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Remote sensing and archaeology in Modern Age: The study case of the Aldea de Buenos Aires in Sierra Morena

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ABSTRACT

In this paper we demonstrate a holistic strategy for the study of the disappeared Aldea de Buenos Aires (Sierra Morena, Aldeaquemada, Jaén, Spain), founded in 1767 within a complex of foundations called "Nuevas Poblaciones" under king Charles III (1759–1788). In order to achieve the goal, we combined different documentary sources – manuscripts, printed materials, maps – and we associated them with information obtained by the use of different remote sensors, such as LiDAR, UAS-based photogrammetry and multispectral data. The final analysis of the collected data enables us to propose a hypothesis on the urban structure and dimensions of Aldea de Buenos Aires, along with its interrelation with the surrounding landscape and agricultural partitions.

1. Introduction

Among researchers in Modern History, a traditional approach is that accurate reading of textual sources would be sufficient to grasp a complete understanding of a certain fact. That sole strategy, however, albeit fairly efficient in the detection of some types of evidence, is in fact prone to uncertainty and interpretation issues. In current research it is becoming widely accepted that a more effective method calls for the integration of different kinds of input along with that focused on archival sources only. Other types of survey methodologies may provide a useful contribution towards the intended research goals (Campana, 2018). Several workgroups in the scientific community of researchers in Modern-History – one of them is at the University of Jaén - are positive that historical landscape can be investigated through an appropriate combination of tools, considering different factors.

Numerous examples support this conclusion. The case discussed in this paper, i.e. the Aldea de Buenos Aires, is a particularly clear one. First of all, a fair amount of archival sources (maps and various other written records) allow to start from a relatively high level of knowledge. In the second place, the material status of the remnants of the Aldea, as they can be seen on the field, allow to identify its components with adequate clarity. Finally, an appropriately integrated set of survey methods, including fieldwork, UAV-based aerial observation and comparison with previously acquired remote sensing data provides information about relationships between the now disappeared Aldea and its historical surroundings. The two latter research lines may powerfully complement purely textual records and hence provide additional information of archaeological type: this can bring about, nevertheless, a more complete historical view of the defunct settlement, by adding crucial, valuable data. Such data, having been kept out of official written sources, are either recovered by integration of multidisciplinary methods, or is bound to remain hidden from the historian's awareness.

From this point of view, it is the authors' opinion that remote sensing techniques such as those described in this paper are the ideal way to shed light on the examined topics. Indeed, in the presented case, the combined analysis of information obtained at different scales and through different sensors enables us to develop an interpretation of the urban core and of its relations with the immediate surroundings.

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2. Research goals

Aldea de Buenos Aires, located in proximity to present-day municipality of Aldeaquemada, in the region of Sierra Morena, is an ideal candidate due to its characteristics.

By ground-surveying the site it is possible to observe ruins of buildings (Fig. 1), yet several doubts remain about them: Do the identified structures correspond to the 100% of the historic village? What was its total size? What was the village's relationship with the surrounding area?… The answers to all of these questions will show the importance of the study area, due to the connections between Aldea de Buenos Aires and the hometown of Aldeaquemada. To achieve the results, we intend to reach the following goals:

Obtain a graphical documentation of present-day conservation status of Aldea de Buenos Aires.
Integrate the information contained in the historical texts and maps with the additional information collected during our surveys.
Develop a hypothetical planimetry in order to reach a better understanding of the urbanistic structure and of its relations with the surrounding area.

3. Historical background

In the northern region of present-day province of Jaén (Andalusia, Spain), around the Despeñaperros Natural Park, spanning across eastern Sierra Morena, there is the Aldeaquemada municipality, one of the so-called *Nuevas Poblaciones de Sierra Morena*, founded since 1767 by king Charles III (1759–1788). These new settlements formed a *superintendencia*,[1] a sort of new province resulting from different *feligresías* (parishes)[2] which gave birth to an aggregation of places, villages and small towns, all of them with a common history, yet with different evolutions and outcomes (Fig. 2).

The new communities of the Sierra Morena were founded and developed through the reigns of Charles III, Charles IV and Fernando VII, in the interval between 1767 and 1833, retaining intact their juridical status, until its dissolution in 1835. They were a symbol of the Bourbon's reforms.

In the case of Jaén's kingdom, now Jaén's province, the following new communities were founded: La Carolina, as the capital, Aldeaquemada, Arquillos, Carboneros, Las Correderas, Guarromán, Miranda del Rey, Magaña, Montizón, Navas de Tolosa, Rumblar y Santa Elena, plus a group of 17 *aldeas* (villages) (Fig. 2).

Aldeaquemada was under the juridical rule of the *Fuero de las Nuevas Poblaciones de Sierra Morena* (1767). King Charles III's colonization project was supervised by superintendant Pablo de Olavide y Jáuregui in 1768. Lands belonged, mainly, to the Casa Ducal de Santisteban, and also to already existing settlements, such as the Viso de Marqués, of stately property, in the province of La Mancha (Pérez Fernández, 2019, pp. 38–47).

Beginning from the issuance of the aforementiond *Fuero,* Aldeaquemada was converted into one of the *feligresías* of the new settlements of the Sierra Morena, whose capital was at La Carolina. The area belonged to the *Superintendencia* of the new communities (Pérez-Schmid Fernández, 2018, pp. 75–77).

Under mandate by Olavide and by the sub-delegate of the Sierra Morena Miguel de Jijón, works began, on August 20th, 1767, for the delimitation and the designation of the *suertes*, i.e. agricultural lots. However, other foundations took place only a year later along the Camino Real with Venta de Linares (Navas de Tolosa), Carboneros or El Rumblar, and along the Camino de Valencia with Arquillos and Venta de los Santos. Therefore, Aldeaquemada, was another example of community founded in 1768, on a secondary access path to Andalusia.

The first report of works commencing in Aldeaquemada is associated with the construction of a chapel on February 10th, 1768 and that of a walled cemetery, far from the town, followed by the construction of a church. The latter was consecrated on January 8th, 1769 (Lanes y Duval, 1787, Fol. 98).

Other sources mention the date of May 12th, 1768, for a letter that superintendent Olavide sent to Miguel de Múzquiz. In the document, Olavide presented the tasks that Múzquiz was supposed to carry out in some areas of the new settlement. While construction was well underway by its civilian commander, Miguel Rubio, it was decided in July 1768 to send two contingents of settlers so as to place 50 families in Aldeaquemada. The community's leadership was assigned to lieutenant colonel Johann Kaspar von Thürriegel. Spanish settlers from Valencia, Cataluña, La Mancha and Andalusia were later added (Pérez-Schmid Fernández, 2018, pp. 298–318).

Due to complications occurred in logistically sustaining the scattered settlements in the *feligresías*, superintendant Olavide built three new hamlets in 1774: Aldea de Santa Cruz, in the route of Santa Cruz de Mudela; Aldea de Buenos Aires (known today as Aldehuela) located in the Castellar route; and Aldea de la Tamujosa. Lanes reported that: "aldea Buenos Aires is located east and about a short half league away" (Lanes y Duval, 1787, fol. 101, our translation) from Aldeaquemada. Hamlets of Buenos Aires and Tamujosa were demolished in 1793, because of poor quality of the buildings and unfavourable local climate, and Aldea de Santa Cruz was abandoned in 1807, its inhabitants moving to the current area of Aldeaquemada.

4. Material and methods

4.1. Sources from archives and libraries

As a starting point we used existing archival documentation about the area: on the one hand, the *Plano Topográfico de la Feligrecía de Aldeaquemada* created by Joseph de Ampudia y Valdés (Fig. 3); on the other hand, the previously cited texts, such as the report by Lanes y Duval (Lanes y Duval, 1787), the distribution books[3] and various documents from repositories and libraries.

The Aldea de Buenos Aires features a modular plan: it corresponds to the pattern used in constructing the new settlements. Its length in the N-S direction is approximately 93 m and a central axis divides it into two symmetric halves.

