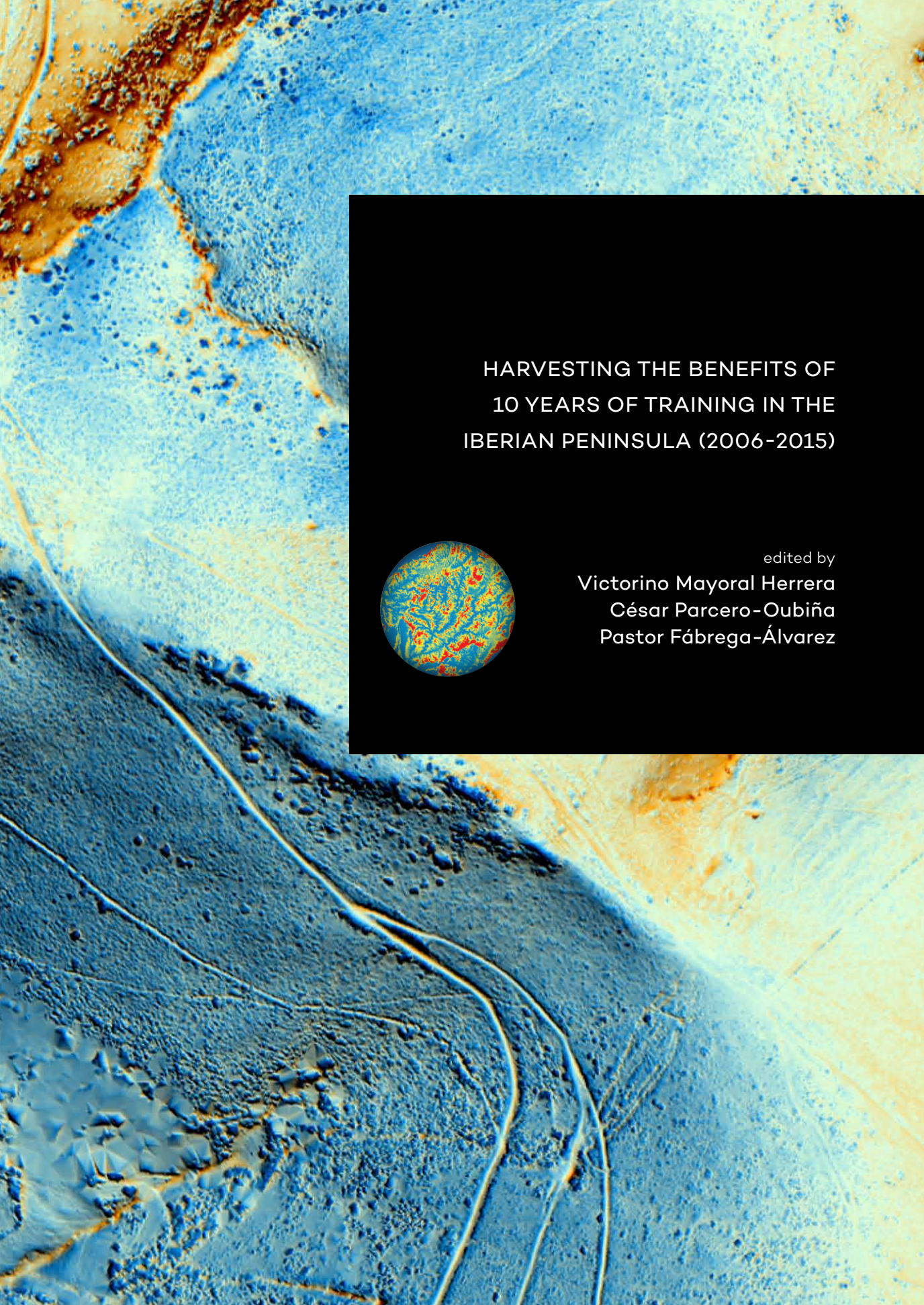

HARVESTING THE BENEFITS OF 10 YEARS OF TRAINING IN THE IBERIAN PENINSULA (2006-2015)

edited by
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Scope and limitations of airborne LiDAR technology for the detection and analysis of Roman military sites in Northwest Iberia

José Manuel Costa-García[1] *and João Fonte*[2]

Remote sensing: towards a new cost-effective methodology

The Roman military sites are frequently characterised by the perishable nature of their structures and material culture. This situation can easily become extreme in the particular case of the marching camps (*castra aestiva*) (Peralta Labrador 2002; Jones 2012). Since these sites are almost invisible in the modern landscape, the use of remote sensing techniques for their detection and study has proved fundamental. Although the integration of some of these tools -i.e. aerial photography- into the archaeological studies of the Iberian Peninsula started several decades ago, the development of the Roman military archaeology as an autonomous discipline demanded a significant renovation and adaptation of the common methodological approaches.

More recently, we have contributed through the *Romanarmy.eu*[3] research project to the development of a cost-effective methodology for the detection and analysis of Roman military sites in Northwest Iberia. This method combines remote sensing techniques (historical and modern aerial photography, satellite imagery, airborne LiDAR), and GIS with more conventional archaeological field survey techniques, alongside place-names distribution and ethnography (Menéndez Blanco *et al.* 2013; Menéndez Blanco *et al.* 2016b). All these tools provide a new and qualitatively

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3 Romanarmy.eu is an independent and self-financed project formed by several researchers particularly interested on the archaeological study of the Roman conquest of the northwest of the Iberian Peninsula: http://romanarmy.eu/en/.

differential approach to the sites, allowing us to study their spatial, locational and morphological characteristics. They lead thus to a more integrated approach, since each technique could potentially reveal different features (Crutchley 2009).

