Gabriele Bitelli[*], Giorgia Gatta[**]

Georeferencing of an XVIII century technical map of Bologna (Italy)

Keywords: XVIII century cartography; Bologna; flat representation; streets; georeferencing.

Summary: The study focuses on an eighteenth century map of Bologna, made by the two surveyors G. Monari and A. Laghi. The map represents the first example of a map of Bologna deriving from a general survey of the city, and the first example of flat topographical representation of the city. A digital copy of the map derives from high quality scanning of the original document, which is kept today at the National Archive of Bologna.
The study aims at testing the metric quality of this map, according to its original technical function. The georeferencing of the map allowed an assessment of map deformations, a comparison with the present situation and with other maps of the same historical period. The comparison, made by means of mutual overlay of the maps in a GIS environment and measurement tests concerning street width and area, proved the high accuracy of the analysed map.

Introduction

The study belongs to a research project which aims at investigating the ancient arrangement and appearance of three main Italian cities (Bologna, Milan, Rome); the research, funded by *Fondazione Cariplo*, is carried out by the pertinent Universities and National Archives. One of the final aims of the research project, in the context of spreading knowledge and access of the citizens to historical cartographic records for these urban environments, is to realize a web based information system which preserves interesting examples of ancient maps of each city and integrates them with other graphical and textual documentation; the main core of the analysed heritage refers to nineteenth century cadastral data.
The work presented here focuses on an ancient map of Bologna, made by the two surveyors Gregorio Monari and Antonio Laghi in 1711-12. The original is kept today at the National Archive in Bologna.

The studied subject

The Monari&Laghi map derives from the assemblage on a large canvas (about 2 x 2.7 m) of 25 colour sheets (Fig. 1). The main aim of the map was to have an accurate representation of the city at the beginning of the 18th century, paying particular attention to the state of the streets, in order to let the Senate know the kind and extent of the streets to be paved or levelled. In fact at that time streets were in bad condition, also because it was the task of each landowner to preserve them on

[*] 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 base of the extension of the building façade on the street. The number of inhabitants of Bologna had recently increased, and at the beginning of the 18th century it had reached the value of 65000-70000 (Ricci, 1985).

The two surveyors began the survey in t 1711 and finished it by the end of the next year, when they delivered to the Senate the map and the original matrixes (from which some copies of the map were derived during the following years) (Assunteria d'Ornato, 1657-1717; Comelli, 1914).

Therefore this map constitutes the first example of a map of Bologna deriving from a general survey of the city, and the first example of flat topographical representation of the city (without building elevation): only streets and city arcades (Fig. 1a), which give the property limits, are carefully represented (with the exception of the perimeter of few buildings), together with gardens, city channels and undeveloped areas (Ricci, op. cit.). The location of the religious buildings is pointed out by a symbol and a letter, according to a list placed in the right side of the map (Fig. 1d), whereas the location of the senatorial buildings is pointed out by the name of the family directly on the drawing.

Here the *forma urbis* of Bologna, the first evidence of which is given us by a Vatican drawing of 1575, is clearly outlined by the walls; it would remain unchanged until the 20th century. A graphic scale in 20 Bologna perches (1 Bologna perch = 3.80 m), corresponding to a map scale around 1:1080, proves the technical function of the map (Fig. 1c). Moreover, in the entire map a grid, parallel to the map sides and largely sized, is drawn in pencil; it can be supposed that it was useful to report on the map surveying measurements, some of which, in Bologna feet (1 perch = 10 feet), can still be clearly read (Fig. 1b).

Figure 1: The Monari&Laghi map (1711-12), kept at the National Archive of Bologna. In the boxes some details: a) streets and city arcades; b) surveying measurements; c) the graphical scale; d) an extract of the list of the religious buildings.

It can be assessed that this map brought an innovation in respect to the previous representations of the city, because it surpassed the artistic product to provide a more scientific one, more similar to the cadastral maps of the subsequent century than to previous maps dating back only few years before. Notwithstanding this, from other aspects it still remains loyal to the tradition. Firstly, a compass-card is lacking, maybe because the traditional map orientation - towards the hills (*i.e.* to the South) as in the previous maps of Bologna (Ricci, op. cit.) - still remains. Outside the city walls and the depicted countryside, the map is decorated with figures (the allegory of Felsina and some images of patron saints) and crests of senatorial families, as in many previous maps of Bologna (Dolfi, 1670). For such decorations, Monari and Laghi were helped by the painter Fiore Pilati, and we know from historical documents today preserved at the National Archive of Bologna that they paid the painter 60 £. On the base of the total amount of money the two surveyors spent, they asked the Senate to be paid 750 £, about twice the amount that had been initially arranged (Assunteria d'Ornato, 1702-1717; Guidicini, 1972).
Unfortunately no information is available regarding the methodology used in performing the work, and we can only speculate about it, on the basis of the kind of instrumentation available at that time and some traces of construction of the drawing that can be found on the map (Fig. 1b).

