GEOREFERENCING THE HISTORICAL MAPS OF ROME BETWEEN THE SEVENTEENTH AND EIGHTEENTH CENTURIES

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ABSTRACT

Historical studies often need to consider both geographic and temporal aspects of the analysed phenomenon. At present, Geographical Information Systems (GIS) can provide historians with a series of extremely useful tools for analysing the territory and its temporal transformations. As already known, historical maps may lack of geographic reference systems or may be expressed in systems which are substantially different from the contemporary ones. The georeferencing of this kind of documents can be performed through the identification of points remained unchanged over time, univocally recognizable in the historical map as well as in actual cartography and/or in the terrain, to be used as tie points. This procedure bears limits of metric precision, but in most of the cases results to be the only one applicable. In this paper we analyse the procedure of georeferencing historical cartography by means of a GPS campaign of measurements, and further on, investigate the conditions of comparison with recent small scale digital cartography, in order to evaluate its eventual use for georeferencing the historical maps.

1. INTRODUCTION

This paper refers to the on going experience of CROMA (Centro di ateneo per lo studio di Roma – University Roma Tre), for the construction of a GIS based Historical Atlas of Modern and Contemporary Rome.
The process of georeferencing historical cartographic sources is very complex and demands, in first place, a careful evaluation of the characteristics of every single map. The techniques of pre-modern cartography vary from the symbolic modality of the XIIIth century representations, to the plastigrafic three-dimensional modality of the perspective views (*a volo d'uccello*), very much appreciated between XVIth and XVIIth century, and finally to the iconographic two-dimensional representations, gradually evolving in terms of geometric precision from the XVIIIth century. It is clear that maps grouped in the third category -which method and instruments of measurement differ from the contemporary ones principally in the phase of densification - are the only ones that can be georeferenced. However, these cartographies, although of remarkable precision considering the early date of production, often present metric errors superior to those conventionally accepted. The GIS techniques of calibration, georeferencing and transformation of projection, enable the comparison between historical and actual cartographies, permitting to reduce the effects of deformation of the media supports (paper) and those due to the different systems of representation and measurement.
The work is articulated in three principal stages:

- study of the historical cartographic sources, paying particular attention to the techniques of measurement and to the overall metric quality;
- georeferencing of two "sufficiently accurate" historical maps using a network of tie points deriving from a GPS survey;
- evaluating the possibility of using last generation digital cartography for georeferencing historical maps, and as term of comparison for studying of the geometric variations of buildings.

2. METHODS AND PROCEDURES

2.1 The historical cartography

The Topographical Plan of Rome, published in 1866 by the *Direzione Generale del Censo*, is the cartographic source at the basis of the first digital thematic cartography expressed in geographic coordinates of the Historical Atlas of Modern and Contemporary Rome. The choice of the source is based mainly on the fact that this map corresponds to the city in 1870. It is the last map, drawn with an acceptable level of accuracy, representing the city before the deep transformations that came up after the Unification of Italy. Moreover, the choice of a late 1800's cartography allows better conditions of comparison with the contemporary cartography initially used as reference for the georeferencing procedure. Bibliographic and archive investigations have been carried out in order to obtain indications on the modalities of production of this map and its degree of accuracy from the cartographic point of view. This has guided us towards a series of considerations regarding previous cartographies that served as bases for its compilation. In fact, the map is an up-to-date version of a previous edition of 1829, compiled on the bases of the cadastral map (1818-22). Both maps consists of a reduction in scale 1:4.000 of the original map of the city cadastre in scale 1:1.000. Concerning the techniques and modalities of the topographical survey of the cadastral map, which is at the basis of almost all the maps of Rome between 1820 and 1870 (until the realization of the first IGM cartography, after the Unification), the archive sources do not offer satisfactory explanations. It appears that the roman architects Salvi e Palazzi, members of the S. Luca Academy, charged of the project by the *Reverenda Camera Apostolica*, suggested as an alternative to a brand new measurement campaign of the city, to take advantage of the Plan of Rome of 1748, by Giambattista Nolli, "introducing all the necessary corrections and integrations where […] any transformation might have occurred" (Ruggeri, Londei, 2000). Work would have then begun at the drawing board by enlarging Nolli's work (approximately 1:2900) and bringing it to a 1:1000 scale, a procedure that would have taken approximately four months, and continued with a longer and more complex phase of field