Within this context, airborne LiDAR allows us to see and understand landscapes from a different perspective. We understand the landscape as a result of the co-evolution of natural and cultural processes. In this way, each period of activity generates its own concrete landscape forms, partly based on the footprints left by the different physical remains that once existed in a particular space. However, a landscape is not just a messy amount of archaeological features, but rather a palimpsest of elements with different temporality and spatiality we need to read and understand (Mlekuž 2013a, 2013b). By picking those little pieces of information we can try to individualise and reconstruct ancient landscapes. For that reason, we need to develop different strategies to increase the visibility of more faint topographic evidence, or what we might call "archaeological topographies" (Opitz and Cowley 2013). Airborne LiDAR is indeed a very powerful tool for mapping the different traces that are engraved on the terrain.

Finally, we must stress that the north-western area of the Iberian Peninsula is not topographically uniform. The vast plains of the Northern Spanish Plateau are dominated by large states and cereal farming. The mountainous areas of Asturias, western León, eastern Galicia and north-eastern Portugal are frequently forested if not dedicated to pastures. The central and western areas of Galicia as well as northern Portugal are occupied by smallholdings with diversified crops, meadows and forests covering valleys, hills and low mountains. This requires the use of a diversified methodology. By analysing the response of every single technique to different landscapes, terrain types and vegetation canopies, we can outline its potential and limitations.

Historical aerial photography and Roman military archaeology

The use of remote sensing techniques is not new in Roman military archaeology, including in Iberia. Indeed, several *ad hoc* flights over Roman military sites were made before World War II, also in Spain (e.g. Almagro Basch 1943; González Reguero 2007). Besides that, a large amount of aerial photographs commisioned for different purposes have also been extensively used by archaeologists: the aerial photos from historical flights -mainly from the 1930s onwards- and satellite imagery archives are good examples of that (Hanson and Oltean 2013). Any user can access these materials easily today. Consequently, it is possible not only to adopt an important diachronic perspective of the sites and landscapes, but also to digitally reconstruct nowadays lost archaeological landscapes by using photogrammetric software (Cerrillo-Cuenca and Sanjosé 2013, Charro Lobato 2015; Risbøl *et al.* 2015).

In the Iberian Peninsula there have been *ad hoc* photographic flights over Roman republican military sites such as Numantia (González Reguero 2007: 239) and Cáceres el Viejo (Almagro Basch 1943). The archaeological use of the "*Vuelo General de España Serie B*" (USAF AST6 54-AM-78), commissioned by the Spanish government to the United States Air Force (USAF), also led to the discovery of new camps as those of Castrocalbón (Loewinsohn 1965), Valdemeda (Sánchez Palencia 1986), O Cornado (Gago Mariño and Fernández Malde 2015),

Monte dos Trollos (Costa-García *et al.* 2015b) or A Chá da de Santa Marta (Costa-García *et al.* 2015b; *Orejas et al.* 2015).

More recently we have used Structure from Motion (SfM) photogrammetry (Verhoeven *et al.* 2012) to orthorectify and georeference historical aerial photos from several historical flights (SPLAL, RAF and USAF[4]) from the 1940s and the 1950s in Portugal (Redweik *et al.* 2010). This allowed us to obtain new cartographic data, namely Digital Surface Models (DSM) and orthophotos. We have also used historical aerial photos taken by the USAF during the 1940s and the 1950s in Spain: series A (1945-46) and B (1956-57) (Pérez Álvarez *et al.* 2013; Pérez Álvarez *et al.* 2014), recently made available by the Spanish Geographic Institute (IGN) through web-mapping services. Roman military sites such as Campos (Blanco-Rotea *et al.* 2016) and Alto da Cerca (Fonte and Costa-García 2016) were analysed doing an intensive use of these tools.

Modern aerial photography and satellite imagery

Aerial photography also played an important -though frequently underestimated- role in the awakening of the Roman military archaeology as a discipline in Spain. The planning of flights with an archaeological aim during the decades of 1990 and 2000 allowed not only the discovery of new camps but also the detailed study of other sites previously known (Del Olmo Martín 1995; García Merino 1996; Peralta Labrador 2011). In the last years, the popularity of multi-purpose aerial photography and satellite imagery has increased at an exponential rate. The possibility of locating traces of hidden structures determined their extensive use in archaeology (Ceraudo 2013).

The open access to data granted by the Spanish National Plan of Aerial Orthophotography (PNOA) or Google Inc. -among others- has allowed the development of a systematic survey method (Menéndez Blanco *et al.* 2013). This is especially effective in mountainous areas without dense vegetation canopy or in plain regions covered with crops. In some cases the ancient earth ramparts are still surviving; in others the trenches were tracked due to the differential accumulation of moisture in the topsoil. The planning of field surveys focused on those potential sites led to the discovery of many *castra aestiua* in the northern areas of Iberia (González Álvarez *et al.* 2008, 2011; Menéndez Blanco *et al.* 2011a, 2011b; Celís Sánchez *et al.* 2015; Hierro Gárate *et al.* 2015).

