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Rectify the river, rectify the map. Geometry and geovisualization of Adige river hydro-topographic historical maps

Keywords: historical maps; topographic maps; Adige-valley/*Etschtal*; archival research; map accuracy; local transformation

Summary: Analysis of historical maps is useful for purposes not only in a qualitative but also in a quantitative way, whereas the latter serve the purpose of assign a geometrical content to early maps, useful for a comparison with current maps. The main problem with old maps depends on their unknown projection and/or their lack of geometric accuracy. Thus, the evaluation of planimetric accuracy (through a *calibration*) represents a previous analysis helpful for a consequent standard geometric correction. This paper analyses as a case-studiy two large-scale historical maps of Adige river (1802-1850) through three steps: firstly, the accuracy has been analyzed; then, we have performed a local geometric transformation suitable for linear topologies; and, finally, we have set up map-tiles/mashup for web mapping.[1]

Hydraulic landscapes and historical cartography: from the strategic requalification to the collective fruition of fluvial systems

In the Alpine landscape, water and mountains are two problematic geographical objects and their convergence is such that any contextual analysis which aims at being philologically correct cannot but deal with them as a single unit and in a systemic fashion. A hydrographic network characterizes the territory, defines places, serves as a reference point and often plays a crucial role in the complex and frequently conflicting trade-off between resources management and containment of risk factors.

Mountains and bodies of water are figures charged with relevant symbolic assumptions; mountainous landscapes and their hydraulic networks are cases of horizontal studies investigating both their morphologies – i.e. the diachronic mutations in the shape of the territory as they are described by maps – but also the dynamic and/or antagonistic relationships between human communities and the hydromorphology of the territory they occupy. Geo-historical maps serve as highly useful tools for a thorough analysis of both aspects, as they bear witness of the evolutions and transformations of the hydrographic system; of how human settlements developed in relation to the presence of water bodies; of the use and abuse of hydric resources and of their traditional management; and, last but not least, of how the conflicting relationships between communities and hydric resources (in the form of floods, instability of mountain slopes, etc.) have been managed over time. While shedding light on these issues, geo-historical maps also provide valuable predictive elements for planning knowledgeable management strategies.

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In the Trentino province, the morphology of the territory is decisively characterized by the natural hydrographic system and by the artificial structures related to it, which result from the numerous processes of land reclamation and from the interventions on the hydraulic system necessitated by the instability of mountain slopes and the vulnerability of watercourses. In Trentino, in fact, different territorial contexts have been affected, in past ages, by hydrological events which required urgent interventions of stabilization and spatial reorganization. Nowadays, the planning of interventions for improving the regional territory, also through works of civil and hydraulics engineering, is a frequently recurring, topical issue in a context such as that of Trentino, whose hydrographic network is characterized by a complex and unstable geomorphology.

Watercourses and bodies of water - as they have been represented in historical cartography - are keys to interpret the transformations in the landscape of Trentino, particularly through the analysis of all the projects that have been designed to respond to calamitous events of the past (Dai Prà, Tanzarella 2010) in the framework of a diachronic reconstruction of critical territorial scenarios. By studying the history of subsequent hydraulic interventions, it would therefore be possible to define the territorial transformations which have led to the present-day landscape of the Province.[2]

Large-scale historical maps of Trentino produced between the Eighteenth and Twentieth centuries testify the need to systematize a territory which was (and is) challenging from a hydrogeological point of view. The cartographic representations of civic and hydraulic engineering bear witness of the variety of technical solutions which have been put in place to deal with the often conflicting relationship between human being and nature and also give evidence of the attempt to renew the territorial structures, undertaken by the Habsburgic administration in the framework of a more articulate policy of reforms.[3]

So far, this rich cartographic production has never been the subject of comprehensive studies, which might indeed be valuable, both in view of interventions of landscape reconstruction and/or preservation, and also for facing present-day issues of hydrogeological instabilities. A systematic analysis of historical maps may pave the way for in-depth studies on the dynamics of transformation of mountainous areas and rivers, or on the reconstruction of historical scenarios of floodings or landslides, or even to verify the recursion of natural phenomena. Such analysis might turn out to be both a device for “decoding” problematic territories, and, more practically, a helpful guideline for the management, safeguard and preservation of territories at risk. Large scale historical maps, along with digital tools and applications, enable the diachronic reconstruction of critical territorial scenarios, in function of a more sustainable management. In addition, the analysis of historical maps would allow systematic investigations on the technical solutions adopted for the management of the hydrographic network and its related infrastructures (e.g., aqueducts and canals for the irrigation of farmlands, bridges, embankments, or rectification of watercourses).

The archival research for historical maps has shed light on two distinct technical phases: i) remedial action (*ex post*) for the reconstruction of the territorial structures in response to a natural disaster; in this case large-scale maps serve as a tool for visualizing and evaluating the amount of damages; ii) technical/projectual preventive actions (*ex ante*) for the qualitative improvement and

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[2] The relationship between hydraulic landscapes and historical mapping has already been matter of investigation in the geo-historical research (Barsanti, Rombai 1986; Masotti 2010). Such a study would probably provide useful insights for all of those areas where the management of natural hydraulic systems is challenging.

[3] It is–under the sovereignty of Austria that the most important projects for transforming spatial planning of Trentino are planned and implemented, such as the Brenner railway (1850-1860), the adjustment of the Adige river in the valley of Trent, the regimentation of the tributary Fersina (see below, Fig. 1), Noce (Fig. 2) and Avisio (cf. Rovereto Municipal Library, *Fondo Cucagna*, Ms 90.89).

quantitative implementation of farmlands in the plain and on slopes and for the rearrangement of watercourses and of viability.

Therefore, large-scale historical maps, especially when analysed in chronological sequence, can work, both as a instrument for gaining a deeper understanding of the morphological dynamics of rivers and mountainous areas, and also as a support device for the planning, management and development of the territory, since a knowledge of the interventions performed in the past is necessary to plan future actions. The usefulness of historical maps lies precisely in the fact that they can be read as a predictive source of information and a reference point for the elaboration of plans and measures for a sustainable management of water resources. Authorities tend to underestimate this potentiality of cartographic sources, even though the nature, magnitude and spatial localization of harmful events of the past can, today, be useful information for the assessment of different levels of natural risk. In addition, geo-historical data can demonstrate that there is some recursion in the manner in which a certain phenomenon occurs (Boulanger, Trochet 2005).

