

**POLITECNICO DI MILANO**

**Faculty of Environmental and Civil engineering**



**POLO TERRITORIALE DI COMO**

**Master of Science in Environmental and Geomatic Engineering**

**A SIMPLE WEBGIS FOR VIEWING THE EVOLUTION OF THE  
CITY OF COMO**

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# 1. Contents

<b>2. Introduction .....</b>	<b>3</b>
<b>3. Short history of Como .....</b>	<b>4</b>
<b>4. Historical maps of Como used for the project .....</b>	<b>6</b>
4.1. Topographic map of Como – the end of XVII century .....	7
4.2. Theresian map – 1722 .....	10
4.2.1. Theresian cadaster in Italy .....	10
4.2.2. Teresian map of Como from 1722.....	16
4.2.3. Map of perishes (Teresian map of Como from 1722) .....	29
4.3. Maps from the series of Lombardo –Veneto cadaster (1858) .....	30
4.3.1. Lombardo Veneto cadaster .....	30
4.3.2. Lombardo Veneto cadaster map of City of Como from 1858 .....	34
4.3.3. Lombardo Veneto cadaster map of Como Borghi from 1861 .....	41
4.3.4. Update of the Lombardo Veneto map of the City of Como (1873).....	48
4.3.5. Update of the Lombardo Veneto map of the Como Borghi (1900-1902) .....	54
<b>5. Georeferencing of the historical maps of Como.....</b>	<b>61</b>
5.1. Basics of georeferencing .....	61
5.2. Process of georeferencing of historical maps .....	62
5.2.1. Collecting homologous points in Quantum GIS.....	62
5.2.2. Finding an optimal polynomial order of the transformation function .....	66
5.2.3. Geometric correction of images (OrthoEngine) .....	67
<b>6. WebGIS .....</b>	<b>67</b>
6.1. Web GIS Architectures.....	69
6.2. Open source Web Server used in the Project: GeoServer .....	69
6.3. Open source JavaScript library used in the project: OpenLayers.....	70
6.4. Implementation of a WebGIS.....	71
6.4.1. Publishing data on GeoServer .....	71
6.4.2. Developing a simple WebGIS with use of Open Layers .....	74
<b>7. Conclusion .....</b>	<b>79</b>
<b>8. References .....</b>	<b>80</b>
<b>Anex 1: MatlabScript for determining the optimal polynomial order .....</b>	<b>82</b>
<b>Anex 2: Results of determination of the polynomial order for transformation (RMSE).....</b>	<b>121</b>
<b>Anex 3: Georeferenced Historical Maps .....</b>	<b>147</b>
<b>Anex 4: WebGIS HTML file.....</b>	<b>153</b>

## 2. Introduction

Historical cartography is a significant part of cultural heritage and a valuable source of information for a wide range of applications, such as historical and territorial research, architecture, planning, etc. Recent developments in digital technologies have opened new possibilities for the exploitation of cartographic heritage. The usage of historical maps in such applications gained a new dimension thanks to the latest advancements in the fields of digital technologies and Geographic Information Systems (GIS), which allowed to study ancient cartography no longer as pure archival documentation, but as real geographic information. In particular, georeferencing converts old maps from pure archival documents to real geographic data.

This project dealt with the process of georeferencing the historic maps of the municipality of Como, which were given to the Politecnico di Milano by the State Archive of Como. These maps represent the areas of Como walled city at the scale 1:1000 and Como Borghi at the scale 1:2000 and belong to different cadastral series: the Theresian Cadastre (XVIII century), the Lombardo-Veneto Cadastre (mid-XIX century) with its updates and the New Lands Cadastre (1905). Additionally, there is also, the oldest map of this area, the map which does not have cadastral meaning, but it is purely topographic one: The topographic map of Como from the XVII century.

The georeferenced historical maps are then inserted into WebGIS system, developed within the thesis. Due to the nature of the maps, which are divided in multiple adjacent cadastral sheets, a preliminary mosaicking of these sheets and cutting of the borders was performed. Using the digital cartographic information of Como municipality from 2006, provided by the Municipality of Como, Ground Control Points and Check Points were collected on these historical maps. Then, optimal polynomial transformation was chosen to georeference each of the maps. All the historical maps can then be visualized in the WebGIS, compared one with another and with the current cartographic status, because now belonging to the same georeferenced framework.

To sum up, the thesis consists of 4 parts. First it reviews the existing literature regarding the short history of Como. Then, the historical maps used in this project were presented, with the wide explanation of their properties and with the particular emphasis of the theory about the cadastral series they belong. Then, the process of Georeferencing is explained, together with the all steps: collecting control points, choosing the optimal polynomial order for transformation, and geometrical correction. Finally, the WebGIS implementation is explained, through the mentions of a GeoServer and the Open Layers as the main components of the WebGIS development.

