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# The documentation of archaeological heritage through aerial photogrammetry and UAS-based LiDAR: the case study of the Espique valley (La Peza, Spain)

The graphic documentation of archaeological heritage has greatly evolved in the last decade thanks to the application of UAS (Unmanned Aerial System). The fast development of these allows for their use as a tool for the documentation of large areas with great efficiency. Furthermore, UAS versatility enables their use with several types of sensor (visible spectrum, multispectral, LiDAR…).

In this paper we present the application of two of these sensors (photo camera and LiDAR sensor) carried on UAS platforms to document the archaeological area of the Espique valley (La Peza, Granada), analysing its advantages and inconveniences. On the one hand, we have performed a photogrammetric flight with a DJI Phantom 4 Pro, georeferenced with Ground Control Points through a GNSS system. On the other hand, we have carried out a flight of the same area with a DJI Matrix 300 with a sensor LiDAR CHCNav AA450 as payload. The possibilities of both techniques have been already explored in literature, but mainly with LiDAR systems with lesser density coverages. This type of sensor has undergone a great evolution in the last years, allowing for a more widespread use in Archaeology.

The results of this research show the utility of both systems to a fast documentation of vast areas of terrain with a remarkable geometric and topographic quality. However, the LiDAR survey has displayed a better performance on those surfaces with higher vegetation, which hinders the photogrammetric survey. But LiDAR surveying with such number of points per m2 forces the use of automatic or semiautomatic classification algorithms. At the end, they are two complementary techniques that are a great step forward in the quality documentation of cultural heritage.

Keywords:
LiDAR; photogrammetry; UAS; archaeology; graphic documentation

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## Introducción.

Archaeology, graphic documents are the fundamental support where to capture the findings, facilitating their location, analysis and dissemination of the results (Martín Talaverano 2014). Having a contextualized and georeferenced record is today an indispensable requirement in any archaeological intervention.

The objective of this study is to carry out a comparative analysis between the new passive (multi-image SfM photogrammetry) and active (LiDAR) remote sensing systems airborne by UAV, and to analyze the subsequent graphic treatment that serves to record the archaeological characteristics of complex sites and especially those covered by large tree masses. The area under study is the valley of the Espique River, located in La Peza (Granada). It is a space of great archaeological interest, with remains of occupation of late antique and medieval times, including ceramics and structures visible on the surface both settlement and a castle, popularly known as the Castillejo de La Peza (Martín and Martín 1999, 369-370; Bertrand et al. 2002; Espinar 2007). This area of work is of great interest for the methodology proposed by the abundant vegetation cover that hinders the visibility of the remains.

This study is part of a complex research project that aims to bring together all the means to identify the evolution of medieval settlement and its relationship with the respective landscapes applying methodologies of Architecture Archaeology and Landscape Archaeology as well as review of ancient written sources.

The current techniques of graphic recording of archaeological and architectural heritage have meant important advances in efficiency and precision, but above all in the way of recording and presenting graphics. The traditional method par excellence of vector representation by means of line planes in plan, elevation and section has been replaced by other means of technological recording, more complex, but more intuitive, by means of three-dimensional models of point clouds and textured meshes. In any case, these "technological reproductions" of reality are not an end in themselves, but constitute the support to interpret and capture the subsequent critical analysis of the element of study. These analytical representations require an interpretive analysis of historical and constructive data that depend on the knowledge and experience of the individual performing the task. Perfectly controlling both representations, technological and analytical, is not an easy task, usually resorting to multidisciplinary teams to obtain a better result of the research.

Chronological analysis requires very detailed graphic records to identify the different historical characteristics as well as their interrelationships. In this sense, the quality of orthophotographs and the ease of use on CAD programs constitute an ideal support to interpret and record the different Stratigraphic Units (UE), key elements to identify the historical nature of a feature.

These technological advances have also caused inconveniences. The huge variety of instruments requires a great specialization. After several tests, multi-image photogrammetry (SfM) along with LiDAR survey in high vegetation areas on board of UAV systems have resulted in the most suitable method for our objectives. These require new necessities for the design of the surveys: type of UAV system, flying licenses, fly height, overlap of the images, hour span for image capture, climatology, position and number of Ground Control Points, size of the targets, etc. These survey techniques generate a huge amount of data for the generation of full 3D models, with geometries equivalent to those obtained with a Time of Flight terrestrial laser scanner. The tests made with different flights with different systems has allowed us to make a comparison between the data gathered and the quality of the results, establishing a clear workflow thanks to the methodological evaluation.