Airborne LiDAR

In forested areas with dense vegetation cover, the identification of archaeological features is still very problematic (Doneus *et al.* 2008). The introduction of airborne LiDAR has helped to overcome this problem because of its unique capability to penetrate vegetation canopies, making it possible to document the underlying topographic surface and identify any cultural remains on it (Opitz and Cowley 2013).

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4 *Sociedade Portuguesa de Levantamentos Aéreos Limitada* (SPLAL) from between 1937 and 1952; British Royal Air Force (RAF) from 1947; United States Air Force (USAF) from 1958. The photos have to be purchased to the Portuguese Army Geospatial Information Center (CIGeoE).

The identification of archaeological features on LiDAR-derived Digital Terrain Models (DTM) is very dependent on visualisation techniques that can enhance our perception and interpretation of anthropogenic features in the high-resolution digital topographic models. Most archaeological applications of airborne LiDAR were undertaken mainly using one type of visualisation technique -shaded relief modelling- where the visibility of potential archaeological features depends to a large extent on the chosen illumination angles that may hinder their detection (Devereux *et al.* 2008).

Different methods have been proposed to highlight microtopographies, from simple hillshading techniques to more complex calculations like those based on a simple combination of slope and hillshade (Doneus *et al.* 2011), Principal Components Analysis (Devereux *et al.* 2008), Sky View Factor (Kokalj *et al.* 2011; Zakšek *et al.* 2011), Local Relief Models (Hesse 2010) or Openness (Doneus 2013). These visualisation techniques have been investigated and analysed (Štular *et al.* 2012; Chalis *et al.* 2012; Bennett *et al.* 2012; Kokalj *et al.* 2013) and the results highlight that no single method outperforms the rest in all types of terrain. Therefore, a combination of these techniques is the only way to obtain a maximum volume of information on potential archaeological traces in relief.

Trend removal procedures (Štular *et al.* 2012) are among the more effective for archaeology. They are based in the theoretical assumption that when a smoothed surface is compared to its corresponding real topography, local small-scale topographic features are contrasted from large-scale landscape forms. One advantage of this technique lies in the richness of the generated data (based on relative heights) because it allows to discriminate between positive and negative microtopographies at a local scale, representing real changes in elevation rather than calculations based on steepness and direction of slope or exposure to light.

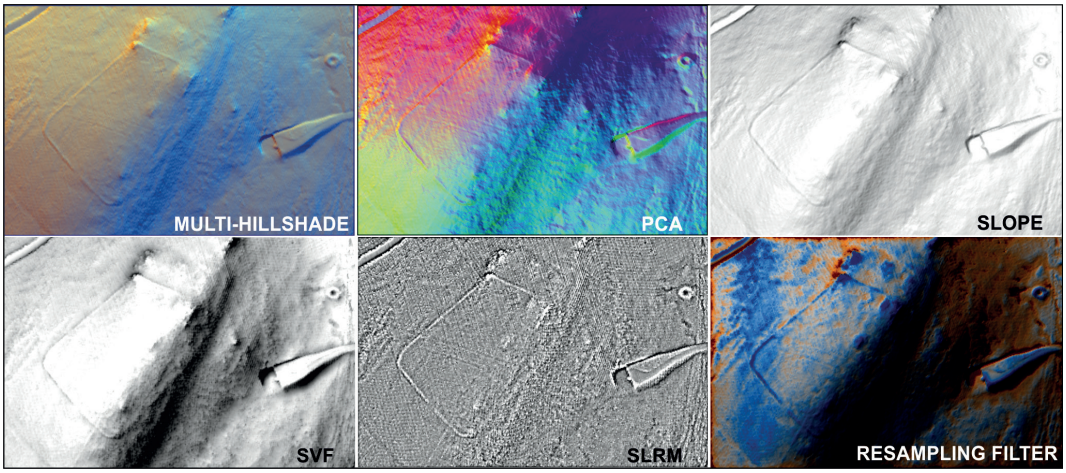

Figure 1: The Roman camp of Moyapán. Different LiDAR visualization techniques.

In Spain an open-access LiDAR coverage of almost the entire territory is available.[5] LiDAR data are already classified. This means that we can directly obtain a DTM from the ground points, although in certain cases it is advisable to do some additional classification (in our case, using the software suite LAStools).[6] In most cases we have used hillshade and slope as standard visualisation techniques, although in other we have applied more complex solutions such as the Resampling Filter available in SAGA GIS software (Conrad *et al.* 2015), Sky View Factor (Štular 2012; Zakšek 2011) or Local Relief Models (Hesse 2010) (fig. 1). The Resampling Filter is a trend removal technique that allows representation of local small-scale elevation differences, in a similar way to Local Relief Models (Hesse 2010).

Geographic Information Systems

GIS allow us not only to integrate different geographic data and to study them together, but also to compensate the main limitations of each technique and to strengthen the global archaeological interpretation. The purpose of this effort is dual: on the one hand, to better characterise the sites (the morphological and locational studies are very important in this case); on the other hand, to understand the landscape in which they are integrated (spatial analysis).