### 3. Short history of Como

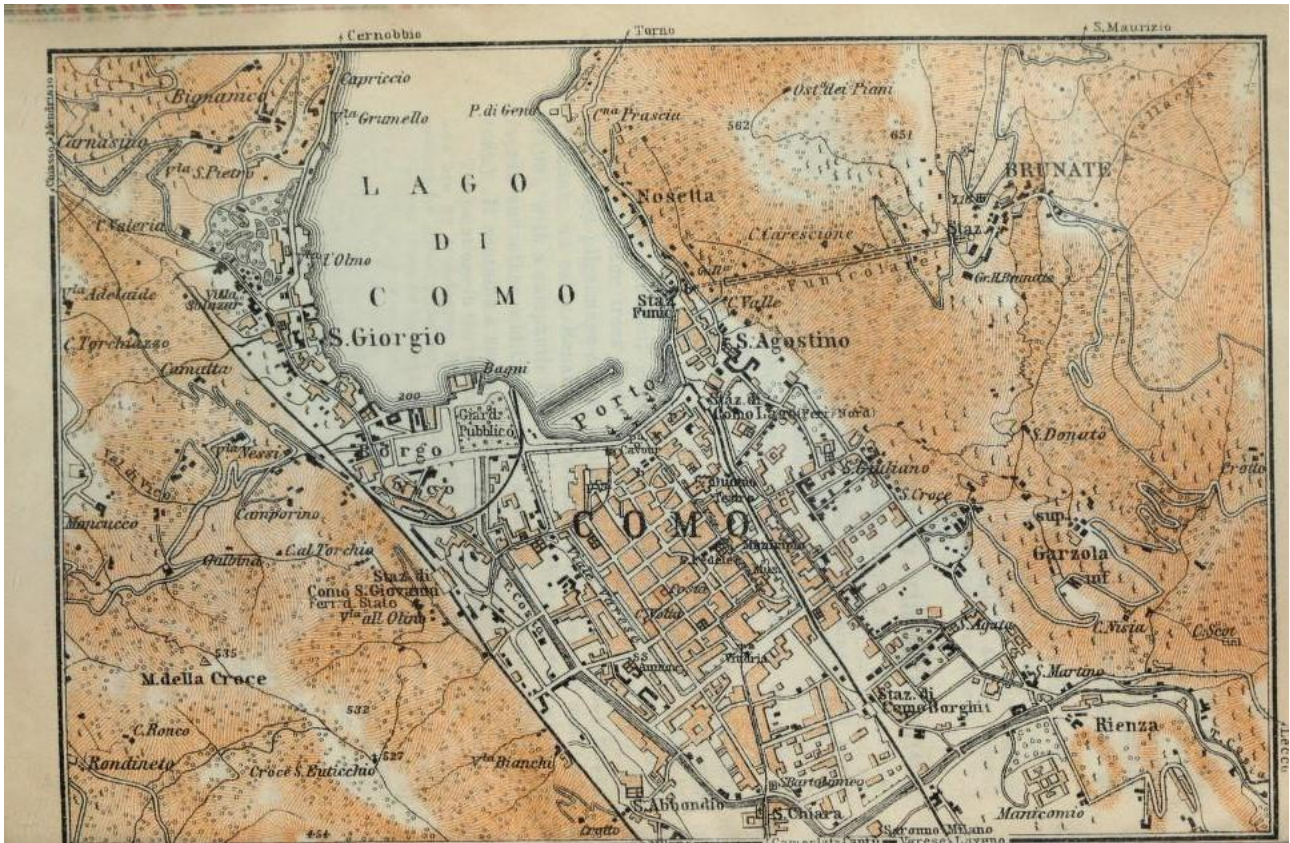


Fig.3.1 Map of Como, 1913. Source: "Northern Italy, handbook for travelers", K. Baedeker

**Como**, Latin *Comum*, city, Lombardia regione (region), northern Italy, rimmed by mountains at the extreme southwest end of Lake Como, the ancient *Lacus Larius*, is north of Milan. As the ancient *Comum*, perhaps of Gallic origin, it was conquered by the Romans in 196 BC and became a Roman colony under Julius Caesar. Como is situated in a strategic position at the end of the Piedmont road and at the beginning of the road up to the mountain passes. This resulted in the city being an important boundary-marker, as well as a rich market place and an important base for organizing communications with the north. The development of the town has therefore been strongly influenced by its strategic importance, although it is still easy enough to make out the town's basic Roman layout.

The area surrounding Como has been inhabited since prehistoric times. Necropolis and remains of Bronze Age settlements belonging to the Golasecca civilization have been found in Brunate, Caviglio, S.Fermo, Cà Grande and Villa Giovia. The territory around Como was developed into village settlements from about 5 BC and Celtic fortifications in the area date back to between 5 and 4 BC. *Comum* itself started life as a Roman outpost in 59 AD and by 89 AD had become a colony. The Roman Consul, Marco Claudio Marcello, conquered the surrounding Celtic tribes in 196 AD. After defeating the Celts, the Romans began to build the town on the edge of the lake. The town centre was built according to a strict "castrense" system which is still noticeable today. This was surrounded by a town wall, much of which can also still be seen. (Archaeological remains of the Roman walls). The town was built during the Imperial period and was therefore crucially important as a military base on the mountain border and as a communication center between imperial headquarters in Milan and the regions of the north.



The town was subsequently destroyed by the Huns and the Goths and conquered in 569 by the Lombards who incorporated into Milanese territory. In the eleventh century, the town began a long struggle for its independence against Milan and, after more than ten years of war, the territory of Como was defeated in 1127. Como was destroyed by the Milanese for having sided with the emperor Frederick I Barbarossa in his conflict with the Lombard League (an alliance of northern Italian towns). Como made peace with Milan in 1183. However Como quickly renewed its fight, rebuilding new town walls outside the old Roman wall. They intensified their trade and industry. These are the centuries which produced some of the region's most beautiful buildings like S. Fedele, the Basilica di S. Abbondio and S. Carpoforo.

After a long power struggle between the Vitani, the Guelphs, the Rusca and the Ghibellines in 1335, the town passed into the hands of the Visconti (who built their stronghold in the north-western corner of the town walls). The Visconti remained in power until the death of Gian Galeazzo in 1402. By 1451, Como had once again been annexed by Milan, this time by a Duke Francesco Sforza, and it has followed the ups and downs of the Lombard capital ever since. During that period its silk industry and wool trade played an important role in the Milanese economy.

In 1521 the town fell after a hard siege and came under Spanish rule along with the rest of Milan's territory. Spanish rule resulted in a sharp demographic decline in the town. Heavy Spanish fiscal duties resulted in economic decay and this was compounded by a plague which struck the city. In 1630, the town came under Austrian rule which brought about a strong development of silk and artisanal production. During the period of French rule between 1796 and 1814, Como became the capital of the Lario department. Tourism in the area began to flourish with the fashion for neoclassicism and the banks of the lake were soon full of parks and villas belonging to the aristocracy of Como and Milan.

Como rebelled against the Austrian government in 1848 and set up its own provisional government. The town was liberated by Garibaldi on 27th May 1859 and became part of Piedmont. In the second half of the nineteenth century the town's layout was modernised and the port was filled in, creating the Piazza Cavour and Via Plinio which led from it up to the Cathedral. This intensified the town's development. The funicular up to Brunate and connection with the Milan Northern Railways were built in 1893, along with the growth in traffic on the lake itself, resulted in the growth in Como's tourist industry.

There was intense architectural and figurative creativity between the wars which was linked to the rationalist movement. In 1934, CM8, a group of rationalist architects, made a proposal for a new town planning scheme. This was adopted several years later but only in conjunction with the fascist regime's noxious criteria which demolished much of the town's old center.

Since the war, Como has been transformed by unexpected urban development. This has resulted in the town filling the valley entrance and absorbing many of the surrounding villages, thus creating the Como conurbation.

Como is now the center of the silk industry in Italy, and according to the census of 1901 had a population of 38,902. It has been the birthplace of many famous men, among them the elder and the younger Pliny, the historian Paulus Jovius, Pope Innocent XI, and the physicist Volta. In 2010 population of Como is estimated to be 84,876.



*Fig.3.2* Como, 2014. Source: Google Earth: Digital Globe image, 2014

## 4. Historical maps of Como used for the project

In this chapter, the historical maps of Como from the eighteenth and nineteenth centuries are presented and described in detail. Outside the historical context and content of these documents, particular attention is paid to the characteristics of the digitized maps, real raw data from which it is possible to begin each of the next stages of processing. The geometric processing of the maps, widely analyzed in the next chapter will therefore be the tool to transform digital images of maps in geo-referenced historical maps, which in turn represent the geographic data input for the development of the WebGIS.

A number of illustrative maps of Como were specially selected to belong to different historical periods. One of the maps considered, moreover, which is not of the cadastral nature, provides an interesting image of the same territory, but in a different point in time, for purposes different from those that are purely taxation ones. With the exception of just that map, all historical cadastral maps used in this project were provided in digital format by the State Archives of Como. The historical series to which the maps belong are those of the Teresian cadaster, the Lombardo-Veneto cadaster and its updates and, in addition, there are maps of the New Land Cadastre.