## Materials and Methods.

The new photogrammetric recording techniques SfM and LiDAR have replaced the classic data collection in the field with tape, distance meter or Total Station, and graphic representations per line by other types of technological representations, more and more intuitive based on the capture of millions of points in 3D with texture and their subsequent digital representations on orhtomosaic and mesh as DSM, DTM. In addition,

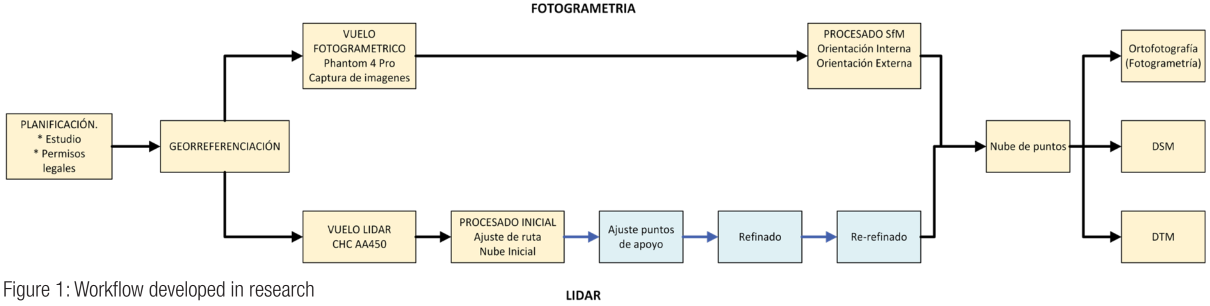

Figure 1: Workflow developed in research

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Table 1: photogrammetry Sfm - Lidar photogrammetry comparison

| Photogrammetry SfM | LiDAR |
|---|---|
| Passive sensor: they capture ambient light. Itis overly sensitive to lighting changes. | Active sensor: generates a laser pulse that bounces off the object. By analyzing the return time it is able to calculate the distance. Not affected by ambient light. |
| Georeferencing: can be direct in UAVs with GNSS RTK and/or indirect based on the identification of support points (GCP). | Direct georeferencing. In case of failure the recording of Data Rinex it is not possible to process based only on points of support (GCP) |
| Photogrammetry can only restore objects that are visible in images. Those objects covered or partially hidden cannot be returned. | Lidar is able to penetrate through the small gaps of vegetation and capture hidden elements such as terrain or structures. It is of great help to locate archaeological sites covered by dense vegetation |
| RGB: The source of photogrammetry information is the geometric and color matrix of each of the pixels of the images, being able to generate hyperrealistic orthophotographs of great metric precision. | LiDAR: The source of geometric information is the different rebounds of the laser pulses. Some systems incorporate additional RGB cameras that allow coloring to the point cloud. Lidar AA450 has a Sony camera synchronized with LiDAR, from the photographs obtained with this sensor we can resort to photogrammetry to generate orthophotography. |
| Image processing: Depending on the number of images and their resolution, the processing of information and obtaining the point cloud can be slow (hours or even days) | LiDAR processing: After the process of synchronization of the Rinex data between the base station and the LiDAR, the point cloud is obtained directly (fast) |
| Point cloud: Each point contains information about its position in space and color information:<br>X, Y, Z, RGB | Point cloud: each point contains information about its position in space, color information and the return in which it has been captured:<br>X,Y,Z, RGB, nº return, intensity. |
| Accuracy: Photogrammetry offers better planimetric accuracy (X,Y) | Accuracy: LiDAR offers better accuracy in Z |
| The density of points/m2 depends on the flight height, being constant throughout the surface. Depending on the level of resolution can vary between 400 and 1000 points / m2. | The density of the LiDAR cloud is variable depending on the height, speed of the aircraft and overlaps. In areas of overlaps, the density is multiplied. Being about 570 to 1700 points/ m2 at 50m high and 5 m/sg. |

its implementation on UAVs allows the capture of complex and extensive lands and archaeological sites.

Although the methodology of surveying by UAV is very similar between photogrammetric systems and LiDARs, there are some differences that need to be highlighted: Table 1: photogrammetry Sfm - Lidar photogrammetry comparison

The advantages and disadvantages that show one and the other means that they have to be treated as complementary techniques, not exclusive. (Alfredsen et al., 2018; Chen & Clarke, 2016)

Undoubtedly, the most important quality of LiDAR systems is to penetrate between the small holes of the vegetation generating several pulses depending on the different rebounds (leaves, branches, terrain, etc.) which allows a classification of the cloud according to the intensity of reflected ray and its depth.

According to these premises in the following diagram we establish the workflow developed in our research based on the UAV registration technology.

1.Planning:

The execution of flight with UAV requires a precise planning that guarantees the total coverage of the area to be lifted and complies with all the technical and legal specifications required.

The flight plan must take into account technical aspects such as meteorology (wind, rain, visibility, etc.), flight height , aircraft advance speed, transverse overlap between passes, or others such as longitudinal overlap between images or camera configuration (diaphragm, shutter speed, focal length, ISO) for photogrammetry capture. It is also necessary to take into account possible obstacles such as cables or electric towers, height of trees, public roads with traffic, uneven terrain or other legal type such as the non-invasion of prohibited or dangerous geographical areas.

There are many commercial or free applications, both for tablets, smartphone and desktop that help us plan the flight, allowing us to program the route of the UAV with ease to guarantee an optimal execution of the flight and capture: UgCS, MapPilot, DJI Ground, Drone Harmmony or Pix4D. etc.