As for the represented houses, two types are documented. On the one hand, rectangular houses of approximately 35 m × 12 m (4 units in total) are located at the northern and southern extremities of the *aldea*. A second type, located in the centre of the *aldea*, appears to be the combination of two modules derived from the rectangular house, but joint together at an angle. Four examples of these second-type-house are symmetrically located in the centre of the aldea, forming a square with an approximate surface of 454 m^2.

4.2. LiDAR data

The Government of Spain, through the data repository of the *Centro Nacional de Información Geográfica* (National Centre for Geographic Information) (CNIG, 1988), in line with European Parliament and the Council directive (I DIRECTIVE 2007/2/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 14 March 2007 establishing an Infrastructure for Spatial Information in the European Community

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[1] A body in charge of management and surveillance of a specific economic or social sector.

[2] A *feligresía* is a part of a diocese, resulting from territorial divisions in the organization of the Catholic Church. In this case with administrative functions, they were already divided into departments.

[3] In Spanish "libros de repartimientos" (a book that lists the families that lived in a certain village and their lands).

Fig. 1. Remnants of a building, possibly a house or a storage depot, of Aldea de Buenos Aires are visible under present-day vegetation cover.

(INSPIRE), 2007) has established datasets which proved very useful in our investigation. We have worked with the 2008–2015 first coverage LiDAR flights. These data are organized in digital files available in 2x2 km tiles with a density of 2.5 pts/m^2, referenced to the CRS ETRS 89 as per current Spanish regulation (BOE, 2007). All the files are coloured with infrared and RGB textures, derived from ortophoto (Organismo Autónomo Centro Nacional de Información Geográfica (CNIG), 1988). The file used was the PNOA_2014_AND-NE_452-4240_ORT-CLA-COL.laz, which included a total of 1,808,269 points, out of which 955,033 were classified as soil (2. Ground), according to the American Society for Photogrammetry and Remote Sensing (ASPRS). To achieve a better balance between processing time and results, the area was reduced to a total surface of 31.62 ha (Fig. 1), hence the points classified as soil decreased to 173,057. Its documentation potential is supported by Chase et al. (2011); Evans et al. (2013); Johnson and Ouimet (2014); Khan et al. (2017) among others.

For analysing the point cloud, we used QGIS plug-in Open LiDAR toolbox (OLI), which is specifically designed around the needs of archaeology. This tool, according to its authors, allows for an improvement in the quality of data, granting access to specific and appropriate tools and a reduction in working time between the 75% and the 90% in terms of data processing (Štular et al., 2021a).

By using this plug-in, we are able to very effectively identify topographic anomalies in the acquired rasters, hence maximizing the usefulness of publicly available data.

This plug-in automatically generates the base cartography to be analysed, the Digital Feature Model (DFM), as well as control information on its quality. This documentation is created by the use of different algorithms: Point Density, Low Vegetation Density, Openness, DEM, Hillshade, Sky View Factor and Digital Feature Model (DFM) (Kokalj et al., 2013; Štular et al., 2021a).

4.3. Aerial photogrammetry

A drone image-based-modelling survey of the area was conducted by two field-work groups using two similar flying devices. The missions were flown aiming to two complementary goals. The first one was to obtain a “general area” survey of a wide zone over and around the Buenos Aires site. This yielded RGB and near-Infrared imagery from a mostly nadiral coverage. The second one was to acquire data for a high-detail 3D model of the formerly inhabited area. In the first case, operations were planned according, mainly, to the available drone endurance and to the specific features of the area. (McLeester et al., 2018). In the second case, flights were planned to collect high-resolution RGB images from different directions and angles.

Flights were carried out in two periods, i.e. October 2021 and September 2022, with topographic references and ground control points taken in both campaigns for enhancing the accuracy of image-based models. The general area orthophotograph was obtained with the structure from motion (SfM) technique (Enríquez et al., 2020) using a DJI Phantom 4 Pro and an EP-O-4 drone - i.e. a customized variant of the Phantom 4 Pro, configured by the Geographic Research and Application Laboratory (GREAL) in Rome, Italy.

The specifications of the performed flights, as well as that of the used hardware, are those used in previous works by some of the authors of this paper (Ortiz-Villarejo and Gutiérrez Soler, 2021).

The survey was planned as a photogrammetric flight following parallel lines under automated drone navigation by using the Pix4D Capture app. Automated flight is necessary to maximize coverage area while also ensuring sufficient image overlap.

Since the 2022 survey campaign called for flying over a wider area, it was necessary to divide the region into two sections, due to drone endurance limitations. The dimension of the two sub-areas where then 383x419 m and 384x455 m. The specified overlap among adjacent pictures was 80%, both vertically and horizontally. For the flight, a maximum height of 60 m a.g.l was programmed, with a maximum speed of 8 m/s. 390 and 401 photographs were taken with this configuration. They were referenced on the ground by 14 control points (GCPS) whose position was determined by a Trimble Geoexplorer Geo7x GPS. The end result of the data processing was the generation of a point cloud made up of a total of 136,000,306 points, which served as the basis for developing two orthophotographs with a resolution of 3.43 cm/pixel and a digital elevation model (DEM) with a resolution of 6.86 cm/pixel. The point cloud has a relatively high density and the result is similar to the point cloud created by a laser scanner, with a density of ∼ 1500 points (Dubbini et al., 2016).

During the 2022 flights, the drone was carrying an additional payload, including a MAPIR 2 survey camera provided by GREAL. This

