
PARTE OCCIDENTALE DELL' EUROPA,
Descritta, e Dedicata
Dal P. Cosmografo Coronelli,
All' Illustrissimo, et Eccellentissimo Signore
GIOVANNI DA MULA,
Senatore Amplissimo,
Nella Serenissima Republica di Venetia
etc.
Settentrione
Mezzo Giorno
Occidente
Oriente
Miglia d'Italia
Leghe di Francia
GROENLANDA
AMERICA
SETTEN OCEANO
DANIMARCA
ISOLA DI GIO. MAY.
Scoperta nel 1614.
Circolo Polare Artico
IS. D'ISLANDA, già detta SNAELAND, Scoperta da Naddocho di Norvegia l'anno 860. al presente posseduta dal Re di Danimarca, è divisa in 32 Prefetture
Primo Meridiano
MARE BRITANNICO
ATLANTICO
MARE DI GERMANIA
Golfo di Lion
MARE DI MAIORICA
MARE MEDITER
MARE DI BARBARIA
PARTE DELL' AFRICA
MARE DI FRANCIA
MARE DI GALICIA
MARE DI SPAGNA
GOLFO DI VENETIA
MARE ADRIATICO
Isole Sorlingue, o Silly, et Silurum Insulæ
ISOLE BALEARIDI
Canale di Malta
Stretto di Gibraltar
Golfo di Cadiz

h

Analytical methods for the projective content of Coronelli's central Europe maps

Caterina Balletti *Università Iuav di Venezia*
Caterina Gottardi *Università Iuav di Venezia*

Abstract

Historical cartography constitutes a factual basis for a diachronic analysis of the city, land an places. Historical maps often contain information that cannot be found in other written sources, such as, for example, place names, boundaries, and physical characteristics that have been altered or completely erased by modern development. Analyzing historical maps makes it possible to understand the territory's current configuration - which is the result of choices made in the past - and to critically assess evolutionary dynamics. The interventions of the past influence the present-day conformation in the same way that today's interventions may someday influence the future.

The development of information technology has recently allowed an evolution in the methods of investigation and dissemination of historical maps, thanks to the introduction of intuitive and immediate interfaces, giving immediate access to complex functions and making them easier to be used than they were in the past. Generally, we are witnessing to a wide spread of new applications, even in disciplinary fields traditionally not involved in computer science, which are characterized by the simplicity in managing complex analysis and by the presence of tools for the visualization of results from a non expert wide public.

Descriptive and cognitive aspects of historical maps can be emphasized in a system where historical, geographical or economic data can be integrated; this tool, which are able to relate heterogeneous information in order to increase and improve their management and communicability, represent, in our time, the basic equipment for every research.

This paper deals with the Europe maps of Coronelli, contained in the Atlante Veneto, and wants to better understand which is the projective system better suitable to these historical cartography.

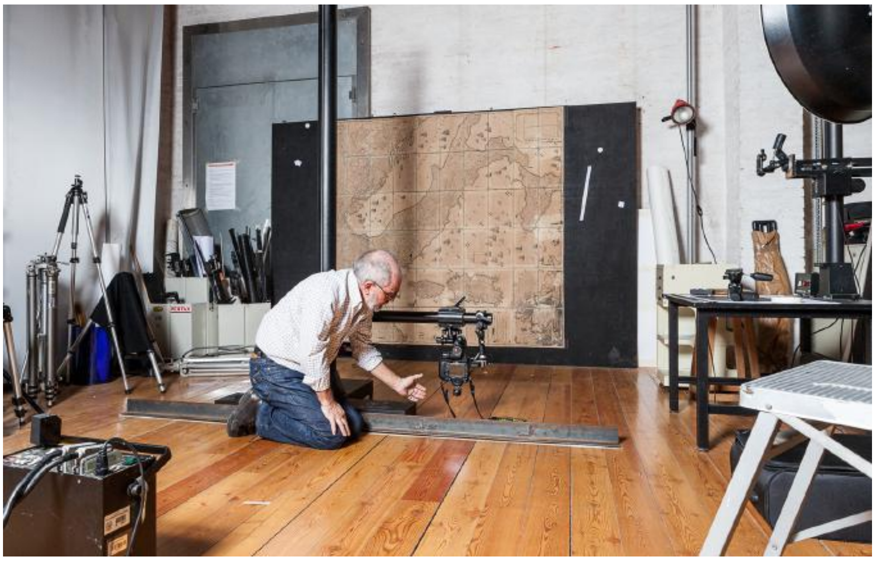
Recently a collection of ancient maps was found in the Institute of Marine Sciences of CNR in Venice (ISMAR-CNR). The collection includes maps, perspective views, pilot books, atlas (such as the Coronelli's one that was used for the projective analyses) and ancient manuscripts: this work took into account a selection of maps and documents representing the Venice Lagoon, the Adriatic coast and a part of Europe.