The process of geo-historical reconstruction that cartographic sources can enhance, results in the re-appropriation of the collective historical memory. The loss of *spatial memory* is a topical issue; even more so is the loss of the multiple knowledge related to the river systems and to the management of water resources through history, which has caused so many failures, also recently, that severely affected daily life in human settlements. In the major, most recent theoretical and normative reference documents, both at national and European level, the critical situation of river systems and its related management perspectives, have finally been dealt with also under a cultural and anthropological perspective, i.e., taking into consideration the problem of the progressive depletion of the relationship between local communities and the waterway; a geographical object that, in the face of a substantial and drastic loss of historical functions (and, therefore, of its socio-economic value resulting from its "productivity" in agricultural, handicraft and energetic productions), is today marginalized from the urban fabric in which it belongs to, whether rural or urban. The recovery of the historical memory of the territory, therefore, is not merely of antiquarian and scholarly interest; it is first of all a strategy for an innovative conservation of the water resource based on the concept of land as a common good (Magnaghi 2009) and, secondly, an epistemological background able to inspire new plans for the requalification and collective fruition of the fluvial system.

In the search for solutions that can help stop the process of removal from the territorial values and practices, a conscious return to the territory – through the synergistic integration of the different territorial actors – would be highly desirable. A territory in which (and not *upon* which) human interventions are thought of as *participative projects of collective management*. This perspective should be reinforced, on the one hand, by an increased focus on the local scale (Governa 2008) and, on the other hand, by a broader notion of *sustainability* that includes not only environmental issues, but also the cultural, social, productive and institutional values of the territory.

This *territorialist* approach considers the landscape as a complex system of interactions of long-term historical, social, cultural and economic structures; such interactions can be considered as a *statute* and should be taken into account in the process of reterritorialization (Dematteis 1995). The territorialist approach also requires a renewed emphasis on the interpretation and representation of the territory in its historical, diachronic dimension. The territorialist model, then, chooses geo-historical sources as privileged analytical tools for investigating the history of long-lasting physical structures, of layering materials, of cognitive values inherited from previous cycles of territorialisation (e.g. environmental systems; ecological/hydrographic networks; historic landscapes; settlement typologies; agricultural textures) in order to re-invest this multifaceted knowledge in the governance of the territory.

Measuring the map. Visual analytics of positional accuracy on large-scale historical maps

The analysis of the geometric distortion and/or accuracy of historical maps is part of the so-called *cartometry*, the branch of cartography that concerns itself with the whole set of procedures to apply *over* a map in order to *measure*[4] it and to perform a quantitative reading *on* it.

Analysis of historical maps is not only useful for qualitative purposes, but also quantitatively, in that by assigning a geometrical content to earlier maps they can be compared to present-day ones and be thus used for the evaluation of landscape changes. Such procedure enables the extraction of features from historical maps, such as river networks or *former* watercourses, in order to implement time-series analysis and change-detection techniques. The evaluation of historical maps is a prerequisite for a subsequent *comparative cartography* research (Harley 1968: 65-66, 70-72), that is, it works as a pre-processing quantitative analysis that enables to perform a qualitative one.

The main challenge with historical maps is their unknown projection, the absence of a grid and, in general, their lack of geometric accuracy. Indeed, map scale and rotation represent the main issues as regards the metrical content of old maps and their visualization, because with a wide range of scale and rotation variation within a map, it is very difficult to compare it with more recent maps (more *recent* simply stands for more *accurate*, and *not* the *real* nor the *correct* map).

Assigning a metrical content to an historical map[5] is necessary in order to compare it with present-day maps (or to cross-compare it with another old map or even to use it as an *intermediate map* in a 3-maps dataset), inasmuch as well as a qualitative analysis of a map as an historical document, assigning a metrical content provides firstly a quantitative "accuracy assessment"[6] and, secondly, the possibility of *integrating* it in a GIS environment (Balletti 2006: 33). Or, on the contrary, also the possibility to *not-integrate* it.

As mentioned above, such an approach allows to evaluate an old map for the consequent features extraction: a preparatory arrangement in order to implement a multi-temporal analysis. The cartometric analysis is thus intended as a pre-processing of a standard geometric correction, in order to assess with precision to what degree topologies have been distorted, the level of accuracy and the consequently distorted topographic representations. In other words, with such cartometric analysis we can study the whole mapping process (whose results we can see *on* a map), from the survey (topography) to the final representation (topology).

Performing the geometric correction of an old map directly (i.e. without having previously carried out an accuracy evaluation, could possibly lead to errors of omission and/or of commission. For instance, a linear feature on an old map (e.g. river bank lines) could result not-shifted in its positional accuracy, or, on the contrary, very shifted if compared with the reference map, but indeed the real cause of such a (un)change could be traced in the different geometric accuracy of the early map. Thus, the standard geometric correction method should ultimately be applied only if

[4] See Harley (1968: 64-65) about the «mathematical tests» to be performed on early maps.

[5] The lack of a geographical or metric grid doesn't mean the absence of a map projection. About old maps' «implicit projection» and the method of *best fitting* to estimate it, see Tobler (1966), Boutoura (2006) and Livieratos *et al*. (2011).

[6] This is an improper, but quite friendly, use of the term "accuracy assessment", because every such procedure must be implemented as an *ex-post* process. On the real accuracy assessment – as a «quality-control method» – for already georeferenced historical maps, see Favretto (2012).

the old map is suitable: not all historical maps are *geo-referable* (i.e. suitable for a geometric correction).

Source large-scale historical maps

This paper analyses as case studies two large-scale historical maps of the Adige river valley:

1. the Adige river map by Leopoldo Claricini Dornpacher[7] (1847), 20 sheets, 43x54 cm, scale 1:3.456, orientation East/top;
2. the *Carta topografica de' due consorzi della destra, e della sinistra sponda del torrente Fersina [...]*[8] by G. Steffanelli, edited by *Delegazione Fersinale* of Trento (1850), 27x52 cm, no scale indicated, orientation East/top (Fig. 1).