work, needed for the subdivision of the building blocks into cadastral units, for the relief of the courtyards, etc.
In such a way, moving backwards over time trying to find information about the techniques and methods of survey of the Census Map of 1866, we ended up by finding about the rigorous relief, carried out with scientific topographical criteria, of the Map of Rome by Nolli, of 1748. The long work of Nolli - lasted twelve years - is characterized by the exceptionally high level of accuracy and detail. Its previous working experiences in the cadastral operations of Lombardy and Savoia had contributed to its technical formation, also as far as it concerns the use of the *tavoletta pretoriana*, employed during the survey (see Figure 1). Perfectly aware that the *tavoletta pretoriana*, in spite of its high precision, could not guarantee a result "of the reduced margins of approximation" (Bevilacqua, 1998), Nolli carried out a triangulation of the entire city within the Aurelian Walls, based on check points situated on columns and obelisks, and along the axis of *Via del Corso*. Consequently, the survey of the single city sectors could be done, starting from the main public squares, streets and monuments, and sharing the eventual discrepancies over less important built up areas.

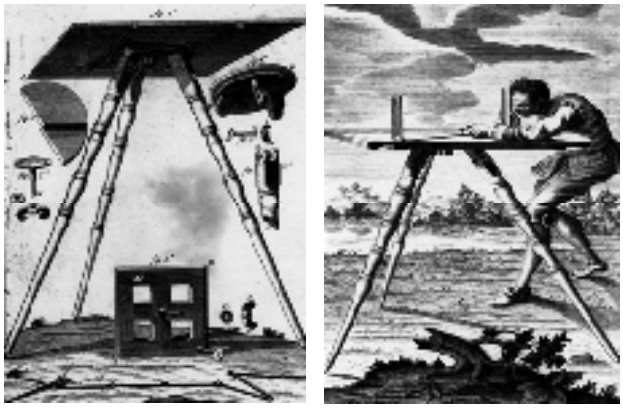

Figure 1. The *tavoletta pretoriana* and its use (from Marinoni 1751).

Coming back to the Topographical Plan of Rome of 1866, by the *Direzione Generale del Censo*[*], it can be considered as an up-to-date version of previous cadastral cartographies which seem to be based on the Nolli's cartography. It appears, according to this hypothesis, that Nolli would have been the only one who caried out a topographical survey of Rome, long ago, in the middle of the XVIIIth century. Keeping in mind the difficulties of comparing such dated products with contemporary cartographies - created with different techniques - the necessity to analyse the urban trasformations, imposes the study of appropriate methodologies for referencing the historical cartography in actual coordinate systems.

2.2 The georeferencing procedure

During the first phase of the project, the georeferencing of the Census Map (1866) was carried out, using as reference the coordinates of the Regional Technical Map of Lazio (1990) in scale 1:10.000, which was at the moment the only official cartography available. The procedure of "tying" parts of historical cartography to modern cartography allows a local esteem of the error, guaranteeing a control over the georeferencing procedure accuracy, necessary for the eventual redefinition of the control points. The overlaying of the georeferenced Census Map with actual cartographies has shown systematic errors occurring in some areas. The major discrepancies remain however within the medium error level, that is of approximately 4 meters, suggesting the existence of probable historical errors, caused by wrong measurements propagated during the survey network. The cartographic error, related to numerous causes, has been subject of a detailed examination, in order to define the influence on the accuracy of the final product. The main causes of error have been identified as follows: (i) deformations of the historical cartography, due to problems of conservation of the original support and probably to the different projection; (ii) historical error of survey, meaning propagation of rough errors along the survey network; (iii) historical error of representation, related to the presence of nonexistent particulars, added to the map for aesthetical reasons; (iv) contemporary error of interpretation, related to the lack of detailed and uniformly distributed information regarding morphologic features, to be considered as unchanged between two successive cartographies; (v) contemporary cartographic error (see Fig. 2), related to inaccuracy in the contemporary cartography to be used as basis for georeferencing the historical cartography.

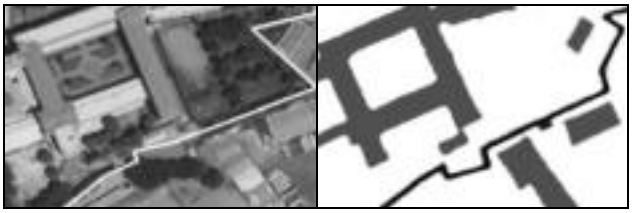

Figure 2.. Contemporary cartographic error. Aurelian walls (*San Giovanni*). On the left, aerial photograph showing the real trace of the walls (white line); on the right, the Regional Technical Map of Lazio, showing a wrong trace.

