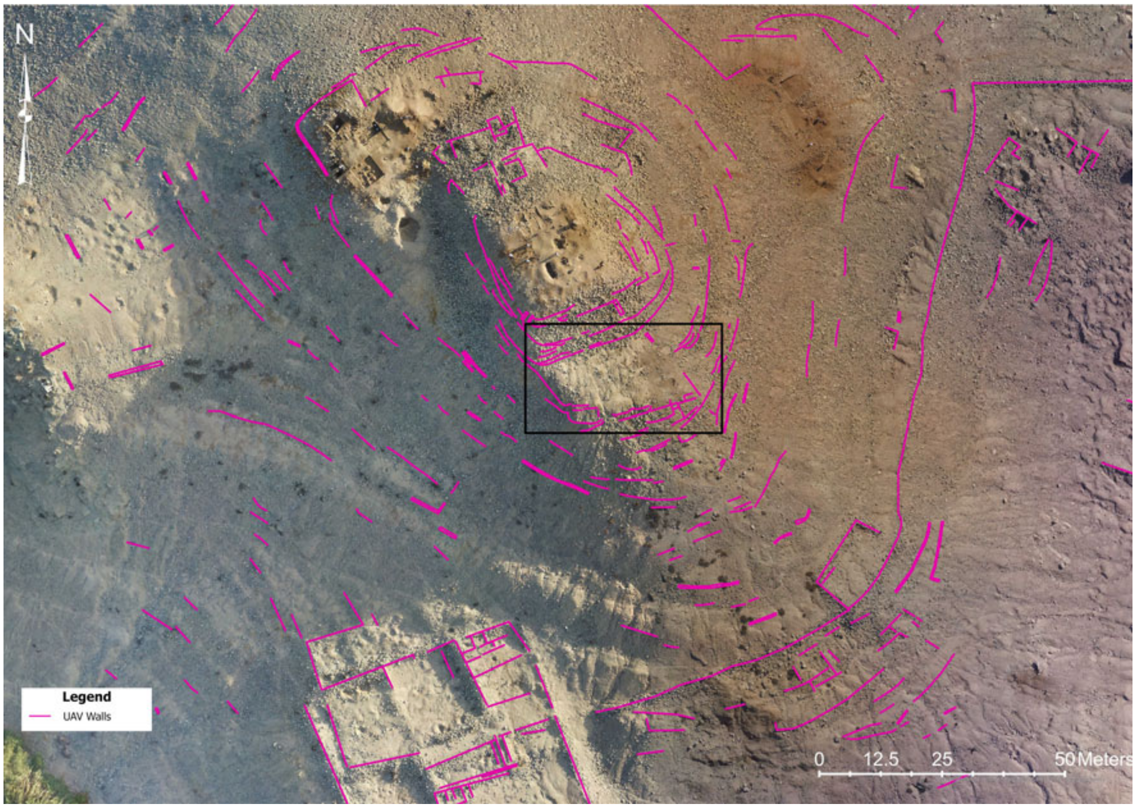

FIGURE 11. Digitized UAV results. The black square indicates the platform area where no surface features were documented. The lack of features in this area would suggest it may have been a plaza.

Step 5 at Cerro San Isidro

This project had two major goals. The first one was to create a detailed architectural map of the settlement to infer the social organization of space (Figure 10). This map indicates that the settlement comprises anthropogenic terraces and a series of clustered architecture platforms. Retaining walls were used to create the shape of Cerro San Isidro as it stands today. Aerial surveying documented a great number of surface features across the core of the site (Figure 7) and provided important information about the spatial organization of the settlement. However, there are many spaces where features are not identified, including multiple platforms (Figure 11), which could have suggested they were plazas. However, subsurface surveying on these platforms identified numerous subsurface features, confirming that these spaces were not plazas but in fact were architectural platforms (Figure 12).

The second goal of this project was to determine the extent of inhabited space at Cerro San Isidro. Whereas previous research recognized Cerro San Isidro as a population center in prehispanic times, the exact extent of this center's reach was unknown. Originally, the settlement core was assumed to be the extent of the population center. Aerial surveying did not document features in the agricultural fields surrounding the site because the surface had been plowed by farmers. Through a combination of GPR and pedestrian surveys, we were able to determine that the site extended beyond the visible central mounds. Individually, the presence of linear features in GPR surveys may suggest the presence of buried archaeological features, but without groundtruthing, we could not confirm that they were features. The presence of ceramics found throughout the fields through step 2 strengthens the GPR data and lends weight to the large extent of subsurface architecture. Although the exact dating of the structures awaits additional research, the preliminary results of our mapping efforts confirm the substantial prehispanic settlement at Cerro San Isidro and hint at its key role in the political consolidation of the area.

CONCLUSION

Multimodal mapping can provide a detailed and accurate spatial representation of archaeological settlements. By combining aerial, surface, and subsurface surveying methods, archaeologists can gather comprehensive data about an archaeological settlement or landscape. Each of the survey methods offers a distinct perspective. Aerial surveying reveals large-scale features and patterns on the surface of the site, providing a comprehensive contextualization of the area. Surface surveying is vital in examining the distribution of features or artifacts, which provides insight into human activities and settlement organization. Subsurface surveying provides detailed information regarding activity areas, subsurface architecture, and, at times, the chronology of the settlement. By combining these three survey methods, as we did at Cerro San Isidro, archaeologists can gain a more complete understanding of