Spatiality is intrinsic to most archaeological data and GIS and geospatial technologies provide an ideal tool for the combination and quantification of different spatial variables, allowing us to create meaning and knowledge from the spatial dimension of archaeological data (McCoy and Ladefoged 2009).

Discussion

Since 2007, within the *Romanarmy.eu* project several Roman military sites have been detected in northwest Iberia by following this non-invasive and integrated methodology (Costa-García *et al.* 2015a; Costa-García *et al.* 2015b; Blanco-Rotea *et al.* 2016; Fonte and Costa-García 2016; González Álvarez and Menéndez Blanco, 2007; Gago Mariño and Fernández Maldeand 2015; González Álvarez *et al.* 2008; Menéndez Blanco *et al.* 2015a; Menéndez Blanco *et al.* 2014; Menéndez Blanco *et al.* 2016; Menéndez Blanco *et al.* 2011b; 2011a) (fig. 2). This effort has not only quantitatively and qualitatively enriched our knowledge about the Roman military presence in the area but also allowed the opening of new research perspectives regarding the military occupation of these territories (see Costa-García in this volume).

Airborne LiDAR has been for us one of the most proficient remote sensing techniques for the identification and analysis of Roman military sites (fig. 3). We are dealing with severely eroded and poorly surviving, almost invisible structures. In addition, they show varying morphologies, although the classical "playing-card" layout is predominant. For this reason it is important to consider the correlation of different factors when dealing with LiDAR data: time of data collection, point

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5 *Plan Nacional de Ortofotografía Aérea* (PNOA), *Instituto Geográfico Nacional* (IGN): http://pnoa.ign.es/coberturalidar. The average point density is 0.5 points per square meter, although this varies depending on the geographic area. In most of the cases, we were able to obtain a 1-meter DTM.

6 LAStools, "Efficient LiDAR Processing Software", obtained from http://rapidlasso.com/LAStools.

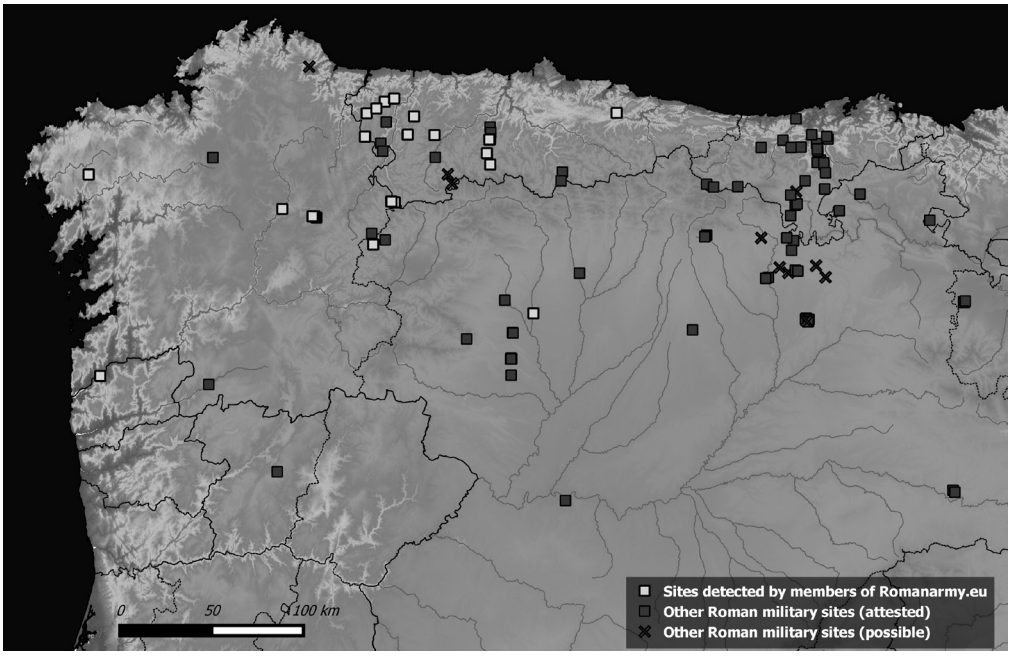

Figure 2: Roman military sites in Northwest Iberia. In yellow, sites located by the Romanarmy.eu research group.