The great unevenness existing in the study area has forced us to make a flight with constant height on the ground (AGL) thus guaranteeing a data capture with the same geometric resolution. Most APPs have this tool that loads a generic DTM that allows the aircraft to move vertically following the irregularities of the terrain.

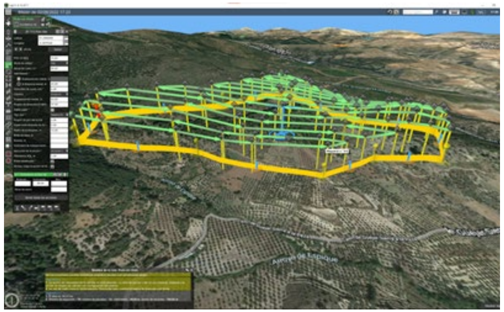

Figure 2: Scheduled flight plan with UgCS app with constant height on the ground from the IGN DTM.

## 2. Georeferencing.

Except for UAV equipment that has GNSS-RTK, the coordinates obtained by the internal GNSS of the UAV, not receiving differential corrections, are not precise enough to obtain a scaled and georeferenced digital model that guarantees the reliability of the data. Therefore, in the case of photogrammetric surveys and prior to the realization of the flight, it is necessary to place a series of control points (GCP) that will be perfectly identifiable in the photographs and that allow the correction of position and orientation of the images to achieve centimeter accuracy (James et al, 2017; Zhang et al, 2019; Cabo et al, 2021).

To obtain coordinates, an Emlid GNSS system has been used, Reach RS2+ model, RTK measurement, receiving differential corrections in Real Time from the Andalusian Positioning Network (RAP). The absolute accuracy of GCPs ranges from 1 to 3 cm, depending on the specific conditions at the time of capture: number of satellites observed, relative situation between them, distance to reference antennas, obstacles and GPRS coverage.

Coordinates of the open-air support points were obtained using GNSS, using the official reference system in Spain for the work area: ETRS89 UTM 30N and using orthometric heights with the geoid EGM08_REDNAP. For the area covered with high trees, where GNSS cannot measure, landmarks were located by using the total station.

The georeferencing of the survey with LiDAR AA450 is carried out, in post-process, once the flight is over, by synchronizing the Rinex data captured by the fixed GNSS equipment and the Rinex data captured and recorded by the LiDAR guaranteeing high accuracy.

## 3. Photogrammetric survey.

The photogrammetric survey system is widely known by researchers, with many references in archaeology and architecture, both in the process of capturing from UAV, as well as in the orientation of images and three-dimensional modeling (Nex & Remondino, 2014; Agudo, 2014; Aicardi 2016; Chiabrando et al, 2017; O'driscoll, 2018; Rouco-Collazo et al, 2020; Arévalo-Verjel, 2022 ).

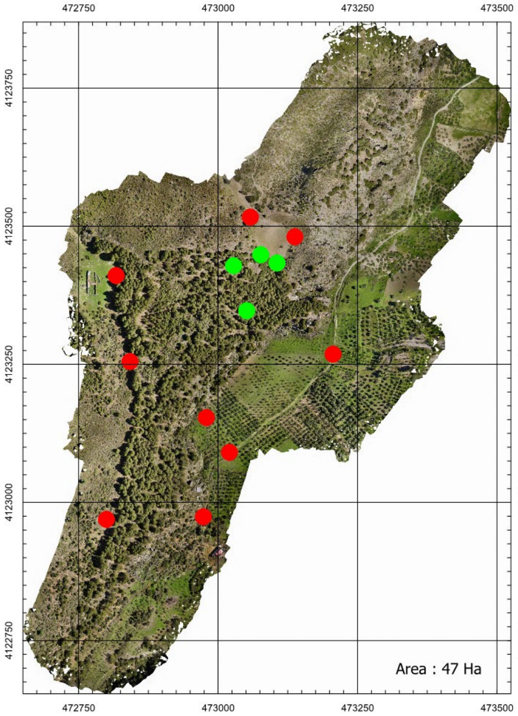

Figure 3: Distribution of Ground Control Point capture by GNSS (red) and Total Station (green). ETRS89 UTM30

Photogrammetry the quality of the results is greatly influenced by the correct capture of the images. Proper configuration of the camera sensors (O'Connor et al, 2017) and flight planning are decisive for the goodness of the results. In this sense, for a higher quality in the acquisition of data in areas with large vegetation it is very important to evaluate the effects of the flight altitude and especially the transverse and longitudinal overlaps of the UAV passes (Puliti et al, 2017).

In our research, a DJI-Phantom 4 PRO UAV has been used programming an autonomous flight using the UgCS APP at a height of 50 m, a speed of 5 m/s, with a camera configuration of 1/1200 shutter speed and ISO 200, which guarantees us sharp images with a GSD of 1.5 cm. Longitudinal overlap of 85% and transverse overlap of 80% has been chosen, increasing the density of points and allowing the capture of higher elements (trees).

For image processing and dense point cloud generation, we use Agisoft Metashape software resulting in a dense unfiltered cloud of 313 million points (600 pt/m2).

