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## Editing historical maps: comparative cartography using maps as tools

*Keywords:* Historical maps, Napoleonic Cadastre, Habsburg Cadastre, Geodetic Reference System, Georeference.

*Summary:* Accurate European large scale map-making was carried out from the late 18th century onwards, initially in France and then throughout the Austrian Empire. The first modern cadastral survey ever was the Napoleonic one (1809-15, 1:2.000) followed by the well-known Habsburg Cadastre (since 1817, 1:2.880). Both were the earliest modern cadastre. In this mainly methodological paper two related case-studies are presented: (i) the Napoleonic Cadastre at 1:2.000 scale (1809-1815) and (ii) the River Adige map (the so-called Nowack-Plan), a “cadastre-comparable” topographical map, contemporary (1803-1805) and at large-scale (1:3.456), whereas the Habsburg Cadastre is used, for both case-studies, as a map as a tool.

Thus, we are faced with cartographies composed of hundreds of map-sheets, with a lack of information about the native reference systems and mainly not yet georeferenced. In short, each map-sheet needs to be localizable (in a common reference system, ETRS89), avoiding a massive initial georeferencing/mosaicking process onto the whole data-set. Following this path, our current work centres on developing a methodology using the index-map sheet.

The first case-study (the Napoleonic Cadastre) is characterized by a lack of index-map, so a new current one was implemented, fitting the grid of Habsburg Cadastre index-map. The second case-study (the Nowack-Plan) provides relevant index-maps, but no information about the native system, so we have georeferenced these index-map in the native system of the Habsburg Cadastre, successively performing the transformation in ETRS89, using the official parameters provided by the Region.

### Introduction

Accurate European large scale map-making has been carried out, since the late 18th century, initially in France and then throughout the Austrian Empire. The first modern cadastral survey ever was the Napoleonic one (1809-1815) in the *Royaume d’Italie* at the scale 1:2.000 (Mastronunzio and Buffoni 2014, Repele et al. 2011) followed by the well-known Habsburg Cadastre at the scale 1:2.880, from the *Grundsteuerpatent* (“land tax edict”) of 1817, in the Austrian Empire (Bundesamt für Eich- und Vermessungswesen 1967 and 1983, *Instruction [...]1824*,<sup>1</sup> Lego 1967).

Cadastre deals with land, law and people, historically and all over the world. This means, respectively: surveying, land tenure and land registration – connected *via* boundaries. The latter mark land parcels, define the limits of property rights and, hence “record” the owners. In short, cadastre has a

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<sup>1</sup> Accessed on the manuscript translated into Italian for former Tyrol territories, *Istruzione per attivare la misurazione dei territorj [...]*, conserved at the Cadastre Museum of the Autonomous Region Trentino-South Tyrol.

key role for government interventions in the relationships between land and people, and the cadastral map is the key player.

Furthermore, if “people’s ideas of geography are not founded on actual facts but on Mercator’s map” (Monmonier 1996: 21), it may be possible to affirm that local communities’ ideas of geography are based on their traditional large-scale maps, notably on cadastral maps, since such kinds of maps are *readily readable* in our every-day lives. Maps that produce a *mapscape*: a map-produced landscape that could modify the actual “morphology” of a cityscape, a riverscape, a borderscape and, in general all -scapes.

The Napoleonic as well as the Habsburg Cadastre were the earliest modern cadastres. *Modern* since they were based on: land measure (geodetic-based or topographic but not limited to a triangulation on a single map-sheet), land estimation (based on certainty of land parcels) and boundary marking (certainty of territorial units).

Our research group in historical geography at University of Trento (Italy) is involved in research projects regarding the Trentino-South Tyrol Autonomous Region (NE Italy), faced with a huge data-set of cartographic heritage, notably at large-scale, as a source for present-day issues. The Region was included in both of the aforementioned cadastral surveys.

### **On map geometric content and positional accuracy**

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 thus be used for the evaluation of landscape changes. Such a 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 oriented research (Harley 1968), in other words, 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 geographical grid and, in general, their lack of geometric and planimetric accuracy. Indeed, map scale and rotation represent the main issues regarding 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 visualize it and compare it with more recent maps, where more recent simply stands for more accurate, and not the real map, nor the “correct” map.

Besides, the lack of accuracy in scale and rotation is nowadays the most visible problem in an old map, because the reading of a map by map-users – the so-called cartoliteracy (Sturani 2008), or map literacy – is now more precise and accurate than in the past, and has been so since at least the 19th century, with the development of “map-driven states” and with the superimposition of a “cadastral-way-of-thinking” (Crampton 2010, Elden 2007).

Whereas map-reading and map-interpretation strictly deal with the geometric content of maps, the conception of the map itself is, above all, to do with the notion of flat or surface “distortion”, that is, with maps geometry. In fact, the 1903 Peirce generalization<sup>2</sup> quotes: “A map [...] represents all the

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<sup>2</sup> The definition of a map by Charles Sanders Peirce (cartographer and philosopher who developed the Peirce projection).

points of one surface by corresponding points of another surface [...] to preserve the continuity unbroken, however great may be the distortion”.