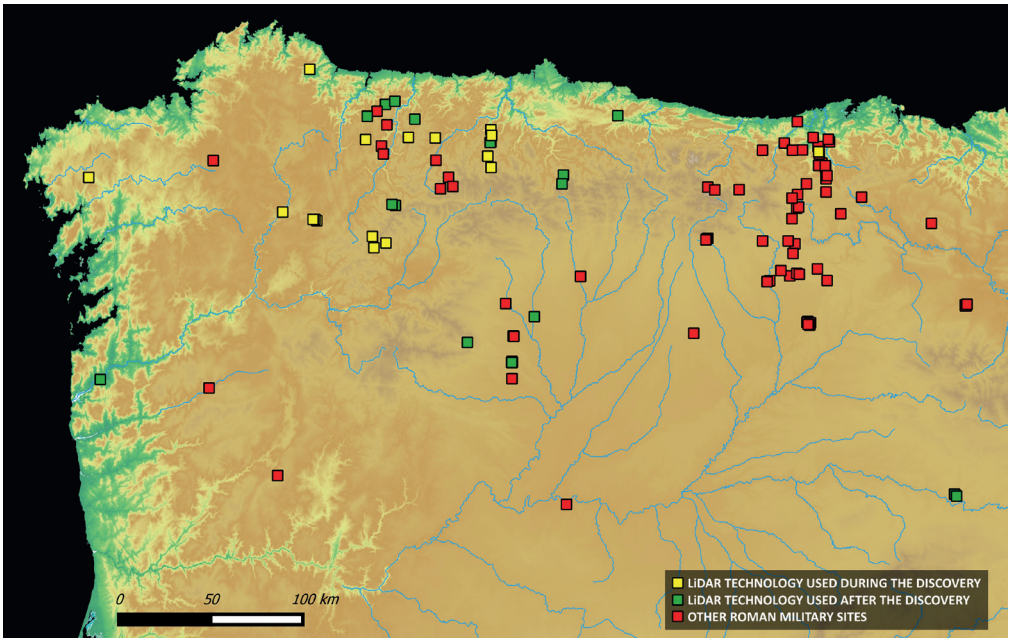

Figure 3: The use of LiDAR technology for the detection and analysis of Roman military sites in Northwest Iberia.

density (Bollandsås *et al.* 2012), classification of the point cloud, interpolation quality and DTMs spatial resolution, terrain type and vegetation cover, as well as the physical properties (size and shape) of the cultural remains (Risbøl *et al.* 2013).

Due to space restrictions, we have selected only a limited number of sites to be analysed here. They have been classified in three big groups that show some similar characteristics in order to stress the differential contribution of airborne LIDAR in contrast with other remote sensing techniques.

LiDAR in lowland areas

The three Roman military enclosures of A Chá de Santa Marta (Lugo, Spain) have suffered the severe impact of the mechanical ploughing and the intense reforestation carried out in this area from the 1960s onwards. The central camp, named Cabianca, was perfectly recognizable in the USAF photos of 1957, but its traces can be hardly detected in modern orthophotos or satellite imagery (fig. 4). The ancient rampart was completely flattened before we could survey the site in late 2014. Only the sunset light allowed us to detect some elevations of about 10-15 cm that resembled lineal structures. Fortunately, the visibility of the enclosure improved after applying the Resampling Filter of SAGA GIS to the LiDAR-based DTM, which was able to enhance those micro-topographic details barely detectable *in situ*.

LiDAR also showed its potential when reviewing another set of camps discovered fifty years ago in Castrocalbón (León, Spain) (Loewinsohn 1965, Costa-García 2015, Costa-García and Casal García 2015, Costa-García 2016). The ploughing activities in this area did not become completely mechanised, so we were able to clearly detect a set of negative and positive structures (fig. 4). They are close to an old path which follows the outline of a Roman road recorded in the Antonine Itinerary (Wess. 422.2-423.5). Some of the ditches are quite clogged and it seems that they were the places from where the materials for the construction of the ancient road were extracted (Moreno Gallo 2011). Other rectilinear trenches draw an enclosure which follows the classical playing-card shape, revealing the presence of a Roman camp previously documented thanks to historic aerial photography. South to this position, several positive structures were detected as well. The presence of a Roman camp and a probable watchtower was already attested here, but the existence of soft terrain elevations configuring another possible enclosure is completely new. Besides, the detailed analysis of the former camp revealed the presence of four *clauiculae*-type entrances.

Unfortunately, a LiDAR-based DTM can also lead us to an erroneous record of the archaeological features. In this way, it is important not to fall in self-confidence or comfort when using these tools: these visualisations must be checked against the results obtained by applying other remote sensing techniques as well as the data recorded on the field.

A good example of how these risks can occur is the Roman camp of Los Llanos (Soria, Spain). This big enclosure was detected through aerial photography in the late 2000's (Didierjean 2008), thanks to the existence of two parallel dark lines which were identified as a *fossa duplex* or double trench. The oldest graphic records of the place already showed these archaeological features. Although the LiDAR

visualisations allowed us to document the existence of a severely damaged, inner rampart, only one depression could be observed in the outside by using these resources (fig. 4). There is an easy explanation for this presumed abnormality: after the initial filling of the ancient trenches, the secular ploughing activities flattened out the ground, the remains of the earth bank which originally divided the ditches were destroyed and consequently a single soft depression was formed (Costa-García and Casal García 2015). In this way, while aerial photography is reflecting the effect of the differential accumulation of moisture in the area occupied by the trenches, the LiDAR-based DTM strictly represents the modern ground relief.

The camp of Huerga de Frailes (León, Spain) (Menéndez Blanco *et al.* 2011b) also reflects the limitations of LiDAR technology in plain areas covered with cereal crops. Given that the archaeological survey on the field attested the complete erosion of the ramparts and the filling of the single trench detected by aerial photography, no success was expected when applying LiDAR visualisations. However, the differential growing of the crops over the ditches was enough to detect some traces in the visualisations derived from both the DTM and the DSM (Costa-García and Casal García 2015).