The first part of this research focused on the application of a scientific method for digital acquisition of historical cartography; thanks to the Geomatic tools and especially to digital photogrammetry it is possible to acquire metric, semantic and symbolic information and also the three-dimensional shape of the geometrical

support to correct the deformations occurred over time.
The applied procedure of recovery and valorisation of historical cartography is divided into three different phases: acquisition, georeferencing and data elaboration of maps in a digital environment. This paper underlines the application of a scientific procedure for the conservation and valorisation of the historical Cartographic Heritage, particularly considering the geodetical and projective content of european maps of Coronelli: as often stated in literature, most of the maps are topographically not accurate, especially regarding the north-south orientation (mainly because the magnetic declination was not known yet), and the projective system is not well defined. The georeferencing process and the residual analyses can offer some considerations on this topic.

Digitizing

In the digitization phase it is not always possible to use contact scanner, as the roll or flatbed scanners, because the physical support has usually deformations that need to be evaluated in order to survey the geometric content of a map.
During the last years different methods were proposed for the digitization in order to record in the digital format both the three-dimensional surface of the support and the bidimensional image with a high resolution (Adami et al., 2007; Daniil et al., 2003; Tsioukas et al., 2009; Tsioukas et al., 2012).
Photogrammetry is the most used technique in this particular field (Ballarin et al., 2014a; Ballarin et al., 2014b): through the acquisition of photograms with a correct capture's geometry it is possible to create a three-dimensional photogrammetric model; in this way it is possible to digitize not only the radiometric values, but also the metric content and the deformations of the physical support.
It is really important to choose the more suitable digitization's method for the historical map that we have to acquire. In this case study, the most part of maps (expecially those binded maps belonging to atlases) were not in a state of conservation suitable for a scanner acquisition; for this reason they were digitally reproduced with an acquisition based on photographs. In this case a digital camera Nikon D800 was used: it has a CMOS full frame sensor (35.9x24 mm) and the images were acquired with the high-



1. Digitizing phase using high resolution camera.

est resolution (7360x4912) and with a fixed lens (60 mm).

The digital acquisition was realized with only one photograph for the most of the analysed maps because of their reduced size and the small deformation of the support. The 2D photogrammetry method was often used for the historical maps' digitization and many researches were done applying this methodology to ancient maps; however for the more complex cases the three-dimensional digitization is the only procedure to use.

Georeferencing

By allowing the cataloging, spatial analysis, processing, and use of historical documents in a digital environment (especially through GIS), the tools of geomatics make it possible to valorize a historical map in modern terms and demonstrate its present-day utility. When the digitalization of a historical map maintains the metrics associated to, it not only in guarantees the map's future conservation in the form of a faithful copy (as we are doing for the ISMAR-CNR archives), it also makes it an object on which a broad spectrum of research may be conducted and permits applications that are not feasible on the original analog support.

With regards to historical cartography, referencing and the issues associated to its application are currently of great interest. The fact remains, however, that assigning a correct metric support is of considerable importance in using cartography not only as a document of qualitative interest but also as a real map from which quantitative metric information can be drawn (Boutoura et al., 2001; Balletti, 2006; Boutoura et al., 2006; Jenny et al., 2007).

An underlying consideration that is both a prompt and a guide in this direction is the fact that these maps were actually made as "maps," which is to say as tools conceived and used for practical purposes. Perhaps the concept of *metricity* or more simply the acceptable threshold of uncertainty has changed.

The accuracy, or better yet, the reliability of an old map has to be considered in relation to the purpose for which it was made. In this way it is possible to take distortions and omissions into account as information rather than mistakes, evaluating therefore the credibility of their content.

But how can historical maps be georeferenced? With respect to current cartography, they present – even if differently with respect to the type of representation and the era in which they were produced – certain particular characteristics, such as an uncertain metric content, an approximate projection system and a semantic content that is hard to interpret.

Moreover, these characteristics are found to a greater or lesser extent in maps of different eras and types and, consequently, specific considerations have to made for each different map.

The geometric transformations applied to a cartographic image can be classified into two main categories: global and local transformations; obviously, the choice of which transformation we have to use depends on the map that has to be georeferenced (Balletti, 2000; Balletti et al., 2001).

Global transformations are those whose parameters are valid for any point of the image after the model is chosen. The position of each point will be calculated applying the parameters starting from the control points. These are the traditional plane transformations that relate a system of points to another set of points in a one to one correspondence, realizing the transition from the o, x, y system to the O, X, Y system. On the other hand, the local transformations are calculated for each individual point of the image and have local validity. The aim of using local transformations is to deform only a part of the image without applying substantial modifications to the whole map.