Subsequently, the point clouds were filtered using a statistical outlier removal algorithm (Zhang, Wu & Yang, 2019) and classified using the fabric simulation algorithm (Klápště et al, 2020) for the location of the terrain points. In our case study, an automatic classification has been made according to the following filtering parameters: maximum angle of 35º, maximum distance between points 8 cm and 30 m of cell size. In this way, we obtained a classification as "terrain points" and "unclassified points" (De Lima et al, 2021).

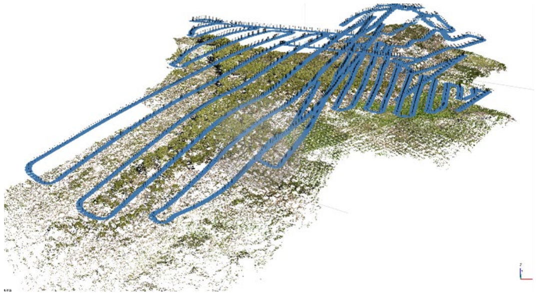

Figure 4: Position of the images and discrete cloud made from the internal orientation in our research.

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## 4.LiDAR Survey on UAVs.

LiDAR is the acronym for Light Detection and Ranging. It is an active sensor, since it produces its own light in the form of laser pulses, measuring the distance between the emission point to the point of impact with the object or surface. To do this, what is really measured is the time it takes that laser pulse to reach a target and return to it, calculating the distance between the two points. The main components of which a LiDAR measurement system is composed include a platform (airplane, UAV, car, tripod, backpack, boat, etc.), laser scanner system, GNSS system (Global Positioning System) and an inertial navigation system (INS) that measures the parameters of rotation, inclination and heading of the system. (Puliti, 2020, Web IGN, 2022).

For our research, the DJI Matrice 300 UAV has been used, mounting as a sensor the AlphaAir 450 LiDAR of the Chcnav brand. This LiDAR works autonomously, independently of the UAV in which it is mounted, integrating a Livox Avia LiDAR sensor and a Sony 26 MP BRAND RGB sensor, with which it is possible to provide RGB color to the point cloud and be able to perform SfM photogrammetry.

Specifications CHC AA450 Lidar.

| | |
|---|---|
| Absolute accuracy | H: 10cm V:5cm (Sin puntos de control, altura de vuelo 50 m AGL) |
| Weight | 950 gr |
| Point density | 570 ptos/m2 a 50 m AGL<br>280 ptos/m2 a 100 m AGL |
| Maximum number of returns | 3 |
| Scan speed | 240 000 pts/sec (first or strongest return)<br>480 000 pts/sec (dual return)<br>720 000 pts/sec (triple return) |
| GNNS System | Dual-frequency GNSS GPS, GLONASS, BeiDou, Galileo, sampling frequency 5 Hz |

It is important to note that before starting the planned mission for LiDAR, it is essential to calibrate your internal IMU, making a small flight with a trajectory in the form of "8", starting the mission automatically once it has concluded. (AlphaAir 450 UAV LiDAR SOLUTIONS MAPPING & GEOSPATIAL, 2022).

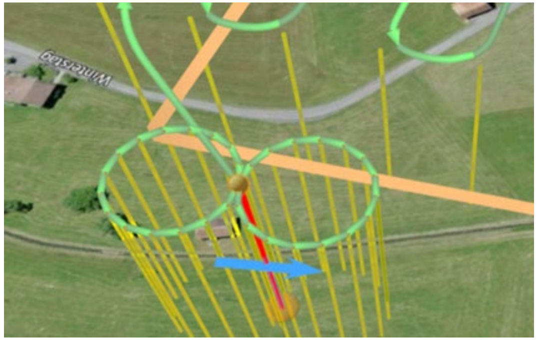

Figure 5: IMU Lidar calibration pattern.

Figure 6: DJI M300 RTK y AA450

### 4.1.Downloading and processing data:

For the precise determination of the georeferenced coordinates of the base is carried out by prost-process with the synchronization of the Rinex data of the fixed equipment and those obtained from the permanent network of antennas of the RAP (Andalusian Positioning Network). The precision obtained in the coordinates of the base is 1mm.

The raw data, also called primary data, constitutes a series of measurements of the time and intensities of the pulses returned. (Lozić & Štular, 2021). In the recording stage this data is correlated with the information from the GNSS base, the images captured by the RGB (coloring point cloud) sensor, the inertial measurement unit (IMU) and the support points (GCP) to calculate the geodesic position of each return. (Wehr , 2018) (Lozić & Štular, 2021). As a result, a point cloud is obtained, in which each point contains information of X,Y,Z, RGB, Return. For this initial processing, a CopreV.2 software is used. In accordance with the objectives of our work, the flight has been carried out with a height of 50 m and a speed of 5 m / s, without using support points on the ground, obtaining a maximum error of: horizontal 5 to 7 cm and vertical 2 to 4 cm.