Since 2001 maps of the State are not, unless authorized by the responsible for studies, consulted in the original. They are made available to interested parties in the digitized version, reproduced in black and white, in PDF format. Such reproduction, made in 1995, today is totally unsatisfactory. The availability of digitized copies of historical maps is now a growing need, in line with the important developments of IT and GIS tools for visualization, analysis and the preparation of maps, as well as the possibility of their online publication. The following chapter describes in detail the digital maps used, taken from different historical series.

Overall, this chapter provides an introductory historical overview, and gives an opportunity for understanding the data used in the project, based on the events that have marked the cadastral map production of the city of Como. The focus is, in particular, on the extraordinary developments of the eighteenth and nineteenth centuries in which, from the great Teresian cadastre time, and even more strongly with the next Lombardo\_veneto cadaster time, cartography becomes a fundamental tool in the strict control of the territory. For both series then it will be discussed about the cadastral purposes, methods and its content.

#### 4.1. Topographic map of Como – the end of XVII century

The oldest map presented in this work is the one that is not preserved in the Archivio di Stato di Como<sup>1</sup> and has no cadastral value: it is a topographic map of the Como, derived from the private archive of a family Giovio, published in 2005 by the Società Archeologica Comense<sup>2</sup>. The original design of the map was missing for a few decades on antiques market. However, in the Biblioteca Civica di Como<sup>3</sup>, an aged photocopy is retained and it consists of about a dozen sheets, which the architect Mario Di Salvo has patiently redesigned, assembled and published in the book of Matthew Gianoncelli: *Como e la sua convalle. Indagine storica sull'origine ed evoluzione urbanistica dei Borghi e Corpi Santi di Como*<sup>4</sup>, New Press Como, 1975.

Map was used by Giambattista Giovio, for the writing of a report that had been requested by the municipality, on August 17, 1795 and which had as its object the worrying situation of torrent Cosia. For the preparation of the report, Giovio drew the studies carried out by the Prof. Francis Luini (astronomer, mathematician and physicist) in 1768 and subsequent years, and by Eng. John Franco Carminati de Brambilla in 1785 (the most well-known professionals of the time).

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<sup>1</sup> State archives of Como

<sup>2</sup> Archaeological society comense

<sup>3</sup> Library of Como

<sup>4</sup> *Como and its valley. Historical Investigation on the origin and evolution of Como Borghi and Corpi Santi*

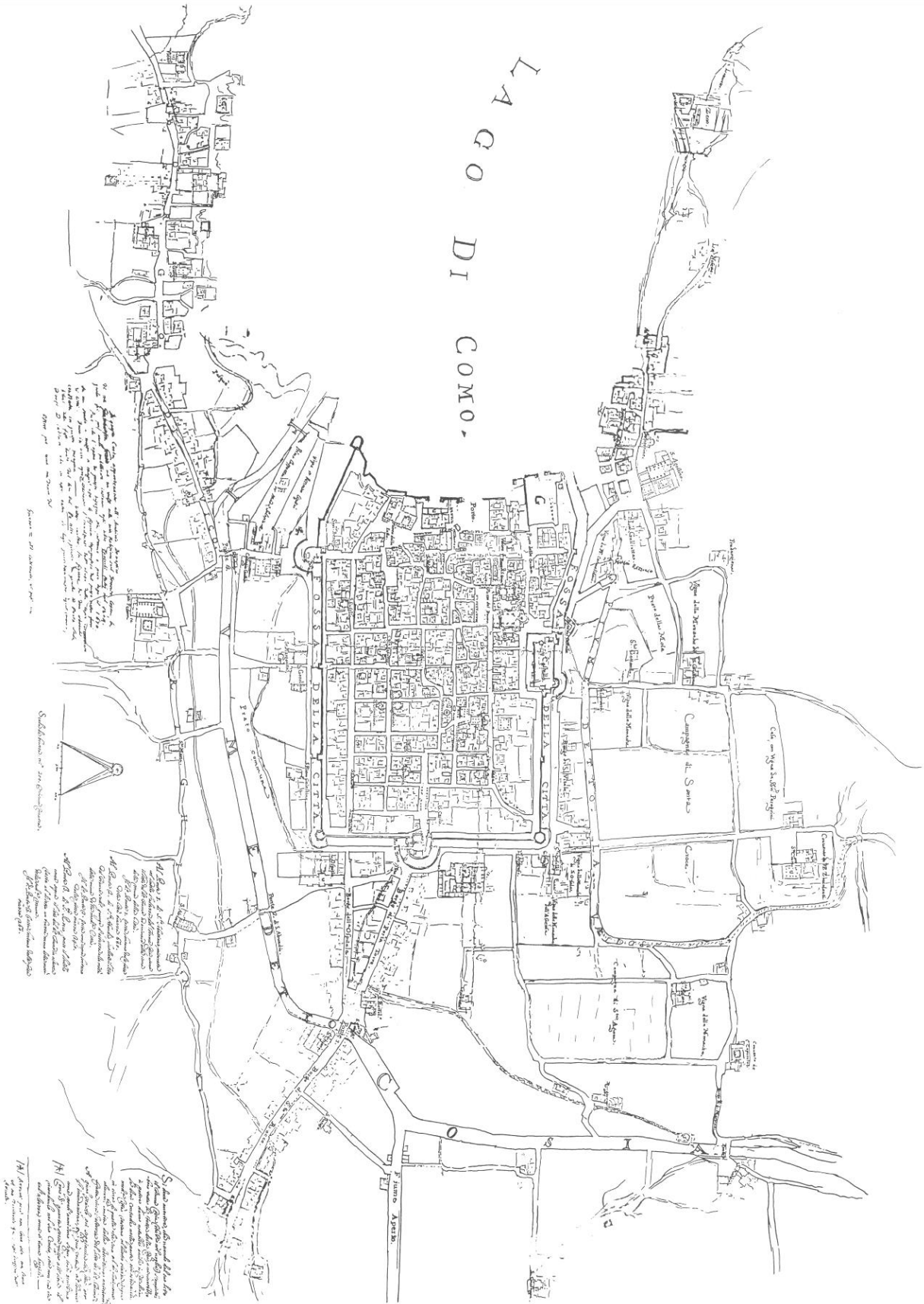


Fig.4.1. Topographic map of Como from the end of XVII century. Source: Società Archeologica Comense

The report was delivered on April 27, 1796. This was published in the form of study, in a volume of the same Giambattista Giovio, published in Como for the typography of Antonio Ostinelli in 1804, titled *Alcuni opuscoli Patrij*. The digitized version of the topographical map of the Giovio family is shown in the Figure 4.1 on the previous page.

Before analyzing the technical characteristics of the digital map, it is interesting to dwell on some particular elements contained in the map (Fig. 4.1.). It is evident that firstly, in the vicinity of the bottom edge, three notes appear, for which there are transcribed texts available. The note placed to the left was added by Giambattista Giovio, which emphasizes the city as it was changed between 1670 and his time. Here, the particular attention is given to the situation of the outlets of the pit around the town, to the lake, which appeared in the map totally free and tributary to the lake, while in his time, had turned to lawn with a stream of water in its center. On the same note, in addition, he remarked in a heavily negative tone, the privatization of the two major ports of the city, known as the *Darsena del Governatore e Darsena del Vescovo*, which had been sold to the family Peverelli.