The global transformations are used in the referencing procedure such as general transformation. At the same time, it is possible to evaluate deformations through the analysis of the residuals. Usually a higher than necessary number of points is used and the value of parameters is calculated with a least squares adjustment; in this way it is possible to evaluate the results of transformation through the analysis of residuals' distribution and verify the transformation's accuracy with respect to the two sets of points used.

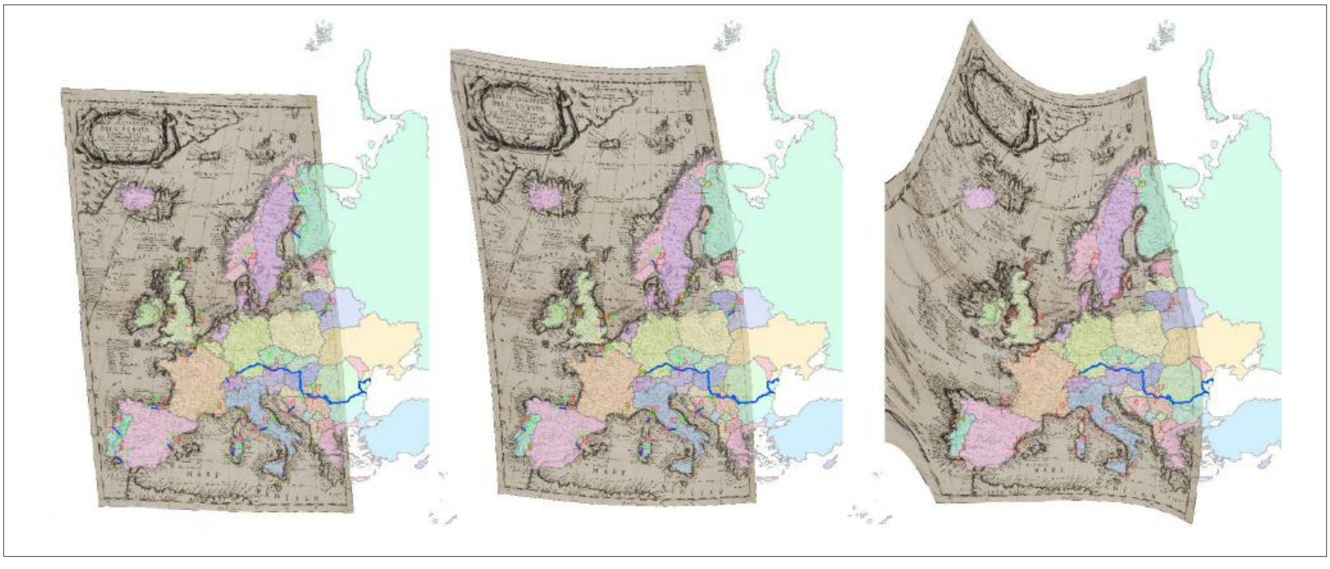
The georeferencing work of ISMAR-CNR cartographic Heritage was done using the ESRI ArcGis software. This application, and in particular the ESRI ArcMap module, allows to apply various transformations, after the recognition of the tie points on both the two maps. We have the choice of using a polynomial, a spline, adjust, or a projective transformation, which have to be chosen from time to time according to the characteristics of the map itself, to determine the correct map location for each cell in the raster.

The first-order polynomial transformation (or affine transformation) is commonly used to georeference an image: this kind of transformation is used to shift, scale, and rotate a raster dataset; it used a polynomial function built on control points and a least-squares fitting algorithm. It is optimized for global accuracy but does not guarantee local accuracy. The spline transformation is a rubber sheeting method useful for local but not for global accuracy. It is based on a spline function and it requires a minimum of 10 control points: it transforms the source control points exactly to target control points.

This transformation is useful when the control points are important and it is required that they have to be registered precisely.

The adjust transformation optimizes both global and local accuracy; it requires a minimum of three control points and it adjusts the control points locally to better match the target control points using a TIN interpolation technique.