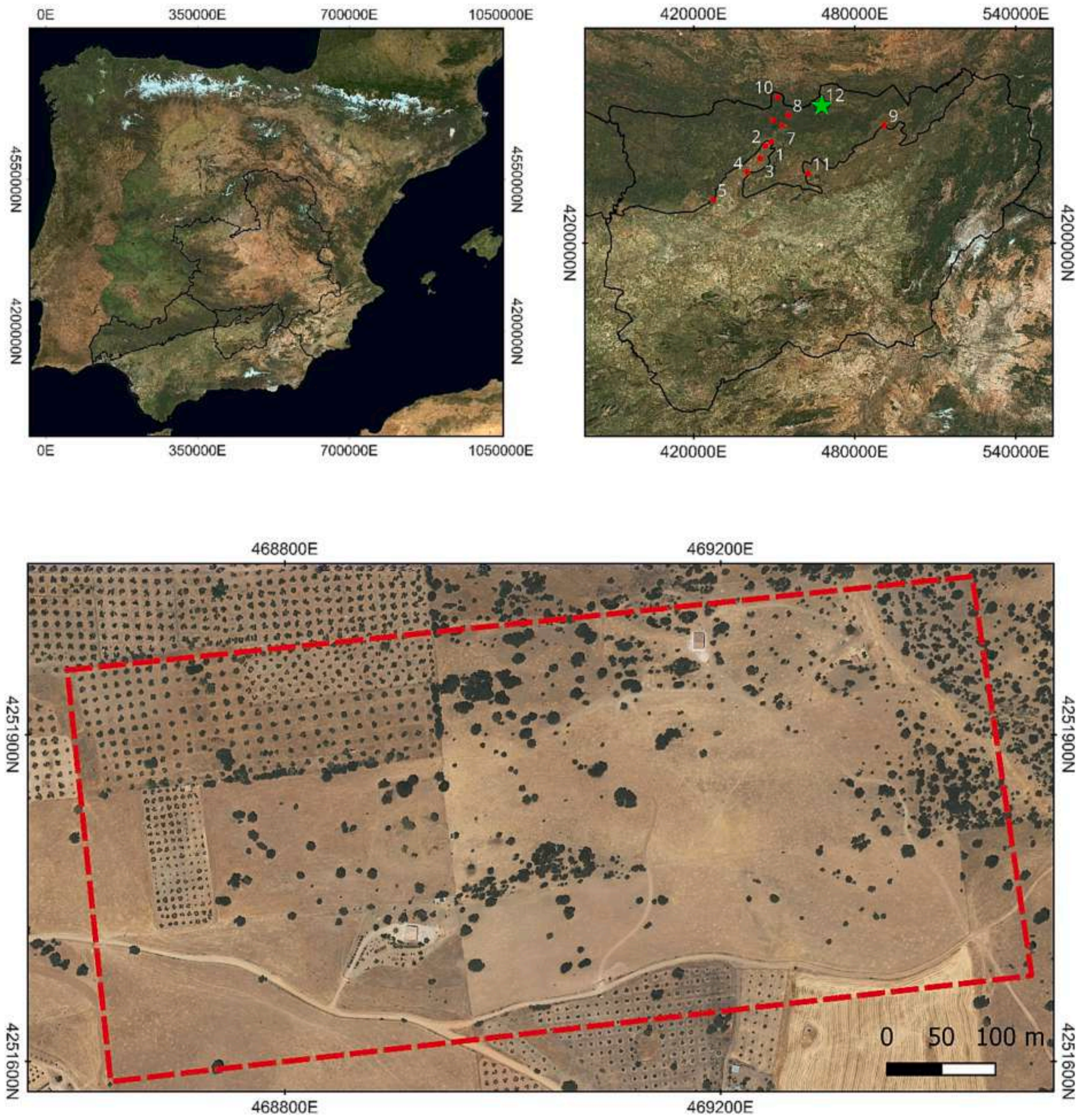

Fig. 2. Localization of the study area (Spain, Sierra Morena, Aldeaquemada and Buenos Aires) and New Populations mentioned in the texts within present-day Sierra Morena boundaries: 1 Navas de Tolosa. 2. La Carolina. 3. Carboneros. 4. Guarromán. 5. Rumblar. 6. Miranda del Rey. 7. Santa Elena. 8. Las Correderas. 9. Montizón. 10. Magaña. 11. Arquillos. 12. Aldeaquemada. The green star marks the study area near Aldeaquemada. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

sensor was mounted on an appropriately installed carbon-fiber rack and was taking time-lapse images which could later be used to generate a multispectral [NIR] orthophotography.

These flights produced a point cloud of 53,320,601 points that allowed to create a multivariable raster. Its spatial resolution of 2.77 cm/pix made it possible to analyze different kind of indexes such us Green-Red Vegetation Index, Red-Green-Blue Vegetation Index, Green Leaf Index, Normalized Green-Red Difference Index as we are going to see in next pages.

The accuracy of the point cloud generated from the described workflow way can be very high. As this was demonstrated in (Agüera-Vega et al., 2017; Kršák et al., 2016; Mancini et al., 2013) among others.

The coordinate system used to georeference the images was that established by default for the aforementioned unmanned aircraft, i.e. the WGS84 geodetic system with ellipsoidal heights.

The general area surveys aimed to maximizing the size of the covered scene. For this reason, once the required level of detail was ensured, the goal was to fly at the maximum possible height above ground. When images from these flights were processed, the reference systems of the output ortophotograph was converted from WGS84 to EPSG 25830 which is the datum used in Spain, allowing a better data fusion among different sources.

As far as 3D modelling was concerned, manual flights were carried-out considering the complexity of all geometries and the necessary multiplicity of views in order to achieve a complete image-based reconstruction of the target (Fig. 4).

In both cases, better topographic and cartographic accuracy is obtained by topographic measurements acquired by Real-Time-Kinematic (RTK) systems handled by professional operators. Geometrical errors in the final model/map are therefore corrected by reference to the network

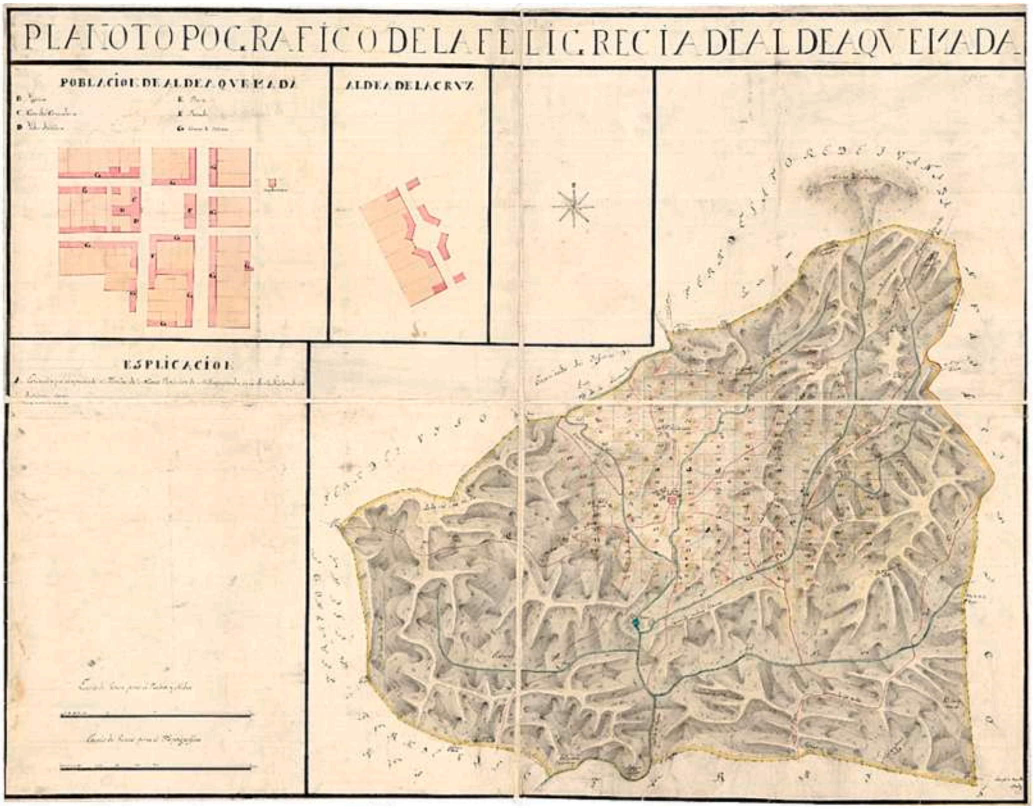

Fig. 3. Topographic map of the Feligresía of Aldeaquemada by Joseph de Ampudia y Valdés.

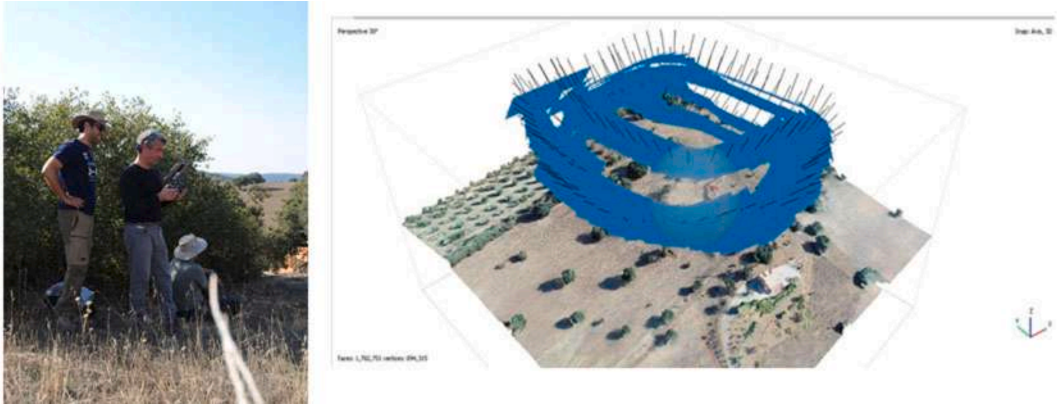

Fig. 4. First-person-view (FPV) piloting and Screenshot from Agisoft Metashape showing camera positions (blue rectangles) during a manually flown, high-detail 3D modelling survey at Aldea de Buenos Aires. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

of topographically determined points.