The other two notations, also written by hand, but with the different spelling from that of Giovio, refer to the height of the bed of torrent Cosia and the risk of a spill from its riverbed, which would have caused the flooding of villages, the pit and, possibly, some districts of the city.

The bottom edge of the map also shows an indication of the scale in which it is drawn: as shown in Figure 4.2, it is *Scala de brazza No. 200. Misura Comasca*. This means, the ancient unit of measurement of the arm, corresponding to 0.594 m was used. It should be noted that, in this as in subsequent maps, the numerical quantity denoted in the indication of the scale does not present the real scale factor applied, but represents a simple extension of the bar scale shown. The actual scale of the chart you can instead derive converting cm in the amount of 200 arms ( $200 * 59.4 \text{ cm} = 11880 \text{ cm}$ ) and dividing that number by the length in inches of the bar of scale, measured with a simple ruler on the original map. Having in mind that this value is approximately 3.9 - 4.0 cm, we obtain that the map scale is approximately 1:3000.

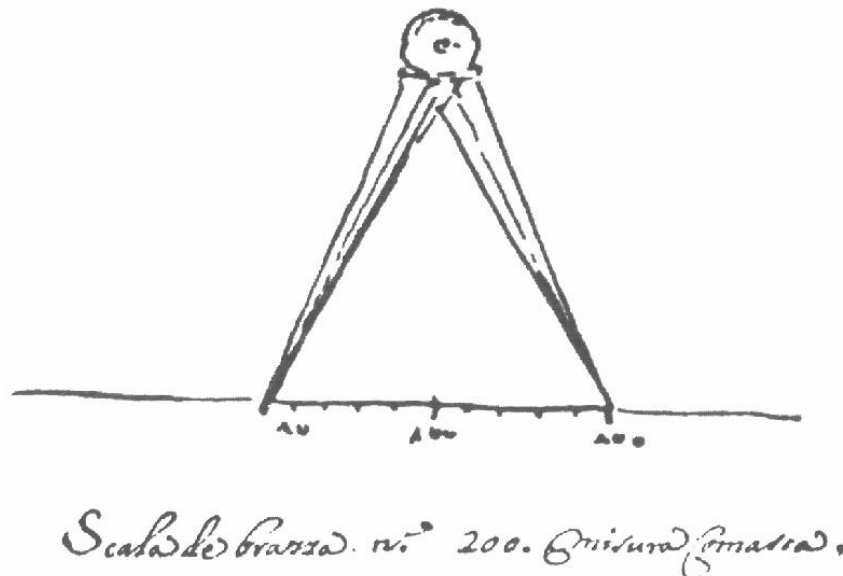


Fig.4.2. Indications of the scale. Source: Topographic map of Como, XVII century



In the context of the local maps, the map of the Giovio family is of considerable importance: the good precision with which the valley is outlined, the highlight of the network of the roads and buildings (especially outside the walls) and the representation of the torrential major and minor system. In addition, the names of places were added for the palaces, churches and convents. It must therefore be taken into account that although it has been noticed a certain similarity, composition and structure, with the next map, map from the Theresian Cadaster (rear of 40 years), compared to it, there is a profound difference, not only and not so much in the instrumentation and mode of relief, but in the final purpose of the document and the its use.

The perimeter of the buildings is the result of a real design without aspiration to a rigorous and precise geometric fidelity, as evidenced by the many curved edges and often rounded corners. The map has however exceptional value, as said, for the accurate representation of the road network and waters of Como at the end of the seventeenth century. This justifies its use, for example, by the Giovio for its report on the torrent Cosia.

The image of the topographical map of Como, already shown in Figure 4.1, derived from a digitization process implemented by the Municipality of Como in June of 2009, can be traced back to the tool used. The size of the paper map, in cm, is 100 x 70, while the extension in pixels of the digital version is 23996 x 19080. Using these data to derive the geometric resolution, or similarly, the sampling density expressed in dpi (dots per inch, which is the number of pixels per inch, equal to 2.54 cm), it is obtained in the horizontal and vertical directions, the values of 609 and 692 dpi respectively. In fact, the resolution is the same in both directions (if it wasn't, the digitization would introduce a deformation of a map) and is equal to 600 dpi. This value is readable by the use of a professional software for image processing. In particular, in this project, *Adobe Photoshop* has been used, in which it is also possible to read the values of the digitized document, expressed in cm. Its extension is 101.58 x 80.70 cm, which shows that incorrect values of resolution previously obtained are due to the fact that, in reality, the process of digitization has also involved a edge zone surrounding the paper map. The image has been provided in TIFF format and has a size of 436 MB of disk. As it is apparent from the Figure 4.1., the image is in greyscale (despite the Giovio, in his note, references to an original blue color when writing about the pit). The radiometric resolution, defined as the number of bits used for the storage of shades of gray for each pixel, is equal to 8, which is corresponding to the level of intensity of each pixel going from 0 to 255.

## 4.2. Theresian map – 1722

### 4.2.1. Theresian cadaster in Italy

The Eighteenth century in Italy constitutes by definition of registers and there, more than elsewhere, the debate on the Land Registry has become one of the key issues to be considered in the society. Different parts of peninsula had different accomplishments by which the economic and social reforms in the time can be seen and also the scientific advances with respect to techniques applied to cartography. Since the Middle Ages, the registers have been regularly updated and recognized by the central authority as essential tools for every mode of tax. These documents, however, appear only rarely linked to a good graphic representation.

But the idea of being able to carry out general reconnaissance campaigns, with the execution of measures and the resulting graphic outcomes (which, however, were attempted and partially carried out in more occasions) was prevented by the persistent sensitivity to the subject of taxation and the uncertain definition of the rights of the central government on private property. Just on these issues hinges the eighteenth-century debate on the cadaster. The understanding of this revolution can not be understood, of course, without the analysis of the history events on which it is based, and without knowing the influence of the events that bind the town Como, Milan and Lombardy in general.

With the death of Charles II, King of Spain, which took place in 1700, the War of the Spanish Succession began, which established the decline of the Iberian domination, in force since the beginning of the sixteenth century, in the Lombardy region. The situation of the State of Milan was that the new ruler was having to deal with all complaints regarding the problems matured in Spanish age: a process of urbanization was completely blocked, a pronounced demographic regression and major difficulties of production activities existed. The agricultural crisis and industrial also adds to the monetary and public finance disorder, which was marked by huge inequalities regarding tax.

The origin of the malaise in the field of taxation (for which already under the Spanish domination there were continuous complaints to the central power from Como) was in the old uncertain tax system of Charles V, in force since 1595. This system generated significant differences from place to place. Also, the presence of measurement errors, due to the imperfection of the techniques of the time, added to the inequalities, since the value of land was obtained solely from an average sales price, taken from a very small number of contracts. Finally, this went to failure, since many mountainous areas not easily accessible had been completely ignored in the surveys.

In this context of uncertainty and discontent, inherited from the previous Spanish government, politics, Charles VI was sensitive to the need for action to stimulate economic development, as evidenced by some of the measures introduced between 1713 and 1720 to support domestic production and domestic manufactures. But the idea of a reform of the tax system soon encountered hostility from widespread part of the clergy, the old owners and commercial speculators and of the privileged Milanese classes, the quite contrary to the principle of equalization and fearful of an overall increase of loads. Facing a long series of controversies, challenges and waste, in 1718 Charles VI gives a mandate to start the cadastral surveys.

