ORIGINAL RESEARCH ARTICLE

Cartographic determination of the dry stone walls of the Mallorcan Tramuntana mountain range (Balearic Islands): Exploratory analysis

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ABSTRACT

The construction technique of dry stone, declared Intangible Cultural Heritage of Humanity by UNESCO, has historically materialized in Mallorca in the form of a varied range of constructions with different functions. The massive construction of dry stone walls in the Mallorcan countryside has left an outstanding landscape and territorial imprint, which constitutes a rich source of geographical analysis. An unpublished cartography of the walls located in the Serra de Tramuntana mountain range in Mallorca is presented as an essay, a cartography that has served as a basis for their classification and provisional quantification. With the support of basic cartographic, photo-interpretation and GIS techniques, the detailed examination of two official cartographic bases has allowed us to determine their usefulness as reliable sources for locating and understanding the dry stone walls in our study area, with a view to a more far-reaching geographical study of them.

Keywords: Analytical Mapping; Cultural Geography; Landscape; Dry Stone; GIS

1. Introduction

The construction technique of dry stone has a worldwide geographical scope and covers all historical periods from the Neolithic to the present day. Its territorial footprint in Mallorca, in the form of xerolithic landscapes—those formed by the massive presence of dry-stone constructions—is well known and has been well studied within the disciplinary framework of geography and from different approaches, such as hydrology, anthropic geomorphology or natural risks. Within the varied group of dry stone constructions, the walls—with all their different types, as will be seen below—form part of the idiosyncratic landscape of the island of Mallorca in general and of the Serra de Tramuntana in particular, as in quite a few areas they are present on a massive scale, making them very difficult to miss with the naked eye. Although the presence of these constructions is mentioned in documents from the 13th and 14th centuries, the bulk of the dry-stone construction and its constructive sophistication began to develop and must be attributed to much later times.

The Serra de Tramuntana (Figure 1) gives its name to a mountain range oriented from southwest to northeast and running parallel to the west coast of Mallorca at a short distance from the coastline or coinciding with it. Its line of peaks is over 600 metres high and the highest part corresponds to the central sector, where the highest points are located (Puig Major de Son Torrella, at 1,445 m, and Puig de Massanella,
The total length of the mountain range is about 90 km, from Cala Figuera (Calvià) to Formentor (Polleńça), while its average width is about 15 km. Physiographically, in this mountain range we can distinguish the aforementioned central sector; a northern sector characterized by a succession of narrow valleys alternating with sharp ridges; and a southern sector in which the valleys are wider and where, at altitude, large sub-horizontal limestone slabs dominate.

On the other hand, the Tramuntana mountain range treasures an abundant and rich natural and cultural heritage, among which is the ethnological heritage formed, precisely, by a large and varied group of dry stone constructions of diverse functionality. They have historically served to make available to man, not without resistance, the resources that nature has provided here—water, land, edible plant species, and ultimately to economically organize the territory\(^1\).

Despite the numerous scientific works that in one way or another have studied, directly and indirectly, the dry stone infrastructures in the Balearic Islands in general and in Mallorca in particular\(^2-10\), their cartographic representation and the problem that this entails have not been explicitly addressed until now. This leads to the need to dedicate work aimed at identifying, in official cartographies, constructions in the form of walls, not only because of their importance in the final configuration of the island landscape—and the mountainous landscape in particular—but also because they constitute elements of great ethnological, historical, agrological and hydrological interest and importance. The availability of a preliminary cartography of these constructions will allow us to undertake with better guarantees subsequent studies aimed at identifying terracing and certain water regulation mechanisms that are still active, as well as inventorying them and, in short, cataloguing them with a view to their effective management. The cartographic layer of the walls constitutes a source of information of the first order in terms of geography, and within it, cultural geography. This is because these walls not only provide information on the economic and territorial organization of the island in past and present times, but also reveal the existence of secular structures of popular engineering\(^11\) intended both for the

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\(^1\) Source: Own elaboration based on a Digital Terrain Model provided by the Spatial Data Infrastructure of Spain (IDEE).