4.3.1. *Topography from the aerial imagery and its referencing*

To decrease errors in the orthophoto and 3D model, so as to correctly measure the small altimetric variations corresponding to the evident mounds formed by the collapsed buildings of the former *aldea*, and also to make sure that new data could be properly aligned and overlapped to existing digital remotely sensed data and cartographic documentation, 14 GCP were measured considering the indications by Ayala and Smars (Ayala and Smars, 2003).

Thanks to the homogeneous distribution of the GCPs over the surface, as well as for the dimensions of the targets used, we were able to achieve an overall precision of 3.43 cm/pix (Fig. 5).

For the absolute georeferencing of the GCPs for the 3D model, we used Trimble Geoexplorer Geo7X. It is an RTK GPS with differential corrections obtained in real time from the Andalusian positioning network (RAP) (Junta de Andalucía, n.d.). It enabled us to reach maximum accuracies of 2 cm, both horizontally and vertically.

4.3.2. *Data processing of the 3D model*

After carrying out a comparative study between Agisoft Metashape and Bentley Context Capture software, we opted for the latter to carry out the 3D modelling of the studied village. It provided us with a more agile way of managing and visualizing the obtained results. In processing, we followed the default workflow designed for the software (Bentley System, 2021):

1. Data upload.
2. Extraction of camera properties.
3. Aerotringulation.
4. Reconstruction.

Fig. 5. Spatial distribution of the GCP in the centre of the former aldea.

5. Production.

We obtained an internal 3D model that will later be used – in the production phase - for generating different sub-products, e.g. the orthophoto, or the actual 3D model in standardized formats.

4.4. *Analysis of multispectral data*

The use of multispectral images has a long tradition in archaeology (R. Lasaponara and Masini, 2007; Rosa Lasaponara and Masini, 2007) but their use was limited due to the cost and difficulty of acquiring and processing this type of images with sufficient spatial resolution (McLeester et al., 2018).

The presence of unknown – or faintly visible – ruins under the terrain surface may determine changes in growth of weed and crops, creating typical “marks” that can be seen from above, by analysing different vegetations indices (Verena et al., 2012). These combinations can reveal characteristics that otherwise would remain hidden (Agapiou et al., 2012; Bennett et al., 2012; Doneus et al., 2022; Verhoeven and Vermeulen, 2016). Differences in vegetation growth can more effectively be detected if visible-light images (VIS) are associated with near infrared imagery (NIR). The most suitable indices to identify these variations are Normalized Vegetation Index (NDVI) and Soil Adjusted Vegetation Index (SAVI). Both indices enable the analysis of vegetation growth and the information they provide can be complemented by the use of the Normalized Difference Water Index (NDWI), especially after rainy periods, to evaluate the ground water content. These indices make it possible to apply remote sensing in highlighting differences in vegetation growth, so that historical traces may become more evident.

For acquiring multispectral data from the Buenos Aires area, a Mapir Survey 2 Red + NDVI multispectral camera was used. The sensor captured data in the red (R), green (G), blue (B) and near infrared (NIR) The maximum resolution of the camera is 16 Mpx.

Finally, we used PhotoScan Pro version 1.4, which enables users to load all four spectral band images (Green, Red, Red-Edge and NIR) as a single multi-band file, simultaneously processing all of the bands to produce an orthoimage (McLeester et al., 2018). Once the orthomosaic was generated, it was processed by the Raster calculator in QGIS 3.22. This tool was used to analyse the imagery after calculation of the aforementioned indices NDVI, NDWI and SAVI indices, defined, respectively, by the following equations:

1. **Normalized Vegetation Index (NDVI)** (Guha et al., 2022; Uribe et al., 2015).

NDVI= (NIR-RED)/(NIR + RED).

2. **Normalized Difference Water Index (NDWI)** (Gao, 1996; Guha et al., 2022)

NDWI= (GREEN-NIR)/(GREEN + NIR).

3. **Soil Adjusted Vegetation Index (SAVI)** (Rhyma et al., 2020)

SAVI= (NIR-RED)/(NIR + RED + 0.428)*1.428.

NDVI and SAVI indices are both related to vegetation growth.

Different colors were used to paint the data of particular interest (Fig. 8).

Once the above-mentioned formulas were applied to the images, the relevant elements were vectorized. It was then possible to achieve a comprehensive understanding of the spatial distribution of the *aldea* and its relations with elements in the surroundings, along with the interpretation of all the different analysis outputs.

Unfortunately, data obtained from NDWI index did not provide any additional information beyond that provided by NDVI and SAVI indices.

Table 1
List of analyzed historical ortophotographs and their spatial resolution.

Name	Date	Resolution (m/pix)	Source
American Flight B Serie	1956–1957	0.5 – 1	(Ministerio de Transportes, 2004)
Interministerial Flight	1973–1986	0.25–0.5	(Ministerio de Transportes, 2004)
National Flight	1981–1986	0.5–1	(Ministerio de Transportes, 2004)
Color ortophotograph of Andalusia	2016	0.25–0.5	(Junta de Andalucía, n.d.)

4.5. Analysis of historical imagery

We analyzed data contained in Table 1 which, like the LiDAR data mentioned in 3.2, fall within the European directive INSPIRE. Their use is justified by the possibility of conducting a diachronic analysis about the urban structure of Aldea de Buenos Aires, its spatial distribution and its evolution through an interval of 60 years, i.e. 1956–2016 (Prus et al., 2020). Thanks to this work it was possible to document, with relative precision, the conservation status of the houses located in the north of the *aldea*.

5. Results

We precisely established the limits of the observable remnants of the *aldea* in the historical images. In this case we will only show data that yielded information not contained in other sources. Especially relevant proved to be the American Flight Series B (1956–57) and the Interministerial Flight (1973–86) (Fig. 6). In both sources, the same number of structures was documented, although in the first one the division of the houses located to the north can be appreciated in greater detail. Specifically, it is possible to see three independent bodies, two of which are at the W and the E, and one more is in the centre. The latter features a rectangular shape with an area of 120.71 m^2. The W structure of the central area is divided in two, presenting a different morphology from the symmetrical one identified at the E end, that appears to feature a continual shape.

With regard to the central zone, according to the planimetry available for Aldea de la Cruz, one should note that it appears delimited by 4 structures, mirroring each other 2 by 2. In the analyzed historical orthoimages, the structure located at the SW end of these 4 structures has been completely lost, with a few remnants still identifiable. The causes of this disappearance are unknown.

Our analysis made it possible to identify the urban distribution of the Aldea de Buenos Aires, which can be divided in three rectangular bodies, with a surface of 0.22 ha each. These sections would contain, spanning from the houses located in the north to the central area, the central area and the houses of the southern zone. These dimensions match perfectly with the alterations of the surface that were documented in A and B, a fact that indicates a possible modulation of the space.

As far as the interpretation of LiDAR data is concerned, it allowed us to go one step further in the identification of possible archaeological structures. The obtained results were different, depending on the used analysis method. By the plug-in OLI (Fig. 7) (Štular et al., 2021b) it was possible to extract information of the Sky view factor (SVF) (Zakšek et al., 2011), Openness positive hillshade (HS) (Yoëli, 1965).

As we have previously said, the information obtained from our survey proved complementary to that acquired from the analysis of the historical images. This can be observed in Fig. 8. The positively identified traces are scarce, but a longitudinal route in the S-N direction to the east of the village stands out. Although it can be seen on imagery from the National and Interministerial flights, it appears to have faded away in the 2016 Color Orthophotograph of Andalusia. However, everything seems to indicate that we are facing a fossilized parcel boundary. Next to it, an irregularly shaped structure has been identified, which was not clearly identified in images from the historical flights. It has an approximate area of 0.039 ha. After visual inspection on the ground, it corresponds to a rectangular structure with an indeterminate function (7-A).