Technical staff for cadastral surveys were recruited not only in the State of Milan and in the neighboring countries, but also in several European countries such as Austria, France and Ireland. The activities were based on some fundamental changes with respect to the previous one. The distinctive look is represented by the geometric partition of land, in which the central authority extends its control to the level of a single particle of good, identifying characteristics, income and the corresponding capital. The calculation of the ability of each subject (Individual or organization) enshrines the equality of condition among all places, land and buildings, to assess and tax across the state according to strict criteria, independent of who owns them, and where they are located. Impelled by this new logic of equality and stability, despite having to continually deal with opposition and attempts to cover-up the council realizes, between 1721 and 1723, the original maps of each community (including that of Como), in the scale of 1:2000 were produced.

These maps were manageable, because the use of color and design allowed the representation with uniform symbology for the different qualities of the crop. Few years after they were made, from the copy of those maps, maps of the small municipalities in the scale 1:8000 were

published in 1726 with the assignment of a value to each part of a land, calculated according to the actual income.

Then, after the War of the Polish Succession (1733-1738), peace returned after the Treaty of Vienna (1738), which confirmed the membership of the State of Milan to the house of Austria. Another years of conflict emerged (1740-1748), known as the War of the Austrian Succession for which the final peace was achieved by Maria Teresa (daughter of Charles VI) , but for that, Milan State was left with about half of the territory which it had at the beginning of the century.

A new Council was appointed in 1749. For the operations regarding land, there were two fundamental problems addressed: measurement and estimation of buildings that had not been done before, and the map update taking into account the changes that occurred in the meantime. This operation was especially necessary for the areas adjacent to rivers, subject to increases of erosion depending on the changes in the regime of water courses. Even the already measured buildings were measured to identify the changes that have occurred at the time, and to make more precise and detailed survey, because previously, in most cases, the built-up areas were represented as a single block, without distinguishing the buildings adjacent to one another. Maps made for this purpose, having the same scale 1:2000, are known as "maps of the second station": the first council, in fact, was occupied only of land , distinguishing them from all other goods. Here, the buildings are then detected and estimated with methodology similar to that of the land, and the numbers have been assigned to them. The tables of the new estimate (dated posteriorly 1755 for the province of Como), containing the list of goods of first and second station, their the data (size, owner, quality of culture) and their estimated value were obtained. Finally the update operations and rectification were finished, while having the tenancy to deal with the deaf and continuing opposition of the privileged classes, and the Cadastre, called Teresian by the name of the sovereign, is activated from the January 1, 1760.

The benefits of the Teresian cadastre can be extended, from the agriculture, to the other sectors such as industry, economy and in particular the trade, as well as a slight increase in population. The maps and material results of measurements aimed to the work of equalization tax. The value of legal document was "exact", and therefore considered to be fair and impartial. The map acquires a central and absolutely new role, around which the debate was born on the cadaster. This cartographic experience in Milan marks anyway strong culture reform in the eighteenth century, creating a high moment of confrontation in the rationalization of knowledge and land management.

Practical arrangements for the implementation and measurement of the Teresian maps respond with general idea of the operation fullness and uniformity of procedures. The instrument is adopted to measure the plane table, the invention of the German mathematician and astronomer Johannes Praetorius (1537-1616) from which it takes its name. The first evidence of knowledge of the instrument in Italy dates back to the early seventeenth century, but it is only through the court mathematician John James Marinoni (1676-1755) that the tablet Praetorian becomes the basis of the extraordinary cartographic operation initiated by Charles VI.

The principle of operation is the simple geometrical theorem according to which, if a triangle in which is known the length of one side and the amplitude of two angles, one is able to evaluate the extent of all elements of the same triangle. To apply this theorem to the geometry practice, therefore, it was needed to know a certain distance (measurable side of the triangle) and to have a circle graduated for the measurement of the angles adjacent to it. The instrument is essentially a tablet mounted on a tripod, called mirrors, and equipped with a row of targets (or a

telescope) said dioptra. The principle of use to derive the map is very simple and is further clarified by the following Figure 4.3. The actual distance between two points A and B, are shown on the sheet as a segment on the chosen scale. The tablet is then placed in the point A, in a perfectly horizontal position and orienting the sheet so that the path segment above coincides with the direction AB. It then uses the pin for sighting natural signals (steeple, trees, etc.) or artificial (poles) placed in the points you want to indicate in the map (for example, C, D and E) and plotting the corresponding directions on the sheet  $c_A$ ,  $d_A$  and  $e_A$ . Subsequently, the instrument is placed in B, the sheet is oriented along AB with the same procedure and are drawn, the same signals sighting places in C, D and E, directions  $c_B$ ,  $d_B$  and  $e_B$ . The points in the intersection of the straight lines are the corresponding location on the map, in fixed scale of the objects considered: the point C, for example, is uniquely identified by intersecting the  $c_A$  directions, plotted sighting C from A and  $c_B$ , plotted sighting C from B. What is presented is, of course, only an elementary example, since in practice, it is not used two, but a series of points of known coordinates.

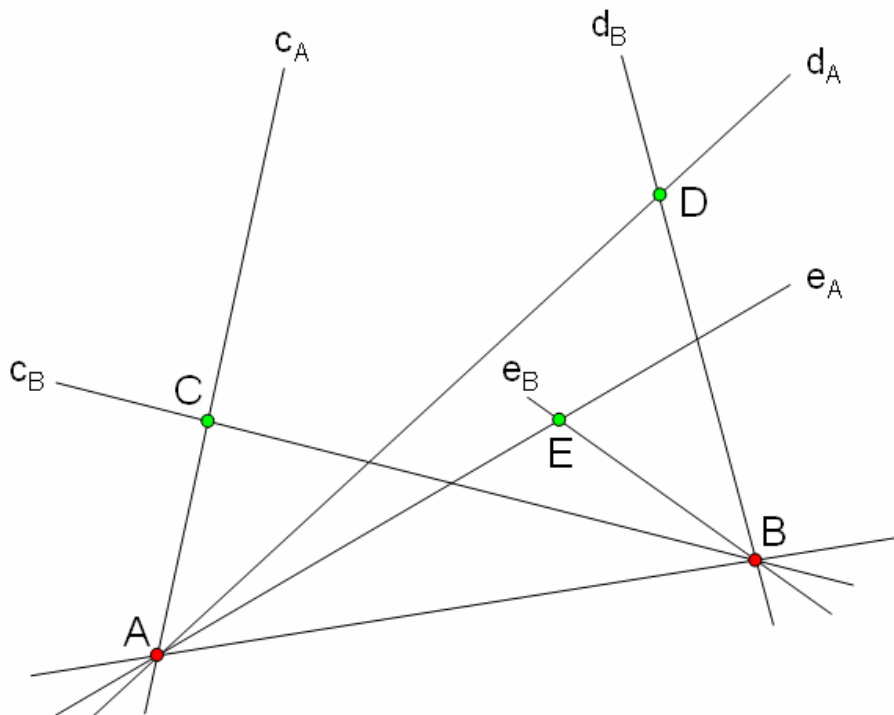


Fig.4.3. Use of the pretorian table for determining the points C, D and E on the map, by starting from A and B. Source: *La misura generale dello Stato – Storia e attualità del Catasto di Maria Teresa d’Austria nel territorio di Como*, New Press Como 1980, p.32.