Figure 1: The Fersinale-Map (1850). The Adige river southwards (left to right on the map) with abandoned riverbed (right) and the Fersina tributary (middle).

The river is among the most common features represented in the historical cartography of Trentino. Archival cartographic projects provide evidence that the river Adige and its tributaries

[7] From this point further as *Claricini-Map.* Currently stored in Trento at the *Consorzio Trentino di Bonifica* archive. German title: *Karte der Etschregulierung.* There are several scale reductions of this map printed from two different lithographs in Innsbruck: the first was made by the lithography studio "*Lithographie Anstalt Joseph Schoepf"* at 1:3.456 scale and in a reduction of 1:13.824; the second lithograph, was made by the *Lithographie Anstalt v. C.A. Czichna* in 1:28.800 scale. In particular, the map with a 1:13.824 scale is stored at the *Consorzio Trentino di Bonifica* too; another part of the map with a 1:3.456 scale is kept in Bolzano/Bozen at *Consorzio di Bonifica "Foce Isarco-Monte"*/*Bonifizierungskonsortium "Eisackmündung-Gmund"*; the maps with a 1:28.800 scale are kept at the *Tiroler Landesmuseum Ferdinandeum* in Innsbruck (*Historische Sammlungen, Kartographie*, number K II/75), at the *Bibliothèque Nationale* in Paris (number GE DD-5842) and at the *Landesbibliothek Dr. Friedrich Tessman* in Bolzano/Bozen (number A 6947; see Werth 2003: 150-151). We would like to thank Ing. C. Geat and G. Morini for their helpfulness with the map's study and reproduction.

[8] From this point further as *Fersinale-Map* (see Mastronunzio 2010). Currently stored at Trento Municipal Library (number TG 1 d 10). We would like to thank Dr. S. Groff and Dr. F. Cagol for their kind helpfulness with the map's study and reproduction.

(Fersina, Avisio and Noce) underwent works of hydraulic assessment, rectification, diversion and digging of the riverbed in reason of the frequent flooding of urban settlements and croplands. Tributary were also included in the projects; the best known of these works was the displacement of the mouth of river Noce (1849-53). On the Claricini-Map the former confluence is on sheet 35 (Fig. 2), the more recent on 39 (see below, Fig. 5), i.e. about 5 km downstream.

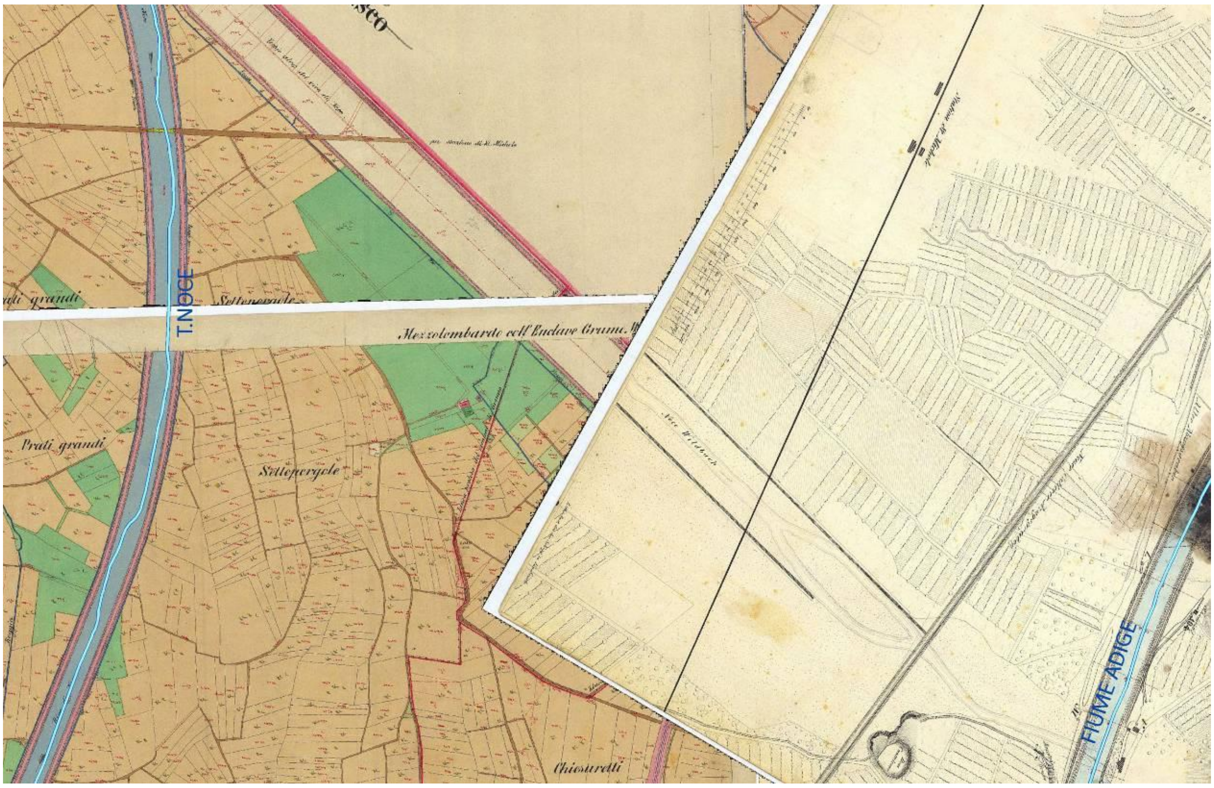

Figure 2: Detail of Claricini-Map (1847) on the right overlayed upon Habsburgic Cadastre (1853-61). In the middle the abandoned riverbed of Noce tributary, on the left the "new" Noce and the Adige on lower right corner.

