

# Recreating past landscapes in 3D using GIS and cadastral cartography from the 19th century: the Horta example of the Province of Barcelona

Alexandre Nobajas  
University of Leicester  
Department of  
Geography  
LE1 7RH  
Leicester, UK  
an179@le.ac.uk

Francesc Nadal  
University of Barcelona  
Departament de  
Geografia  
Montalegre 6, 08001  
Barcelona, Spain  
fnadal@ub.edu

## Abstract

Many historical maps can be integrated with Geographical Information Systems to perform spatial analysis as with contemporary digital data. Even if the integration is possible, it is often difficult due to geometrical or geographical inconsistencies present in many historical maps. A type of historical map which gives relevant information and has a good level of accuracy are cadastral maps. Many 19<sup>th</sup> century cadastral maps from municipalities of the province of Barcelona have been found in recent years, giving an open window to the past for researchers. A combination of historical cartography from the town of Horta and GIS is shown in this paper, both as a way of recreating past landscapes in 3D and as a means of distributing research results to the public on-line.

*Keywords:* Historical cartography, cadastral maps, distributed GIS, visualisation, Horta, province of Barcelona.

## 1 19th century cadastral cartography in the Barcelona Province

One of the peculiarities of the Spanish tax system introduced in 1845 by the ruling Liberals was the lack of rural cadastre plots. This deficiency affected the Spanish tax system until well into the twentieth century. Thus, in 1846, the Spanish Government began to apply the Contribution of Properties, Cultivation and Livestock tax, which charged agricultural and livestock wealth of municipalities. The tax worked via a vertical spread quota system, with a certain element of arbitrariness, and was collected by the Spanish Treasury [1].

The quota system meant that the Treasury assigned to each of the different Spanish provinces –with some exceptions– a certain share of money to collect. Then the heads of the various provincial treasuries distributed the quota allocated to the province between the towns that were part of it. Finally, local authorities were responsible for distributing among local taxpayers a share of the land tax that had been assigned to their town [2]. Towns had, moreover, the obligation to deliver to the provincial fiscal authorities a document: the town's *amillaramiento*. The *amillaramiento* was a written document, created by local authorities, which numerically described the list of land and cattle taxpayers that lived in the town.

The management of this tax soon generated many fiscal conflicts which were solved in two ways. First, in 1847, the government passed a law whereby local councils that thought they had been unfairly overtaxed by at least 12% could file a claim before the authorities of the Treasury to adjust the amount allocated to the real amount of farming wealth and cattle the town had [3]. In second place, in 1848 the Ministry of Finance created provincial statistical committees nationwide, led by public servants and composed by surveyors and agricultural experts. The function of these committees was to prevent tax fraud in the *amillaramientos*

and to try to resolve tax disputes raised by the new fiscal law [4].

To resolve the generated conflicts, or just to avoid them, many municipalities decided, when drawing up their *amillaramientos*, to hire qualified surveyors –known as *agrimensores*– to measure the different plots in the existing rural municipality. As a result of their work, surveyors generated two different types of tax documents: the "Books of Measurements of Land" and a diverse and rich cartography of the rural composition of municipalities. The first type of documents informed about the number of the plot, the name of the taxpayer, the surface of the plot and the type of existing crop. In the province of Barcelona a total of 17 Books of Measurements of Land relevant to as many municipalities were drawn between 1847 and 1852 [3]. The second type of documents contained the same type of information, but in this case expressed in a map. The preparation of rural maps and atlases was mainly an initiative of municipal nature, but also provincial authorities of the Treasury became involved. The realization of this mapping activity was very expensive, which is why many councils only decided to carry it out in case of major conflicts with the provincial authorities or in situations of intense conflict between some of the prominent local taxpayers.

However, between 1849 and 1883 162 rural plot maps of 105 different municipalities were drawn in the province of Barcelona. Although most of these cartographic maps were drawn using a scale of 1:5000, 19 were municipal atlas which used a scale of 1:2500 [5]. This mapping activity was carried out by a small army of 46 different cartographers, of which 29 were surveyors, 4 architects, 10 master builders and 3 workers from other professional fields. One area of the province of Barcelona which held an especially intense cartographical activity during this period was the Plain of Barcelona, where old town of Horta is located [3].