The main advantage resulting from the use of the plane table, and that justifies the massive success, is linked to the possibility to realize it with the desired map directly on the field. It is not surprising, however, that, in line with the opposition and closures that accompany the entire cadastral reform, the proposal of Marinoni usage plane table will be accepted only at the end of a long controversy. The defense of traditionalism against the proposed professional development by Marinoni necessitates some experiments to measure in order to settle the dispute. In such experiments in May-June 1720 some of the most

influential architects and engineers from Milan did the field work to measure land with the traditional method, while the experts of the Council, mostly foreigners, performed surveys with the help of the tablet. Checking in all circumstances that the use of the tablet allows to reduce the time of the measurement, sometimes up to halve, the Government obtains sufficient arguments to put to rest any bad mood and, in August of same year, 1720, a final decision was taken, adopting the method proposed by Marinoni.

The use of the plane table was however not the only innovation that was suggested by this mathematician. His thinking was in fact oriented to the realization of measurement according to the principles of generality and uniformity expressed by Charles VI. In addition to the use of tablet, a strong emphasis is placed on the unification of the unit of measure, with the choice of the Milan trebuchet, equal to 2.61111 m, for distances, and the Milan pole, corresponding to 654.517962 m<sup>2</sup> for the area. The mathematician defined also the adoption of a single scale (equal to 1:2000, for all maps), the use of chains for direct measurements (ie those in which you are physically comparing the length to be measured and a sample length of a known measurement) and the organization teams for measurements (distinguishing the roles of surveyor, assistant, chain guide, etc.).

Although maps from the Teresian Cadastre present for the first time characteristics of uniformity, they inevitably present clear limits of accuracy. The design run on the plane table in fact corresponds to a simple planimetric projection of the area, without concern for the deformation resulting from the projection of the Earth's surface on the floor. This is of course acceptable as long as the extension of the surveyed area does not exceed the so-called topographical field area where the use of the formulas of plane trigonometry and geometry results in a negligible error. This is exactly the case of the Teresian maps, which are collected and compiled by municipality. There is therefore, like Marinoni was aware, no possibility of their use for more general purposes, and in particular, no possibility to move from the mapping of individual communities to a map of the whole of Lombardy. The maps in fact, show a precision that decreases from the central areas towards the end, where mistakes accumulate so forth more and more evident. A further limitation of the Teresian maps is detected independently by individual communities (which are divided into modular sheets for copying maps), is the lack of bond that can be found between the representations relating to adjacent areas. Due to this, in fact, it is not uncommon that the boundaries of several municipalities, coincide with each other only in the approximate way.

Regardless of these limitations, the maps, which remained in use for many decades and were replaced only after the mid-nineteenth century, were in the time of Charles VI work of an amazing accuracy and far superior to any previous topographic production. Also, very date of their discovery, which anticipates the great economic expansion, makes Teresian maps an extraordinary testimony of Lombardy pre-industrial settlement represented even more indicative of that of previous centuries.

The analysis of the methods of design and representation of Teresian maps deserves some consideration, also. Primarily, it is important to state the fact that, contrary to what one can imagine today, the planimetric representation adopted with the use of the plane table also for the designers of that time represented anything but natural. On the other hand, however, the cadastral representation requires the designer to bring the exact projection of the territory on the horizon, for which is vital to be able to obtain the actual extent of the plots, from the map. If, therefore, the maps Cadastre Teresian mark a crucial step towards the preparation of



planimetric topographic maps, it is equally clear that some consistency issues will be resolved only many decades after the birth of geometrical registers. One of this is the one concerning the paper representation of the height of land, which will be resolved in accordance with the conventions, with the introduction of the contour lines. The designers and surveyors of Charles VI experienced instead other methods, such as drop shadows and lines that approximate those of maximum slope, or prospectively represent elements of the landscape, rocky profiles or tree-lined slopes. The inclusion of such topography characterizations often reveals a clear inconsistency. The next Figure 4.4, taken from the Teresian map of the Village of St. Augustine (which now belongs to the Municipality of Como), clearly shows some of the techniques described above to identify the high places: the steep slopes of land overlooking the lake (identified in the left of the image) are well expressed by a set of shadows, lines that run along the side and wooded slopes.