2. The effects of different models of trasformations (1st, 2nd, 3rd order polynomial transformation).



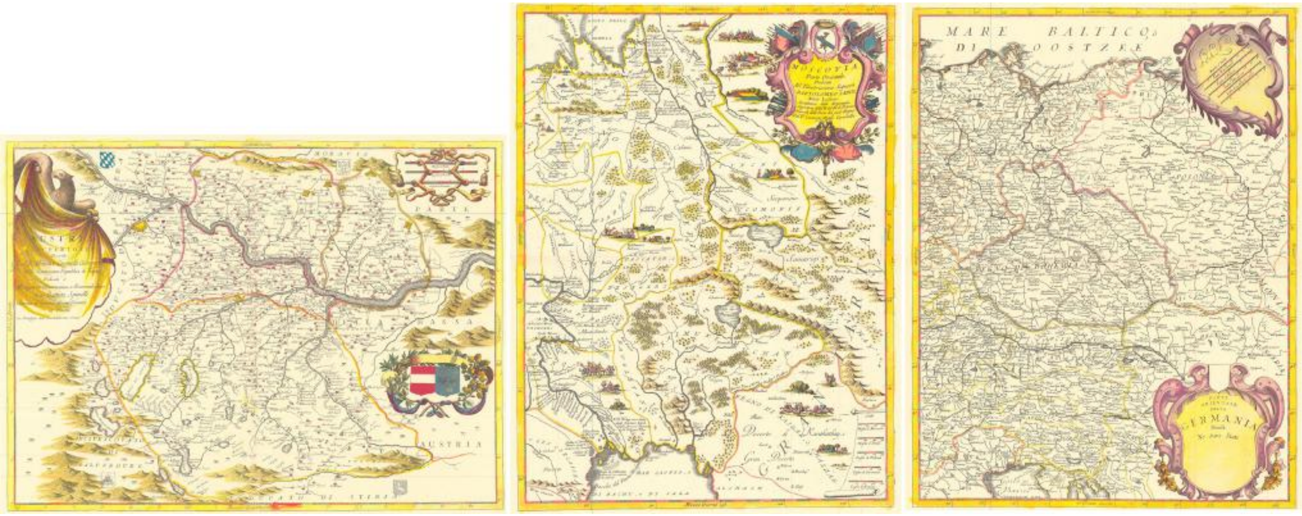
A digital approach to understand the projective system

In this case study, geometrical transformations are the analytical tools, not exactly to ectract features allowing spatial analysis and the description of land changes, as usually, but to understand the projection system adopted by Coronelli in some maps representing the central Europe, considering which was his knowledge on this topic. At the end of the XVII century it was known the description of some methods for the construction of maps based on projection systems borrowed from astronomy: Tolomeo's conic projections, the Mercator's one, the so-called Sanson's sinusoidal projection, used for the first time by Jean Cossin, the Werner's one…

The projective properties of historical maps, is a proper topic in the specialised literature on the map-history (Fiorini, 1881; Campbell, 1987; Tobler, 1966) in order to approach, understand, explain or approximate the projective nature of the cartographic background of these fascinating maps.

This field of analysis is also associated to the study of the deformational patterns of old maps when compared to the modern counterparts

3. The Coronelli's Atlante Veneto map *Parte Occidentale dell'Europa, descritta e dedicata dal P. Cosmografo Coronelli, all'Illustrissimo ed eccellentissimo signore Giovanni da Mula, Senatore Amplissimo nella Serenissima Repubblica di Venezia etc.* Scala: Miglia d'Italia 300 = mm. 66; Leghe di Francia 125 = mm. 66 [Venezia, 1690 circa] 460x600



4. The Coronelli's Corso Geografico maps: AUSTRIA SUPERIORE Descritta Dal P. Maestro Coronelli Cosmografo della Serenissima Repubblica di Venetia Dedicata a' Monsignore Illustrissimo, e Reverendissimo Gio. Battista Spinelli Chierico di Camera di sua Santità in Venetia Con Privilegio dell'Eccellentissimo Senato; *PARTE ORIENTALE DELLA GERMANIA Divisa ne suoi stati; MOSCOVIA Parte Occidentale Dedicata All' Illustrissimo Sig. BARTOLOMEO SARDI, Nobile Lucchese Accademico degli Argonauti, Segretario della M. del Re di Polonia, Generale delle Poste del med. Regno, dal P.M. Coronelli Lettore e Cosmografo Pubblico".*

(Koussoulakou et al., 1983; Badarioti, 1987; Mekenkamp, 1990; Livieratos et al., 1999; Balletti, 2006)

In the literature many scenarios have been reported covering a broad spectrum of hypotheses supported either by theoretical intuition or by analytical evidence. The main stream of approaches to the problem on the projective nature of maps use as models cylindrical, conic or azimuthal equidistant projections and their variants.

The scheme proposed here is referred to some maps of central Europe coming from the *Atlante Veneto* and from *Corso Geografico*, offering different scale of representation.

They are transformed in digital raster-form and alternative "best-fitting" processes are used in a unified processing and visual environment, which permits the on-line control of both the graphical and the numerical parameters of the fitting. The results allow some possible classifications and the study of deformations analysis (Boutoura and Livieratos, 1986) in linear, and rotational sense.

The projection-fitting approach in treating the projective properties of old maps can be simply summarized in: if we have a map (call *m'*) with unknown projective properties (i.e. the old map) we can find to which map (call *m*) of known projective properties it fits best.