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**Figure 1.** Situation map of the Serra de Tramuntana in the context of the island of Mallorca, and of Mallorca in the Mediterranean and European context.
terracing of slopes and the delimitation of plots of land or the control of erosion and excess water\textsuperscript{[12]}. The fact is that the geographical study of dry stone walls comes up against a foremost problem: the problem of their cartography, i.e. the faithful transfer of the geographical location of these constructive elements to a map. Certainly, for the island of Mallorca, there are four digital cartographic products in which the walls appear georeferenced and categorized: the 1995 Topographic Map of the Balearic Islands at scales 1:5,000 and 1:25,000 (MTB 1995); the Map of the island of Mallorca and Cabrera from 2006 and at a scale of 1:5,000 (MTIB 1:5,000 2006 Mallorca); the Topographic Map of Mallorca from 2010 and at a scale of 1:5,000 (MTIB 1:5,000 2010 Mallorca); and the National Topographic Base (BTN) at a scale of 1:25,000. In addition to these products, there are other cartographic bases, in this case on a municipal scale, that show the walls, such as the topographic maps of the municipal district of Palma from 1998 and 2010, both at a scale of 1:2,000, or the urban topographic maps of other Mallorcan municipalities, such as Manacor and Llucmajor.

With regard to the first of these maps, the 1995 Topographic Map of the Balearic Islands is a partial update, based on aerial photography from 1995, of a topographic map from 1990. Because of the year in which it was produced, it originally used the ED50 coordinate reference system, which has been converted to ETRS89. It was produced by the former Ministry of Public Works and Territorial Planning of the Balearic Government, and carried out by the Municipal Computer Company, S.A. (EMISA) in Palma. The 2006 Topographic Map of the island of Mallorca and Cabrera was drawn up from an aerial flight of the same year. Finally, the National Topographic Base is a three-dimensional topographic reference database, managed as a Geographic Information System, which describes, at a scale of 1:25,000 and in a uniform manner, the geographic reality for the whole of Spain. This base constitutes the direct support for the National Topographic Map of Spain at a scale of 1:25,000 (MTN25), and provides reference information for other state-wide projects such as CARTOCIUDAD or SIOSE (Information System on Land Occupation in Spain).

2. Objectives and method

The aim of this paper is to carry out an exploratory examination and diagnosis of the dry stone walls of the Serra de Tramuntana mountain range in Mallorca, as well as their different types, as these entities are mapped in two main official reference cartographic databases: on the one hand, the 1995 Topographic Map of the Balearic Islands (MTB), scale 1:5,000; on the other, the 2006 Map of the island of Mallorca and Cabrera (MTIB), also scale 1:5,000. The work also has the subsidiary objective of determining the usefulness of these two cartographic bases as reliable sources for locating and characterizing the stone walls in the study area.

Due to the year of production, these two sources were produced in Microstation system, so each cartographic sheet corresponds to a vector format. DGN file, which for the purposes of this work has been transformed, in a GIS information layer management environment, into shapefile format to obtain their respective entities of points, lines, polygons and annotations. We then proceeded to selectively empty the layers corresponding to the construction elements representing walls—all of them line entities, although, as will be seen, these elements are of various types, basically terraced walls, retaining walls, stone fences, mere walls and barricades—parats, in the local Catalan terminology. These parats are common in ravines and narrow river valleys, and are placed perpendicularly.
to the theoretical course of the water in order to regulate the force of the water during occasional episodes of torrential rain. The system is by no means exclusive to mountain riverbeds, but is widespread in crops grown on dry valley bottoms in flat areas, i.e. those with greater water stress and poorer soil.

In order to avoid further statistical errors, a process of elimination of duplicates has been applied to the vector layers representing the walls, as well as the suppression of those lines or segments whose length is less than 5.5 m (Figure 2), which, due to their limited extension, have been considered to have no cartographic or geographical significance for the examination that we intend to undertake here. The drawing of these minimal segments responds to a varied set of circumstances that make this suppression advisable: segments that form an auxiliary part of main line symbols, unions of longer lines, human errors in the digitization and georeferencing, etc. Although discarding these minor lines may sacrifice those that may correspond to minor walls, the benefit of removing them completely is greater.