Thus, the investigation of the geometric content of old maps – in this paper of native reference systems or a comparable reference system – is a prerequisite for a full data-processing which includes: i) a global and/or local geometric correction using the appropriate geometric transformation; ii) a consequent integration into a GIS environment (Balletti 2006) or simply into a georeferenced framework (Grosso 2010) – because to set-up a full GIS is by no means necessary: a framework with two linked maps with at least one reference map is enough.

Our historical maps (presented here below as case-studies) are mostly unpublished, with poor current literature as well as contemporary document references, with a lack of information about the native reference systems, mainly not yet georeferenced (except some sample areas and case-studies) and, above all, composed of hundreds of map-sheets.<sup>3</sup>

These maps are characterized by a suitable geometric accuracy (positional and planimetric), generally since such maps were produced from the late 18th century (Zentai 2013), and particularly, according to map accuracy analysis implemented on sample sheets (e.g. Dai Prà and Mastronunzio 2014, Mastronunzio and Dai Prà 2016). The positional accuracy could appear important for maps at such a fine scale, from 1:2.000 up to 1:3.456 (at least 3 times the graphic error, up to approximately 10 times).

Nevertheless, it should be underlined that these kinds of maps present certain inaccuracies (see e.g. Monti et al. 2009) principally due to the map paper itself (material degradation) on the one hand, and to the digitization (anisotropic deformation), on the other – the latter due to several causes (e.g. defects of optical lenses, nonlinearity of the electro-optical sensor, minor motion between paper and scanner/camera, wrong focus). The first cause is more considerable, that of paper degradation, essentially caused by their being over 200 years-old, which leads to two types of deformation: i) shrinkage of the original map due to paper dehydration and ii) stretching of the original map due to several subsequent reproductions by heliography. This lead to important “stratified” distortions: a shrunken (reduced) map, reproduced and stretched (extended) on a fixed (immovable) support.

Regarding the Habsburg Cadastre at scale 1:2.880 – meaning a graphic error of 0,576 m – it was measured with manual procedures (sample measure of the distance between 2 points inside the range of 1 Km, both graphically on the map as well as by surveying on the terrain) a mean positional error of 6-8 metres per kilometre (Regione Autonoma Trentino-Alto Adige 1981).

Moreover, «a map of good planimetric accuracy is a prerequisite for editing» (Wiberley 1980: 504). This is precisely the case of the Napoleonic Cadastre here presented. One could choose a “copy-text” of an old map and, using it as a basis, produce a map that conveys, in modern form accompanied by variants, the essence of what the makers of the original intended (Wiberley 1980). Such a “modern” form was used when producing a brand new map-sheets overview of the Napoleonic Cadastre, not produced at that time, but important to carrying out the intention of such a cadastral survey: measuring and controlling a vast territory, where the term vast means composed of several territorial census units bordering on each other. Furthermore, the boundaries of these territorial units are mostly the same as the subsequent Habsburg Cadastre.

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<sup>3</sup> Digitized using flatbed cold-light scanner in multi-resolution format; bit depth RGB 24 bits, TIFF master files 600 dpi, JPEG 300 dpi and 72 dpi for web

## Case-studies

In this mainly methodological paper two related case-studies are presented: (i) the Napoleonic Cadastre at scale 1:2.000 (1809-1815) and (ii) the River Adige map (the so-called Nowack-Plan), a “cadastre-comparable” topographical map, contemporary (1803-1805) and at large-scale (1:3.456), whereas the Habsburg Cadastre (or simply, the Austrian Cadastre) at 1:2.880 scale (1853-1861, for the Tyrol)<sup>4</sup> is used, for both case-studies, as a “map as a tool”. In short, each map-sheet needs to be geolocalizable (in a common reference system, ETRF89), thus avoiding a massive previously georeferencing/mosaicking processing onto the whole data-set. Following this path, our current work centres on developing a methodology using a map-sheets overview (index map-sheet), often neglected in a GIS-framework.

### *The Napoleonic Cadastre at scale 1:2.000 (1809-1815): a new index-map*

The first case-study is focused on a number (approximately 200) of unpublished Napoleonic cadastral maps at scale 1:2.000 (1809-1815) nowadays stored in Innsbruck, at the Tiroler Landesmuseum Ferdinandeum.<sup>5</sup>

Survey maps (always indicated as “original map”)<sup>6</sup> are at 1:2.000 scale, whereas a number of reduced copies at scale 1:4.000 and 1:8.000 are present too. More important is that each “original map” represents a single and complete territorial census unit, but due to this, each one is drawn on a number of paper-sheets physically merged together: this leads to significant accuracy problems regarding the map globally. However these problems are avoidable by means of appropriate local geometric transformation on specific features.

Furthermore, the Napoleonic Cadastre has no geodetic basis: the triangulation is limited “inside” each map-sheet and the triangulation map fits with the mapped area (this means that each territorial unit has undergone its own survey, implemented with plane tables and theodolites).