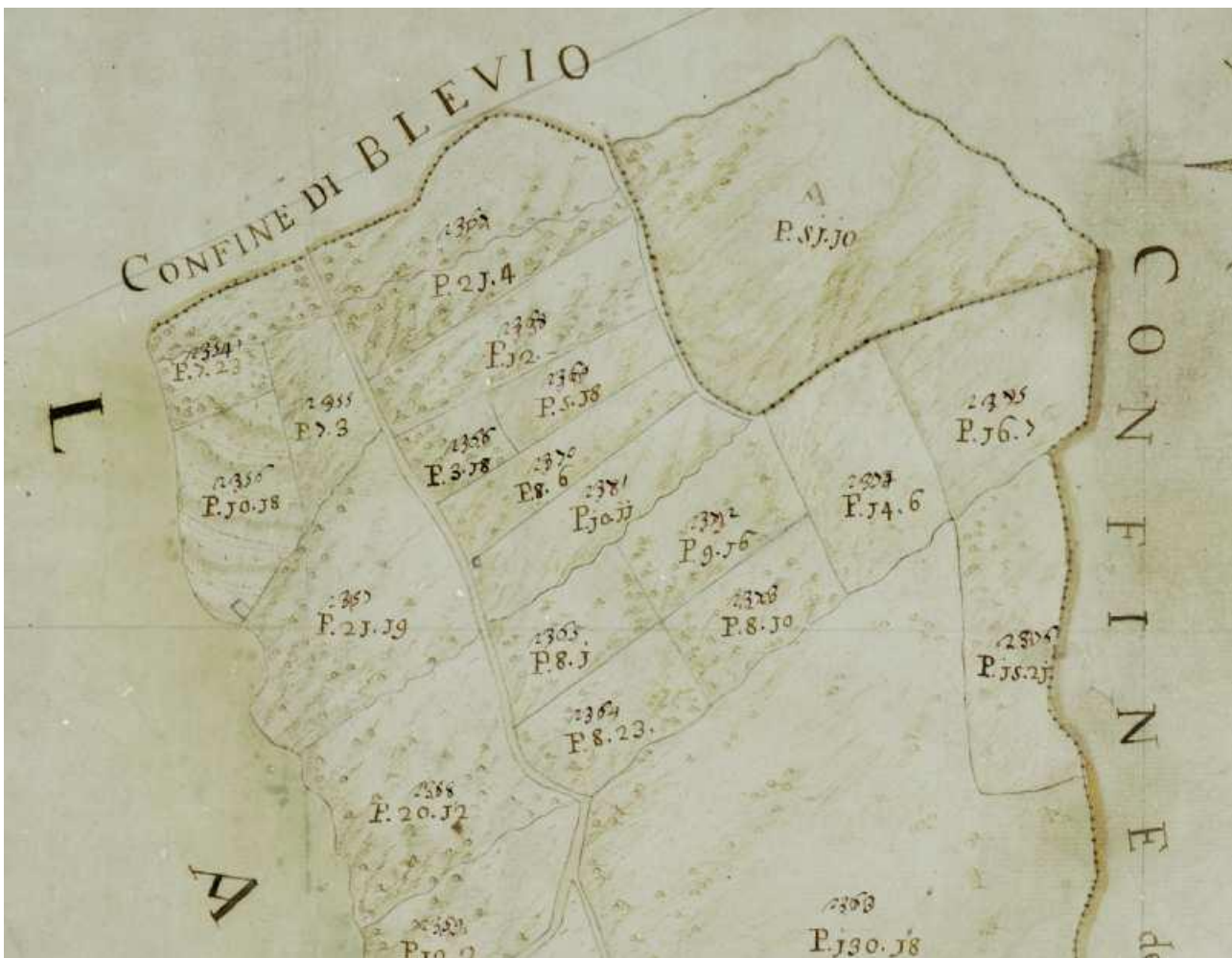


Fig.4.4. Part of a Teresian map of Borgo di S. Agostino, Sheet I. Source: Archivio di Stato di Como.

The maps are made carefully in pen and watercolor. They are generally signed and dated. Also, the corrections, additions and updates made both during the preparatory operations, carried out between the first draft and activation are present. The numbering of the sheets several times changed which is another track of the progressive formation of the Cadaster.

The boundaries of land ownership, which constitute the main object of cadastral maps, are represented by continuous lines in pen, different and distinguishable from the dotted lines that mark municipal boundaries. This general characteristic is seen also in Figure 4.4. above, where both the division of the land delimitation, was appreciated respectively on the top and

right from Blevio and the Municipality of Como. Another specific aspect is the distinction between land of varying quality, which binds the designers to use graphic symbols for well-differentiated different crops, such as pasture, wood, etc. These symbols, which arise naturally from the realistic representation of the campaign, are defined by the iconic signs: for example, the forest is represented by trees, the lawn with a green pattern, etc. Despite the codes to which these signs refer, they were actually constantly changing (just think of the endless ways of drawing a tree), and it is clear from the maps that there exists a certain tendency towards the disappearance of the variants and the stabilization of relevant features. This is in agreement with the principles of uniformity and generality that are basis of the reform of Charles VI

The last graphic that deserves to be investigated concerns the decorations often found on margins of the Teresian maps. They abound in scenic views, landscapes with ruins, figures and numerous other mythological themes in line with the products of the decorative arts of the period. It is interesting that this use to enrich the topographic sheets with decorations, which has roots far back in time, persists even in the general measure and coexist with its explicit ambition of universality, accuracy and rigor. It is probable, however, that much care for the ornamental part is due to, more than to superior orders, the taste of the designer: the variety of decorations on the maps seems to confirm that the right to introduce elegance is left to the author.

So, the Teresian Cadastre, from the one hand, recognizes and welcomes expressions of elegance inherited from tradition, but on the other, for the first time, imprints objective and rigorous extent that characterize globalization to all subsequent topographical production. Classic decorative proposals, such as views, inserts and figurative representations will in fact already be abandoned in subsequent campaigns of surveying and mapping in the time of Napoleon.

#### 4.2.2. Teresian map of Como from 1722.

The second map used in the thesis, is the one belonging to the Teresian Cadastre series of maps. It is the oldest and most valuable one of all those currently preserved in the State Archives of Como.

This map is a copy of the map sheets derived from the original, recorded in the period from February 18<sup>th</sup> to May 6<sup>th</sup> of 1722 by the surveyor Pietro Paolo Banfi. The note included in the Sheet 1 which is represented by the Figure 4.5 contains the official letterhead: *Mappa della Città di Como con parte de suoi Borghi e Corpi Santi sotto le Parochie di S.Martino, S.Bartolameo & S.Pietro Celestino*<sup>5</sup>.

Also the names of the artists who copied in the same year (1722) the original map of the Banfi are indicated in this sheet: Lieutenant Gerolamo Corradini and Carlo Marchioni. As can be inferred from the header, the map represents only a small part of the province of State Como in Milan, including the Walled City along with a few neighboring parishes.

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<sup>5</sup> *Map of the City of Como with part of Como Borghi and Corppi Santi under the Parochie of St. Martino, S.Bartolameo & St. Pietro Celestino.*

