Gabriele Bitelli*, Giorgia Gatta**

Experiences on georeferencing of maps from the XIX century Gregorian Cadastre of Bologna (Italy).

Keywords: Gregorian Cadastre; Bologna; georeferencing; mosaicking

Summary
The study focuses on the nineteenth century Gregorian Cadastre of Bologna, kept today at the State Archive of the city. In these maps the city is divided into several sectors; for each sector there are ground floor maps and maps for the floors above and below.
In the study, results from metric analysis of these maps are reported. The analysis consists in a preliminary georeferencing of digital images derived from high quality scanning of the original documents, together with an assessment of map deformation. Moreover, digital mosaics from each floor were sequentially superimposed. Finally, a comparison with the original edition map kept at the State Archive of Rome was performed, in order to highlight possible differences between the two editions and digitally restore the worn maps of the Bologna edition.

Introduction

The study belongs to a research project which aims to investigate the ancient order and appearance of three main Italian cities (Bologna, Milan, Rome), with specific interest for historical cadastral cartography; the research, funded by *Fondazione Cariplo*, is carried out by the pertinent Universities and State Archives. One of the final aims of the research project is to realize a Geographical Information System (GIS) which preserves interesting examples of historical cartography of each city and integrates them with other documentation.
The study presented here investigates the nineteenth century Gregorian Cadastre of Bologna, kept today at the State Archive of the city. The Gregorian Cadastre was promoted by Pope Pio VII in 1816, to have an instrument to better rule over the ancient Papal State, but its name derived from Pope Gregorio, who inaugurated it in 1835. It was a geometric cadastre based on parcels: it used maps to identify the specific properties. To realize the cadastre, the Napoleonic survey carried out in the previous years (1805-1814) by the once Italic Kingdom was exploited, and many rules from it were adopted: the decimal metric system, to make uniform the measurement system all over the territories, the map scale, modalities for drawing up the registers, etc. A real innovation was the use of plane-table to survey. The Gregorian Cadastre was realized in the form of maps and related registers: the originals were kept at the *Presidenza del Censo* of Rome, and the copies were kept at the various *Cancellerie del Censo* of the Papal State, where maps and registers were subject to updates over time (Buonora, 2009).

* Professor of Digital cartography, Photogrammetry, Remote Sensing and GIS; member of the ICA Commission on Digital Technologies in Cartographic Heritage; DICAM Dept., University of Bologna, Viale Risorgimento 2, 40136 Bologna (Italy) [gabriele.bitelli@unibo.it]
** PhD in Geodetic and Topographic Science; DICAM Dept., University of Bologna, Viale Risorgimento 2, 40136 Bologna (Italy) [giorgia.gatta@unibo.it]

The studied subject

The cadastral maps of Bologna, like all maps from the Gregorian Cadastre of the territories subject to government of the ancient Papal State, are copies of an original document now preserved in the State Archive of Rome; the latter derives from the Napoleonic survey carried out in the years 1812-14. Three editions are today preserved: the first one (analysed hereinafter) goes back to the Napoleonic survey but is updated to 1831; the second one (1873) is the real updating after the Napoleonic survey; the third one goes back to 1889-1901, with updates until 1927.
In the cartographic documents of the first edition of the Bologna Cadastre, the city is divided into fourteen sectors, without overlap between the sheets of two adjacent sectors (Fig. 1). For each sector there are ground floor maps and maps for the floors above and below, at 1:1000 scale; the dimensions of the documents are 94.5 x 58 cm (Capoferro Cencetti, 1981; Tura, 2004). Being cadastral maps, they are correlated to specific registers (*Brogliardi* and *Sommarioni*, in 12 volumes), where written information concerning the land lots drawn on maps is kept (Orciani et al., 2006).
The overall database constitutes a precious and rich documentation, very detailed and of high quality, for historical studies on the city and its evolution over time, and a reference base for architects and city planners.
Drawn and written analogical documents were digitalized by means of special high quality scanners for maps and big documents, according to standardized parameters of resolution, colour depth and file format (Balk, 2009; Sgambati et al., 2006).