On the other hand, since all cartographic representation requires spatial limits, in order to establish the specific geographical area of the Serra de Tramuntana considered in our work, we have used the delimitation used by the technical proposal for the declaration of the Serra de Tramuntana as a UNESCO World Heritage Site in the category of cultural landscape, a declaration that came into effect in 2011. The geographical area thus considered covers a total surface area of 834.2 km² (83,417 Ha), which represents 23.05% of the total area of the island of Mallorca.

Certainly, there are other delimitations such as the one used by the Community of Tramuntana—in this case, a delimitation based on the administrative limits of the municipalities that make it up—or the one established to define the territorial scope of the Serra de Tramuntana Natural Park, a protection figure that as such was approved by agreement of the Governing Council on 16 March 2007 (BOIB no.54 EXT, 11 April 2007). This is the same geographical area of work established in the Natural Resources Management Plan (PORN) of the Serra de Tramuntana, approved in 2007 (Decree 19/2007 of 16 March). In any case, if the delimitation established in the declaration of the Serra de Tramuntana as a World Heritage Site has been chosen, it is because, as it is a mountain range, the main criterion followed in specifying these limits was the criterion of its physiographic unit, the starting point of which is its orography. Within these limits, the Serra de Tramuntana is constituted as a physiographically and scenically unitary region, without detriment to the fact that the region also forms a cultural unit.

3. Dry stone walls on the 1995 and 2006 topographic maps at a scale of 1:5,000—Conceptual definition

The cartographic bases examined include the various types of dry stone constructions present in the area, although in doing so they use disparate and not always coinciding criteria. This means that, if these maps are used to identify the stone walls, the first problem encountered is the formal distinction between the different types of walls that colonize the territory studied.

To begin with, in the 1995 Topographic Map of the Balearic Islands, a distinction is made between terraces (in the legend they are indicated with the Catalan name of “Murs”, which translates directly into Spanish as “Muros”), and plot delimitation walls (in the legend they are indicated with the Catalan name of “Tanques”, which can be translated as “Cercas” or “Cercados”). This means that in this map, a functional criterion is used to distinguish between the two types of walls: those that are, on the one hand, walls of terraces in Mallorcan Catalan, marges, and those that, on the other hand, have the function of delimiting or enclosing agricultural and forestry plots. Both types of walls refer to two different types of parietal construction, as the plot delimitation walls have two visible faces, while the bancal walls are single-sided walls. In any case, if these constructions are viewed on an aerial photograph, although on the maps they appear typified as “walls” or “fences”, in reality they cover a broader typological spectrum. For example, it has been found that the denomination of “Walls” used in the 1995 Topographic Map of the Balearic
Islands also includes the level walls surrounding the old threshing floors where wheat was threshed. Consequently, this designation is broadly ambiguous, which makes it impossible to specify not only the type of construction to which it refers, but also whether these walls are indeed dry stone constructions, although it can be assumed that this is the case in the vast majority of cases.

In the case of the Topographic Map of the island of Mallorca and Cabrera from 2006, there is not so much typological diversity, as in this map the legend classifies the walls into three different categories: firstly, one whose denomination is “Mur, Paret o Tàpia” (“Wall”); secondly, one whose denomination is “Marjada” (“Bancal”); and thirdly, one whose denomination is “Mur de contenció” (“Retaining wall”). In relation to this categorization, it must be said that “bancal” and “muro de bancal” (marjada and marge respectively, in the Catalan terminology of Mallorca), are not only two semantically derived terms, but also go hand in hand as they support or shape each other. If the bancal wall is the stepped wall lined with stones or other material, which separates two fields of land situated at different levels (or which serves to stop landslides), the bancal is the portion of land bounded by one or more walls and which, seen as a whole, gives rise to a territory which we call terraced or terraced territory.