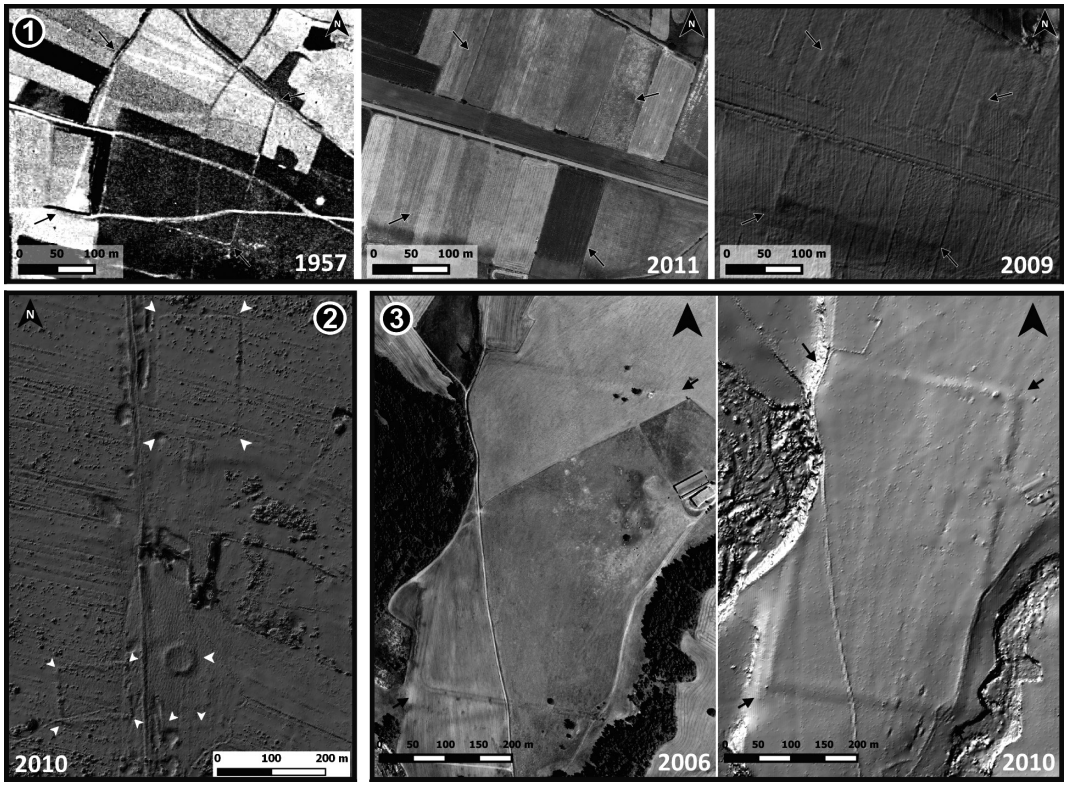

Figure 4: The enclosures of Cabianca (USAF aerial photography, PNOA aerial orthophoto and Resampling Filter visualisation) (1), Castrocalbón (Resampling Filter visualisation) (2) and Los Llanos (PNOA aerial orthophoto and Multi-hillshade visualisation) (3).

LiDAR in forested areas

From the 1960s onwards several areas of Northwest Iberia have been affected by different projects of reforestation. The impact of these policies on the archaeological heritage cannot be generalised, since it depends on various factors such as the type of species introduced, the reforestation techniques or the actual degree of preservation of the remains before the process. The site of Valdemeda, discovered long time ago after reviewing the USAF aerial photos of 1957 (Sánchez Palencia 1986), was considered lost for archaeological research due to the aggressive reforestation. Although not very well preserved, the use of LiDAR technology has revealed that the Roman military camp is still there (Costa-García 2015, Costa-García and Casal García 2015, Sánchez Palencia and Currás Refojos 2015) (fig. 5). Moreover, it is possible to appreciate the effects of two types of reforestation plans: the zone occupied by grown trees allow the penetration of a greater number of laser pulses and this implies the production of a more precise DTM, while the area covered by lower, younger trees produces a 'noisy' picture. This situation can also reflect the introduction of modern machinery in the second sector which could have severely damaged the archaeological features.