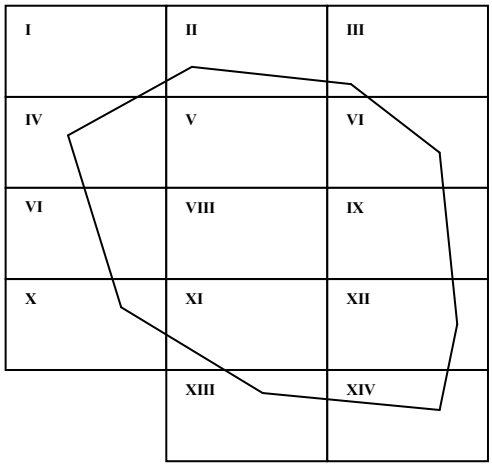


Figure1: Scheme of the division of the Bologna cadastre (1831 edition) into sectors.

Georeferencing

Study of map deformation

A preliminary analysis of the maps was performed in order to assess map deformation. Using a specifically designed software tool (Jenny & Hurni, 2011), it was possible to calculate the average scale and to display the local scale variation within the map, coupled with the visualization of the distorted grid of the present cartographic reference system. The Ground Control Points (GCPs) used in the calculation of the transformation parameters derive from an accurate examination of descriptive and graphic historical documentation (Bocchi et al. 1998), to detect the buildings of

Bologna which have not been subject to significant changes over time. The cartographic coordinates for the GCPs were derived from the current large scale numerical cartographic base of the Municipality (CTC), realized in UTM-ED50 system, fuse 32.
The restrained scale variation (with a mean value equal to 1:1030) and the practically undeformed grid showed an accurate original draft stage.

Mosaicking

Afterwards, all ground floor maps were georeferenced basing on the same GCPs used in the previous stage. The direct georeferencing (i.e. on the base of the current CTC) was performed on the ground floor maps, as they, depicting the land lots described in the cadastral registers, will be used as a cartographic base for the final GIS.
The adopted transformations were polynomials of an order variable from 1 to 3, according to the amount of GCPs and their distribution on each map. In order to assess the quality of the process, 10 additional CPs (Check Points) were used for each sheet; in table 1 a summary of the statistical analysis of GCPs and CPs residuals is reported. The average residuals can be considered acceptable for an XIX century cartography, since it was drafted with instruments less precise than the present ones and has been subject to inevitable deformations in its life (Gatta, 2010).

	Control points	Check points
number of sheets	14	14
polynomial order	1 ÷ 3	1 ÷ 3
average number of points / sheet	30	10
total RMS [m]	**1.2**	**1.6**

Table 1: Statistical analysis of the georeferencing residuals for the ground floor maps.

Therefore a mosaic from the ground floor maps was produced, on the base of geocode/ georeferencing information only. Such a choice was motivated by the lack of overlay of the drawing between adjacent sheets, and the consequent impossibility to recognize homologue points.
In order to maintain the natural colour of the maps, no colour homogenization algorithm was applied. Superimposition of the georeferenced mosaic on the current cartography resulted good (Fig. 2), with maximum displacements in accord to the residuals summarized in Table 1.

Figure 2: A detail of superimposition of the ground floor mosaic on the present numerical cartography.

Overlay of the single floor map mosaics

Secondly, georeferencing of all other maps for the floors above and below was performed (Tab. 2). This was carried out on the base of the ground floor mosaic, due to two factors: i) the need to best fit the map of each floor with the corresponding map of the ground floor; ii) the recognition of a higher number of GCPs on the ground floor mosaic.
Digital mosaics, each one coming from assemblage of the georeferenced maps belonging to a single floor, were sequentially superimposed, to display the variation of the land lots increasing the floor level, and to give a first – although not very reliable – idea of building heights. Other display modes are under study.

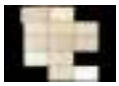
	Floor							
	-1	0 (reference)	1	2	3	4	5	6
scheme								
preview								

Table 2: A scheme of the mosaics coming from the maps of each single floor.