Digitization of the map

A digital copy of the map derived from a high accuracy scanning made by means of a high quality acquisition system, by Metis. It is composed by a *Digital Macro Camera* and one great-sized vertical glass panel (able to maintain flat the support during digitization), highlighted by a *SyncroLight* system based on IR/UV free LED (able to shed an uniform light on the map). Such a choice derives from the great dimensions of the map and a slight deformation of the support (due to the fact that the map had been preserved in the past hung on a wall), associated with the need to have a high digital resolution, and to maintain uniformity of light and colour during the digitization of the map.
The native tiff digital image (at an 800 dpi resolution) was converted in the lossless jpeg2000 format, in order to maintain the original quality of the image together with a reduction in the file dimensions. In fact, as well known, a great advantage of this format is the possibility of being lossless like the tiff format, but reducing the memory space by about half. Moreover, the jpeg2000 is a multi-resolution format, can contain geocoding and georeferencing metadata, and can save information of colour in 48 bit images like the tiff format; due to these advantages, it is increasingly becoming a new format for digital repositories (Buonora and Liberati, 2008; Sgambati et al., 2006).
In order to take advantage of the visualization of the full-resolution image, a specific software application, able to pan and zoom at a very high speed, was also exploited (Přidal, 2010), allowing good performances for the consultation of the huge file.

Metric analysis

The study presented here aims at testing the metric characteristics of the map, according to the supposed level of quality deriving from the original technical function of the map.
Firstly, the metric analysis consisted of a georeferencing of the map coupled with a study of map deformation. This allowed the comparison with other maps, both ancient and recent. Finally, a

vectorization of the georeferenced map was useful for calculating the amount of area covered by streets at that time and for comparing the result with the historically declared value.

Study of map deformation

A preliminary analysis of the map was performed in order to assess map deformation, which might exist due to deformation of the analogical support or to the kind of map representation. Using a specifically designed software tool (Jenny and Hurni, 2011), it was possible to calculate the average map scale and the rotation angle with respect to the cartographic North 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 183 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. Obviously, in such a particular kind of city representation (where the perimeter of each single building is missing), it was possible to take into account only peripheral buildings (*e.g.* buildings on crossroads) to detect useful GCPs. The cartographic coordinates for the GCPs were derived from the present large scale numerical cartographic base of the Municipality (CTC), realized in UTM-ED50 system, fuse 32.

Results from the study of map deformation showed an accurate original draft stage (Fig. 2): scale variation appears quite restrained (with a mean value equal to 1:1090) and the cartographic grid appears only slightly deformed (Table 1).