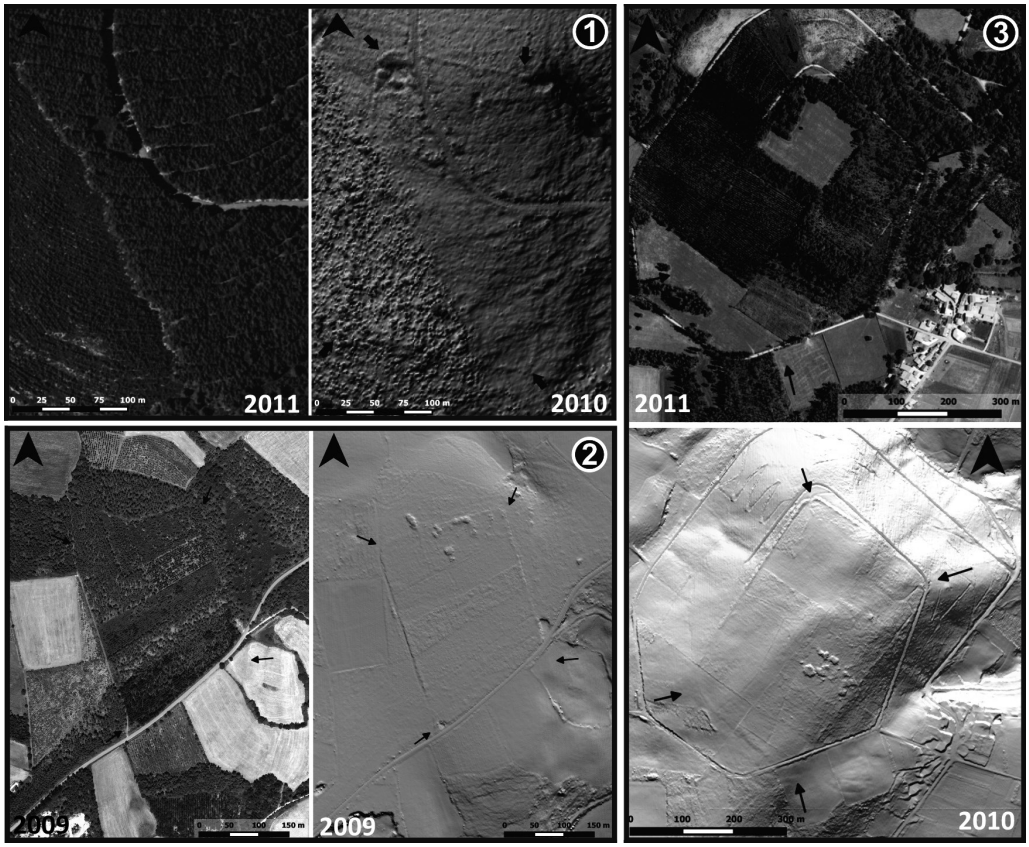

Figure 5: The sites of Valdemeda (PNOA aerial orthophoto and Resampling Filter Visualisation) (1), Monte dos Trollos (PNOA aerial orthophoto and Slope visualisation) (2) and O Cornado (PNOA aerial orthophoto and Multi-hillshade visualisation) (3).

The enclosures of Monte da Chá and Monte dos Trollos (Lugo, Spain) show a different degree of deterioration in the same geographical area (Costa-García *et al.* 2015b). Both Roman camps are perfectly distinguishable in the historical aerial photos of the 1950s. The former has been almost obliterated by reforestation and re-parcelling activities. Still, LiDAR visualisations show at least some additional traces which we could not observe on the field until 2014. Regarding the latter, its defences are surprisingly well preserved in the areas covered with trees, while the modern paths have practically wiped out the ancient trenches in the western sector (fig. 5). In this way, the enclosure detected in LiDAR visualisations shows almost the entire shape and limits documented in the aerial photography six decades ago. In this case, we can clearly appreciate the dissimilarities between a traditional reforestation plan and another one which introduces heavy machinery.

The situation of O Cornado (A Coruña, Spain) (Gago Mariño and Fernández Malde 2015) is quite different due to the smallholding: some parcels have been reforested, while others are ploughed (fig. 5). The LiDAR-based DTM outperform modern aerial photography and satellite imagery, and reveal how the constant ploughing have soften the relief of the ancient ramparts and trenches (Costa-García *et al.* 2015, 2015b). On the contrary, they still preserve a good size in several areas below the tree canopy.

LiDAR in upland areas

The upland regions have been generally less affected by anthropogenic activities than the plains or the valleys, so several of the best preserved Roman military camps are located in such areas. That is the case of enclosures like El Chao de Carrubeiro, Moyapán or El Mouru, among others (González Álvarez and Menéndez Blanco 2007; González Álvarez *et al.* 2011, 2012; Martín Hernández 2015; Menéndez Blanco *et al.* 2014). These sites were detected by using modern aerial photography, but the application of LiDAR technology has helped not only to better define their defences but also to detect new archaeological features previously unknown, such as *clauiculae*-type entrances or new ramparts (Costa-García 2015, Costa-García *et al.* 2015b) (fig. 6). Moreover, the systematic use of LiDAR-based DEMs in archaeological survey has allowed the discovery of new sites in areas where the review of aerial photography and satellite imagery was unsuccessful.[7]

But the archaeological structures of these regions are not free from human aggressions. The reforestation, the building of roads, the opening of firebreak or the installation of TV and radio masts are concentrated in the same mountain ranges where the Romans established their camps about two thousand years ago. The site of El Pico El Outeiro (Asturias, Spain) (Menéndez Blanco *et al.* 2014) perfectly exemplifies this situation and the traces of the ancient ramparts are only partially distinguishable in LiDAR visualisations (fig. 6). Fortunately, it was possible to

7 The discovery of sites such as A Penaparda (Lugo, Spain), El Xuegu la Bola (fig. 6), El Cueiru, El Chao or Resieḷḷa (Asturias, Spain) has been reported to the Regional Cultural Heritage authorities of those territories between the years 2015 and 2016. They are also included in some forthcoming papers.