If we consult the dictionary of elements of the cartography of the Topographic Map of Mallorca of 2006, we can see that the category of “Wall” is defined, according to what we are told, by those constructive elements “generally made of brick or concrete (and wood)”. The category of “Retaining wall” is defined by those constructive elements “for holding earth”, while the category of “Bench” is defined by those constructive elements “for holding earth intended for cultivation”. Thus, the most ambiguous category turns out to be that of “Muro, Pared o Tàpia”, since by this denomination it is not possible to specify which distinctive function is fulfilled in each case, when and where those walls, ramparts or walls are made of dry stone, or if they are brick or concrete constructions (or perhaps even wood). However, we can assume that, since the 2006 cartography makes a distinction between terraces, retaining walls and walls, paredes or tapias, the latter, if they are not terraces or retaining walls, can only refer to fence or plot boundary walls, i.e. two-sided walls.

On the other hand, according to the Diccionari Català-Valencià-Balear [13], “tapia” is defined as that piece of wall made of earth kneaded and pressed into a mould and dried in the air, so genuinely, it refers to the tapial technique. For its part, the “wall” is defined as that work of masonry, relatively wide, raised plumb to a certain height to enclose a space of land, but also to serve as a lateral face in a building or room, or to support the roof of a construction. Finally, “Muro” is defined as a construction made of juxtaposed and superimposed stones, of sufficient consistency, to enclose and serve as a defence for a city, castle or other enclosure. Accordingly, the designation “Muro” in the 2006 Map should only refer to constructions erected to enclose an enclosure.

4. Results and discussion

Based on the considerations made in the previous sections, regarding the cartographic discrimination of the walls in the official cartographic sources consulted, several maps have been prepared for the case of the Majorcan Tramuntana mountain range, showing the distribution of these constructions in the area of study, as they are presented in these sources. This distribution and its quantification is summarized in Table 1. In the 1995 Topographic Map, the set of “Walls” and “Fences” (Figure 3) totals 86,693 elements or stretches of more than 5.5 m in length in the Tramuntana mountain range. A visual comparison of these stretches with the orthophotos consulted allows us to infer that, on this map, both terraces and fences are generally classified as “Walls”, without prejudice to the fact that they may refer to other types of entities that are not strictly speaking terraces or fences. In any case, in the Map the category “Walls” (Figure 4) totals 78,469 segments and an absolute length of 4,309,152 m (4,309.1 linear km). In this regard, it is interesting to note that there are walls that are more than 1,000 m long in themselves, a circumstance that shows the importance that the profession of marge (wall builder) acquired in Mallorca and the
quality of his works, as in many cases these constructions have survived in their original form for hundreds of years. As for the “Fences”, in the 1995 Map they total 8,224 segments and 767.6 linear km, but for practical purposes these figures cannot be taken into account, as it so happens that in a good part of the southern half of the Tramuntana mountain range these fences are not mapped (Figure 5), in what seems to be an obvious error in the quality control of the product.

Table 1. Length (km) of the walls of the Serra de Tramuntana on the topographic maps of 1995 (MTB 1995) and 2006 (MTIB 2006), scale 1:5,000

<table>
<thead>
<tr>
<th></th>
<th>MTB 1995</th>
<th>MTIB 2006</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Walls”</td>
<td>4,309.1</td>
<td></td>
</tr>
<tr>
<td>“Fences”</td>
<td>767.6</td>
<td></td>
</tr>
<tr>
<td>“Bancales”</td>
<td></td>
<td>733.4</td>
</tr>
<tr>
<td>“Muros, Paredes or Tapias”.</td>
<td>2,426.2</td>
<td></td>
</tr>
<tr>
<td>“Retaining walls”</td>
<td></td>
<td>75.8</td>
</tr>
<tr>
<td>Total length (km)</td>
<td>5,076.7</td>
<td>3,235.5</td>
</tr>
</tbody>
</table>

Source: Own elaboration based on the count and calculation of the length of the walls mapped in the topographic maps of 1995 and 2006.

On the other hand, in the 2006 Topographic Map, the walls of the Serra de Tramuntana, in any of their types, total 51,510 segments longer than 5.5 m (Figure 6). This indicates that the 1995 cartographic base, in which 86,693 walls are drawn, is more complete than the 2006 cartographic base, an aspect that can be verified by visually comparing the maps in Figure 3 and Figure 6.

