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Urban and landscape changes through historical maps: The Real Sitio of Aranjuez (1775–2005), a case study

C. San-Antonio-Gómez [a], C. Velilla [a], F. Manzano-Agugliaro [b,*]

[a] Dpt. Cartographic Engineering, Geodesy and Photogrammetry, Polytechnic University of Madrid, 28040 Madrid, Spain
[b] Dpt. Engineering, University of Almería, 04120 Almería, Spain

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ABSTRACT

When determining the evolution of a territory or town over time, comparing historical maps with contemporary maps is indispensable. In this study, we applied the methodology of georectification to compare historical maps with current orthophotos from 2005. We propose colour and lines code as useful tools for the analysis of the urban and landscape changes that the town has undergone since the 18th century, and we graphically reconstruct certain former heritage items that no longer exist. For example, these techniques are applied to the Real Sitio de Aranjuez (Spain) using the two most important historical maps: the 1775 *Domingo de Aguirre* map, which shows the full extent of the royal site for the first time, and the 1835 *General Town Plan*, which is the most characteristic of available 19th-century maps, as it displays the consolidated historical town. Next, using two rectified rasters and the orthophoto, we overlay a grid of nine 1 × 1 km squares, allowing us to "see the town and its territory" at three moments in history: 1775, 1835 and 2005. Thus, we obtain formal and dimensional information allowing analysis of the evolution of the territory, urban area and historic buildings. Among the many applications of this methodology in the fields of urban development and monumental-heritage conservation, we propose the graphical reconstruction of three urban elements that no longer exist. We determined that graphical reconstruction, in conjunction with traditional historical research, provides the greatest benefits for recreating an historical landscape. These methodologies will aid in the development of long-range management strategies and facilitate the assessment of threats posed by anthropogenic activities and environmental change to preserve the landscape heritage.

1. Introduction

Urbanisation can be defined as the changes that occur in the territorial and socioeconomic progress of an area, including the general transformation of land cover/use categories from being non-developed to developed (Weber, 2001). Urbanisation is a worldwide phenomenon that has increased significantly in the last century (Aguilera, Valenzuela, & Botequilha-Leitão, 2011). Landscapes are characterised by dynamic and continuous change, which may be expressed by quantitative changes in landscape structural characteristics (Skaloš, 2006).

Although photographic techniques are highly accurate, they are unable to provide measurements of the landscape prior to the 1950s (Bromberg & Bertness, 2005). Thus, when graphically reconstructing the landscape, we must resort to historical cartography. Historical cartography all over the world is a fundamental part of cultural heritage (Bitelli, Cremonini, & Gatta, in press), and such maps are a potential source of information for historical studies (Jenny & Hurni, 2011). Large map collections are available in many countries, representing great potential for describing and understanding the development of landscapes through time (Vuorela & Toivonen, 2003). In landscape studies, maps have been used for a variety of purposes, such as analysing changes in land use or reconstructing landscape and vegetation transitions over time (Simpson et al., 1994). For example, Tucci, Giordano, and Ronza (2010) used historical maps dating back to the eighteenth century and a 2005 official city map, and they applied methods of spatial analysis and geovisualisation techniques to determine which parts of the city (Milan) changed the most in the time interval considered.

Technically speaking, it is possible to digitise all historic sources and integrate these seamlessly into new reconstructions. Historical maps have their own limitations, which can lead to unreliable virtual reconstructions (Benavides, 2004). Most of historical maps were created before standardised map projections were being used. It is almost impossible to perfectly align an old map to modern coordinate systems (Rumsey & Williams, 2002). Thus, transformation has been the only option for transforming unprojected historical maps to compare them with projected GIS data layers.

* Corresponding author. Tel.: +34 950015396; fax: +34 950015491.
E-mail addresses: c.sanantonio@upm.es (C. San-Antonio-Gómez), cristina.velilla@upm.es (C. Velilla), fmanzano@ual.es (F. Manzano-Agugliaro).

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The act of overlaying two maps introduces error into the results, a fact well documented in the GIScience literature (Tucci & Giordano, 2011). An important consideration is the spatial accuracy and/or spatial resolution of the data used as inputs in the spatial urban analysis (Herold, Couclelis, & Clarke, 2005). When historical map data are compared with modern cartography, the accuracy assessment is often made by root-mean-square (RMS) error (Manzano-Agugliaro, San-Antonio-Gómez, López, Montoya, & Gil, 2013; San-Antonio-Gómez, Velilla, & Manzano-Agugliaro, 2011). The RMS error is a measure of the distance the historical map points were refitted to match the current map projection.

Using historical maps to reconstruct the landscape has been used for various purposes and in many different places. Bromberg and Bertness (2005) used such maps for salt marsh losses in New England, obtaining a RMS between 160 and 440 m for 5 maps from 1773 (scale 1:25,000) till 1832 (scale 1:24,000), with an RMS average of 245 m. Vuorela, Alho, and Kalliola (2002) analysed land cover and land uses changes in the island of Ruissalo in SW Finland, obtaining a mean RMS error for the 1690 map over 27 m in all polynomial transformation functions and less than 7 m on 1846 maps. Tucci and Giordano (2011) calculated the RMS of the 1884 map of Milan compared with the 2005 map to be equal to 7.7 m, with a rotation of 4° counter-clockwise and at a scale of approximately 1:4000. Maio, Tenenbaum, Brown, Mastone, and Gontz (2013) used historical landscape reconstruction to preserve the potential of historic lands in urbanised settings in Boston (Massachusetts). This work was based on 1775 and 1847 maps, and the sources of potential error were budgeted and overall horizontal uncertainty calculated to less than 9.7 m for the shoreline feature displayed on the base map (2008 orthophotos).