For all the maps (“original maps” to scale 1:2.000 and relative reduced scale copies in scale 1:4.000 and 1:8000) a file system was used with, amongst other information, archive key, formal characteristics, localization relative to the map-sheets of the Austrian Cadastre and hyperlinks to low-resolution previews. The territorial census units represented on the Napoleonic Cadastre maps largely coincide with the territorial census units of the Austrian Cadastre (Fig. 1).

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<sup>4</sup> The authors would like to thank Dr. Dino Buffoni (Head of the Geodetic Office of the Autonomous Province of Trento’s Cadastre Service) for his precious help with all issues regarding cadastral surveying.

<sup>5</sup> The authors would like to thank Prof. Wolfgang Meighörner (Head) and Dr. Claudia Sporer-Heis (Historical Collection) of *Tiroler Landesmuseum Ferdinandeum* for all archival issues regarding the maps and for the digitization (archival records: *Historische Sammlungen-Kartographie*, K60/100-299).

<sup>6</sup> *Mappa Originale* in Italian. Generally, all maps are labelled in Italian, contrary to the contemporary Napoleonic mapmaking at smaller scale.

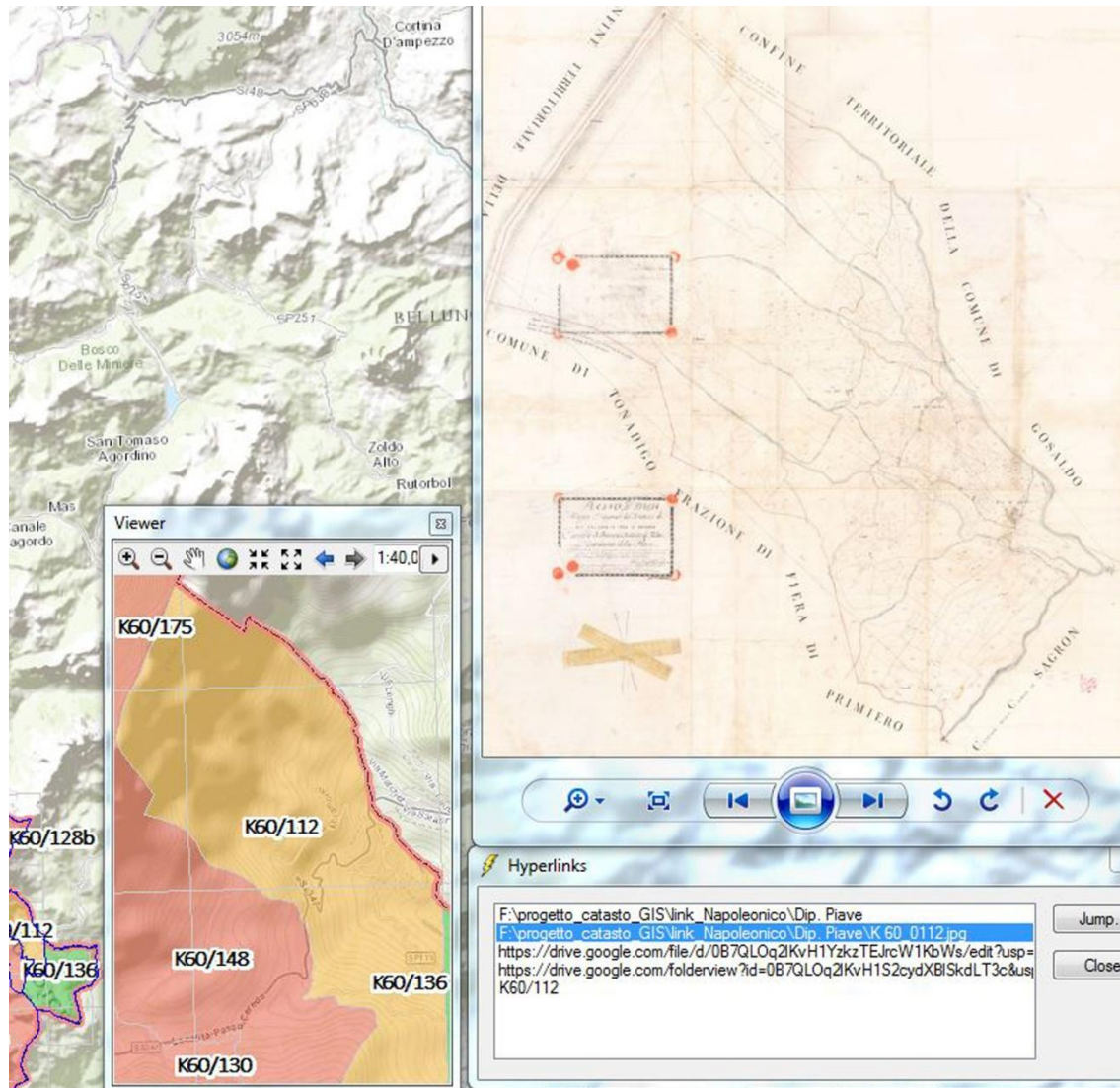


Figure 1. Map of the Napoleonic Cadastre showing territorial census unit boundaries. Source: courtesy from *Tiroler Landesmuseum Ferdinandeum* (Innsbruck). Adapted by the authors.