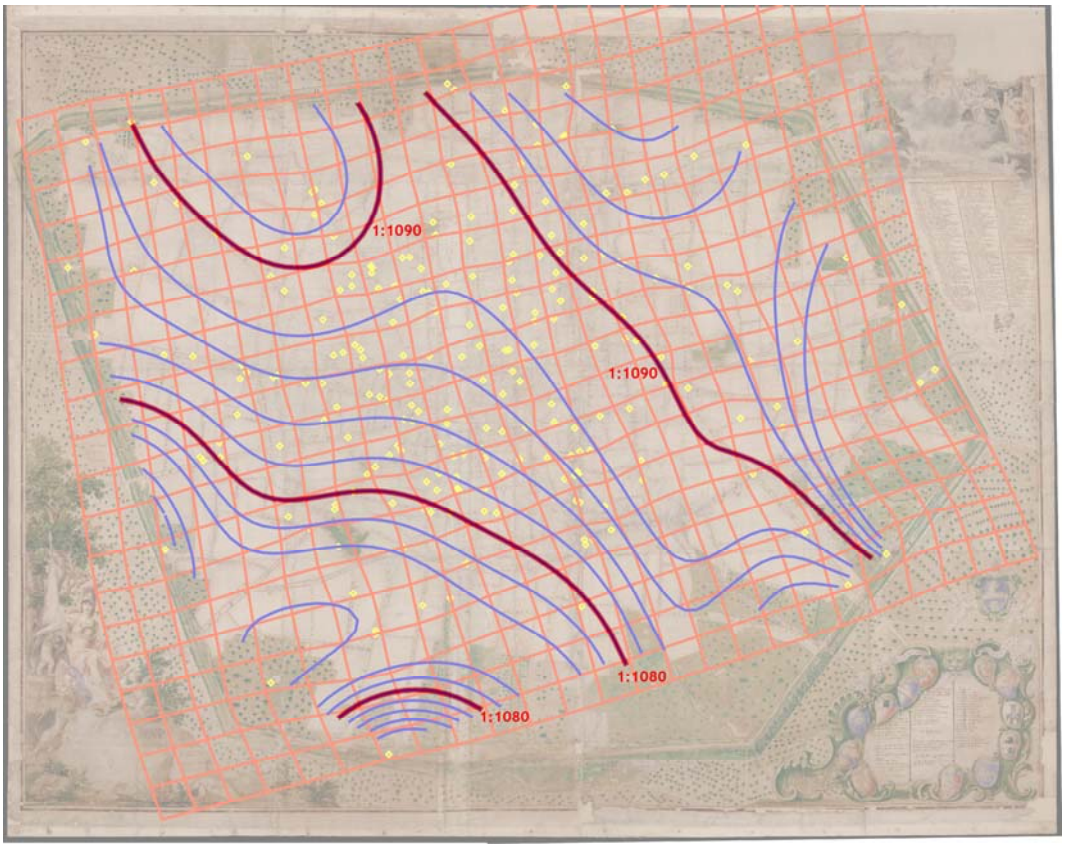

Figure 2: Graphical results from the study of map deformation: UTM grid (mesh size = 100 m, exaggeration x5); scale isolines (variation = 2), used GCPs (in yellow).

range of scale factor	1.070 ÷ 1.100
average scale factor	**1.090**
scale factor inferred from the map	1.080
counter-clockwise rotation angle [°]	195

Table 1: Numerical results from the study of map deformation.

Georeferencing

Using the same GCPs detected for the assessment of map deformation, the map was georeferenced by means of a second order polynomial transformation, thanks to the high number of GCPs which were detected. The Root Mean Square on the GCPs and the Check Points (CPs) showed a global error equal to about 4 meters, a value that can be considered good enough for an early XVIII century map. In particular, statistical analysis on CP residuals is the best way to estimate the quality of georeferencing beside the metric quality of the map.
An overlay of the georeferenced historical map with the reference present cartography has been useful to visually check the quality of georeferencing: the result appeared good (Fig. 3), with maximum displacements in accordance to the residuals summarized in Table 2. Moreover, a display through views side by side allowed an easy comparison between the ancient and the modern maps, very efficient when supported by measurement instruments (Fig. 4).

Figure 3: A detail of the overlay of the georeferenced historical map with the present numerical cartography (in blue).

	number	**total RMS [m]**
Ground Control Points	183	4,1
Check Points	40	**4,6**

Table 2: Numerical results from georeferencing by means of a 2nd order polynomial transformation.