## 2 Integration of a cadastral map with GIS: Horta's map from 1861

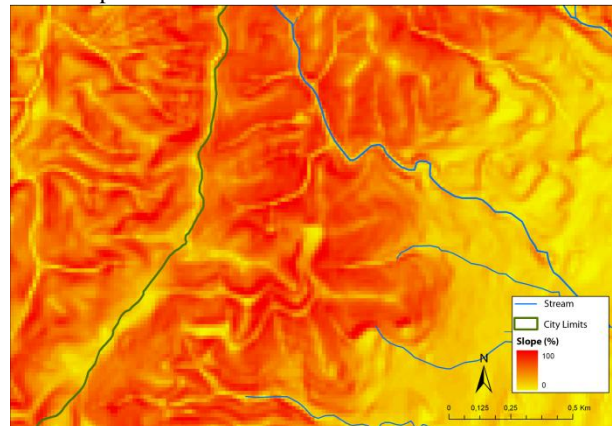
Nowadays Horta is a composing part of the city of Barcelona and one of its neighbourhoods, but until 1904 it was an independent rural town [6]. Its once independent city council commissioned the surveyor Joan Serra and Bonet, a recent graduate from the School of Fine Arts in Barcelona, to make the necessary measurements and drawings to elaborate a cadastral map of the fields which laid within Horta's town limits [7]. In the year 1861 he delivered a map entitled "Plano geométrico del pueblo y término de San Juan de Horta" [3]. The map is the only cadastral plan known of Horta in the 19th century. It is a manuscript map, coloured, drawn on a scale of 1:5000 and a size of 105 x 136 cm, of which several copies exist [8]. The map divides the surface within the town limits into five sections, which are subsequently divided using the cadastral boundaries, which means that each agricultural plot is assigned to its legal owner. If more than a crop was grown in a single parcel of land, agricultural plots are further divided. Apart from the agricultural plots, the map also has the name of the owner of each parcel and it represents the municipal road network, the streams and rivers, human settlements and several place names as well [7]. Surface measurements in the map are not represented using the International System of Units but in 'mujades' and 'mundinas', local units of measurement nowadays deprecated. A last singular characteristic of the map is that it is not oriented to the north, but to the NW, following the traditional system used in the Barcelona shire by which the Mediterranean sea is represented at the bottom of the map. Since the map is manuscript and over 150 years old, obtaining a digital copy of it is a delicate matter as the original map could be damaged in the process. This is the reason why it was considered to be more suitable to take a high resolution picture of it than the traditional scanning approach. The problem when using a picture is that there is a risk of distortion in the scale of the points furthest from the centre of the map. In some cases, as in the case of aerial photographs to prepare topographic maps, this phenomenon requires performing a photogrammetric restitution to minimize this effect [9]. For the map at hand, however, it was not considered necessary to rectify the image since the map itself occupied the central portion of the picture and it was far away from the margins, greatly reducing the levels of distortion in the area of interest.

Integration between historical cartography and modern digital cartographical tools like GIS software is not as straight forward as it is with modern maps or data. The process of georeferencing the digitised historical map is critical when displaying historical information within a GIS. There are a series of challenges that can render a historical map as unsuitable for georeferencing like the lack of common reference points between old and new maps, lack of geometrical consistency or lack of geographical accuracy. If the georeferenced historical map does not comply with those minimum qualities the image may be dramatically warped [10], making it unsuitable for a GIS unless major adaptations are undertaken.

The old town of Horta is nowadays a integrant part of the city of Barcelona, but a hundred and fifty years ago it was a rural

town which relied heavily in farming to sustain its inhabitants. During this time changes in land use have been radical, making it a difficult place to georeference since there are not many common points with other maps whose coordinates are known accurately. In this case, the document used as a cartographic base map to georeference the historical map was the 2008 edition of the 1:10,000 topographic map of the Cartographic Institute of Catalonia [11, 12, 13, 14]. Fortunately, some common points were found; the country house of Cal Mariné, the chapel of St. Cyprian and the corner between the current Tajo Street and Torrent de Can Mariné Street, represented as rivers on the map. Those points, in addition to other topographical control points as the top of the Tibidabo Mountain or the Collserola ridge, helped to georeference the map. The overlap between the old map of Horta and a slope map generated from a DEM of the area [15] shown in Figure 1 proves that the final result has been quite positive, as the municipal boundary north of the old town of Horta matches the crest of the Collserola Mountains, which was what defined the administrative divide. Also, rivers digitised from the original map follow almost in a seamless way the lower part of valleys, where current rivers flow nowadays.