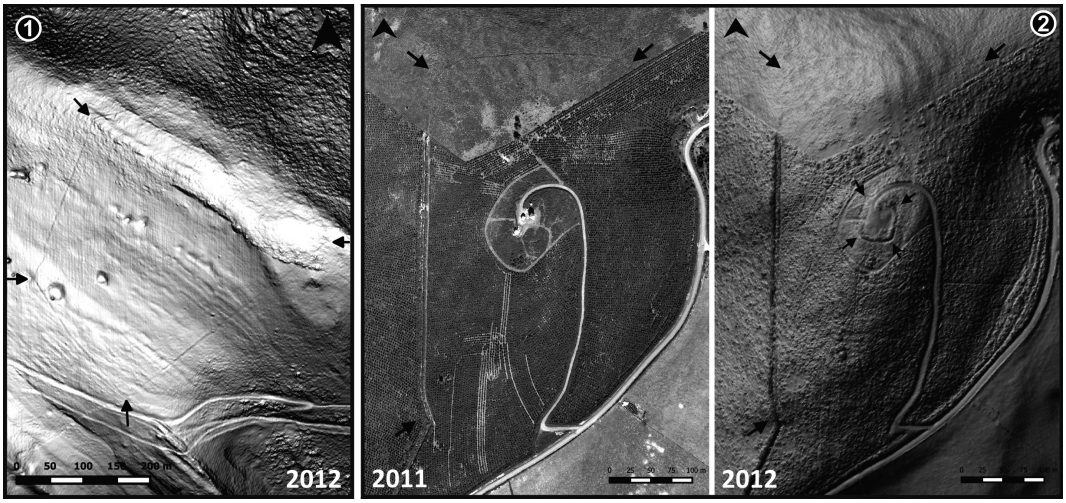

Figure 6: The enclosures of El Xuegu La Bola (Slope visualisation) (1) and El Pico El Outeiro (PNOA aerial orthophoto and Resampling Filter visualisation) (2).

detect a small *castellum* here thanks to the combined use of this technology and the USAF aerial photos of 1946 (Costa-García *et al.* 2015b).

Grazing activities can also make LiDAR-based remote sensing technology difficult in these areas. If in the lowlands the presence of "false friends" usually derives from the regular parcelling of modern times, the existence of livestock enclosures can usually lead to the incorrect identification of Roman military sites in mountainous landscapes. The grazing and opening of pastures continuously erodes the soil, destroying the remains of earth banks and trenches. Paradoxically, these activities allowed us to partially observe the defences of the Roman camp of Serra da Casiña (León, Spain) by using aerial photography (Menéndez Blanco *et al.* 2016). However, it was thanks to the LiDAR-based DTM that we could reconstruct the whole perimeter of the site and also attest its poor preservation. Other enclosures such as A Pena Dereta (Asturias, Spain) are in a very similar situation (Menéndez Blanco *et al.* 2014).

Conclusions

The reason why airborne laser scanning is being increasingly used in archaeological research is no longer a secret: it allows the generation of high-resolution topographic maps, even under a dense vegetation cover. Nevertheless, we must remember that airborne LiDAR has a specific temporal nature, since it documents the surface conditions at the time of data collection. In this way, its potential dramatically increases when combined with other geospatial datasets that can better contextualise ancient practices and post-depositional processes (Randall 2014). In addition, field validation of the digital data interpretation is also very important in order to reduce the risk of "false friends". Nonetheless, we also tried to demonstrate here that there are different variables (time of data collection, point density, classification of the point cloud, interpolation quality and DTMs spatial resolution, terrain type and vegetation cover and size and shape of the archaeological features) that could

influence the quality of LiDAR data and the derived products. Therefore, this technique is not the definitive answer to every research question that deal with a Landscape Archaeology perspective. It is simply a new way to see and understand archaeological landscapes from topography: it enables the detailed recording and new interpretation of the archaeological topography (Opitz and Cowley 2013).

Regarding the detection and study of Roman military sites in Northwest Iberia, airborne LiDAR has proved to be a powerful archaeological tool. Is has clearly contributed to the exponential increasing of discoveries in the last years and its potential is far from being run out. Moreover, the announcement of new LiDAR flights in Spain to be commissioned by the IGN through the PNOA project looks very promising. Yet, several studies have demonstrated that this tool cannot be used as a standalone technique and let alone replace the field survey. This is a key principle that should be extended to every remote sensing technique in order to avoid future misinterpretations.

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Archaeology and Geomatics

Digital technologies have numerous applications in archaeology ranging from the documentation of the archaeological evidence and the analysis of research data to the presentation of results for a wider audience. This volume consists of various studies on the use of methods such as LiDAR (light detection and ranging), archaeological prospection, visibility, mobility and the analysis of the spatial distribution of archaeological objects, applied in various contexts. The case studies vary widely and include the Late Pleistocene in the Northern Iberian Peninsula, the Roman Republican period in Southern Italy, the Formative period in the Andes and the 1936-39 Spanish Civil War.

In 2005 a (then) pioneering postgraduate course on the applicability of digital geospatial technologies for archaeology was launched in Spain. Quite unexpectedly, the course has been alive annually for more than 10 years so far, having trained around 300 young archaeologists from Spain, Portugal, and Latin America in the critical use of nowadays popular tools such as GIS, GPS, remote sensing and LiDAR for the documentation and analysis of the archaeological record.

To commemorate the first 10 years of the course, a conference was organized in Mérida (Spain) in October 2015. Former students were invited to present and discuss their research in which these technologies were used intensively; this edited book is a selection of those contributions. Through a series of widely varying case-studies, both technically sophisticated and theoretically informed applications of such digital technologies are presented.

All the contributors are young researchers, either young doctors or doctorate students, coming from fairly varied archaeological contexts and approaches.

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