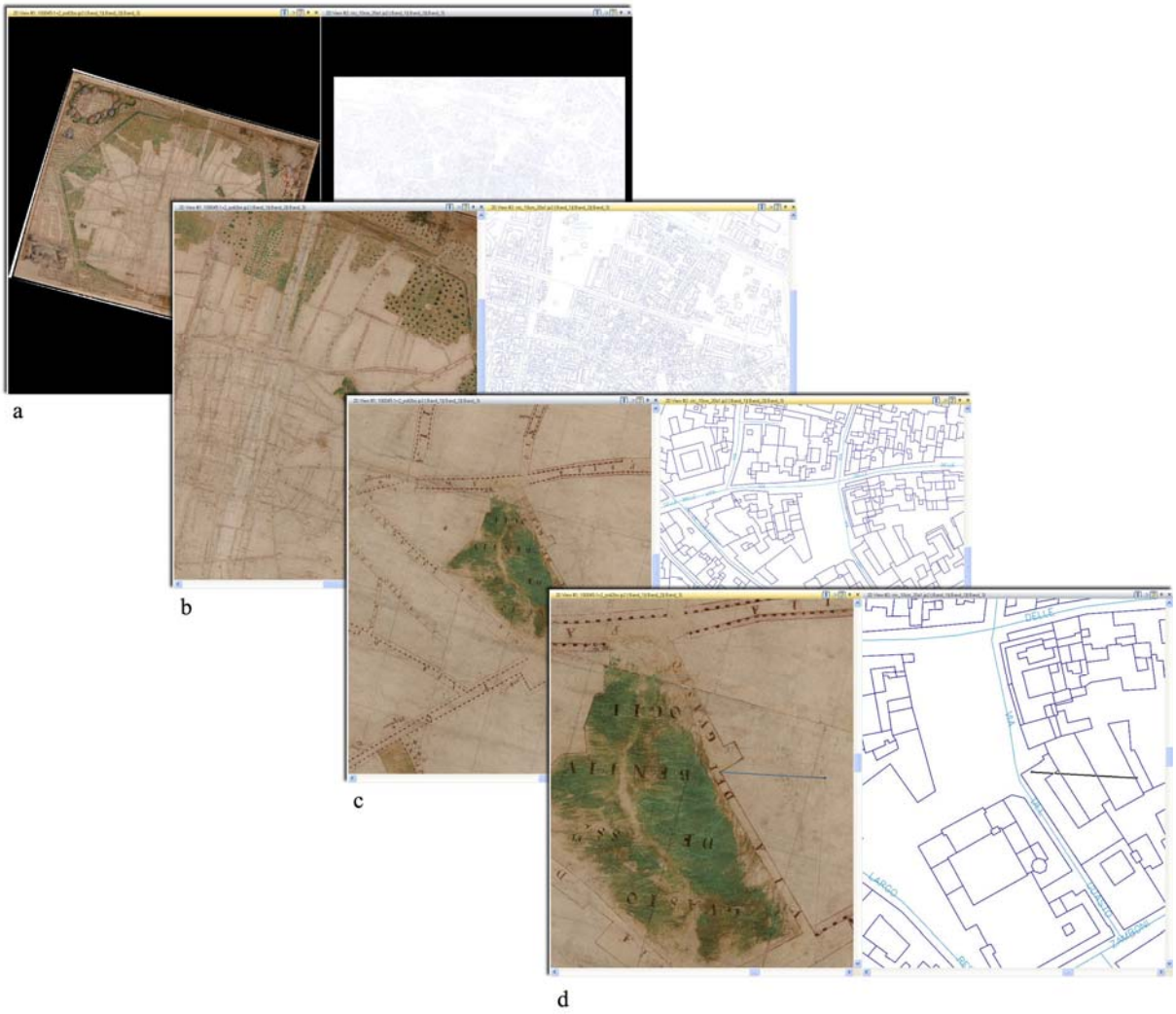

Figure 4: Visualization side by side of the historical and the present maps: a-d) different level of zoom; d) comparison of surveying measurements, reported in the ancient map (see Fig. 1b), with the present cartography.

Comparison with other maps

In a GIS environment, an overlay of the resampled Monari&Laghi map, not only with the present cartography but also with other historical maps (before and after the years 1711-12), was tried, in order to perform measurement tests on the metric quality of the map. The other historical maps taken into account were the coeval *Ichnoscenographia* of Bologna, by Filippo de' Gnudi (1702), and the Gregorian Cadastre of Bologna (1835). The first map was clearly drafted for non-technical purposes, as it is characterized by a scenographic representation (Bitelli and Gatta, 2011a); the second map opened the Bologna topographic cartography, as it had to be an instrument to better rule over the ancient Papal State (Bitelli and Gatta, 2011b).

The first performed test concerned street width: a series of about 40 streets, well recognizable on the three ancient maps and on the present numerical cartography because they have not been subject to significant changes over time, were taken into account in order to be measured. The results were reported in a histogram (Fig. 5): it is possible to confirm the high metric quality of Monari&Laghi map, especially when compared with the values resulting from the comparison of the *Ichnoscenografia* with the present cartography, even if the latter is dated only 10 years before the

Monari&Laghi map (Table 3). However, it must be considered that the nature of the three-dimensional graphical representation for the second map probably required an alteration in size of some streets by the author, in order to make the representation more readable; in fact in some cases the medieval streets of the city were narrow and then they would have been not clearly recognizable in a scenographic map.