In order to obtain a reference to the detail of each single map-sheet an index map was generated of the Napoleonic cadastral maps – not produced at the time of the drawing up of the maps: therefore a procedure of editing of historic data (Wiberley 1980). The Napoleonic cadastral maps were divided according to the frame of the Austrian Cadastre map-sheets and indexed using the archival key as the primary key.

This was possible thanks to the use of the official vector file (of the Autonomous Province of Trento), which provides the map-sheet framework of the Austrian Cadastre and relative centroid coordinates (in the UTM ETRF89 system) of each single map-sheet. Since no index-map is provided a new one needed to be produced (and Napoleonic Cadastre has no geodetic basis), therefore the appropriate way was to produce such an index-map directly in the current official reference system (ETRF89).

The Napoleonic Cadastre thus appears geolocalized: the maps are not georeferenced, but only the index-map sheet is. Referring to the Austrian Cadastre map-sheets (Figure 2), it is immediately comparable to the latter, enabling a flexible localization of the single Napoleonic maps.

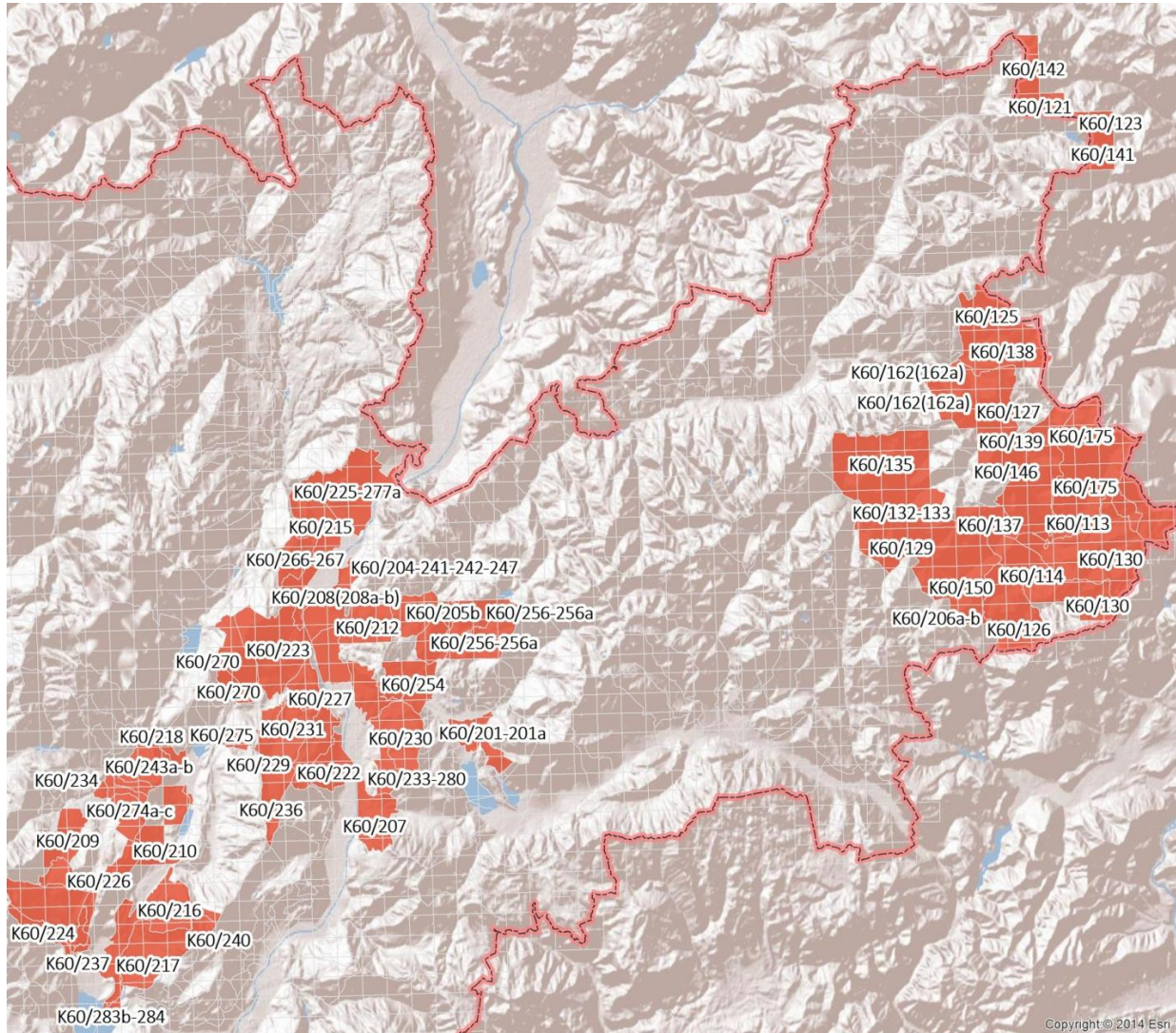


Figure 2. Detail of in-progress index-map of the Napoleonic Cadastre of Trentino region, showing the territorial census unit boundaries, the graticule of the Austrian Cadastre and archival keys used for the indexing of the Napoleonic map-sheets. Source: adapted by the authors.