Figure 1: City limits (green) and streams (blue) overlaid over a slope surface.



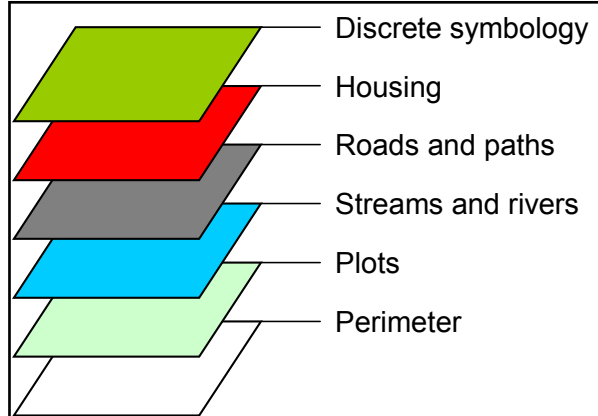
Source: Author's work.

Furthermore, the deformation of the map after its georeferencing is minimal, with a root mean square error (RMS) very close to zero. Therefore the geometric quality of the map drawn by the surveyor Joan Serra in 1861, even if it lacks a projection system, is remarkable. The overlap of the old map of Horta with modern base maps, like Google Maps or the Catalan Cartographical Institute has attested that the outcome of the georeferencing is almost entirely coincidental, mainly thanks to the drawing and technical abilities of Joan Serra.

The next step in the GIS integration process was to manually digitise the map into different layers to allow performing spatial analysis. The generated layers can be seen in Figure 2. Once created, the layer containing the plots was linked with information –including the owner, the crops grown or the quality of the land– obtained from the correspondent amillaramiento. Inconsistencies between the original map and the amillaramiento were found, some of them understandable

because the amillaramiento is a year older than the map, some due to typing errors, and some arbitrary. Once the map has been linked with the information of the amillaramiento, it is ready to be integrated with an elevation model and to perform analysis.

Figure 2: Layers digitised from the cadastral map

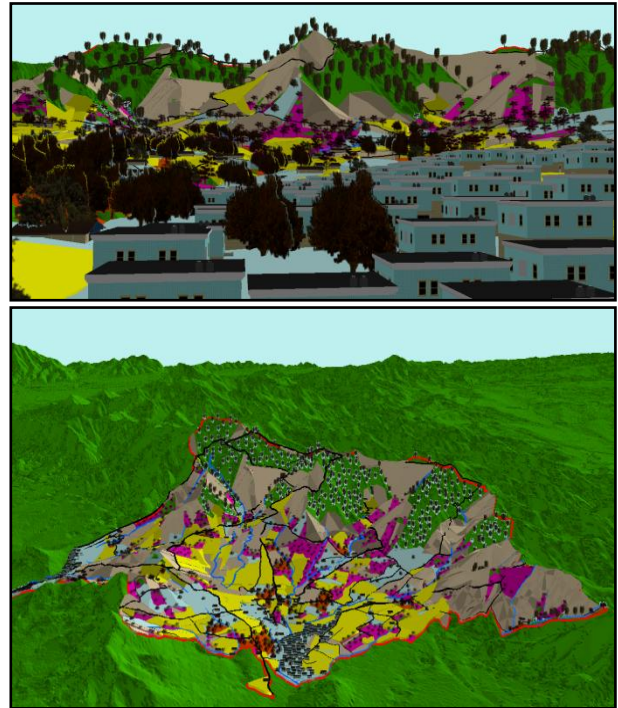


Source: Author's work.

### 3 Results

The original map from 1861 is planimetric and therefore it does not provide information about the terrain's altimetry. However, when linked with the appropriate data, the newly created layer can be visualised in 3D representing the relief of the mapped area [10]. To graphically represent the altitudinal distribution of Horta's land use a Digital Elevation Model (DEM) was utilised. Since the scale of Horta's map is quite large, a highly detailed DEM was used with a resolution of 15x15 meters and an altitudinal average quadratic error of 0.9m [15], provided by the Cartographic Institute of Catalonia [16]. With the digitised old map overlaid on top of the DEM, historical three-dimensional reconstructions can be created. These representations can be made directly with the raster layer or turning it into a TIN (Triangulated Irregular Network), although the final visual result does not change greatly. The advantages given to these types of representations are such as seeing the data in 3D, make virtual recreations of historical cartography or observe the altitudinal distribution of land uses (figure 3).