By the Openness technique (7-B), the presence of a possible path in the southern zone of the central nucleus with an estimated width of 7 m was detected. The path runs in the W-E direction with an average slope of 6%. Although it is true that this width does not exactly coincide with that defined in the General Responses (Sánchez-Batalla Martínez, 2010) in which a width of 8 *varas* is established for the paths between boundaries, the information obtained could be adjusted to these dimensions once a field review is carried out. As we can see, this information is extracted from a low-resolution DEM and, therefore, we are within the margin of error that would made a re-interpretation feasible.

The analysis of the Hillshade technique, (Fig. 7-C) identified clearly what appears to be a rectangular structure with an area of circa 0.045 ha. This possible structure is located in the olive grove at the W end of the studied area, close to a cabin. A relationship can be established with others identified marks of rectangular shape. Its surface is 0.4 ha.

From the spectral indices calculated by the multispectral camera, only the NDVI and SAVI provided new information and, in this case, it was related with the surrounding landscape of the *hamlet.* The analysis of the NDVI index (Fig. 8A) gives us a few new data, that had not been identified through other sensors. On the one hand, it shows the presence of possible remnants of buildings which left no trace on the ground surface. On the other hand, it enables us to establish a possible partition of the farming area, as it appears in the central zone of the image that we are about to consider in more detail.

Complementary to the analysis of the NDVI, we calculated the SAVI index (Fig. 8B), from which an essentially geological information comes. We consider that the NE-SE traces suggest the presence of some paleochannels which, similarly to information obtained from the previous index, did not leave traces on the ground surface. It appears that these channels, especially the largest one, could have played some role (we could not determine the influence level as we are still in the domain of hypothesis) in the internal organization of *suertes*. We doubt, however,

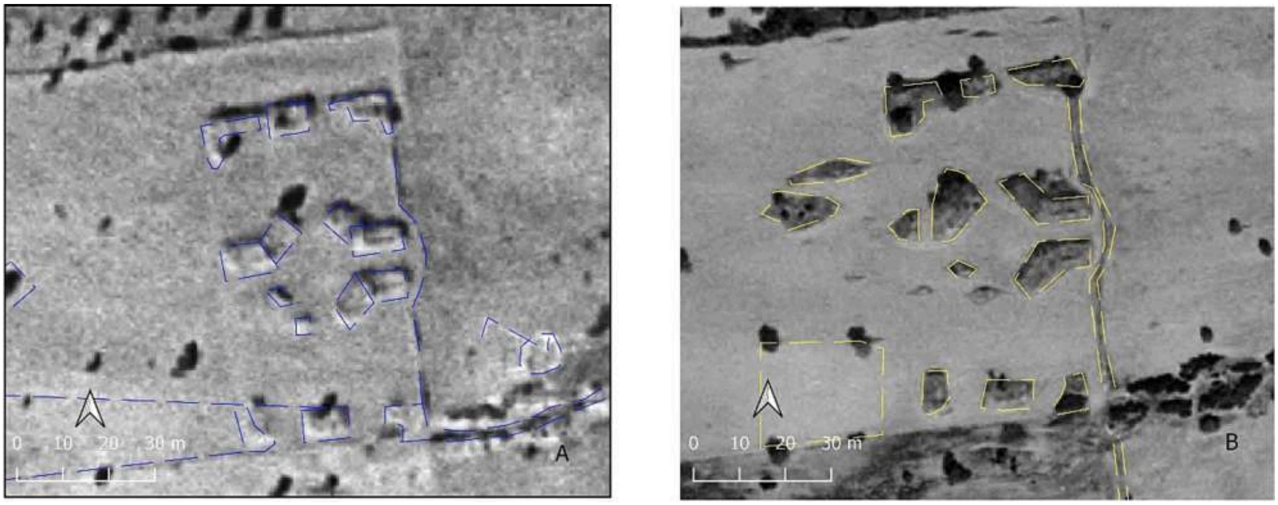

Fig. 6. Photointerpretation of the Aldea de Buenos Aires based on: American Flight B serie (a) and Interministerial Flight (b).

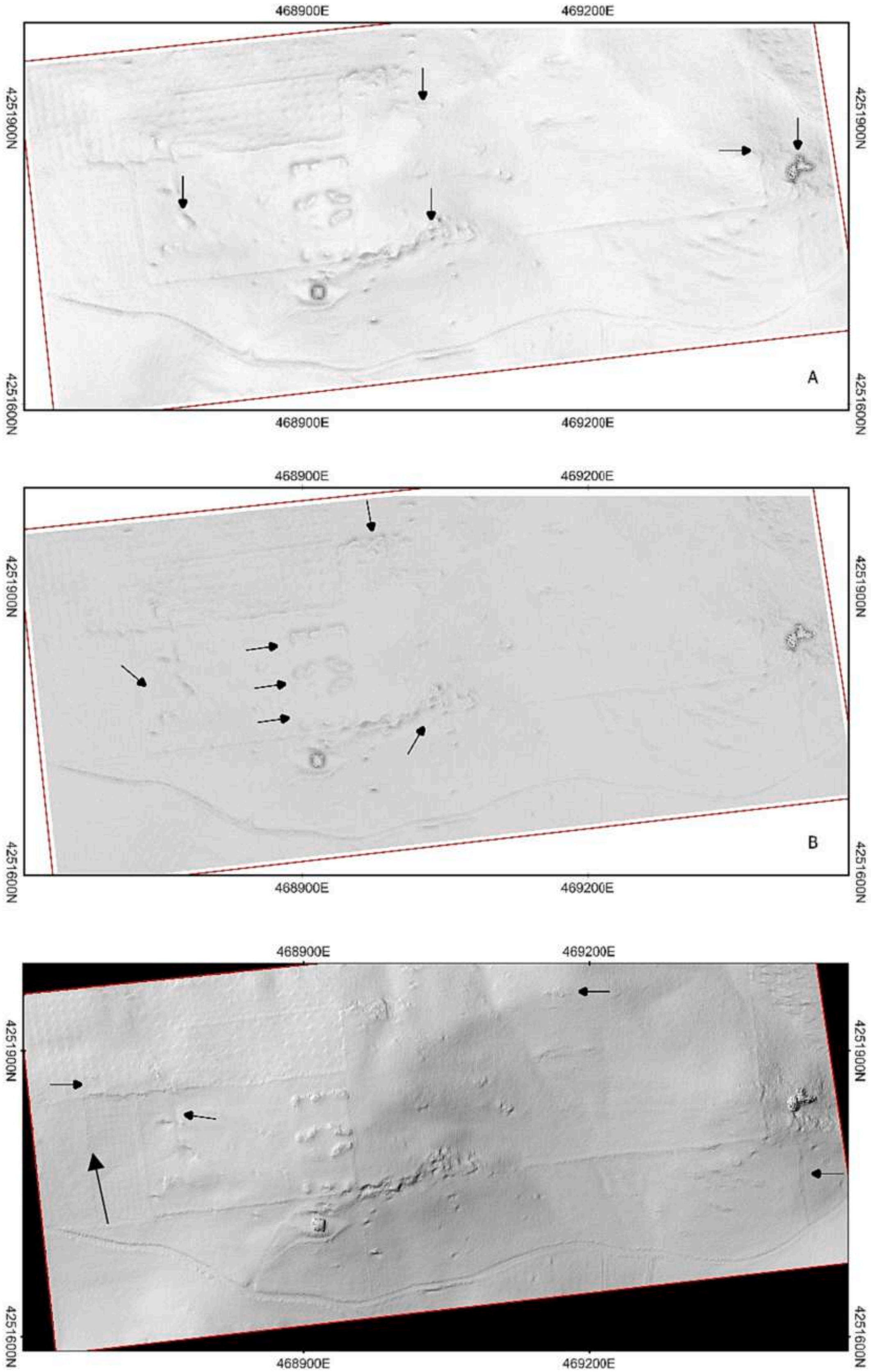

Fig. 7. Interpretation of the DFM as obtained by the use of OLI. A) Skyview factor. B) Openness Positive, C) Hillshade. CRS: ETRS89 – EPSG:25830 UTM Zone 30 N.