The creation of an index-map sheet with such a procedure (in-progress) constitutes an initial mosaicking onto non-georeferenced raster images, which are only subsequently georeferenced as a whole. This avoids the pre-processing of roto-translation and variations of scale factors (Brovelli et al. 2012, Lanfreniere and Rivet 2010) which may go to the detriment of the maps' global geometric accuracy. Lastly, such a method of geolocalization with a geometric reference constituted by a single point (the centroid coordinates of each map-sheet) was chosen inasmuch as, subsequently and according to the needs of each case-study, it is possible to geometrically align certain map-sheets (avoiding a massive time-consuming initial georeferencing beforehand) using zero-order polynomial geometric transfor-

mation (Ashburner and Friston 1997). Such a transformation is useful when there is the need for transformig a previously georeferenced raster image which also requires some “adjustment” (aligning). The zero order transformation works, in fact, by identifying only a two-point correspondence (it uses only one point): thus we are able to align and re-sample the single Napoleonic map-sheet using the centroid coordinates of the relative map-sheet inferable from the index-map.

*The Nowack-Plan at scale 1:3.456 (1803-1805): the original index-map*

The second case-study (strictly related to the first one since it uses and refers also in this case to the Austrian Cadastre) focuses on the River Adige map (hereafter known as the Nowack-Plan), a “cadastre-comparable” hydro-topographical map, inasmuch temporally comparable (1803-1805) and at comparable large-scale (1:3.456). Nowadays conserved in Innsbruck too, at the Tiroler Landesarchiv,<sup>7</sup> the Nowack-Plan is composed of 131 map-sheets. Contrary to the Napoleonic maps, in the case of the Nowack-Plan, the original index-map sheet is provided alongside the map (Fig. 3).

The most accurate way is to reference a map in its native system first. However, as well as the aforementioned Napoleonic Cadastre, no information about the native reference system is provided, and almost certainly, like a numbers of contemporary Habsburg maps, the Nowack-Plan was produced without a fundamental geodetic surveying (no ellipsoid,<sup>8</sup> no datum), but using its own proper triangulation<sup>9</sup> and then executed graphically with plane tables and theodolites (that is: a topographic - trigonometric surveying).

In short we have georeferenced the Nowack-Plan index-map in the native system of the Austrian Cadastre (contrary to the previous case-study, where the native system of the Austrian Cadastre was not used): due to the lack of proper information regarding the native system and the absence of a geodetic basis, a comparative approach seems to be the right way, using a comparable reference system (the Austrian Cadastre one). The native reference system of the Austrian Cadastre, for the former Tyrol (including the present-day Trentino-South Tyrol region) is well-known (e.g. Buffoni et al. 2003, Lego 1967) and simply termed as “Land Cadastre Coordinates”.<sup>10</sup> Specific technical features are: (i) Zach-Oriani hybrid ellipsoid 1810 (semi-major axis  $a=6376130$  m; inverse flattening  $1/f=310$ );<sup>11</sup> (ii) Datum Innsbruck Pfarrturm (*city-parish church south-tower*) with fundamental point coordinates Lat.=47°

<sup>7</sup> Archival records: *Baudirektionsplänen* O2b. Publishing authorization TLA-F-03/2227-2014.

<sup>8</sup> Only one ellipsoid was developed before the Nowack-Plan, the Laplace 1802 (the first ellipsoid ever), and afterwards, the Bohnenberger 1809, the Zach 1809 and the Zach-Oriani 1810 were used for imperial mapmaking (Timár and Molnár 2013, Mugnier 2004). In particular, the Bohnenberger ellipsoid was used for the Second Military Survey, but such a Survey started in 1806, after the completion of Nowack-Plan. Moreover, the so-termed contemporary “Babel-Scheppler” ellipsoid by 1803 (Mastronunzio and Dai Prà, 2016) was considered valid for Italian territories, but no information was found about it regarding the Nowack-Plan.

<sup>9</sup> It seem very unlikely that the Liesganig triangulation used for the First Military Survey (1763-1787), was used for the Nowack-Plan too, since the First Survey did not include Tyrol. Likewise the von Zach triangulation, used for the *Kriegskarte* of Venetian territories (1798-1805) was not used, since such a triangulation was centred in Padua and did not include the vast upper part of the Adige, but only its southern stream (Mastronunzio and Dai Prà 2016).

<sup>10</sup> *Coordinate Catasto Fondiario* in Italian.

<sup>11</sup> Please note that only the Zach-Oriani 1810 ellipsoid was used for cadastral surveying, and not the previous Zach 1809 ellipsoid, that has the same  $1/f$  but a different semi-major axis ( $a=6376480$  m).

16' 44.10" N; Long.=29° 03' 25,90" E of Ferro prime meridian;<sup>12</sup> (iii) The Cassini-Soldner projection centred on the Innsbruck meridian (positive X-axis is Eastward and positive Y-axis Southward).