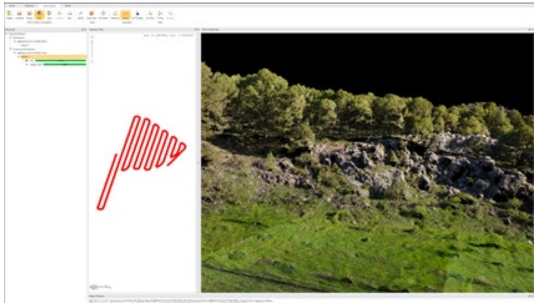

Figure 7: CoPreV2.0 Lidar point cloud and path processing software.

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### 4.2. LiDAR point cloud classification.

The most important of the LiDAR methodology is the automatic classification of terrain or non-terrain points. This is a probabilistic process, in which any classification includes positive failures (ground points classified as non-soil) and false negatives (non-terrestrial points classified as soil). (Lozi□c & Štular, 2021).

There are numerous algorithms for filtering: groundFilter, implemented in Fusion software , max local slope and elevation threshold with exand filter implemented in the free ALDPAT (Airborne LiDAR Data Processing and Analysis Tools), Simple Morphological Filter avaiable as a tool for MATLAB, Lasground and Lasground-new part of Lidar processing toolkit LAStools, etc. . (C□□eanu & Arcadie, 2017)

Para la clasificación de la nube densa generada con LiDAR AA450 se ha aplicado el algoritmo lasground (LAStools), con los siguientes parámetros: todos los retornos, natura and ultra-fine. (Yang et al, 2016; Rizaldy et al, 2018, Doneus et al, 2020; Nurunnabi et al, 2021).

## 5. Results.

### 5.1. Point cloud.

As a result we have 3 classified point clouds. The LiDAR point cloud from the high-altitude flight of IGN-PNOA is barely observable because it has a very low point density (0.5 to 2 points/m2). LiDAR point clouds on drone at low altitude and the one made from photogrammetric flight have a good density of points. It can be seen how the cloud of LiDAR AA450 presents points inside the vegetation and shows a continuous line of terrain, while the cloud by photogrammetry represents only the outer part captured by the image, showing discontinuities in the terrain.