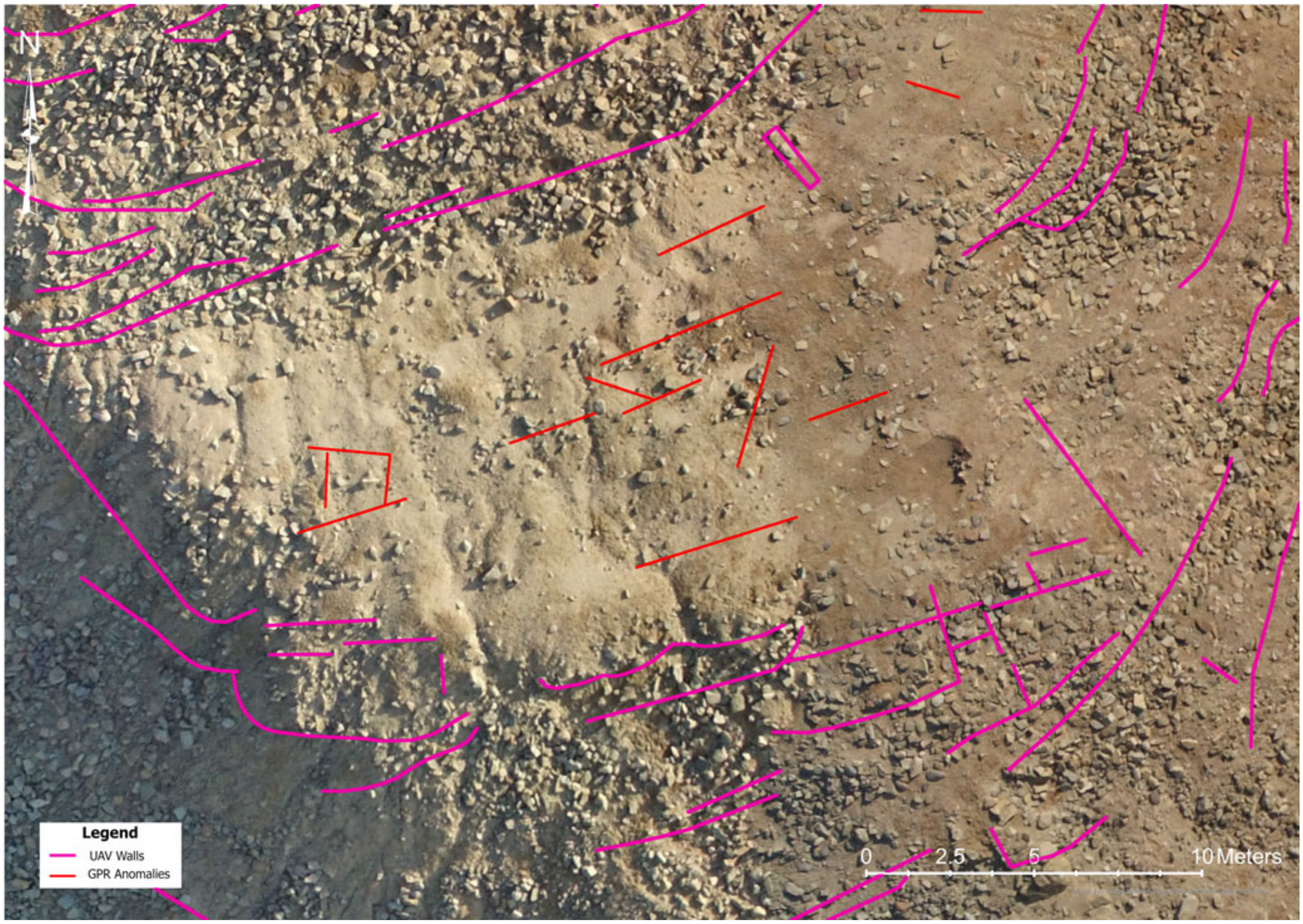

FIGURE 12. Comparison of GPR and UAV digitized results. UAV fails to document the presence of features on the platform, whereas GPR documents multiple anomalies, suggesting that it is an architectural platform and not a plaza.

the material and architectural features and begin investigating their spatial and chronological relations. The methods are complementary and minimize the limitations of each method type in turn, producing a more holistic understanding of the past.

A challenging aspect of coastal archaeology in Peru is navigating the expansion of agricultural fields over archaeological settlements. Through the combination of UAV, GPR, and pedestrian surveys, our multimodal mapping emerges as an ideal method for investigating archaeological features buried under modern cultivation. This method might be deployed in other arid landscapes where modern land use encroaches on partially intact archaeological deposits and architectural vestiges.

Multimodal mapping is a very useful survey protocol. The methods can be tailored to meet the specific research goals of a project and can be used in multiple ways to gain insights into different aspects of a settlement. For example, it can provide a broad overview of a settlement, which can be used to plan future research, such as identifying areas for excavation. This can help researchers target specific areas of interest and those with the greatest potential to yield tangible research results. In addition, multimodal mapping can be used as a research program in its own right, allowing investigators to explore questions about settlement organization and landscape relationships. This can provide valuable insights into the ways in which settlements were organized, how they evolved over time, and their relationships with the surrounding landscape.

Multimodal mapping is minimally invasive and relatively cost effective when compared to a full-scale excavation with its high cost and time requirements. By using multimodal mapping, researchers can gain valuable insights into a settlement without the need for extensive excavation, which can help conserve valuable resources and minimize the impact on the site. Overall, multimodal mapping is an approach that offers archaeologists a unique and flexible approach to exploring archaeological settlements.

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Data Availability Statement

All physical data collected in the field are managed and stored in accordance with regulations from the Ministerio de Cultura del Peru. Data are archived at the Department of Anthropology at McMaster University and Louisiana State University's Department of Geography and Anthropology.

Competing Interests

The authors declare none.

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