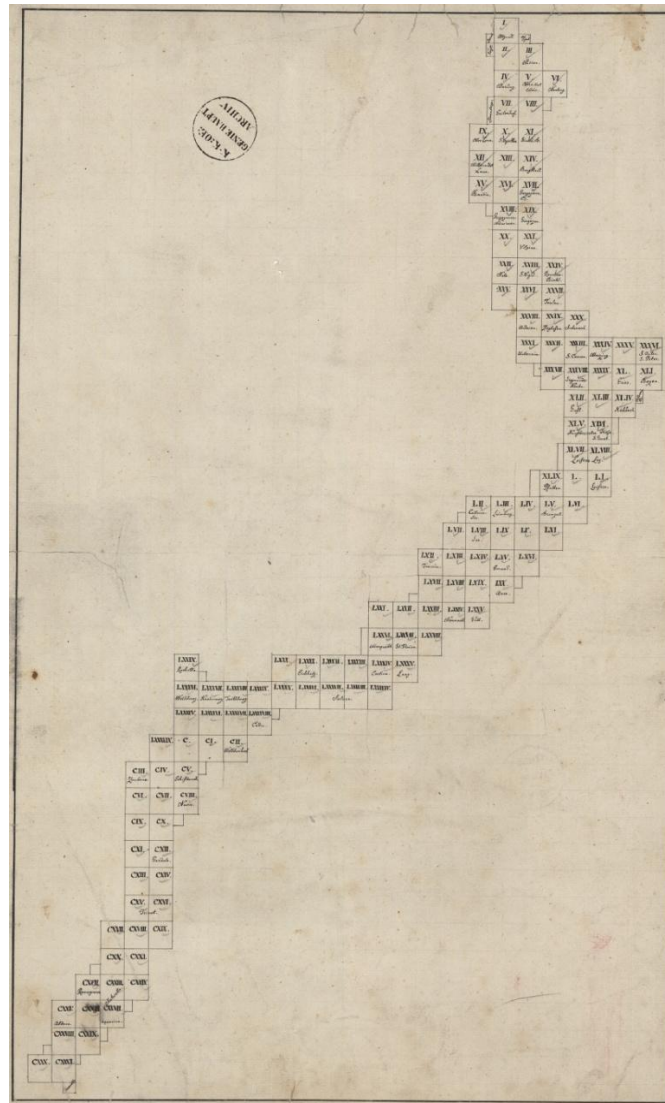


Figure 3. Index-map of the 131 map-sheets of the River Adige map (Nowack-Plan). Source: *Tiroler Landesarchiv* (Innsbruck).

The proposed approach is a map-to-map warping methodology. First of all, we assigned the “Land Cadastre Coordinates” system to the Nowack-Plan index-map and we selected well-distributed control points assigning the relevant planimetric coordinates from the Austrian Cadastre. The control points’ selection was crucial, but the Austrian Cadastre provides an impressive amount of points coordinates, both from each map-sheet corner as well as a number of control points representing land-

<sup>12</sup> Long.= 11° 23' 39,88" E of Greenwich (following the Albrecht-deviation of 17° 39' 46" used throughout the Empire). These values are the official ones for the Trentino-South Tyrol Region (and according to Buffoni et al. 2003). There are some inconsistencies between the Innsbruck fundamental point coordinates: Lat.=47° 16' 11.306" N and Long.=29° 03' 25,3357" E of Ferro (according to Mugnier 2004); Lat.=47° 16' 14.1" N and Long.=29° 03' 25,90" E of Ferro (according to Timár 2009). In our case the official ones were chosen, also because the longitude coordinate is the same for different sources.



marks and the planimetric grid onto each sheet. Notably, such a planimetric grid was “overlaid” throughout the decades (clear evidence of the daily use of such a material cultural heritage), in pencil and it reports the coordinates numerical values too (Figure 4). Moreover the vector version of the planimetric grid (reporting only map-sheet corners)<sup>13</sup> was used.