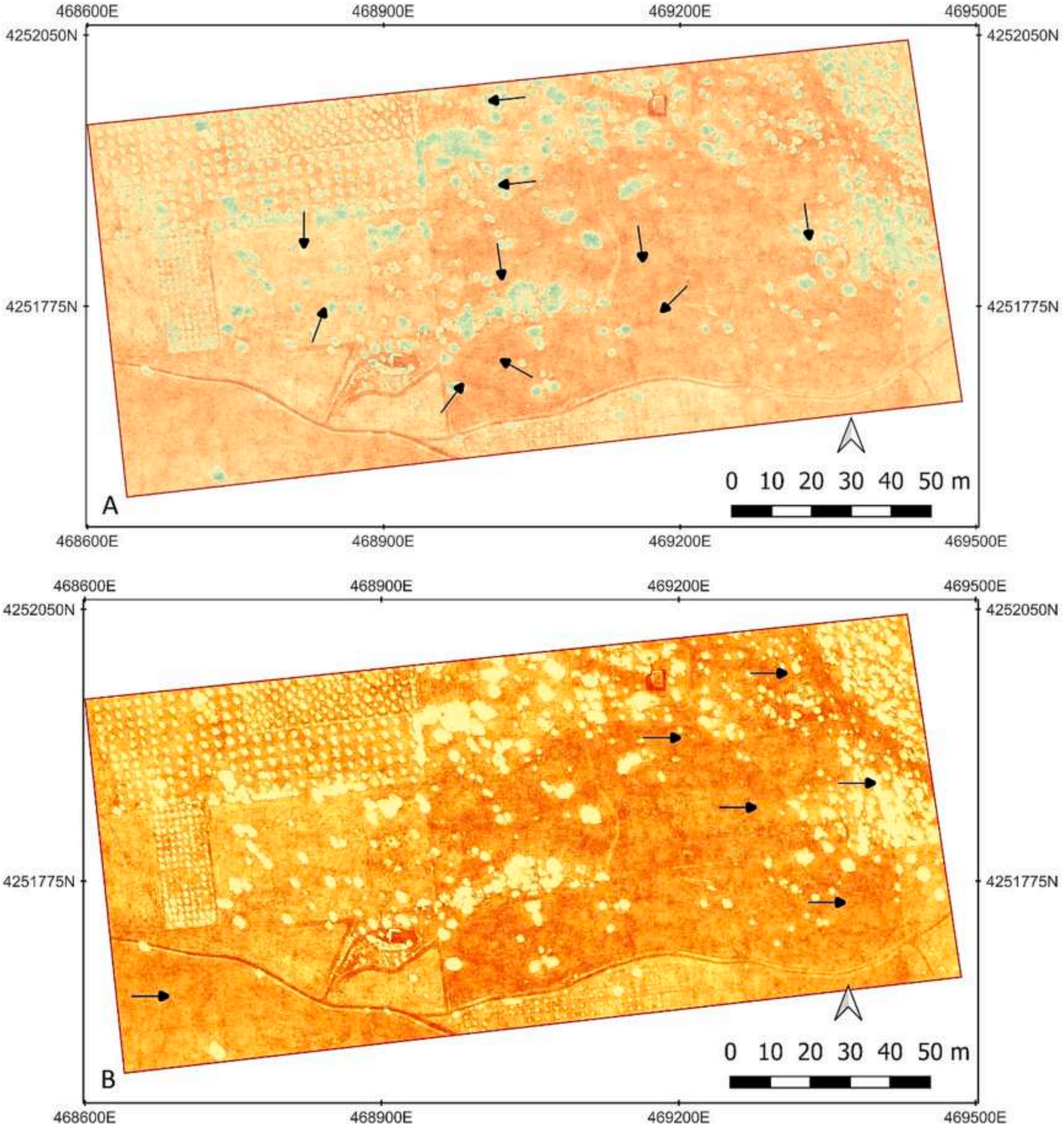

Fig. 8. A: Interpretation of NDVI variations indicating possible archaeological evidences. B: Interpretation of SAVI imagery showing potential archaeological evidence. At the eastern extremity of the image the discussed paleochannels have been highlighted CRS: ETRS89 – EPSG:25830 UTM Zone 30 N.

that they were related to the settlement of the *Nuevas Poblaciones*. At least two theories can be considered: either the archaeological remainings are from before the 18th century, or they are from after the eighteenth-century foundations. We opted for the first option, since the paleochannels are far from the core of Buenos Aires and, therefore, they must correspond to remnants from before the foundations. Besides, if the parcellation and agricultural use had been implemented at a later time, like in the 19th or 20th centuries, such interventions would have left information in notary protocols or cadastral documentation.

We are aware that the surfaces of the identified rectangular units (59.88 m × 37.47 m) do not coincide with the standard dimensions of the *suertes* (800 m × 300 m) established on Art. VIII of the Fuero de Población and reflected by the aforementioned Joseph Ampudia y Valdés' map. This appears evident once the historical map is superimposed on current cartography, but the fact that the vegetation clearly defines that space makes the detail worth noticing. In addition, the module coincides with the division into bodies of the village of Buenos Aires as described above. In order to verify if this subdivision was feasible in the studied area we transferred the *suertes* identified in the aforementioned plan on the orthophotograph from the drone flights (Fig. 9).

The result of this overlay allows for the identification of two different directional patterns, a result of historical evolution. On the one hand, there is a NW-SE orientation that, although aligned with the current elements of the vegetation, is consistent neither with the divisions of the same *suerte*, nor with the other identified elements. On the other hand, with respect to the partitions oriented according to general features in the W-E direction, a superposition of 6 divisions can be seen on the vertical axis while, on the horizontal axis, they appear to be compatible with the paleochannels.

6. Discussion

If we proceed to the joint analysis of the evidence described, the obtained data do not seem to make sense, at least if they are all assumed to belong to the same chronological period. We must not forget that the information obtained with the applied methodology lacks any precise chronology until an archaeological excavation or prospecting campaign is carried out to extract precise information for this purpose. It would be necessary to correctly contextualize the elements for more valuable

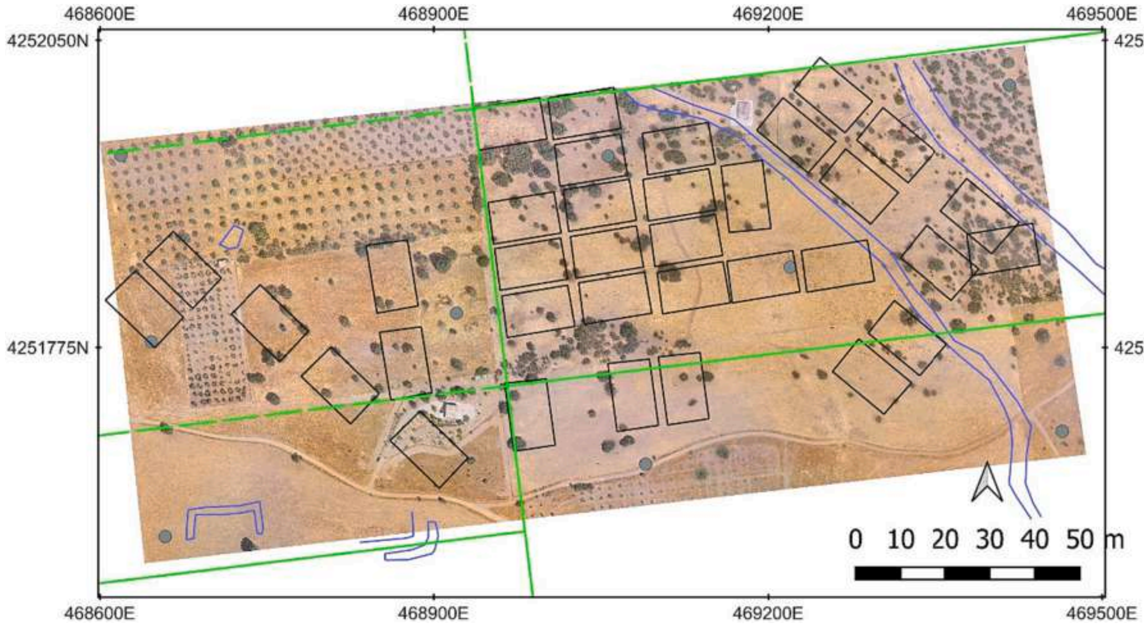

Fig. 9. Overlay of possible internal subdivision of a suerte. It can be noticed that the subdivision fits well with the possible paleochannels. The green lines correspond to part of suertes extracted from the map by Joseph Ampudia y Valdés. CRS: ETR89 EPSG:25830 UTM Zone 30 N. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

information to be acquired.