For all the Nineteenth century, these maps were used as a basis for sketching new projects of regulation of the Adige, as well as for recording floods (Werth 2003: 150-151). When the different map-sheets are put together, these maps are quite long (e.g. the Claricini-Map measures 250cm) and provide a synoptic view of the river and of the subsequent projects for intervening on its course (most of which were accomplished, such as, for instance, those related to the urban area of Trento).

Methodology

Three methodological steps were carried out: i) the accuracy Claricini-Map has been analyzed/visualized (with the open-source software MapAnalyst); ii) we have performed a local geometric transformation, suitable with linear topologies representing the river network, on the Claricini-Map; iii) only onto the Fersinale-Map, we have set up map-tiles to provide a mash-up for web mapping (with the free-software Mapcruncher, also used for evaluating the accuracy of this old map).

Global and local transformations

A well known fact is that the georeferencing process (a geometric correction) of a raster image (i.e., in this case, a scanned or camera-digitalized old paper map) is a procedure that assigns to the *target map*, the CRS (Coordinate Reference System, geographical or planimetric) of a different map, called *reference map*, which is a current – or at least more recent – map than the target one. The process assigns to an *old map* the CRS of a *new map* through the so-called image-to-image georeferencing (or map-to-map registration or warping), by comparing corresponding pairs of common points (CPs: Control Points) onto the old and the reference map, using a geometric transformation (Balletti *op. cit*.; Bitelli, Cremonini, Gatta 2009; Boutoura, Livieratos *op. cit.*; Lloyd, Lilley 2009; Zitova, Flusser 2003). For an old map, in absence of a CRS, it is customary to use the pixel grid of the raster image and, in the aftermath, the resampling procedure assigns the CRS values of a modern map's pixel grid to the old map grid.
A global geometric correction of an early map is performed using the appropriate global geometric transformation that estimates the correction parameters for the whole map, through a procedure that alters the metrical values of CPs. That is: the parameters calculated on the basis of corresponding pairs of common points are applied to all the other pixels of the raster image, as well as to those that do not match the CPs and even if the CPs are not uniformly distributed throughout the raster map. So, these locally estimated parameters are applied to the whole extent of the map. Due to the fact that these parameters are *extended* to the whole map, such transformations are also called *not exact*. Geometric corrections are generally executed by means of a polynomials transformation (e.g. a first order transformation also called *Affine transformation*).
On the contrary, with a local geometric correction using CPs based on a local transformation, the estimated correction parameters are valid only for a local area – located inside the CPs, in order to perform an interpolation – or even only for the CPs themselves. Local transformations are known as *exact* transformation, because the parameters calculated on the basis of CPs are applied only to the corresponding pixel of the raster image, and the metrical values of CPs do not change. All other pixels are *forced*: the local parameters are not extended to the whole map. Such a transformation therefore provides high correction accuracy for specific areas inside the map and a low positional accuracy outside these areas.
Thus, when the analysis is focused on specific topological features (e.g. when linear features are important) it is better to process a map-section using a local transformation. On the contrary, for a geometric correction of a map in its whole extent, or for the evaluation of its planimetric distortions, it is better to use a global transformation since it provides a global rotation, shift and scale-variation. On the whole, the best results can be obtained by applying both procedures, using first a global and subsequently a local trasformation: the first in order to operate a quantitatively significant geometric correction onto the old map and the latter for a local "refinement" of the globally corrected map (Guerra 2000).

Calibration

Thus, the evaluation of planimetric accuracy represents a helpful prerequisite analysis for the consequent standard georeferencing methods. Instead of carrying out a geometric correction with pixel-values resampling of historical maps through global/local geometric transformations, those same transformations can be applied not to rectify the maps but to *compare* (Boutoura, Livieratos

op. cit.; Guerra *op. cit*.; Forstner, Oehrli 1998) with current maps, through a process called *calibration* (ERDAS 2009: 35), in order to visualize and cross-compare the accuracy variations between the maps. *Calibration* is an *on-the-fly* procedure that applies a geometric transformation *without* resampling and therefore does not perform any geometric correction.
For the calibration of our case study maps, we used two geometric transformation: a 6-parameters Affine transformation and the 4-parameters Helmert conformal transformation. The Helmert transformation is a roto-traslation with a variation in the scale factor:
X_0 (Horizontal Translation [m]);
Y_0 (Vertical Translation [m]);
α (Rotation in Counter-Clockwise Direction [deg ccw]);
m (Scale Factor).
The 6-parameters Affine transformation needs two more parameters:
α/ β (Rotation in Counter-Clockwise Direction for Horizontal/Vertical Axis [deg ccw]);
mX/mY (Horizontal/Vertical Scale Factor).
In this case, scale factors are intended as global (i.e. concerning the whole map).

Spline Local Transformation

As mentioned above, the best way to proceed is to apply first a global transformation and subsequently a local one, so as to *refine* the results of the former. Therefore, the Claricini-Map was georeferenced first with the 6-parameters (global) Affine transformation (as done previously with its *calibration*) and subsequently with the so-called *spline* local transformation, a *rubber sheeting* process which optimizes local accuracy to the detriment of global accuracy. It is an exact transformation in that it transforms with precision the CPs of the map which is being corrected (source CPs), by georeferencing them into the same CRS of the target CPs. The *pixels* located outside the CPs are not as accurate as those within the CPs.
The Spline transformation is optimal when CPs are represented by *pixels* (or areas next to them) which need an exact rectification, i.e. when the accuracy of topologies (Mastronunzio 2011) is more important than the accuracy of the map in its entirety.

Using MapAnalyst and MapCruncher

The open-source software MapAnalyst (http://mapanalyst.org/, Version 1.3.22 and 1.4) was used to assess the planimetric accuracy of the map (Jenny 2006; Jenny *et al*. 2007). MapAnalyst generates different types of visualizations of the map's planimetric distortions. After having identified the CPs and having applied the global transformations, the software visualized the distortion grid, the vectors of displacement, the scale/rotation isolines and calculated the map's global scale/rotation. In particular, the distortion grid enables the visualization of the rotation angle of the map as a whole. Each mesh of the grid corresponds to a specific area on the reference map: if the historical map has no distortion (or if its distortion equals that of the reference map) the grid is regular; conversely, if the meshes are deformed they indicate a local distortion within the historical map. The vectors of displacement connect the CPs on the historical maps with the CPs on the reference map where the former should be if the historical map were as accurate as the reference map. Finally, the scale/rotation isolines work as contour lines, connecting points having the same scale factor/rotation angle. By means of isolines, *local* scale variations can be visualized in distinct areas within the map.