This process usually requires:

- a set of properly distributed common points recognisable in both maps,
- a transformational machine/operator, which brings *m* and *m'* into a best fitting relation, and
- the choice of an evaluation criterion on which the final acceptance of the best fitting is based (transformation residuals).

In the first case of requirements, the common points are used as control points in the transformation process. Here, the projection coordinates of the control points of *m* are compared to the plane coordinates of the *m'* as obtained by digitalisation. The transformation normally used is the Helmert's model, which safely preserves the actual figure of *m'* (i.e. conformality) allowing only global alterations in the position of the reference system origin, in the rotation and in scale. The transformation translates the digital coordinates of *m'* into the projective coordinates of *m*. In Coronelli's case it was used the affine transformation too, just because it is one of the first order transformation given in Arc-

Map (the others are the translation, too simple, and the projective, not appropriate for the research). The affine transformation are particularly suitable to correct deformations due to scanner digitizing process.

Maps *m* and *m'* are digitised raster-wise and/or vector-wise and introduced into widely spread software environments (Balletti, 2000; Boutoura, 1999, 2000) which support graphics as well, (MatLab package, I/RAS C, ERMapper) or, as we did in this research, with ArcMap in combination with Didger® and Surfer®. This approach is a type of analysis in which the projection under investigation is postulated: it is an *a-priori* assignment of the projective properties.

The criterion for the acceptance of the fitting is usually the magnitude of the scalar standard error of the residuals. But it seems that it should be more realistic to use as criterion, the spatial distribution of the residuals, as can be seen in figure 6, since it gives a pattern of higher or lesser areas of discrepancies between *m'* and *m*.

In many cases, visualisation indicates the proper path to follow, in association to the computed residuals. A "trial and error" approach is sometimes the only realistic way to tackle the problem regulated by the researcher's expertise in map projections. This is easier today, using the efficient software for the raster treatment of the map file transformations both computationally and visually in the same digital environment. The advantage of working in a unique digital environment is focused mainly on the simultaneous visual control, which follows the computational fitting process. In this way the "trial and error" control is visually accepted or rejected leading to a convergence on the final fitting approximation.

It was applied an image-to-map "trial and error" procedure (Boutoura, 2000) due to which, a current map *m* in a proper projection is searched, in order to fit optimally the old one (*m'*).

The Coronelli's map was analytically compared with a current vectorial map of Europe, covering the same geographic area of the old one, originally in oblique conformal conical projection (Lambert's type) ad having the ED50 as Datutum.

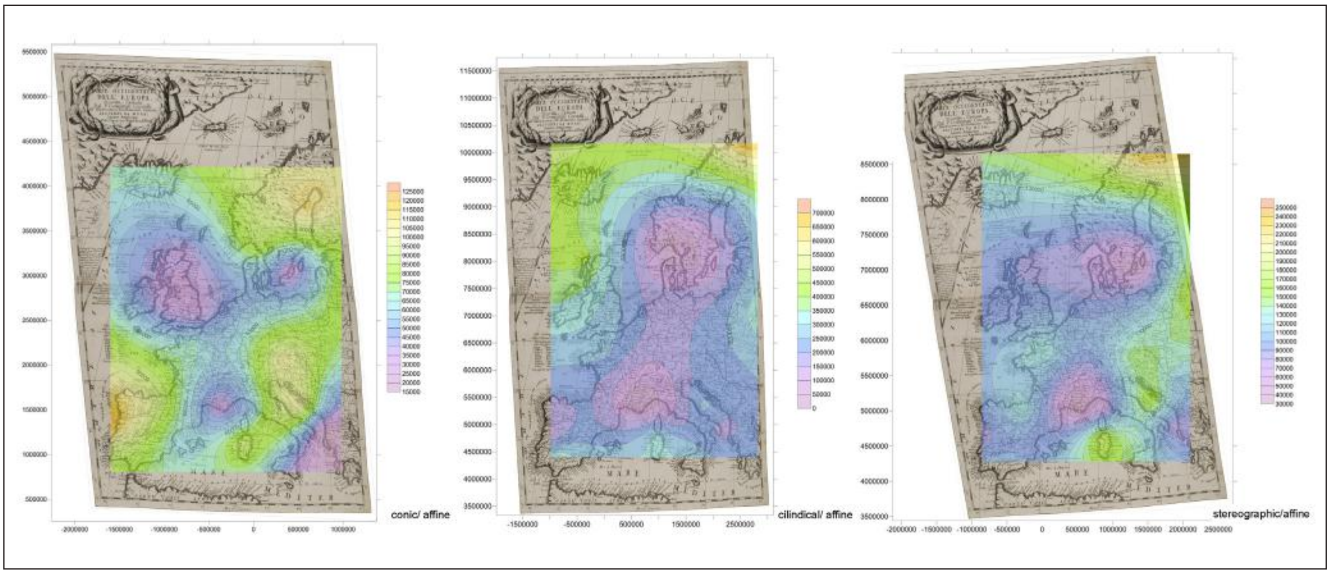
The European vectorial map was re-projected, by using ArcToolbox of ArcMap, into the Mercator's, the stereographic (only for the Corso Geografico's maps, representing a smaller area) and the sinusoidal projections, just considering which were the known systems.