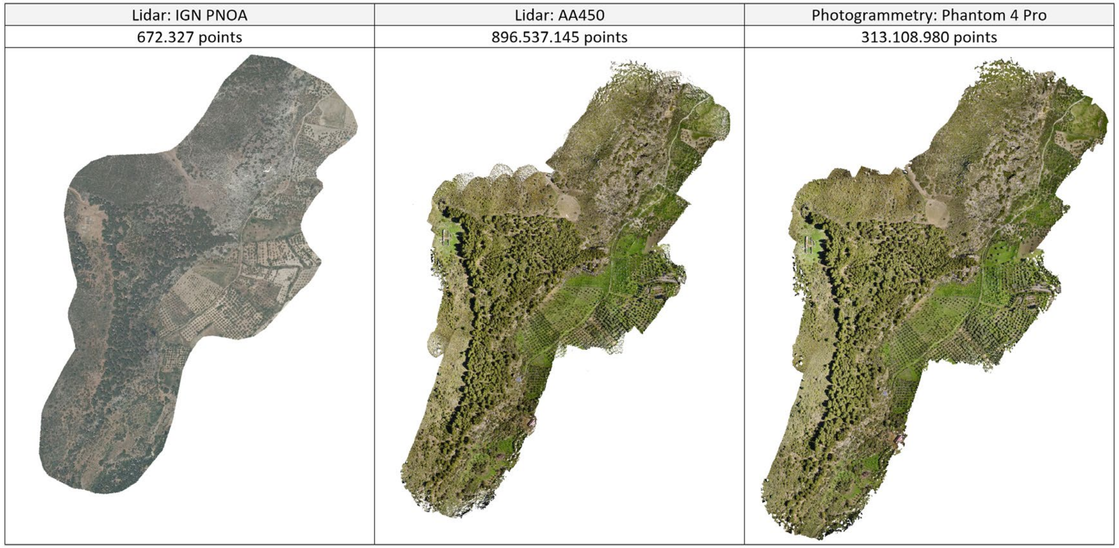

Figure 8: : IGN PNOA Point Cloud - AA450 Lidar - Phantom 4 Pro Photogrammetry

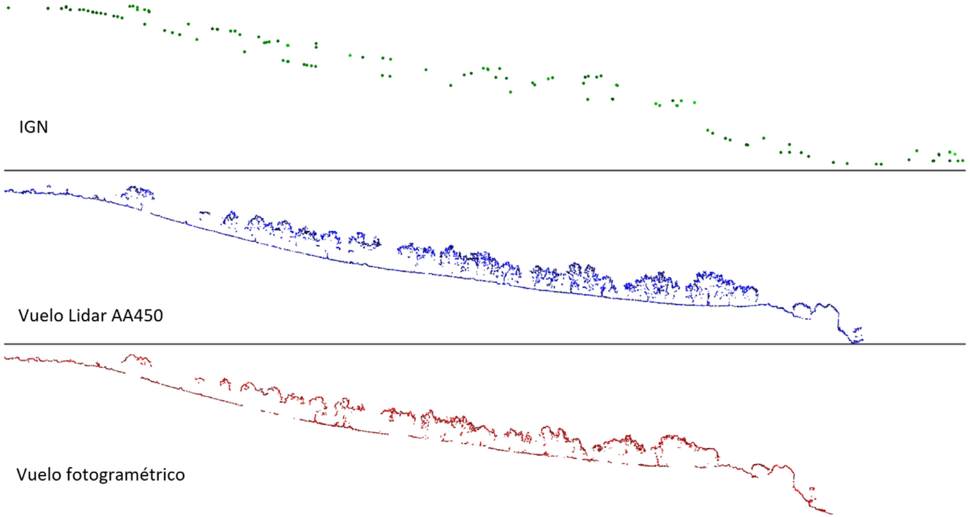

Figure 9: : Profile on point clouds.

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5.2. Orthophotography:
The IGN offers orthophotographs of the PNOA flight whose pixel resolution of the image is 25 cm. In Spain the maximum flight height for UAVs in the field is 120 m (400 ft), therefore, the largest GSD that can be produced with a Phantom 4 Pro is 3.3 cm. To increase the GSD you should fly at a higher altitude and exceed the limit of 120m. Therefore, a flight with UAV will offer a high resolution spelling.

5.3. Dsm. Digital model of surfaces, is calculated with the surface points obtained, representing vegetation, buildings, etc. For a better visualization of the result, a Hillshade algorithm has been applied to the DSM. The result allows an interpretation of the terrain to be made with the naked eye. The IGN cloud-generated DSM does not show sufficient detail for the needs of our research. The photogrammetry DSM offers a good level of detail, but tends to soften the shapes, with the DTM of the AA450 Lidar showing the full level of detail both in terrain, trees and other objects.

5.4. DTM. Digital model of the terrain. It is calculated with the points classified with terrain (Zietara et al, 2017),class defined by the ASPRS: 2 (soil). The DTM of the IGN continues without giving resolution for the objectives of our study. The photogrammetry DTM correctly shows terrain details, but those areas where it does not have terrain points because there is a lot of vegetation, photogrammetry programs perform a triangulation with the perimeter points of those holes, generating flat elements from the available information. In contrast, the DTM generated by the AA450 LiDAR faithfully displays the terrain details and does not remove any information.