The free-software MapCruncher (Version 3.2.4 http://research.microsoft.com/en-us/um/redmond/projects/mapcruncher/)[9] uses an approximation to reproject source maps into the Web Spherical Mercator projection. Instead of modelling the source projection and Bing Maps projection, MapCruncher directly approximates the relationship between the original map and Bing Maps, using either an affine or a quadratic polynomial transformation.

The main features that make it suitable for planimetric accuracy analysis are the *error distances* and *error wands* tools, that display to what degree the approximation could match up points on historical maps. The error wands connect the selected CPs with those identified as the "correct" points (similarly to the MapAnalyst *vectors of displacement*). MapCruncher allows to import historical maps (also as multiple layers and from web URLs), publish relevant mash-ups and overlay them into Bing Maps: all of this with a user-friendly process (*crunching* a map). After the warping process, MapCruncher generates a set of image-tiles that can be mashed-up.

Case-studies

Claricini-Map: geometric accuracy and geometric correction with local transformation

The nominal scale of the Claricini-Map is known (1:3.456) and has supposedly been used uniformly in all the sheets of the map. Only section 35 was consequently compared (with a *calibration*, to visualize its geometrical accuracy) with the corresponding area on OpenStreetMap (OSM) by means of MapAnalyst and the selection of 24 CPs.

The number of CPs selected is relatively scarce on account of the difficulty in locating with certainty a more considerable number of *landmarks* on both source-maps, since they either were lost with the passing of time (on the land, and are consequently no longer present on more recent maps), or have now another localization or a different land-use. It is worth noting that the Claricini-Map is 160 years older that OpenStreetMap and they both represent a borderland on which historical events have left indelible marks.

Landmarks – mostly localized in rural or agroforestry areas – were identified also on further cartographic sources: the Claricini-Map at 1:28.800 scale (the copy kept at the *Ferdinandeum*)[10] and the Habsburgic Cadastre in 1:2.880 scale. The first map, having a smaller scale, provided a rapid synoptic view of the cultivation plots and country lanes (this map does not indicate land use and is therefore more easily readable by virtue of its geometric layout). The Cadastre, instead, was exclusively used as an intermediate source (between Claricini-Map and OSM) for better identifying the landmarks, on account of the fact that it has a very large scale and that it was produced just a few years later than the Claricini-Map.

Regarding the visualization parameters, the mesh-size of the distortion grid was set to 200 m (Fig. 3), the distance between scale isolines (illustrating the local scale variations) was set to 1:500 and the *radius of influence*[11] was set to 400 m; vectors of displacement were also visualized (Fig. 4).

[9] MapCruncher was not designed to perform metrical analyses; however, some of its features make it suitable for this purpose.

[10] See above, note 7.

[11] This last visualization parameter defines the radius within which localizing the CPs to assess local scale variations (instead of using the whole map): the accuracy of local variations increases with the decreasing of the radius of influence.

The test for geometric accuracy of the Claricini-Map with the 4-parameters Helmert transformation and the 6-parameters Affine transformation yielded the following results:

Helmert Transformation (4-Parameters)

X_0 = 1279 [m]

Y_0 = 751 [m]

α = 120 [deg ccw]

m = 3.462 (1:3.462)

Affine Transformation (6-Parameters)

X_0 = 1289 [m]

Y_0 = 758 [m]

α = 119 [deg ccw]

β = 120 [deg ccw]

mX = 3.521 (1: 3.521)

mY = 3.436 (1: 3.436)

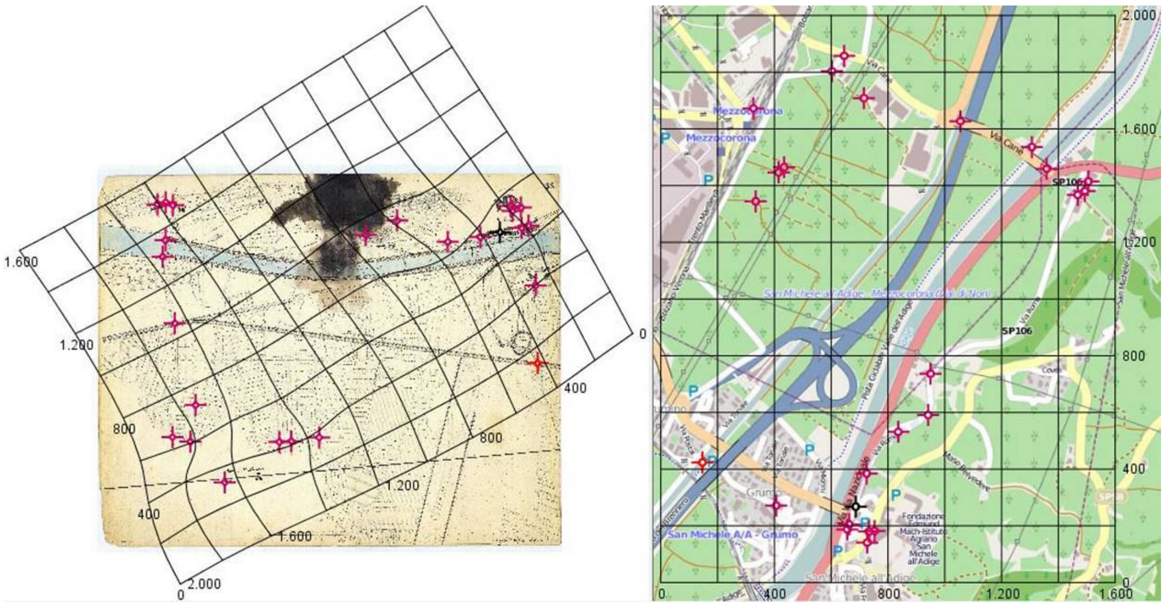

Figure 3: Distortion grid of sheet 35 of Claricini-Map and OSM not-distorted grid, computed with 24 CPs.