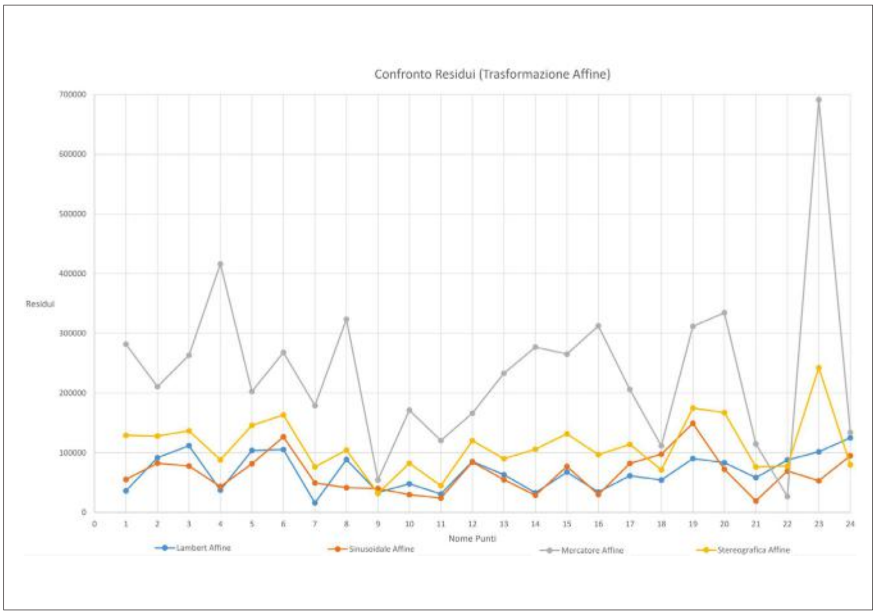
These projection models comply to certain hypotheses defended in the existing literature, namely to the obliquity of conic projections and cylindrical one which might be used - among other possible projections - by mapmakers or map-copyists.

The *m'* map of the *Atlante Veneto*, representing the west part of Europe, was georeferenced using about 30 control points and compared with all these projections via affine transformation in ArcMap (fig. 5) and the Helmert transformation, much more suitable for the best fitting, in Didger®.

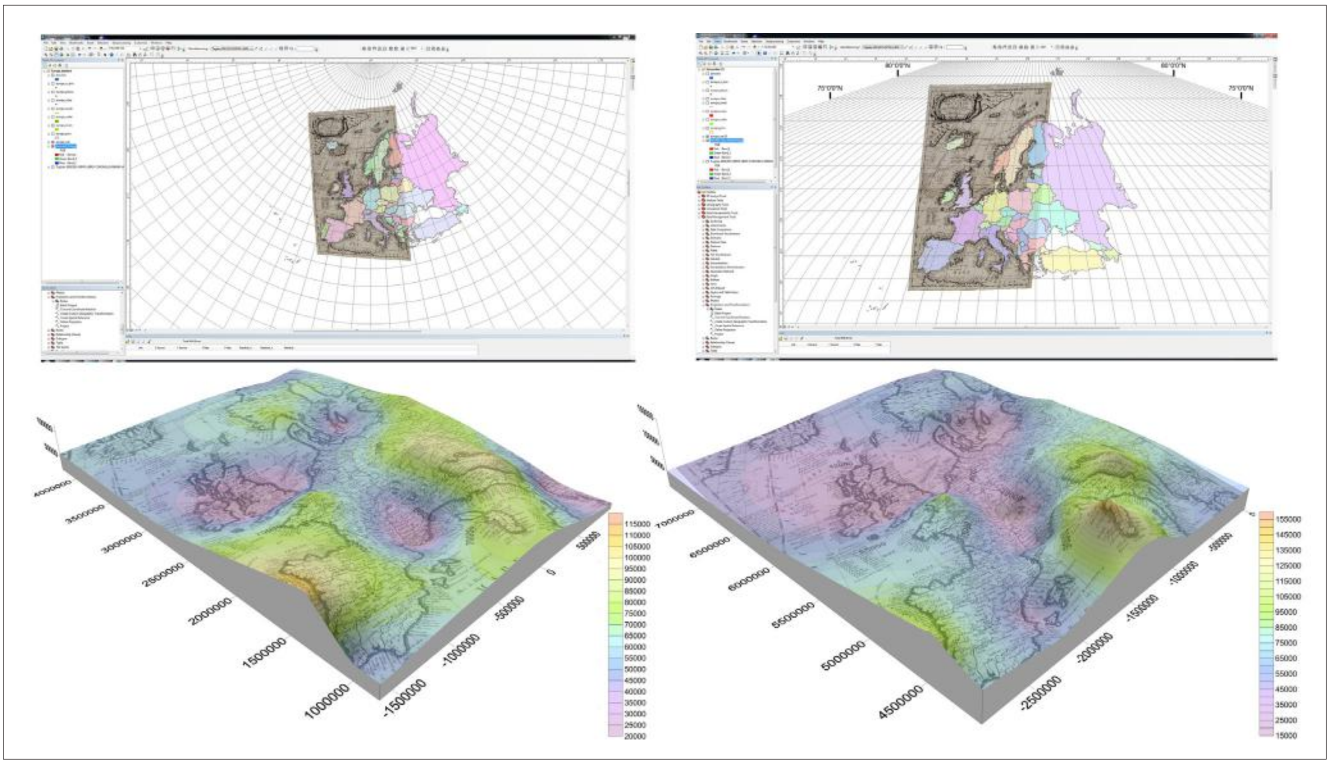
The fitting to the normal Mercator projection gave the worst results, both applyng affine or Helmert transformation, such as the stereographic as can be seen in residual spatial distribution (fig. 6-7)