We believe that the results obtained from the analysis of the multispectral data, NDVI and SAVI, along with those obtained from the analysis of the historical cartography and particularly of the Interministerial and American Series B Flights, are the most relevant for our study. On the one hand, they made it possible to confirm the urban structure of the village as it appears both in the historical planimetry of Josep Ampudia y Valdés and in the written documentation, as well as the deterioration it suffered. On the other hand, they have enabled us to elaborate a proposal for the internal division of the lots, opening the way to new hypotheses about the internal distribution of crops within a lot in a diachronical perspective.

With regard to the documented decay of the area, we consider that two causes might have been involved: first, a demise due to meteorological causes, along with the concurrent growth of vegetation in the area (Fig. 2); second, possible anthropic causes. As a concrete example of the latter, we refer to the disappearance of one of the structures in the aldea's square, since the obtained data suggest, for it, a higher degree of deterioration than the one observed for the other structures. This makes us think that its disappearance might have been caused by anthropic factors like ground mowing or like the re-use of building materials somewhere else, as there are evidences of both phenomena in the area.

The identification of a possible measure of the surface that could concur to the internal organization of farming areas within a suerte remains uncertain; there is no reference on this matter. However, we consider that the proposed module fits well both with the local orography and with a superimposition to the current plants and crops that correspond with relative precision. Particularly the latter is a circumstance that can hardly be accidental. For this reason, we put forward our hypothesis that should be proven – or disproven - by future research campaigns in the area.

7. Conclusions

Recent studies in landscape history have shown that traditional approaches, though used and trusted for long times, could not provide sure answers to many of the questions we addressed here.

This study, in which some new remote sensing techniques are used to test, is highly innovative in Modern History (16th – 18th centuries). Until now, the research approach to archaeological remaining's dating back on this period was limited to studies on historical cartography, analysis of documents and, in some cases, representation of some elements within a GIS. However, as we said in the introduction, while relatively efficient in detecting some types of evidence, this strategy is affected by inherent uncertainty and interpretability issues that can only be partially solved by taking into account other sources and survey methods. The interdisciplinary focus applied to this research enables us to explore and understand important aspects of phenomenology, making it possible to interpret the landscape by exploring a combination of different factors in an area. By doing so, it becomes possible to provide new knowledge that would otherwise will remain inaccessible. The methodological approach developed in this paper makes Aldea de Buenos Aires the most comprehensively studied settlement within the *Nuevas Poblaciones* de Sierra Morena and, probably, in the whole Mediterranean for the considered period. This fact makes it possible to consider it as a reference case for investigating the relations of settlements with their immediate surroundings.

Thanks to the combined interpretation of the collected data, it was possible to document the conservation status of the site and to move a step forward in the elaboration of hypotheses on the causes of its deterioration, wether climatic or anthropogenic. It is also possible to define action proposals to mitigate further degradation of the site. Furthermore, the set of used techniques made it easier to compare the urban structure with that represented in the historical maps and reported by textual accounts. This is crucial to detect possible changes from the original plan; an example can be seen in the DIGITALESCAPE Project (Ortiz Villarejo and Delgado Barrado, 2023, p. 18). Based on this, we can assert that the urbanistic trace of the Aldea de Buenos Aires was accurately represented in the historical cartographies and, last but not least, we could establish a hypothesis about the internal division of farmlands within *suertes*.

With regard to the first point, i.e. the urban morphology of the whole Aldea de Buenos Aires, it includes the village itself and the surrounding area. We can affirm that we have located building structures beyond the main urban layout which appears to be well represented in the historical cartography. There is evidence of a second perimeter to the N and S of the central square, and also of a third group of structures to the W. The latter is yet to be studied and catalogued.

With regard to the second point, the results of our work provide an effective example of the advantages of using the innovative techniques presented in this paper. They enable us to “see” the possible agricultural division of farmland, which is quite an important piece of information, especially if it appears not to exactly fit the indications established in the historical maps or archival texts or, even more, if we do not have any information whatsoever about it in those sources. Furthermore, the ability to read this kind of elements in the once inhabited space may help to better understand relationships with the historical context. It could also help to find answers to other questions, such as why did the population chose this particular location to settle instead of another? Why was this internal division of suertes defined? Why was this particular kind of cultivation selected? And, particularly, when did those transformations occur? Indeed, it would become possible to establish a historical chronology of the spatial organization of the village centre and its immediate surroundings as they evolved in time. The suggestions about Aldea de Buenos Aires, as proposed in this paper, due to their novelty, should be confirmed or disproven by future research campaigns in the area.

Methodologically speaking, the integration of different sensors and of the obtained final products has been challenging because of the heterogeneous nature of data, as well as for their complex interpretation. Cooperation by specialists from each one of the involved fields is paramount and this makes it evident that in order to properly address studies on landscape and territories it is fundamental to create multidisciplinary teams, one of the objectives of the application of Digital Humanities.

Although data obtained by remote sensing are promising towards the study of human landscape, one should not forget that they must be verified by fieldwork by integration with other techniques, such excavation campaigns and archaeological prospecting, as well as geophysical investigations.

The analysis of multispectral data enables to obtain information on elements which are not immediately visible in current landscape. It my provide knowledge about how changes caused by earlier populations came to condition present-day areas.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available upon request.

References

Agapiou, A., Hadjimitsis, D.G., Alexakis, D.D., 2012. Evaluation of broadband and narrowband vegetation indices for the identification of archaeological crop marks. Remote Sens. (Basel) 4, 3892–3919. https://doi.org/10.3390/RS4123892.

Agüera-Vega, F., Carvajal-Ramírez, F., Martínez-Carricondo, P., 2017. Assessment of photogrammetric mapping accuracy based on variation ground control points number using unmanned aerial vehicle. Measurement (Lond) 98, 221–227. https://doi.org/10.1016/j.measurement.2016.12.002.

Bennett, R., Welham, K., Hill, R.A., Ford, A.L.J., 2012. The application of vegetation indices for the prospection of archaeological features in grass-dominated environments. Archaeol. Prospect. 19, 209–218. https://doi.org/10.1002/arp.1429.

Campana, S.R.L., 2018. Mapping the Archaeological Continuum. Filling “empty” Mediterranean Landscapes. Springer Briefs in Archaeology. Springer. 10.1007/978-3-319-89572-7.

Chase, A., Chase, D., Weishampel, J., Draje, J., Shrestha, R., Slatton, K., Awe, J., Carter, W., 2011. Airborne LiDAR, Archaeology, and the ancient Maya landscape at Caracol, Belize. J. Archaeol. Sci. 38, 387–398.

Doneus, M., Banaszek, Ł., Verhoeven, G.J., 2022. The impact of vegetation on the visibility of archaeological features in airborne laser scanning datasets from different acquisition dates. Remote Sens. (Basel) 14. https://doi.org/10.3390/rs14040858.