As already pointed out, georeferencing an historical map – which lacks of reference system – can only be done by calculating the coordinates of well identified cartographic elements. The fastest way to determine these coordinates is by retrieving them from actual cartographies on which the same elements are visible. It is clear that for a correct procedure, the actual cartography should be of a greater scale than the historical one, in order to avoid "forcing it" to a less accurate geometry. Since such a cartography at the time was not available, and the comparison with actual cartographies at smaller scale had led to contradictory results, we decided to proceed with a differential GPS survey of the entire city centre, for calculating the position of the identified cartographic elements in an absolute coordinate system.
The survey, initially imagined exclusively for controlling purposes, was planned to homogenously cover the study area. In the first stage the localization of "correctly measurable" points on the historical cartography was carried out. The most suitable points are those incorporated within building bodies (for example building corners). Less suitable are to be considered easily recognisable points such as fountains or obelisks, that could have encountered modifications in the course of the years, due to urban rearrangements or street surface repairs. Unfortunately, the coordinates of the building corners are difficult to measure with GPS receivers, since the positioning into their base does not guarantee a good GPS cover (great part of the sky is invisible), while reaching a wall or a building corner at the top, so as to assure a complete GPS cover, involves an increase of logistic access problems. The first GPS network comprised approximately twenty suitable points, distributed as uniformly as possible over the city centre. This enabled the evaluation of the statistical shifting parameters. The geometric

[*] From now on "The Census Map"

correspondence between the measured points and their equivalents in the Census Map was very encouraging. The georeferencing based on these points, applying a first degree polynomial transformation has given satisfactory mean residual values (quadratic mean residual X=0.7 m, Y=0.8 m) .

Id punto	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Media quadratica
Residuo x (m)	-75	26	25	-33	14	03	08	20	-09	36	-71	12	-05	03	03	-02	18	28	07
Residuo y (m)	-52	31	00	-12	53	-27	-35	-26	-09	-05	06	-24	-11	28	27	-18	80	-07	08

Table 3. Residual values of a first degree polynomial transformation applied to the Census Map.

The georeferenced Census Map has been overlaid and compared to a series of actual cartographies, showing an optimal superimposition in some areas and shifts greater than the acceptable cartographic error in others. The causes of these shifts are probably related to deformations of the original support and to survey measuring problems. It is necessary to emphasize the fact that the modalities of acquisition of the GPS network in this stage of the work had privileged points of easy access, mostly situated on open spaces: public squares, ruins etc.. Consequently the cover of some densely built up areas resulted to be totally inadequate. Nevertheless, in many of these areas a high degree of "agreement" between historical and actual cartography can be observed, probably related to the high density of important buildings (churches, palaces, etc.), which are thought to be used as check points during the historical survey operations, and therefore "correctly" positioned on the space (Bevilacqua, 1998).

The successive phase of work consisted on the densification of the GPS network, specially in the areas showing greater shift values. The new points were situated mostly on the top of historical buildings. There have been acquired 24 points of a local GPS network called *Forma Urbis*, instituted from the *Sovrintendenza Archeologica* of Rome, and 11 new points (see Figure 4). The points of the *Forma Urbis* network have been differentiated and compensated referring to two fixed stations, with sessions of 30', and some of the points have been reacquired at a distance of days in order to validate the measurement's repeatability. The precision of such points is to be considered geodetic.

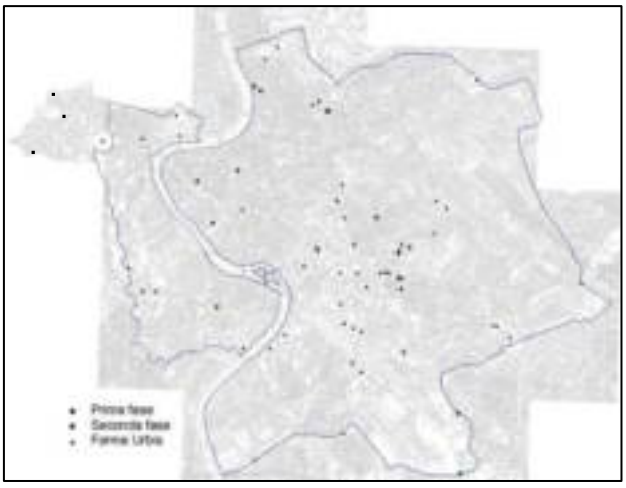

Figure 4. Various phases of the acquisition of the GPS network.

The acquired points have remarkably contributed to the improvement of the georeferencing result, although, it is worth mentioning the fact that the difficulties of access for practical and bureaucratic reasons, have sensibly delayed the survey.