Comparison with the original edition

Finally, a comparison with the original Napoleonic map (one single sheet, and better preserved), kept at the State Archive of Rome, was performed, in order to: i) highlight possible differences between the two editions; ii) digitally restore the Bologna edition maps, providing mapping information (i.e. geometry and the number of land lots) where data are lacking because of wear and tear of the original analogical support (Fig. 3) (Federzoni, 2008).
A digital copy of the map (provided by the Rome State Archive) was referenced on the base of the ground floor mosaic. In the latter, all areas of lacking data were delimited and were given a transparency; the product was superimposed on the Rome edition map, in order to make visible the

Napoleonic map (1812-14) through the 1831 map. The correspondence between the two editions resulted good, even though not everywhere uniform.
The result was also useful to compare drawing style and representation details of the original with the copy; for example, lines of cutting, probably drawn with a pencil, have been recognized in the original edition, from which the Bologna edition sheets were derived.

Figure 3: A detail of the digital restoration of the 1831 edition by means of the original edition (in yellow).

Conclusion

The study reports results from the georeferencing of the 1831 edition of the Gregorian Cadastre of Bologna, coupled with a metric analysis of the cartographic product. The georeferencing of the fourteen sheets composing the ground floor (and in a similar way of all sheets belonging to the other floors) allowed their mosaicking and the reconstruction of the 1831 asset of the city. This procedure made possible a direct comparison with the original cadastral edition (1812-14), and allowed a sort of digital restoration of the worn maps.
The ground floor mosaic will be used as an ancient cartographic base in the GIS that will be created as a result of the research project. Each land lot will be linked to its specific register pages, permitting an effective consultation of the overall database.

Acknowledgements

The research is funded by Fondazione Cariplo, Milano, in the framework of the project "*Ritratti di città in un interno. Consolidare la memoria collettiva della città attraverso l'informatizzazione e la divulgazione della cartografia storica*"; coordinator Polytechnic of Milan. Current numerical cartography was realized by the Municipality of Bologna, U.O. SIT. We would like to thank the Bologna State Archive for the permission to use cadastral maps of the city and the fruitful collaboration, together with DAPT Dept. of Bologna University. We are grateful to the Rome State Archive for giving us a digital reproduction of the original Cadastre of Bologna.

References

Balk L. (2009). The National Archives of the Netherlands: Manuscript maps and digital access. *e-Perimetron*, Vol. 4, No. 4, 203-211.

Bocchi F., De Angelis C., Dondarini R., Greco G., Morigi Govi C., Ortalli J., Preti A., Passatelli G., Tarozzi F. (1998). *Atlante storico delle città italiane, Emilia-Romagna, Bologna*. Bologna: Grafis.

Buonora P. (2009). Digitization, online utilization and preservation of cadastral very large format cartography. *e-Perimetron*, Vol. 4, No. 3, 192-198.

Capoferro Cencetti A.M. (1981). *Le mappe catastali di Bologna come strumento ausiliario per lo studio della città antica*. In Gambi L., Carozzi C., *Città e proprietà immobiliare in Italia negli ultimi due secoli*. Milano: Franco Angeli, 328-344.

Federzoni L. (2008). The digital restoration of ancient maps in Italy. Experiences and reflections. *e-Perimetron*, Vol. 3, No. 1, 1-9.

Gatta G. (2010). *Valorizzazione di cartografia storica attraverso moderne tecniche geomatiche: recupero metrico, elaborazione e consultazione in ambiente digitale*. PhD thesis, University of Bologna.

Jenny B., Hurni L. (2011). Studying cartographic heritage: Analysis and visualization of geometric distortions. *Computers & Graphics* 35-2, 402–411. Elsevier.

Orciani M., Frazzica V., Colosi L., Galletti F. (2006). Gregoriano Cadastre: transformation of old maps into Geographical Information System and their contribution in terms of acquisition, processing and communication of historical data. *e-Perimetron,* Vol. 2, No.2 [92-104].

Sgambati G., Benassati G., Biancini L., Buonora P., Sinisi D., Cantile A., Delfino L., Di Angelo Antonio M., Falchetta P., Mancinelli M.L., Sanguineti M.T., Serratrice G., Truci I., Valerio V. (2006). *Linee guida per la digitalizzazione del materiale cartografico.* ICCU (*Istituto centrale per il Catalogo Unico delle biblioteche italiane e per le informazioni bibliografiche*).

Tura D. (2004). *Le carte catastali: il territorio bolognese nell'opera di periti ed ingegneri in: Memoria disegnata e territorio bolognese. Autori dal XX al XV secolo*. In A.M. Guccini, *Atti*. Bologna: Tipografia moderna, 157-176.