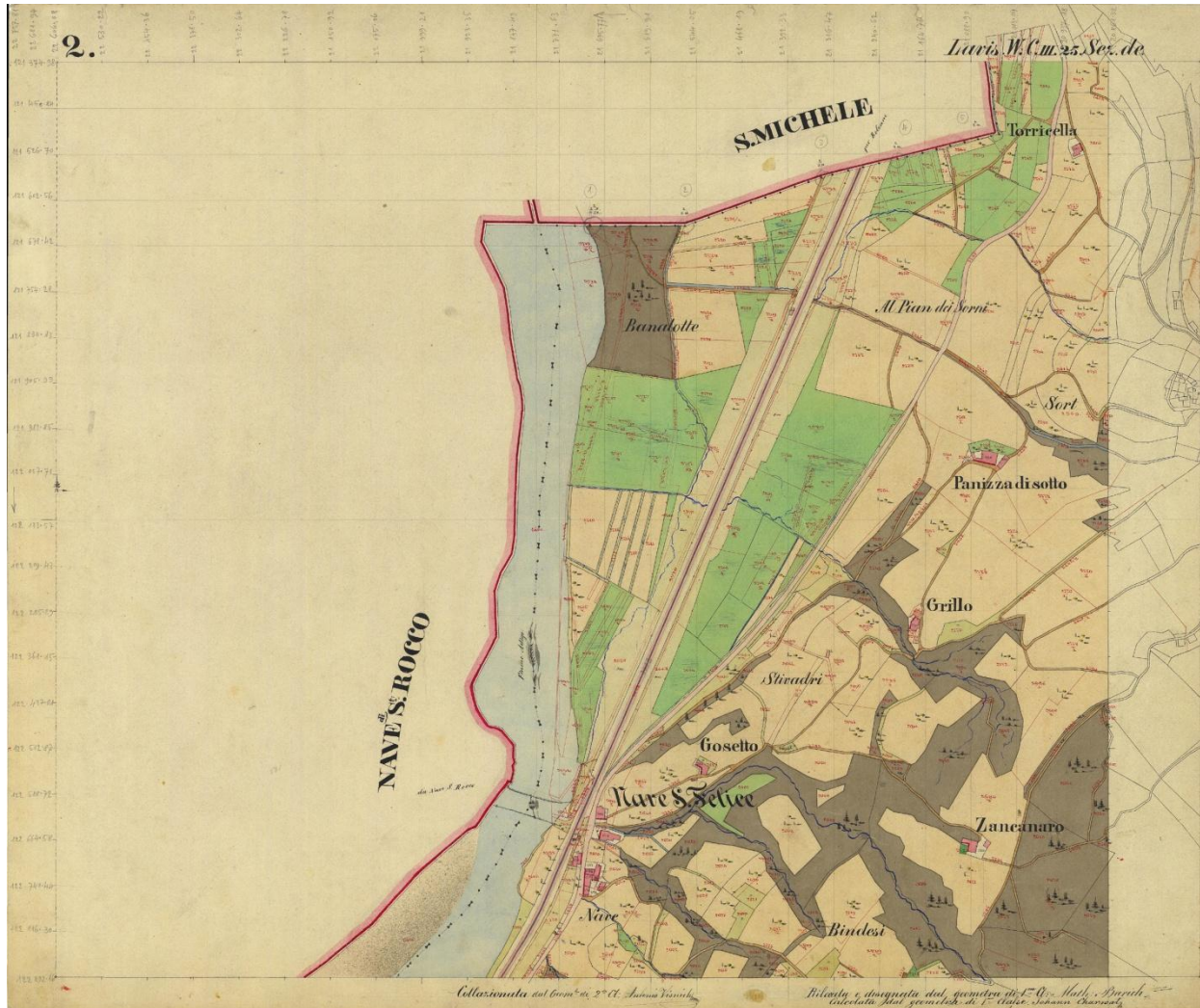


Figure 4. Detailed planimetric grid in the native reference system “overlaid” on Austrian Cadastre. (Territorial Unit: 185 Lavis-Trento; Map-sheet n. 2). Source: courtesy from Cadastre Service-Autonomous Province of Trento (Italy).

Thus, a large number of points were readily readable, leading to such a multi-source georeferencing process that made it feasible to select on the Nowack-Plan index-map a well-distributed corner point of the graticule also using some single map-sheet of the Nowack-Plan as a target map, in order to directly identify some landmarks as control points (from the Austrian Cadastre as a reference map). Due to the high number of control points available a local geometric transformation should be the most suitable approach/method, but on the contrary, we chose a global one since we are in the pres-

<sup>13</sup> The official one developed by the Trentino-south Tyrol region, in the “Land Cadastre Coordinate” system.

ence of an index-map and therefore we need a global accuracy of the map, also despite the local accuracy. For this reason we implemented a 1st Order Polynomial, with a RMS Error of 6,4197 m. For accuracy assessment we georeferenced a sample map-sheet (sect. 112) of the Nowack-Plan using the 4-corner coordinate selected from the index-map (the relevant corners of the graticule corresponding to the “box” of section 112), using a 1st Order Polynomial, with a RMS Error of 2,40469 m. The first outcome was to obtain the Nowack-Plan index-map sheet georeferenced in the “Land Cadastre Coordinates” system (Figure 5).