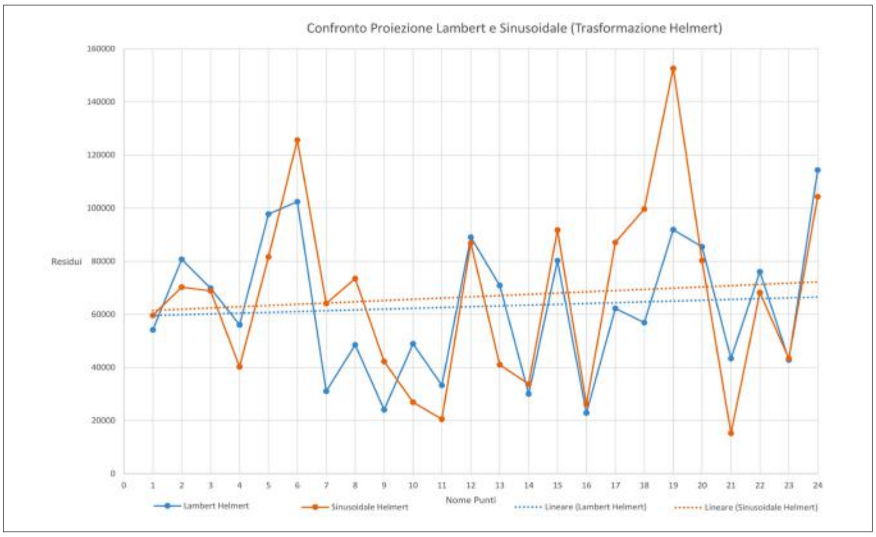
The choice of conformal conic projection gave more satisfactory results in the fitting process (as can bee seen in RMS comparison in fig. 8-9), both in configuration and in numbers, such as the sinusoidal pro-





5. The Coronelli's map re-projected in cilindrical, conic, stereographic projections.
6. Residual space distribution comparison.
7. Graphic of the residual trend comparison.





8. Conformal and sinusoidal projection residual distribution comparison.
9. Graphic of the conformal and sinusoidal residual trend comparison.

jection were RMS are lower: this last test can confirm the "affinity" with some maps of Nicolas Sanson (fig. 10).

Concluding remarks

As confirmed by these test on Coronelli's map, it is not indeed possible to draw a definite conclusion on the proper projection to be assigned to a map.

The various conclusions do not formulate a globally consistent theory on the matter because the spectrum of possible answers to the question varies on the base of different parameters, beginning from the total absence of a projective background to the support of specific map projections governing the geometric parameterisation of such maps. The outcome can be contradictory so it is not possible to arrive to a defi-

nite, consistent and generally accepted theory on the matter (Boutoura, Balletti, 2001). But it is possible to classify the "reliability" or to validate the conclusions obtained by each of the methods used in order to treat the problem, if this method is subject obeying some rigorous analytical rules: conclusions with no analytical foundation are highly valuable because they allow the understanding of the general or specific historic conditions, which could - or could not - influence the introduction of a certain projection in designing the maps. But from the experimental point of view, these conclusions are lacking the evaluation criteria, which are necessary in order to derive and control a possible solution to a mathematical problem (as the map-projection is) using analytical tools, which fit the mathematical problem.