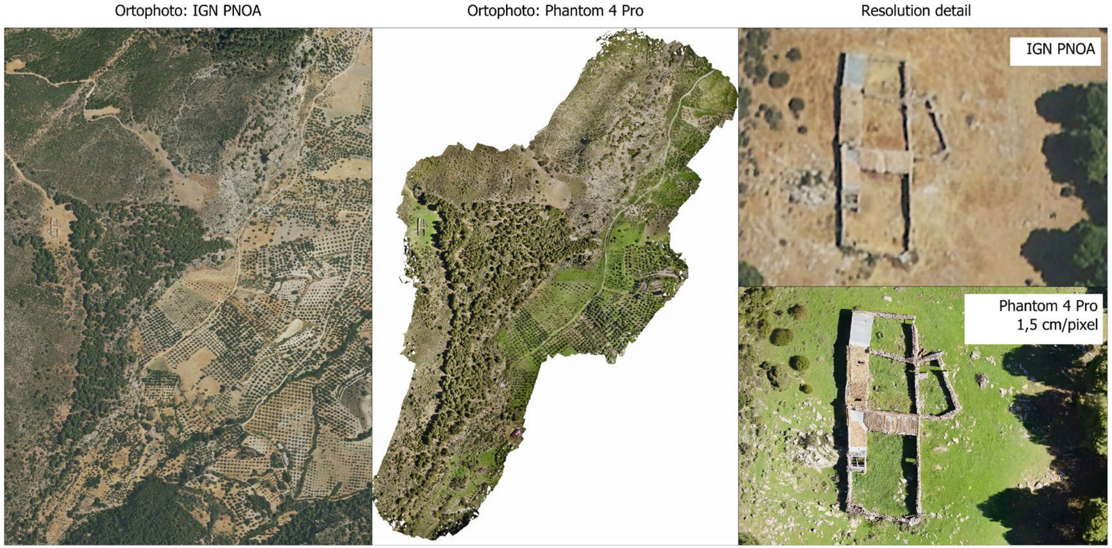

Figure 10 : Orthophographs: IGN PNOA and flight P4 Pro

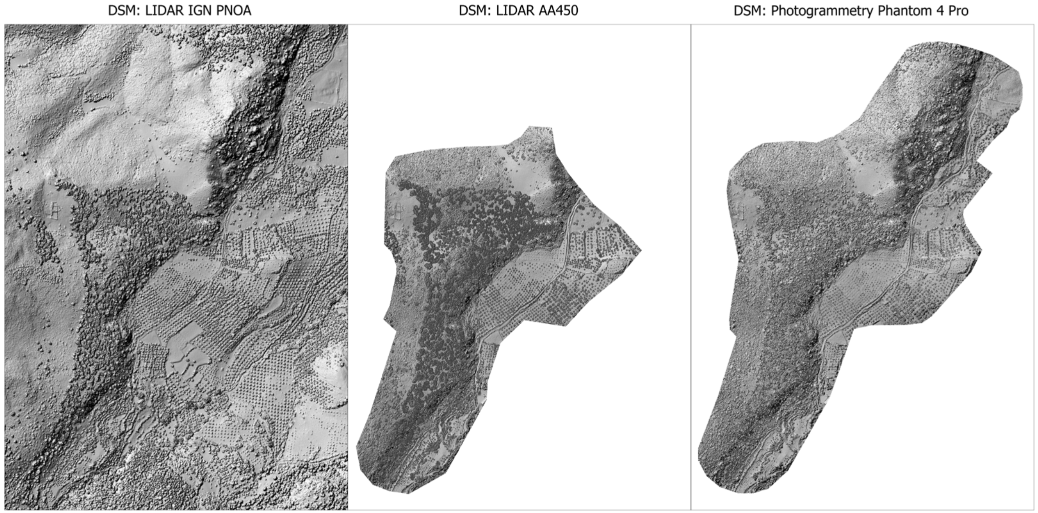

Figure 11 : DSM results.

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## Results and conclusions.

The information offered by the IGN with its PNOA flights does not offer a high enough resolution to work with them at the scales of archaeology. Therefore, they are only useful in previous phases of study, such as the location of possible remains and serving as reference models to perform AGL flights with UAV. At the largest scales required for the topography and analysis of archaeological remains, photogrammetric surveys and LiDAR with UAVs are a fundamental working tool due to the high resolution they have demonstrated. Both techniques are complementary, although in the case of areas with dense trees, the penetration capacity of LiDAR has made it possible to fill the gaps of photogrammetric surveying. Thus, analyzing the results of the DTM, two areas can be found in which the Lidar shows structures not visible in the photogrammetry of interest for subsequent archaeological study.

Straight alignments are shown that are not typical of the natural terrain. Some structures that are visible in both photogrammetry and Lidar, areas in which vegetation leaves visible gaps. However, there are structures that are only recognizable in Lidar flight because the vegetation cover is too dense.

The Lidar transported in UAV provides a great advance in the archaeological documentation under high vegetation as has been verified in this work. Its usefulness is manifest both for the previous phase of documenting large areas of land quickly, identifying anomalies that can be later checked in the field and that could go unnoticed in a traditional prospection on foot, as well as for the mapping of them with a fairly high precision for archaeology both with topographic support or without it.

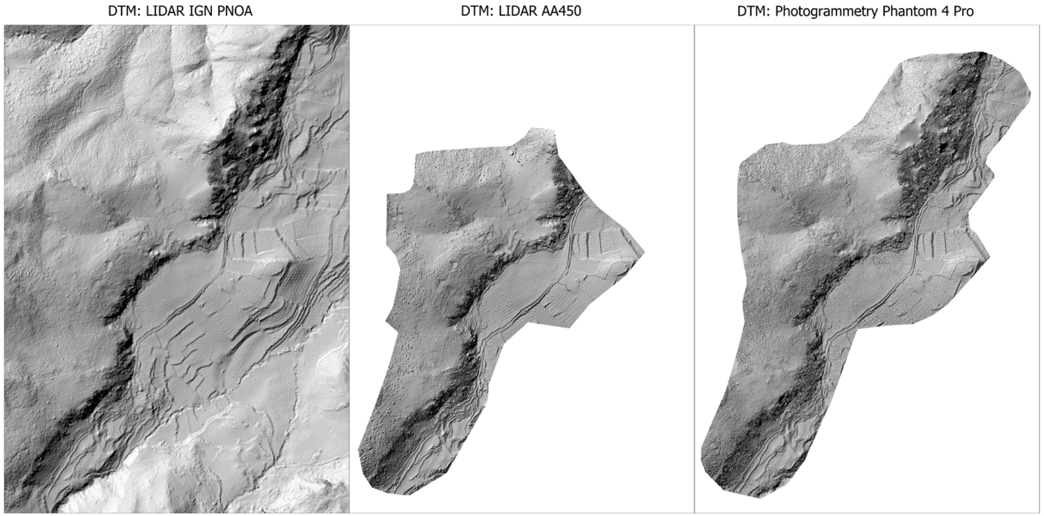

Figure 12 : DTM results.

Since the purpose of the work was to locate possible locations of structures for archaeological study, the initial precision without topographic support is more than sufficient: H = 10cm V = 5cm. For future research, the Lidar workflow will be completed with topographic support and refinement of the point cloud, as well as a Lidar-Photogrammetry processing will be carried out only with the AA450 Lidar.