Once the GPS network was completed, the georeferencing procedure was carried out for the second time on the Census Map (1866) in order to improve the previously obtained results, and for the first time on the eldest Map of Nolli (1748). This last map is composed of twelve elements. The copies used for the acquisition in raster format showed anisotropic deformations that demanded a preventive image calibration in order to correctly mosaic the elements.

At the contrary of what it could be thought, the agreement between the Nolli's Map and the actual cartographies is not at all inferior than the one of the Census Map. Moreover, the accuracy of the geometric representation of the buildings is clearly better in the Map of Nolli (see Figure 5). Regarding the thesis that supports the "paternity" of the the Nolli's Map over many XIXth century maps (see paragraph "the historical cartography"), the overlaying between the two georeferenced historical cartographies brings about some doubts. The case illustrated in Figure 6, depicts a portion of the Aurelian Walls, whose course is much different in the two versions. The trace on the Nolli's map corresponds with the actual trace, while the one depicted on the Census Map (identical to the one of the Pio-Gregoriano Cadastre) shows a detachment of approximately 25 meters from the actual situation. This seems much like a survey error made during the cadastral operations of the XIXth century.

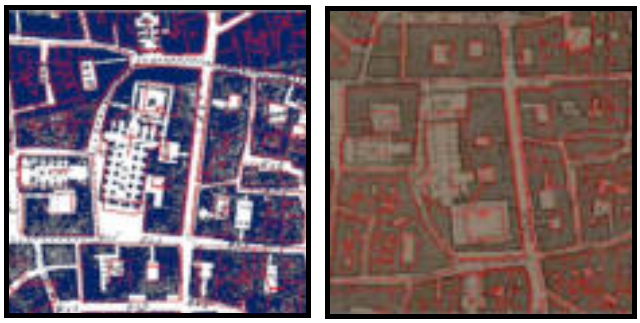

Figure 5. Different representations of the S.Agostino church (North of Piazza Navona). The same actual digital cartography is overlaid to the Map of Nolli, on the left, and of Census, on the right. The shape of the church in the Nolli's representation corresponds to the "true" shape, while is different in the representation of the Census Map.

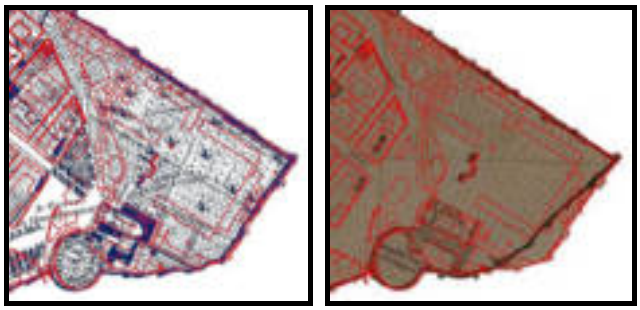

Figure 6. Same conditions of comparison as in Figure 5: the trace of the Aurelian Walls in the reppresentation of Nolli, on the left, corresponds to the actual trace, while in the Census Map, on the right, is detached of approximately 25 meters.

In synthesis, it can be affirmed that the Map of Nolli represents the first geometrically correct representation of Rome within the city walls, being the only map deriving from a topographical survey of which the procedures are known. The existence of such a work constitutes a precious source of information and a valid cartographic basis, able "to support" the representation of the successive phases of the city's development.

2.3 A comparison with the most recent digital cartography

As previously pointed out, the lack of official small scale cartography for the city of Rome has strongly influenced our project. We were, in fact, forced to use cartographies of inadequate scale (Regional Technical Map of Lazio, 1990, scale 1:10,000) or not tested (vectorial, presumably scale 1:2000). This deficiency has determined the choice to undergo an appropriate GPS survey in order to georeference the historical maps. Recently, a new three-dimensional numerical cartography of the Comune di Roma has been elaborated. The necessity to use such a product as a basis for georeferencing several historical cartographies and as term of comparison for the analyses of the building variations, has lead us to acquire the product in order to estimate if its characteristics can satisfy our requirements and replace the complicated and time consuming procedure of the GPS survey.