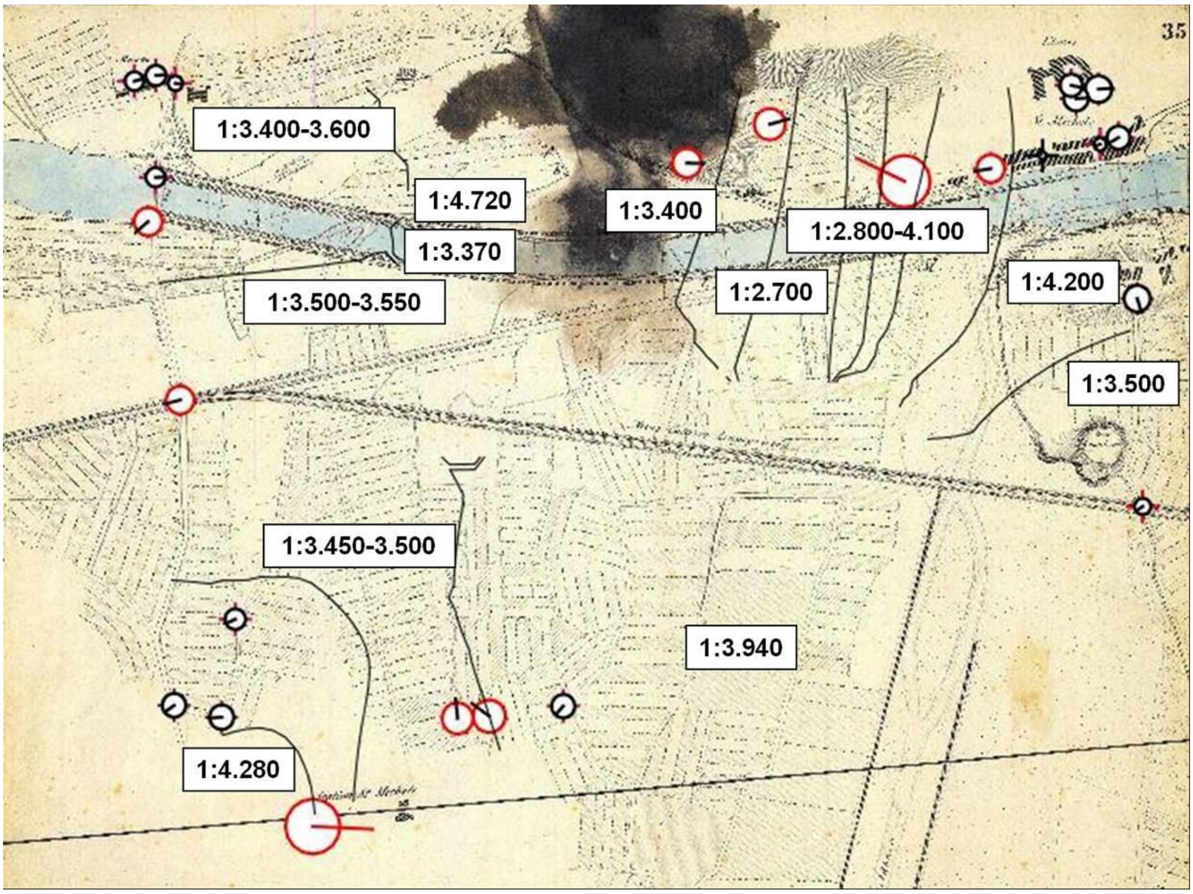

Figure 4: Local scale variations (scale isolines) of sheet 35 of Claricini-Map. Vectors (and circles) of displacement of 24 CPs.

Sheets 35 and 39 of the Claricini-Map were geometrically corrected, first with a global and subsequently with a local transformation, in order to obtain more refined results[12]. Sheet 35 was globally rectified by applying the 6-parameters Affine transformation with 41 CPs (among which, 24 were the same CPs used for calibration) and sheet 39 (which was not calibrated, since the scale is supposedly uniform throughout the sections of the same map) was rectified with 19 CPs (Fig. 5). The resulting Root Mean Square Error (RMSE) was 5,96 m (whereas with a 3rd order polynomial global transformation, RMSE was 4,77 m).

[12] The CTP was used as reference map (geometric correction), whereas the reference map for calibration was OSM.