If attention is now focused on the categorization of these constructions in the 2006 map, here the “Bancales” (Figure 7) total 13,570 elements and add up to an absolute length of 733,456 m (733.4 linear km). The “Muros, Paredes or Tapias” (Figure 8) total 36,095 elements and have an absolute length of 2,426,232 m (2,426.2 linear km). The “Retaining Walls” (Figure 9) total 1,845 segments and have an absolute length of 75,851 m (75.8 linear km).

In relation to these figures, it is worth mentioning the calculation by Grimalt et al. [4], based on the delineation of sectors terraced by walls, using aerial photographs from 1979 at a scale of 1:18,000. According to this calculation, 167.6 km² of terraced sectors were counted in the Sierra, which coincides with the calculation of Alomar et al. [7], which establishes an extension of 169.6 km², and which, ac-
cording to the latter publication, means approximately 17,134 linear km of walls.

Figure 6. “Muros, Paredes or Tapias”, “Bancales” and “Retaining walls” of the Serra de Tramuntana, according to the categorization of the Topographic Map of the island of Mallorca and Cabrera of 2006.
Source: Topographic map of the island of Mallorca and Cabrera from 2006. Prepared by the authors.

Figure 7. “Bancales” of the Serra de Tramuntana, according to the categorisation of the Topographic Map of the island of Mallorca and Cabrera of 2006.
Source: Topographic map of the island of Mallorca and Cabrera from 2006. Prepared by the authors.

In the case of the present work, the latter figure is substantially reduced to the 4,309.1 km shown in the 1995 map. In any case, this is still a provisional figure, as the two cartographic sources analyzed, for various reasons, do not include all the walls that actually exist. This means that both the final number of walls present in the territory and the calculation of their total length may, in the future, be corrected upwards. As a note, it should also be remembered that, according to an estimate noted by the Spatial Data Infrastructure (SDI) of the Island Council of Menorca, on this other Balearic island, the dry stone walls that make up the enclosed land total 11,120 linear km, a calculation taken from the 2002 Topographic Map of Menorca. Mascaró et al. give the figure of 10,802 km, warning that this could be increased to 15,000 km if the digitization work by photo-interpretation takes into account the walls hidden by forests.

Figure 8. “Muros, Paredes or Tapias” of the Serra de Tramuntana, according to the categorization of the Topographic Map of the island of Mallorca and Cabrera of 2006.
Source: Topographic map of the island of Mallorca and Cabrera from 2006. Prepared by the authors.

Retaining walls
Topographic Map of the Balearic Islands, 1995, E. 1:5, 000

Figure 9. “Retaining walls” of the Serra de Tramuntana, according to the categorization of the Topographic Map of the island of Mallorca and Cabrera of 2006.
Source: Topographic map of the island of Mallorca and Cabrera from 2006. Prepared by the authors.

The exploratory analysis of the maps consulted, together with the figures indicated, point to some aspects that account for the problems encountered. Firstly, the constructions that appear on the 1995 Map labelled as “Muros” also correspond, in general, with the constructions that appear on the 2006 Map as “Bancales”. However, in the southern half of the Sierra, precisely where fences are missing in the 1995 Map (Figure 5), within the category
“Muros”, there is a mixture of terraces and fences. Thus, stone fences are relatively well represented in the 2006 Map (“Muros, Paredes or Tapías”), but on the other hand, this Map does not show the terraces that are shown in the 1995 Map.

On the other hand, although our analysis has not been carried out following a municipal criterion —since the limits of the chosen study area are not based on this criterion either—the maps of terraces show how there are certain areas where the density of these constructions is higher, and areas where it is lower or perhaps non-existent. The areas of higher density appear in municipalities such as Sóller, Alaró, Deià or Estellencs, while in the extreme municipalities of Pollença or Andratx the density of terraces appears to be much lower. This coincides with the data on terraced areas provided, for example, by Alomar and Barri[15], according to whom terraced areas in the Sierra cover 208.6 km² (this figure is provisional). These concentrations and densities are not surprising in a region like the Serra de Tramuntana, where the maximum exponent of the use of stone is represented precisely by the terraced fields, an essential system for creating cultivation plots on steep slopes. If sloping land favors soil erosion and there is a gradual loss of the upper profile of agricultural land, these difficulties are imaginatively and effectively resolved by terracing the slopes. Hydraulic systems for water channeling and drainage made of dry stone are also common.