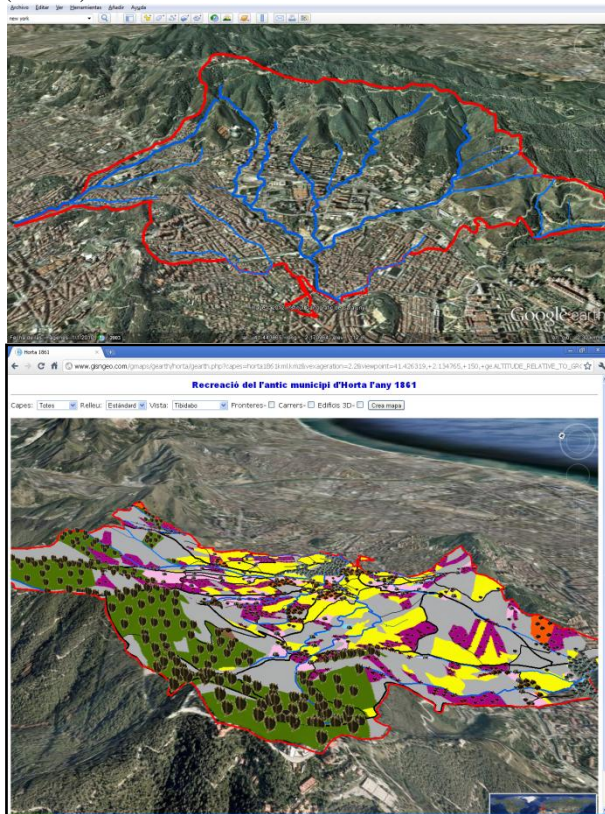
Figure 3: Detailed (top) and general (bottom) view of Horta's 3D recreation showing the altitudinal distribution of land uses with forests on higher areas, vineyards and cereal at lower levels and orchards near the town



Source: Author's work.

The visualisation power of 3D recreations of the past can be seen in figure 3, where a thematically coloured map representing land use is overlaid over the DEM showing the altitudinal distribution of crops and forests. Scientists or users can navigate across the recreation to view and analyse different aspects of how was a certain area in the past. In addition to in-depth analysis in local GIS systems, distributed GIS allows sharing historical findings with users worldwide. To achieve this purpose, an interactive web application that allows the virtual reconstruction of Horta in 1862 was created and made public on the Internet [17]. The application (Figure 4) uses the Google Earth web browser plug in to reveal the results of the work described throughout the paper. It allows not only navigating the 3D recreation, but it also permits adding or removing layers to see, for example, where streams or paths were located overlaid with current imagery of the area.

Figure 4: Horta's 3D recreation overlaid over Google Earth –showing streams- (top) and embedded within a web browser (bottom)



Source: Author's work.

## 4 Conclusions

There are many well preserved maps from before the Digital Revolution, but many of them have yet to be digitised and georeferenced. Once the information they contain has been extracted in a format compatible with GIS, spatial analysis, past representations or land use evolution analysis can be carried out. However, the process is full of challenges; historical maps have to have a minimum degree of geometrical correction to avoid unbearable map deformation. There must also be common recognisable points with modern cartography to achieve a proper integration within GIS. In addition, unless an automation system can be used –for example if maps from the same series are digitised-, it is a time consuming process since each layer has to be digitised by hand.

Nevertheless, once a historic map has been successfully integrated within a GIS, it can be used to perform spatial analysis of past periods, to visualise historical data in a non planar way or to distribute it on-line. The potential for geographers, historians, economists, anthropologists... when using GIS with historical data is almost unlimited [18]. The Horta case presented in this paper shows that integrating Catalan cadastral maps from the 19th century with a GIS is possible due to the high geometrical quality of the maps

created by the *agrimensores*. If a systematic digitalisation, georeferencing and digitalisation of all the 19<sup>th</sup> century cadastral maps found in Catalonia was carried out, a magnificent source of information would be made available to researchers of many fields.

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