Dubbini, M., Curzio, L.I., Campedelli, A., 2016. Digital elevation models from unmanned aerial vehicle surveys for archaeological interpretation of terrain anomalies: case study of the Roman castrum of Burnum (Croatia). J. Archaeol. Sci. Rep. 8, 121–134. https://doi.org/10.1016/j.jasrep.2016.05.054.

Enríquez, C., Jurado, J.M., Bailey, A., Callén, D., Collado, M.J., Espina, G., Marroquín, P., Oliva, E., Osla, E., Ramos, M.I., Sarceño, S., Feito, F.R., 2020. The UAS-based 3D image characterization of Mozarabic Church Ruins in Bobastro (Malaga), Spain. Remote Sens. (Basel) 12, 1–16. https://doi.org/10.3390/RS12152377.

Evans, D.H., Fletcher, R.J., Pottier, C., Chevance, J.-B., Soutif, D., Tan, B.S., Im, S., Ea, D., Tin, T., Kim, S., Cromarty, C., De Greef, S., Hanus, K., Baty, P., Kuszinger, R., Shimoda, I., Boornazian, G., 2013. Uncovering archaeological landscapes at Angkor using lidar. Proceedings of the National Academy of Sciences. 10.1073/pnas.1306539110.

Gao, B.C., 1996. NDWI—a normalized difference water index for remote sensing of vegetation liquid water from space. Remote Sens. Environ. 58, 257–266. https://doi.org/10.1016/S0034-4257(96)00067-3.

Guha, S., Govil, H., Taloor, A.K., Gill, N., Dey, A., 2022. Land surface temperature and spectral indices: a seasonal study of Raipur City. Geod. Geodyn. 13, 72–82. https://doi.org/10.1016/j.geog.2021.05.002.

I DIRECTIVE 2007/2/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 14 March 2007 establishing an Infrastructure for Spatial Information in the European Community (INSPIRE), 2007.

Johnson, K.M., Ouimet, W.B., 2014. Rediscovering the lost archaeological landscape of southern New England using airborne light detection and ranging (LiDAR). J. Archaeol. Sci. 43, 9–20. https://doi.org/10.1016/J.JAS.2013.12.004.

Khan, S., Aragão, L., Iriarte, J., 2017. A UAV–lidar system to map Amazonian rainforest and its ancient landscape transformations. Int. J. Remote Sens. 38 https://doi.org/10.1080/01431161.2017.1295486.

Kokalj, Ž., Zaksek, K., Oštir, K., Čotar, K., 2013. Relief Visualization Toolbox, version 1.3, Manual Special Issue “Applications of Micro-and Nano-Satellites for Earth Observation” View project.

Kršák, B., Blišťan, P., Pauliková, A., Puškárová, P., Kovanič, L., Palková, J., Zelizňaková, V., 2016. Use of low-cost UAV photogrammetry to analyze the accuracy of a digital elevation model in a case study. Measurement (Lond) 91, 276–287. https://doi.org/10.1016/j.measurement.2016.05.028.

Lanes y Duval, J., 1787. Poblaciones nuebas hechas en esta Sierra Morena desde el año de 1767. Biblioteca de Toledo.

Mancini, F., Dubbini, M., Gattelli, M., Stecchi, F., Fabbri, S., Gabbianelli, G., 2013. Using unmanned aerial vehicles (UAV) for high-resolution reconstruction of topography: the structure from motion approach on coastal environments. Remote Sens. (Basel) 5, 6880–6898. https://doi.org/10.3390/rs5126880.

McLeester, M., Casana, J., Schurr, M.R., Hill, A.C., Wheeler, J.H., 2018. Detecting prehistoric landscape features using thermal, multispectral, and historical imagery analysis at Midewin National Tallgrass Prairie, Illinois. J. Archaeol. Sci. Rep. 21, 450–459. https://doi.org/10.1016/j.jasrep.2018.08.016.

Ministerio de Transportes, M. y A.U., 2004. Plan Nacional de Ortofotografía Aérea [WWW Document]. https://pnoa.ign.es/pnoa-historico.

Ortiz Villarejo, A.J., Delgado Barrado, J.M., 2023. DIGITALESCAPE Project—Aerial Remote Sensing, HBIM, and Archaeology for the Preservation and Dissemination of the Cultural Heritage at Risk in the Sierra Sur and Sierra Morena Regions. Remote Sens (Basel) 15, 3315. 10.3390/rs15133315.

Ortiz-Villarejo, A.J., Gutiérrez Soler, L., 2021. A low-cost, easy-way workflow for multi-scale archaeological features detection combining lidar and aerial orthophotography. Remote Sens. (Basel) 13. https://doi.org/10.3390/rs13214270.

Pérez Fernández, F.J., 2018. Olavide, del pensamiento teórico al práctico: una aproximación al asentamiento de colonos y a los propietarios en las Nuevas Poblaciones. Rev. Tiempos Modernos 37.

Pérez Fernández, F.J., 2018. La Intendencia de Nuevas Poblaciones: creación, desarrollo y tránsito de unas colonias al régimen general del Estado, in: Pérez Fernández, F. J,, Rodrigo Sanjuán, P. (Eds.), 250 Aniversario de La Promulgación Del Fuero de Población. Fundación Caja Rural de Jaén.

Pérez Fernández, F.J., 2019. Aldeaquemada, in: Filter Rodríguez, J.A. (Ed.), Las Nuevas Poblaciones de Sierra Morena y Andalucía. Un Sueño Ilustrado En La España de Carlos III,. Universidad Pablo de Olavide y Fundación de Municipios Pablo de Olavide, Sevilla, pp. 38–47.

Prus, B., Wilkosz-Mamcarczyk, M., Salata, T., 2020. Landmarks as cultural heritage assets affecting the distribution of settlements in rural areas-an analysis based on LIDAR DTM, digital photographs, and historical maps. Remote Sens. (Basel) 12. https://doi.org/10.3390/rs12111778.

Rhyma, P.P., Norizah, K., Hamdan, O., Faridah-Hanum, I., Zulfa, A.W., 2020. Integration of normalised different vegetation index and Soil-Adjusted Vegetation Index for mangrove vegetation delineation. Remote Sens Appl 17, 100280. https://doi.org/10.1016/J.RSASE.2019.100280.

Štular, B., Eichert, S., Lozić, E., 2021a. Airborne LiDAR Point Cloud Processing for Archaeology. Pipeline and QGIS Toolbox. Remote Sens (Basel) 13, 3225. 10.3390/rs13163225.

Štular, B., Eichert, S., Lozić, E., 2021b. Airborne lidar point cloud processing for archaeology. Pipeline and qgis toolbox. Remote Sens (Basel) 13. 10.3390/rs13163225.

Bentley System, 2021. ContextCapture 1 User Guide ContextCapture User Guide.

Uribe, P., Angás, J., Pérez-Cabello, F., De La Riva, J., Bea, M., Serreta, A., Magallón, M. A., Sáenz, C., Martín-Bueno, M., 2015. Aerial mapping and multi-sensors approaches from remote sensing applied to the roman archaeological heritage, in: International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives. International Society for Photogrammetry and Remote Sensing, pp. 461–467. 10.5194/isprsarchives-XL-5-W4-461-2015.

Verena, H., Krauss, G., Götze, C., Sandow, C., 2012. Index DataBase. A database for remote sensing indices [WWW Document].

Verhoeven, G., Vermeulen, F., 2016. Engaging with the canopy-multi-dimensional vegetation mark visualisation using archived aerial images. Remote Sens. (Basel) 8. https://doi.org/10.3390/rs8090752.

Yoëli, P., 1965. Analytische Schattierung: Ein Kartographischer Versuch. Kartographische Nachrichten 15, 141–148.

Zakšek, K., Oštir, K., Kokalj, Ž., 2011. Sky-view factor as a relief visualization technique. Remote Sens. (Basel). https://doi.org/10.3390/rs3020398.