This being the case, since the Muros, Paredes, Tapías, Bancales and retaining walls recorded in the cartographic bases analyzed may or may not appear to be dry stone constructions, and may also indicate, circumstantially, other types of constructions such as albarradas, which are very numerous in Mallorca. The only way to ascertain all this is through fieldwork. Although the photo-interpretation of aerial photographs or the analysis of satellite images are very limited techniques when it comes to distinguishing the material and the construction technique used to build these walls (dry stone, brick or concrete), they are really effective when it comes to distinguishing their types and functions, as the spatial arrangement of the walls is different when they are terraces, stone fences or albarradas (Figure 10).

In any case, empirical evidence can show that the walls depicted are usually of dry stone, although there are modern cases of stone walls in which cement is used, which is a malpractice for this vernacular type of construction.

Furthermore, the cartographic sources examined allow us to locate walls and therefore serve as a reference and fundamental support for the final cartographic determination of these constructions and, in short, for their quantification and characterization. After all, in the preparation phase of all fieldwork aimed at locating dry stone infrastructures in situ, it is enormously advantageous to consult topographic maps on which these constructions are drawn. In order to locate them cartographically, it is also essential to use aerial photographs, as Grimalt et al.[4] did in the case of the Tramuntana mountain range. Recently, LiDAR technologies and data[16-19] and high-resolution Digital Terrain Models (DTM)[20,21] have been used to semi-automatically quantify the surface area and density of terraced spaces supported by stone walls.

![Figure 10](image.png)

**Figure 10.** Combination of terraced walls (“Marjades”) and fence walls (“Tanques”) on a mountain estate in the municipality of Pollença, on an orthophoto from 2006. The stone fence enclosing the estate has a total length of 2,730 m.

5. Conclusions

The problems encountered in diagnosing the cartographic representation of the dry stone walls on the official maps consulted are limiting but also limited, which allows their technical treatment. They are limiting insofar as they do not allow us to obtain an exhaustive inventory of the walls, and
they are limited because the available cartography, although provisional, constitutes a solid initial basis for determining the final presence of these constructions. One of the first problems is the determination of the length at which the mapped segments actually correspond to walls, as it has been found that segments with a length of less than 5.5 m in many cases do not indicate the physical presence of walls. A second problem lies in the discrimination between walls of bancals, albarradas, fence walls or tapias, as the cartographic sources examined do not allow this uncertainty to be resolved with certainty. In relation to this point, it is also not possible to discern completely whether the georeferenced walls are dry stone constructions or of another type of material (concrete or brick), although field experience would allow us to affirm that the great majority of these walls were built using the dry technique.

The subsequent problem, of a more general nature, consists of deciding which of the cartographic bases of Mallorca is most reliable when it comes to locating the walls and, in short, to characterizing them and analyzing their spatial distribution. Thus, the official topographical maps of Mallorca and the Serra de Tramuntana are relatively useful for various reasons when it comes to determining the presence of walls cartographically. On the one hand, although these maps show these constructions, there are terraced or fenced areas where the walls are not always properly mapped. On the other hand, the categorization of the walls is not always correct, as in some cases the terraces are labeled as simple walls, or certain stone fences are labeled as terraces. In this sense, the cartographic base that seems most appropriate for further studies is the Topographic Map of Mallorca and Cabrera of 2006, as its legend categorizes separately the terraces, the fence walls and the retaining walls. However, in this map, stone enclosures are much more accurately represented than terraces. The 1995 predecessor map is the one with the highest number of walls represented, although sometimes their categories are mixed, an aspect that should be taken into account when undertaking more extensive studies on these constructions. Certainly, the usual photo-interpretation techniques, although necessary, leave out of the catalogue the open areas covered by forest as a result of the forest transition process, so that future studies could and should complement these techniques not only with field work but also with techniques and methods of analysis of LiDAR data and high spatial resolution Digital Terrain Models. These analyses can make a substantial contribution to completing existing inventories of dry stone structures in the Serra de Tramuntana in particular and in Mallorca and the Balearic Islands in general.

Conflict of interest

The authors declare that they have no conflict of interest.

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