This whole treatment has to be seen as a contribution in the field of analysis of old maps giving new impulses thanks to the new integrated digital processing technologies, which fit the nature of the problem.

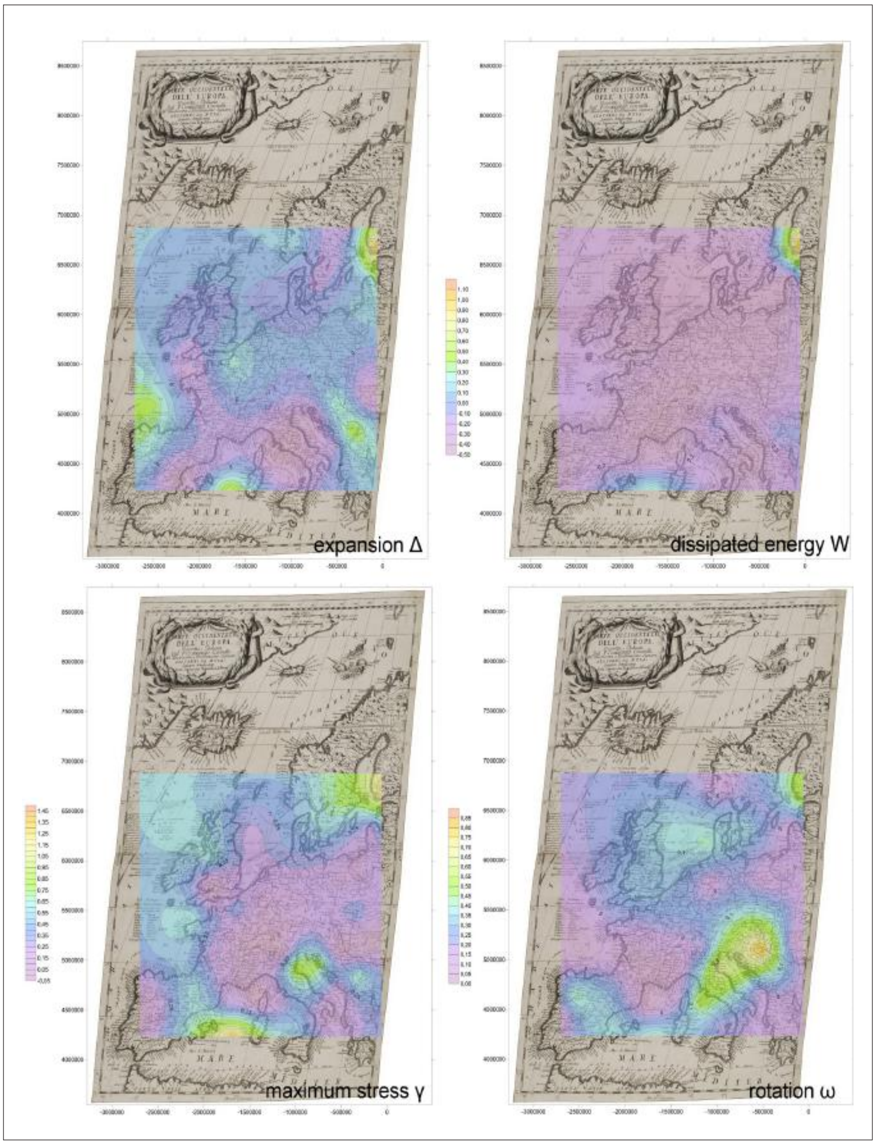
In the last years, thanks to the new digital tools, properly designed for the analysis and transformation of

10. Overlapping of Coronelli and Sanson maps.

maps in raster-form, the study of the projective background of the historic maps becomes a friendly, easy to handle and fast process. Moreover, the new raster-wise digital approaches are combined and integrated with relevant graphics offering for this purpose, a unique processing and visual control environment. This integration allows alternative testing, becoming, thus, the whole issue of old maps analysis indeed attractive and highly productive. It gives a new impulse and insight in this field of studies, showing the great potentiality of modern digital tools and common processing environments with visualisation, which indeed facilitate the testing of alternative hypotheses and theories.

Concluding: the purposed "trial and error" approach, lead to interesting solutions requiring on the other hand systematic tests and intuition in selecting variants of known projections which fit best the old maps.

Further research should be done in evaluating and then integrating the methods combining the best fitting with deformation analysis (fig. 11) testing systematically a great number of old maps in order to construct consistent interpretation models on the projective properties of old maps.



11. Strain analysis to describe the behaviour of a map compared with another one: the elasticity theory can provide fundamental information about the geometric differences between two representations of the same object. Introducing invariant quantities and applying an analytic process, it is possible to obtain a more objective and quantitative description of a map's geometrical distortion compared to the other one.