The map image is conventional, coded, avoid appearances, and demands the rational control of the form (Gombrich, 1994). Maps contain heterogeneous landscape information, which is represented on a map as graphic signs and texts (Vuorela et al., 2002). Graphic signs have been geometrically categorised into points, lines and areas, and further to different size, shape, colour, hue, texture and orientation forms (Monmonier, 1996). Colour has the potential to enhance communication (Light & Bartlein, 2004). Colour mapping is an important technique used in visualisation to build visual representations of data and information, so, it is particularly important to make the right choice to build visualisations that depict the desired information in a clear manner (Silva, Sousa Santos, & Madeira, 2011). Colour offers a three-dimensional structure, which can be used to organise symbols for multivariate mapping (Brewer, 2004). Choosing effective colour schemes for thematic maps is surprisingly difficult (Harrower & Brewer, 2003). Visualisation technique efficiency is important for the reliability of the technique regarding representation level of the spatial content in the process of urban planning (Koramaz & Gulersoy, 2011).

Urban and landscape graphical reconstruction needs to overlap elements of historical cartography that no longer exist onto modern cartographies (or orthophotos) and vice versa. We propose a code of lines and colours to facilitate the viewing of urban graphics elements over both cartographies. We argue that the combined application of photogrammetric techniques as rectification of historical maps and an the proposed interpretation code (colour and texture) can provide more spatially consistent and detailed information on urban and landscape structure and change than either of these approaches used independently. Indeed, coupling these two approaches can improve the change analysis of urban and landscape through their historical maps. This approach is applied to the Real Sitio de Aranjuez.

The Real Sitio de Aranjuez, located 49 km to the south of Madrid, was a place of rest for the Spanish monarchs. In addition to the royal palace, it consisted of gardens, woodland, orchards, farmland and farm buildings (Sancho, 1995). The first map of the royal site to be conserved is attributed to Juan de Herrera (1581) and was made for Philip II (Anonymous, 1991). The various modernisations that monarchs since Philip II have made to the palace, gardens and orchards were not included on any map. For that reason, the Duke of Grimaldi (1720–1786), Secretary of State of Charles III (1716–1788), commissioned the captain of the Spanish infantry, Domingo de Aguirre, to draw the first of the maps described in this study, which was completed in 1775. The aim was to represent the huge modifications projected by the King, as well as embody a rational agricultural model of the Illustration period, taking into account that "maps are pre-eminently a language of power" (Harley, 1968). The cartographer of the second map is unknown, but it was commissioned by the Regent Queen Maria Cristina of the Two Sicilies (1806–1878). This map's purpose was to propose extending the urban area to the south and south-west with 27 new street blocks, some of which were never actually built.

2. Materials and methods

2.1. Material: historical cartography

To analyse the urban and landscape changes that have occurred at the Real Sitio de Aranjuez between the 18th century and the present day and perform a graphical reconstruction of some of the lost elements of its heritage, we have used two historical maps: the 1775 *Domingo de Aguirre* map and the 1835 *Plano general del pueblo*. The contemporary map used is an orthophoto from 2005.

The title of the first map is *Topografía del Real Sitio de Aranjuez por D. Domingo de Aguirre* and consists of 16 sheets, each 64 × 84 cm, conserved at the Royal Palace in Madrid under reference number AGP 563. The plates are kept at the Spanish *Calcografía Nacional*, and the copy consulted for this study is kept at the Army Geographical Centre (CGE). The map dates from 1775. The unit of measurement used is the Castilian rod. Its scale, calculated from the graphic scale drawn on sheet 15 (800 rods = 160.1 mm), is 1:4166.48, with 1 Castilian rod considered to be equivalent to 835.9 mm.

Digital images were taken of sheets 10 and 14 of this map, which were then joined to create a single map, which we shall henceforth refer to as *Original Map 1775* (Fig. 1). We chose 20 control points on historical buildings that are still standing (Fig. 2). Most of the area studied is covered by sheet 10, including the town

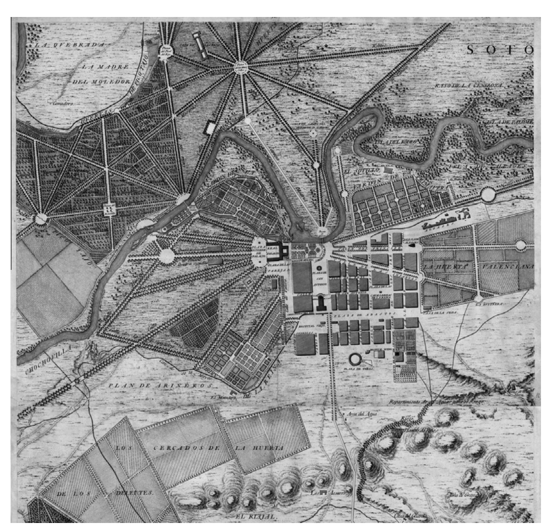

Fig. 1. Raster of *Original Map 1775* (sheet 10 and part of sheet 14).