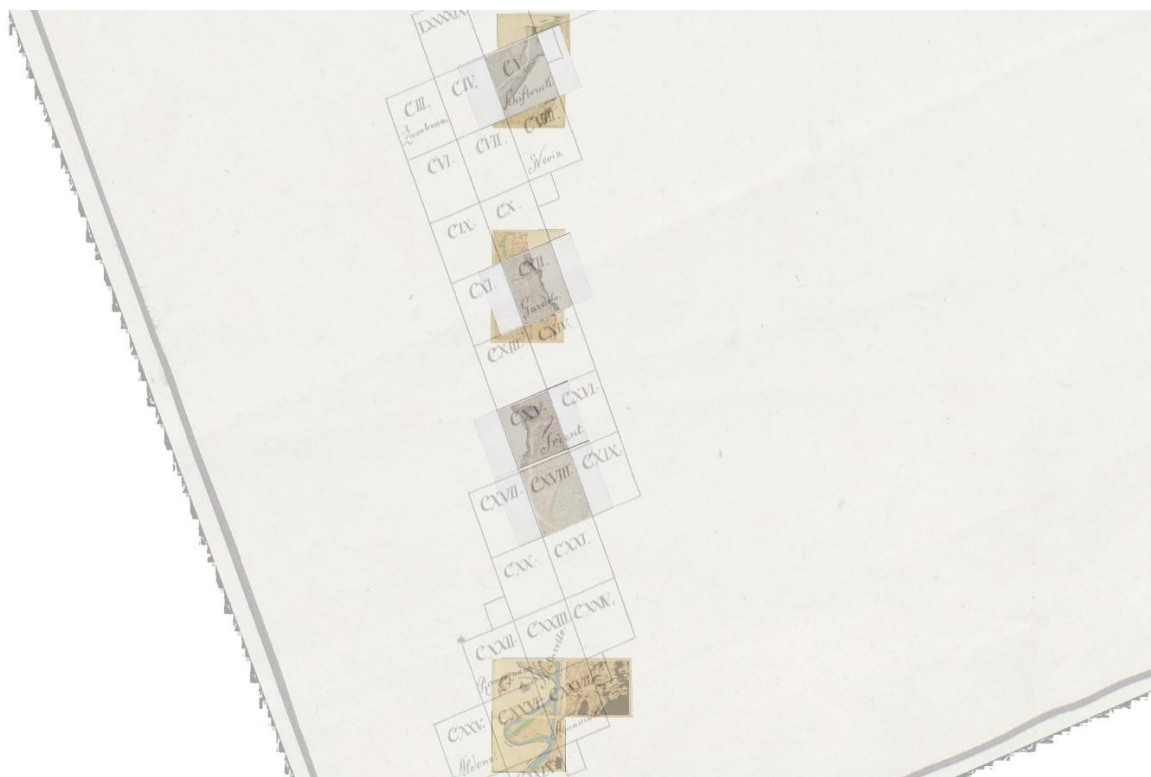


Figure 5. Detail of the Index-map of the Nowack-Plan georeferenced in the native reference system of the Austrian Cadastre, with overlaid sample georeferenced map-sheets of the Nowack-Plan and sample of the Austrian Cadastre. Source: courtesy from Cadastre Service-Autonomous Province of Trento (Italy) and *Tiroler Landesarchiv* (Innsbruck). Adapted by the authors.

Afterwards it was possible to perform the transformation to the current official reference system (UTM ETRS89) using the official parameters calculated and provided by the Trentino-South Tyrol region,<sup>14</sup> valid only for regional territory and applying the methodology that implements the parametric grid (Buffoni et al. 2003). Such a grid is the same as previously mentioned, available not only in the “Land Cadastre Coordinates” system but also in the former official Italian system (termed “Roma 40”, with the Hayford ellipsoid, Datum Monte Mario and the Gauss-Boaga projection) as well as in the geocentric system UTM ETRS89. The direction of the transformation was from “Land Cadastre Coordinates” to “Roma 40” and finally to UTM ETRS89 (Figure 6).

<sup>14</sup> Naming by the Cadastre Services of Trento Province and of the Bolzano Province (see *Bollettino Ufficiale della Regione Autonoma Trentino-Alto Adige*, n. 19, 20.04.1999).



Figure 6. Detail of the Index-map of the Nowack-Plan reprojected in ETRS89, overlaid on sample map-sheets of Austrian Cadastre (ETRS89) and on Official Topographic Base Map (CTP) of the Trento Province. Source: courtesy from Cadastre Service-Autonomous Province of Trento (Italy) and *Tiroler Landesarchiv* (Innsbruck); adapted by the authors.

### Final remarks

What results, for both case studies, is a georeferenced index-map that readily provides the 4-corner coordinates of each single map-sheet for subsequent georeferencing, assigning the corner ETRS coordinates (from index-map) to corresponding corner-points (onto single sheets) without identifying landmarks/control points both on old and current reference maps. Moreover, from 1 to 3 additional landmarks/control points are needed to align (zero-order transformation) the old map to the current target one, but avoiding a massive selection of control points in both historical and reference maps required for a standard method and in the whole data-set.

This ongoing process, which is not so easy-to-use but really scalable, could provide a scientific informative tool suitable for a wide range of research fields. We need a more precise representation for web mapping with Google Maps, OpenStreetMap and the myriad of wiki-maps or other web platforms, in which, positional accuracy and geospatial analysis are currently secondary to user-friendly displays of geographic data. That means, in order to use our old maps – which are part of our cultural heritage in general – we firstly need to evaluate their geometric content quite precisely for a consequently precise representation. These processed maps could be used as a tool for a number of purposes and scholars of different fields, such as: landscape planning, historical geography, environmental history, historical ecology and, furthermore, could be crucial for retracing the *history of mapping* as a bridge-subject between human geography and GIScience.

As such, the history of mapping would represent the key strand of enquiry for interdisciplinary areas of investigation and multidisciplinary research – i.e. the digital humanities. Linking the history of cartography (the critical, qualitative approach) with historical cartography (the amount of data available, where cartography represents the data from which the geo-information can be “extracted”), such a multifaceted approach could represent a useful tool for spatial humanities, enabling the study of the whole mapping process (whose results, come what may, we can see *on* the map), from the surveying to the final representation: from topography to topology.

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