The analysis focused on two aspects: the accuracy of the cartographic positioning, and the correctness of the building restitution. Regarding the first point, it has been carried out a preliminary test that doesn't represent an exhaustive control of the overall precision, being meant to give only an approximate idea of the obtainable precisions. It is necessary to stress out that the original cartography is georefenced in the Gauss-Boaga coordinate system, while the GPS points obviously are georeferenced in UTM-WGS84 coordinate system. The transformation necessary in order to make them comparable has been carried out using the software *Transfo* (a prototypal software created from laboratory POMA of the Ministry of the Environment) which according to previous studies (Baiocchi, Crespi, De Lorenzo, 2002) results to be the most reliable. The software introduces errors inferior to 40 cm (remaining therefore within the admissible cartographic error for this type of cartography), but reduces the precision of the transformed product, therefore estimated in the order of 80 cm. The points utilized for the comparison with the new cartography are those of the *Forma Urbis* network, which, as already described, have the greatest precision. There have been selected and evaluated 10 univocally recognizable points on the cartography, of which only one showed a greater shift than the one admissible.

As far as it concerns the correctness of the building restitution, some incongruence have been observed, that could strongly influence the utility of this product, if we consider the fact that the overlay between historical and actual cartographies should guarantee optimal conditions of comparison between the buildings in order achieve a correct georeferencing result. One of the most outstanding examples is represented by the the restitution of the *Anfiteatro Flavio* (see Figures 7, 8). In the eastern extremity of the external vestment, restored with supporting wall at the beginning of the XIXth century, it has been considered as part of the main building body a portion of the original (roman) pavement. Moreover, a recess in the building body, more to the West of the area previously indicated, might give the wrong impression of the presence of an architectonic particular which simply does not exist, being in fact the wrong restitution of a missing part of the cornice. The western extremity of the external vestment has been also drawn unfaithfully.

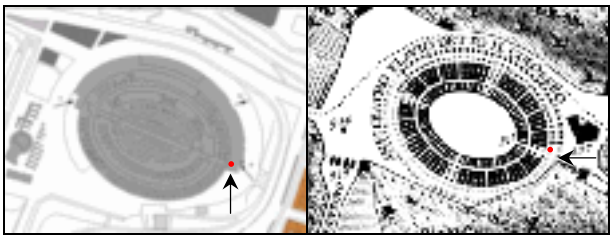

Figure 7. Cartographic representations of the *Anfiteatro Flavio*. On the top left, the new numerical cartography. The letters a), b) and c) show the observed discrepancies; beneath is shown a precedent numeric cartography, correctly drawn. On the top right, the Map of Nolli showing that the supporting wall in the Eastern extremity didn't exist yet; beneath, the Census Map with the already constructed supporting wall. The point indicated by the arrow in the four representations **should** be situated outside the building body.

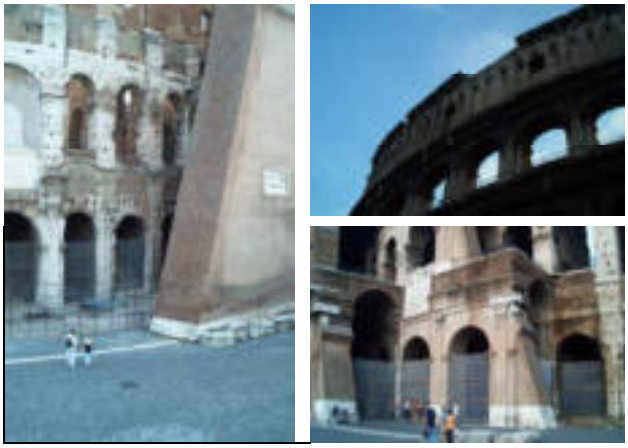

Figure 8. On the left, the huge vestment built up in 1807, under Pio VII, to support the eastern extremity of the external circle. On the right, the missing part of the cornice. Beneath, the other extremity of the external circle, restored with walls in 1827, under Leone XII.

3. CONCLUSIONS

The georeferencing of historical cartography from different periods has shown that cartographic products of different ages and scales can have comparable precisions. The restitution of the building geometry can even be more accurate in older cartographies.

The use of a GPS network for georeferencing the historical maps of Rome starting from XVIIIth century, has given positive results, going far beyond the initial expectations. Nevertheless, such approach bears strong limits related to the time needed for the realization of the GPS campaign, and to the accessibility of places. The densification of the GPS network, initially thought for improving the georeferencing results, revealed useful also for the evaluation of the reliability of an actual cartographic product.

The accuracy evaluation of the last generation digital cartography has demonstrated a reliability from the geometric point of view, but the necessity of further investigations regarding the eventual existence of discrepancies in the building restitution not always imputable to building transformations, but to a wrong restitution of the contemporary cartography. In this case it would be preferable for a precise identification of the unchanged points in the historical cartography and in the reality,

to use contemporary orthorectified images of adequate scale and precision.

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