At present, the use of UAVs in archaeological research is well known, allowing to obtain very accurate graphic documents and in a shorter time. In addition, all data is recorded, stored, processed and analyzed through the use of digital tools (Previtali and Valente 2019). The registration and management of heritage assets through three-dimensional digital models allows a better study and knowledge. Without ever underestimating topographic measurements and classical representations by line, inmost cases, it is easier and more useful to generate three-dimensional models that retain both their complex

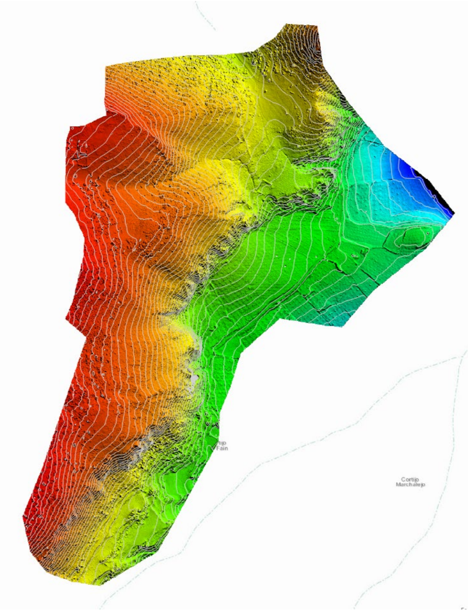

Figure 13 : Hypsometric plan of the Valle de Espique site (La Peza)

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geometry and their original texture, than to take measurements and write them down directly in the field.

The generation of graphic documents is increasingly complete and accurate, making virtual reproductions that can be considered hyperrealistic. Three-dimensional models of point clouds or textured meshes are managed by a wide range of computer applications to produce 2D representations or three-dimensional models and views that improve and facilitate their compression and diffusion (Martín Talaverano, 2014). Similarly, digital technologies facilitate exchange and interoperability between the agents involved.

The analysis and comparison of results from photogrammetric surveys, LiDAR on UAVs and topographic with GNSS and Total Station has allowed us to check the metric reliability of the different registers and establish a workflow for field and processing tasks according to the final needs.

An aerial survey with LiDAR sensor on UAVs is often the optimal solution for prospecting and mapping archaeological structures in terrain covered by dense layers of vegetation, but due to the lower geometric accuracy and lack of texture it is not enough for a detailed archaeological record, so it is necessary to be completed with other records from the ground with TLS LiDAR systems or terrestrial photogrammetry.

The low resolution of the LiDAR surveys generated by manned flights at high altitude of the IGN-PNOA (0.5 to 2 points / m2) have proven to be an effective means for the global analysis of the territory but are not useful for the location of sites and the recording of archaeological remains.

The research carried out on the medieval site of La Peza provided interesting data on the distribution of archaeological structures in the archaeological area of the Espique Valley. Especially in the wooded area of the slope adjacent to the castle, which points to the existence of a medieval settlement unknown until now that will have to be confirmed by future archaeological work. This provides new data on spatial distribution and chronology using non-invasive methods.

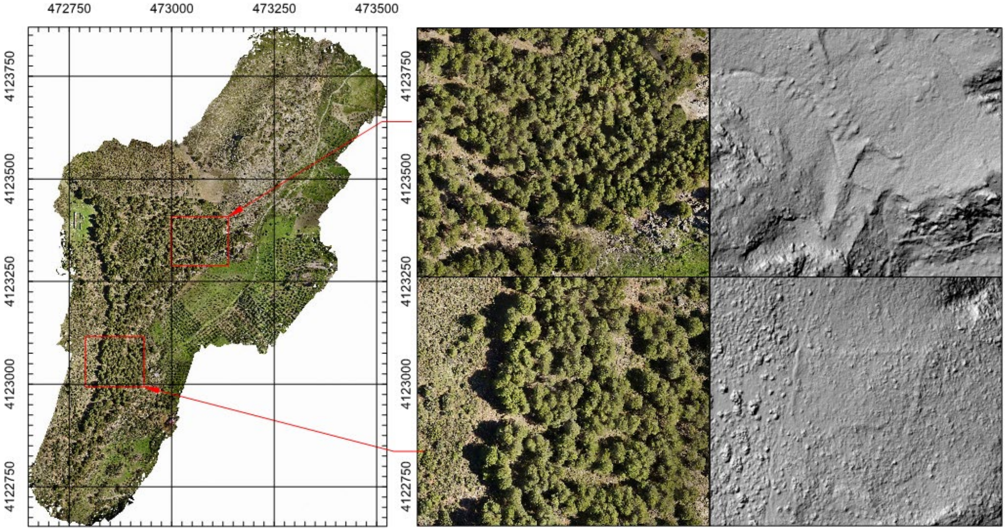

Figure 14 : Location of study areas.

After this case study, the use of photogrammetry and LiDAR mounted on UAV have shown great effectiveness for the detection and topography of archaeological remains. In addition to being able to use both techniques in a complementary way to obtain as much archaeological information as possible, LiDAR has been a useful tool to survey the surface of areas of thick vegetation, penetrating under the tree cover. The cheapening of these equipment in recent years, although they continue to require specialization for their management, opens an interesting field of experimentation and application to the documentation of archaeological remains, with great potential to modify our knowledge about the patterns of settlement in the territory of past times.

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