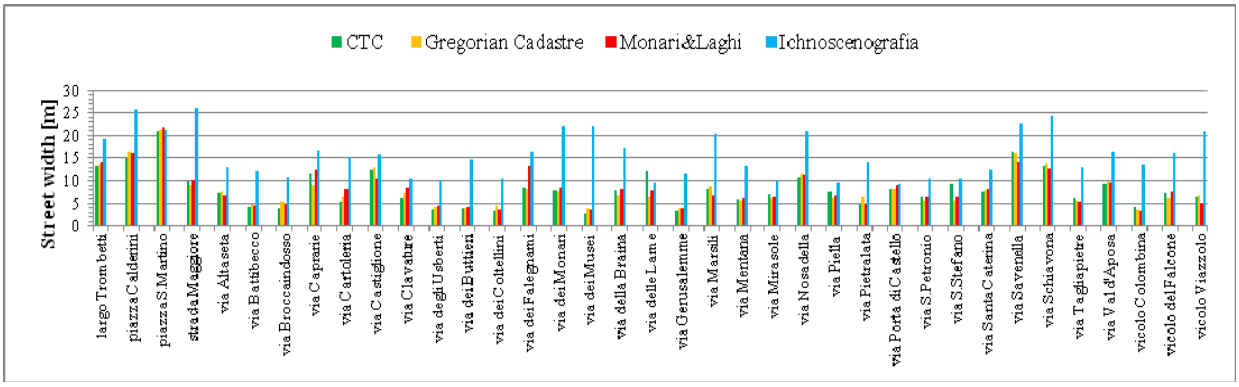

Figure 5: Histogram comparing the measured values of street width in the present numerical cartographic base of the Municipality (CTC) and the three analysed ancient maps (Gregorian Cadastre, Monari&Laghi, *Ichnoscenographia*).

		Gregorian Cadastre (1831)	Monari&Laghi (1711-12)	*Ichnoscenographia* (1702)
Absolute differences	Mean [m]	0,9	1,1	7,6
	Max [m]	5,0	5,6	19
Number of measurements		37		

Table 3: Numerical differences regarding street width between the present numerical cartographic base of the Municipality and the three analysed ancient maps (Gregorian Cadastre, Monari&Laghi, *Ichnoscenographia*).

Vectorization

Another test on the metric quality of the Monari&Laghi map concerned measurements of street area, according to the specific aim for which the ancient map was drafted (the estimation of the area of the streets to be worked on). In order to perform the test, a vectorization of the georeferenced map resulted necessary. In particular, it resulted useful to distinguish between paved streets, non-paved streets and other elements (groups of buildings, channels, gardens, undeveloped areas), due to the specific aim of the map. Moreover, the religious buildings (pointed out on the map in accordance to a list of nouns) and the senatorial buildings (highlighted directly on the map by means of the name of the family) have been vectorized by means of points. Results show very clearly the high number of the religious buildings in the entire city (over 200 among churches, monasteries, cloisters, colleges, etc.), in accordance with the fact that in the beginning of the 18th century about 1/6 of the land properties was occupied by churches and monasteries, even though the religious population was only 6% of the whole (Ricci, 1985) (Fig. 6).
The test on street area aimed at verifying the value of 30000 square perches (probably, a rounded value) that is reported in the annals of Bologna history, regarding streets to be paved (Muzzi, 1870). The results of the measurement, made by means of vectorization of the streets, are reported in Table 4: the value deducible from the map is very similar to the historically declared value of 30000 squared perches, proving the high quality of the Monari&Laghi map once again.

Figure 6: The vectorization of the streets (in red) on the georeferenced Monari&Laghi map; in green senatorial buildings, in yellow religious buildings.

	square perches	square meters
Declared value (see annals)	30000	433000
Measured value	32200	465000
Difference	2200	32000

Table 3: Results from the test on street area: comparison between the value declared in the annals and the value measured in the vectorized Monari&Laghi map.

Conclusion

The study reports results from the digital elaboration of the technical 1711-12 map of Bologna, made by the two surveyors Monari and Laghi, and converted in digital format by means of high resolution scanning. The insertion of the full resolution image in a specific high speed visualization tool could be useful for consultation of the map, as well as for creation of a digital archive resulting from the research project.

The georeferencing of the map allowed an analysis on the metric quality of the cartographic product, comparing it with the present cartography as well as with other ancient maps (before and after the years 1711-12). According to the original technical function of the map (the estimation of the area of the paved streets of the city), some metric tests, regarding measurements on width and area of the streets, were performed. They proved the high accuracy of the surveying and drawing steps of the Monari&Laghi map. Results are especially evident when the analyzed map is compared with historical maps which were clearly edited for non-technical purposes.

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