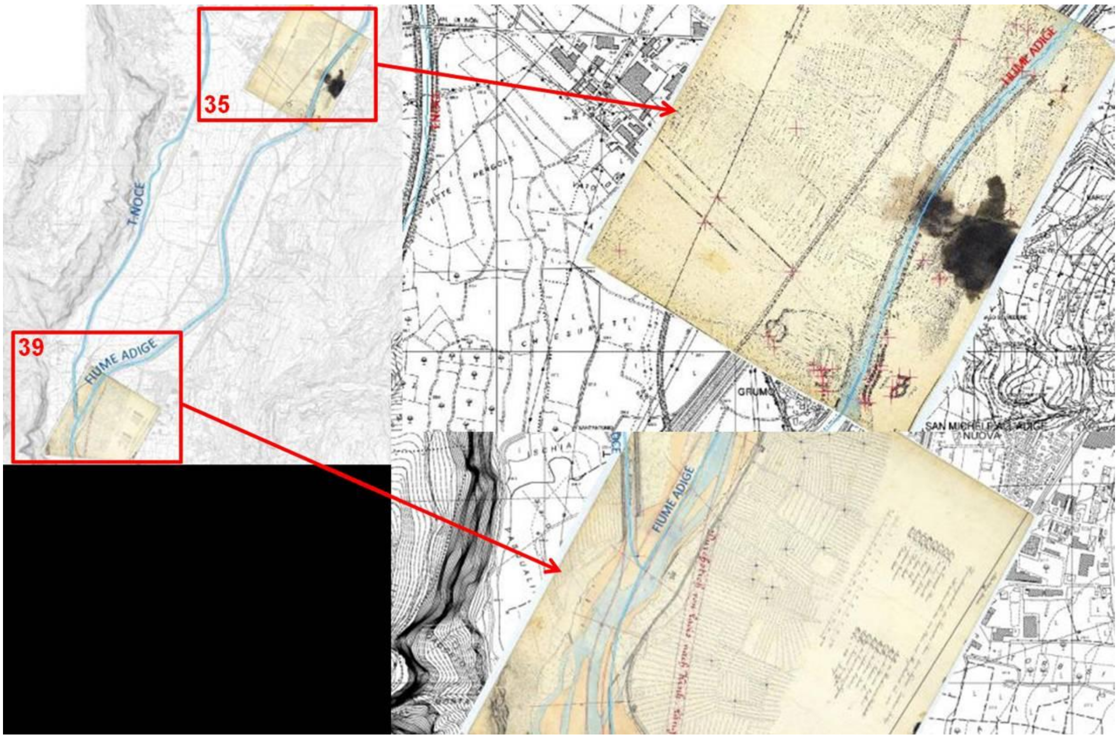

Figure 5: Global transformation (Affine) of sheets 35 (computing with 41 CPs) and 39 (19 CPs) of Claricini-Map. In evidence the old riverbed (sheet 35) and the "new" Noce riverbed (sheet 39).

The *spline* local transformation (which requires a minimum of 10 CPs) was applied exclusively to sheet 35 and computed with the same 41 CPs used for the global transformation, thus ensuring the highest possible level of accuracy of the CPs' localization. That is: my source points *exactly* correspond to my target points (Fig. 6).

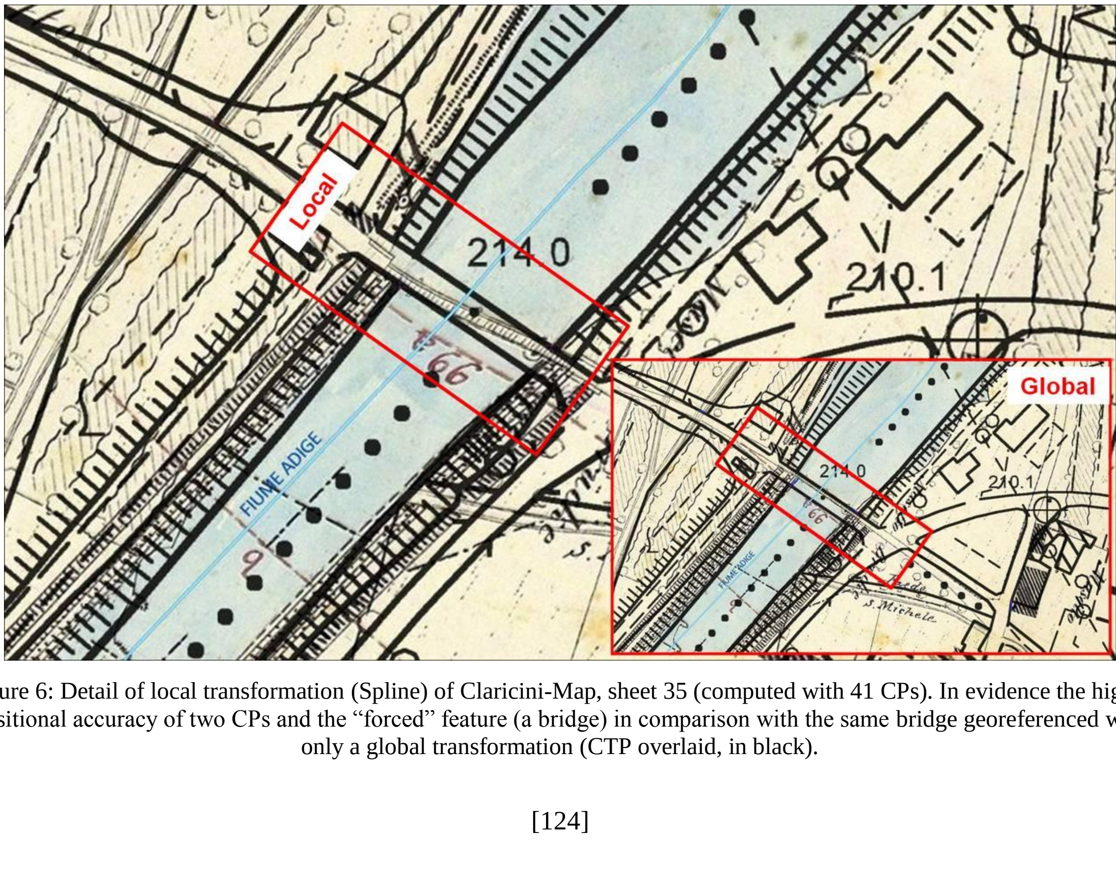

Figure 6: Detail of local transformation (Spline) of Claricini-Map, sheet 35 (computed with 41 CPs). In evidence the higher positional accuracy of two CPs and the "forced" feature (a bridge) in comparison with the same bridge georeferenced with only a global transformation (CTP overlaid, in black).

Finally, the Fersinale-Map was processed with MapCruncher, (MapAnalyst was not used in this case), using Bing Maps as a reference map and locating 46 CPs. MapCruncher allowed an on-the-fly evaluation (without resampling) of the map's geometric accuracy: contrarily to MapAnalyst, though, the software does not allow to calculate the global scale and to overlay a distortion grid on the historical map; it only allows the visualization of *error wands* (a tool similar to MapAnalyst's vectors of displacement) and of the relevant *error distances*. The main difference between the two software is that with MapCruncher the user is able to perform – in the same package – also a standard Affine geometric correction with the tool "Force Affine". Results showed that the Fersinale-Map was quite accurate, with several error distances in the range of centimeters and a maximum error distance of 11 m (Fig. 7).

Figure 7: Detail of Fersinale-Map accuracy visualization regarding CP no. 38: measured error distance (on the left), error wand visualized on old map (center) and CP indentified on Bing Maps (right).

In reason of its high positional accuracy, the map was considered suitable for performing the Affine geometric correction with the same software in the CRS Web Spherical Mercator – and its subsequent webmapping. Thus, we have rendered a set of 3.213 image-tiles (.png) of our old map and overlaid them to Bing Maps creating a Mashup Sample html Web Page: a fully detailed webpage (Fig. 8), containing legend, map-preview, table-of-contents for multiple layers, search toolbar and the possibility to visualize the old map onto Bing Maps road-map, aerial and bird's eye views.

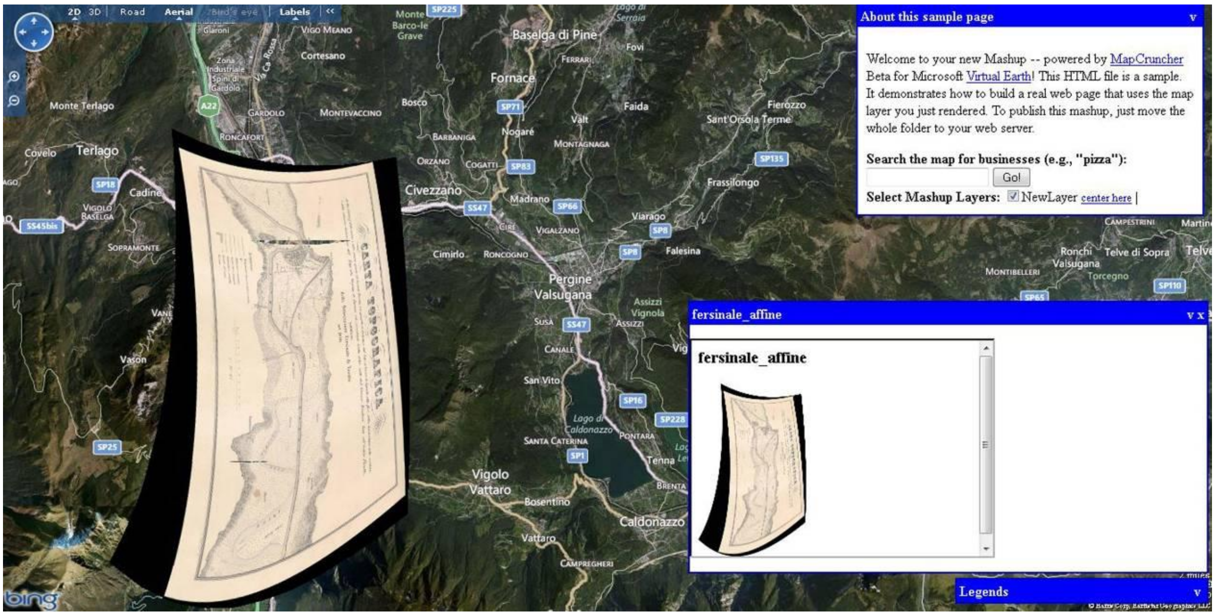

Figure 8: Mashup sample html Web page of Fersinale-Map overlaid to Bing Maps.

Final remarks

The proposed 3-stages methodology (positional accuracy analysis, georeferencing with local transformation and web mapping) over our different old maps enabled us to perform an integrated set of procedures (pre-processing, data-processing/geovisualization and web publishing) which can be considered quite user-friendly and suitable for further research in digital humanities.

Both of old maps analysed in the present study showed good accuracy levels when compared with the current reference maps and this is mainly due to the significant improvement in the accuracy level (with respect to current cartography) of topographic technologies occurred between the Eighteenth and Nineteenth century, at least in the Habsburgic and Napoleonic cartographic productions. Such high planimetric accuracy manifestly provided a suitable basis for the maps' geometric correction: a preliminary step necessary for their subsequent webmapping.

The Claricini-Map presented significant values of horizontal and vertical traslation (especially when such values were compared with the nominal scale, i.e. 1: 3.456), as well as a marked rotation value of 120 deg. ccw. The latter, however, should be reconsidered on account of the fact that the map is East/top oriented and already has therefore an intrinsic rotation of 90 deg. ccw; so, the effective rotation amounts to ca. 30 deg. ccw. As for the other parameters, the map's global geometric accuracy was attested by the computed global scale values, which practically matched the nominal scale (1:3.456), and from the minimal – although not insignificant, if compared with the global scale – local scale variations within the map, which ranged between 1:2.700 e 1:4.720.

Given the high accuracy level, the map was consequently georeferenced with the Spline local transformation. The procedure yielded excellent results, considering that the identified *landmarks* were represented by single *pixels* (or areas close to – or around – them) which need a precise rectification in cases such as the present study, where the accuracy of single topologies (i.e. the hydrographic network) is more important than the accuracy of the map in its global extent. We thus obtained a highly accurate representation of the linear topologies, namely the Noce and Adige riverbeds, as well as of the river banks and of the infrastructures related to them (e.g. bridges), to the detriment of the accuracy of other sections of the map where no part of the hydrographic network was present. In fact, the 6-parameters Affine transformation would have ensured a higher global accuracy of the whole map, but only a poor local accuracy with respect to the representation of linear topologies (i.e., the riverbed).

Finally, the Fersinale-Map was analysed for positional accuracy exclusively with a visual analytics process on MapCruncher, a software which does not allow the detailed analysis of traslation values, rotation and local scale but is nevertheless useful for computing the position error of CPs. Such test, in fact, showed that geometric accuracy was quite high also in the Fersinale-Map. The main advantage with MapCruncher is that a complex workflow can be implemented in a single software environment. *Crunching a map*, in fact, means being able to import historical maps, to web mapping in Web Spherical Mercator projection (useful for Bing Maps publishing but the same projection for Google Maps), and, eventually, to perform a global georeferencing process. If we consider that accuracy analysis and georeferencing are two contextual processes (even though the latter is discretionary) MapCruncher proves a decidedly user-friendly software which enables its users to publish their maps on the web *without* georeferencing them. Ultimately, the user can also create a Mashup sample html Web page, in order to visualize the results immediately. In other words, it provides a ready-to-use web page for web map publishing, simply moving it (and relevant tiles) to a personal web server.

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