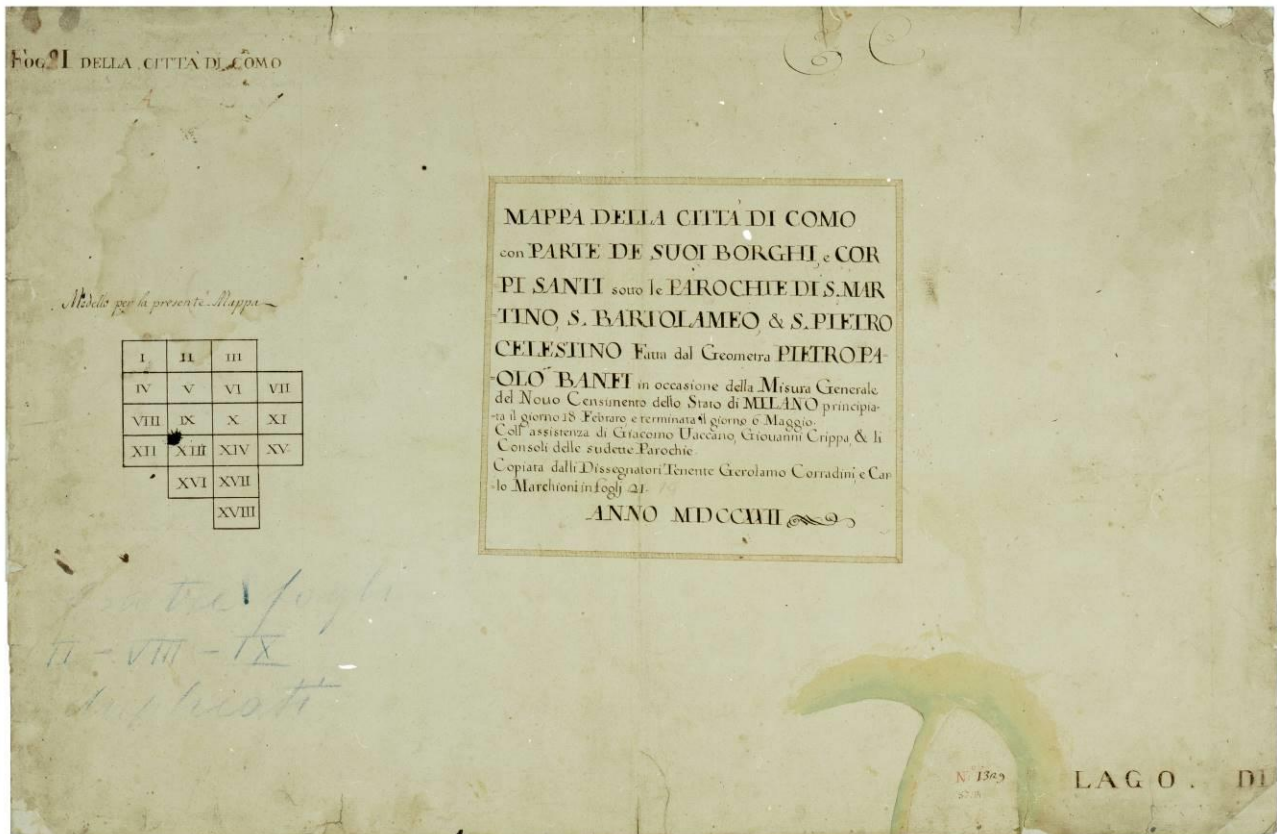


Fig.4.5. Map of the Como from the Teresian cadastre series, sheet I. Source: Archivio di Stato di Como

In the following Figures: 4.6, 4.7, 4.8, 4.9, 4.10, 4.11, 4.12, 4.13, 4.14, 4.15, 4.16, 4.17, 4.18, 4.19, 4.20, 4.21, and 4.22, the images obtained under digitization promoted by the State are shown, relating to 18 sheets that make up globally the Teresian map of Como from 1722. In accordance with the production of the Teresian Cadastre, the map sheets are painted in ink and watercolor and the element of color is rich in meaning.

The sheets of the map, were digitized using the Epson Perfection V700 Photo with the sampling density of 600 dpi. The images have been provided in TIFF format and include not just the sheet of interest, but also a large area surrounding it. In this area, in order to promote a better reading of the image obtained, color scale, which shows the shade "true" to some basic colors with which to compare those of the digitized sheet, and a ruler with double grid in centimeters and inches, useful for get an idea of the size of the details shown in the mapcolor scale, were inserted in the first phase of digitization. The images on Figures: 4.5, 4.6, 4.7, 4.8, 4.9, 4.10, 4.11, 4.12, 4.13, 4.14, 4.15, 4.16, 4.17, 4.18, 4.19, 4.20, 4.21, and 4.22 were obtained, therefore, after having cut out, starting with the original, the rectangle containing each map sheet. It is therefore convenient to refer to such images all technical features of interest: the map sheets, each having a size of 68.5 x 45.0 cm are constituted, in their digital version, to 16181 x 10630 pixels; the disk space occupied by them is reduced to 57 MB each. In contrast to what was seen for the Topographic map of Como, the map sheets are color images and can therefore be interpreted by the RGB model, according to which each color is identified by a specific combination of the values of red, green and blue. Referring to this, it is said that the pictures have radiometric resolution of  $3 * 8 \text{ bits} = 24 \text{ bits}$ .



Fig.4.6. Map of the Como from the Teresian cadastre series, sheet II. Source: Archivio di Stato di Como

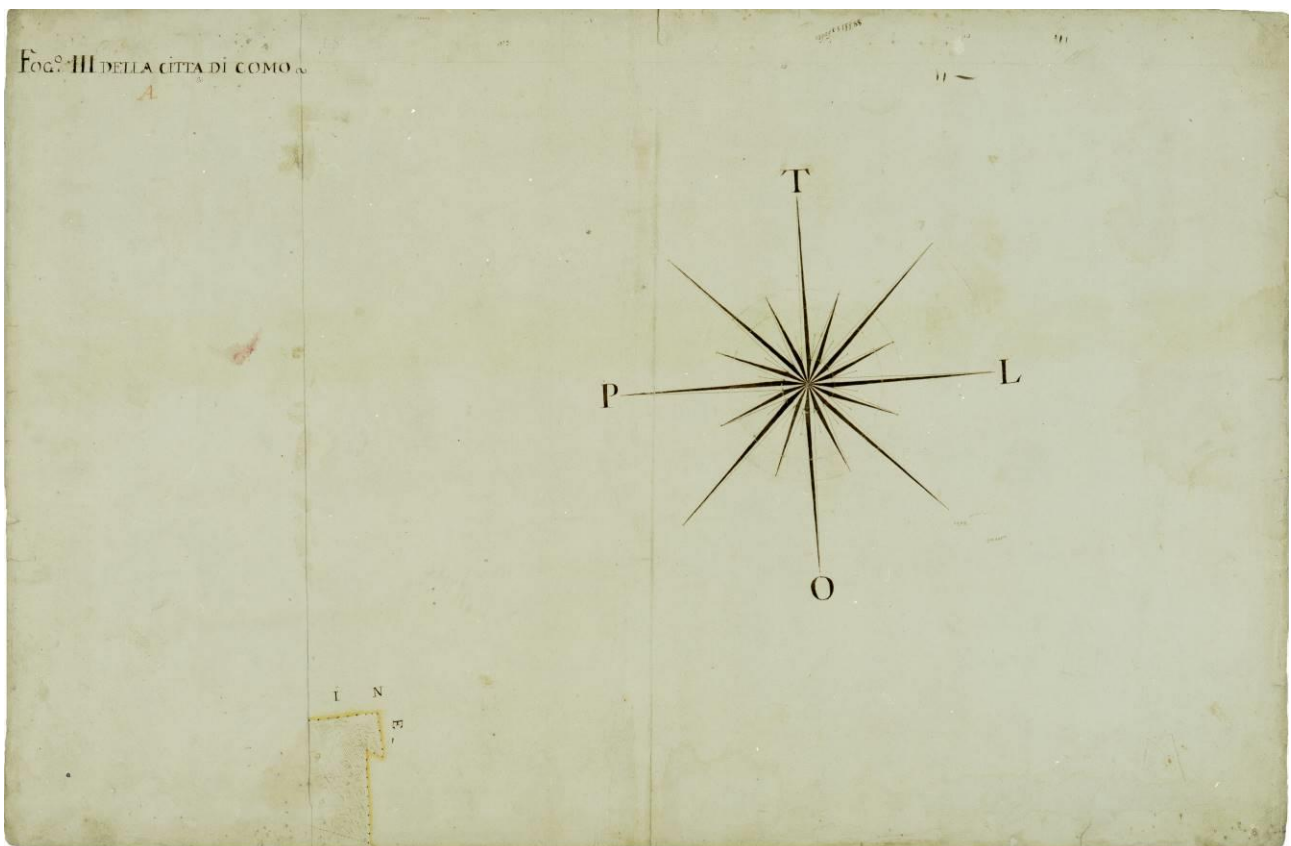


Fig.4.7. Map of the Como from the Teresian cadastre series, sheet III. Source: Archivio di Stato di Como





Fig.4.8. Map of the Como from the Teresian cadastre series, sheet IV. Source: Archivio di Stato di Como



Fig.4.9. Map of the Como from the Teresian cadastre series, sheet V. Source: Archivio di Stato di Como





Fig.4.10. Map of the Como from the Teresian cadastre series, sheet VI. Source: Archivio di Stato di Como

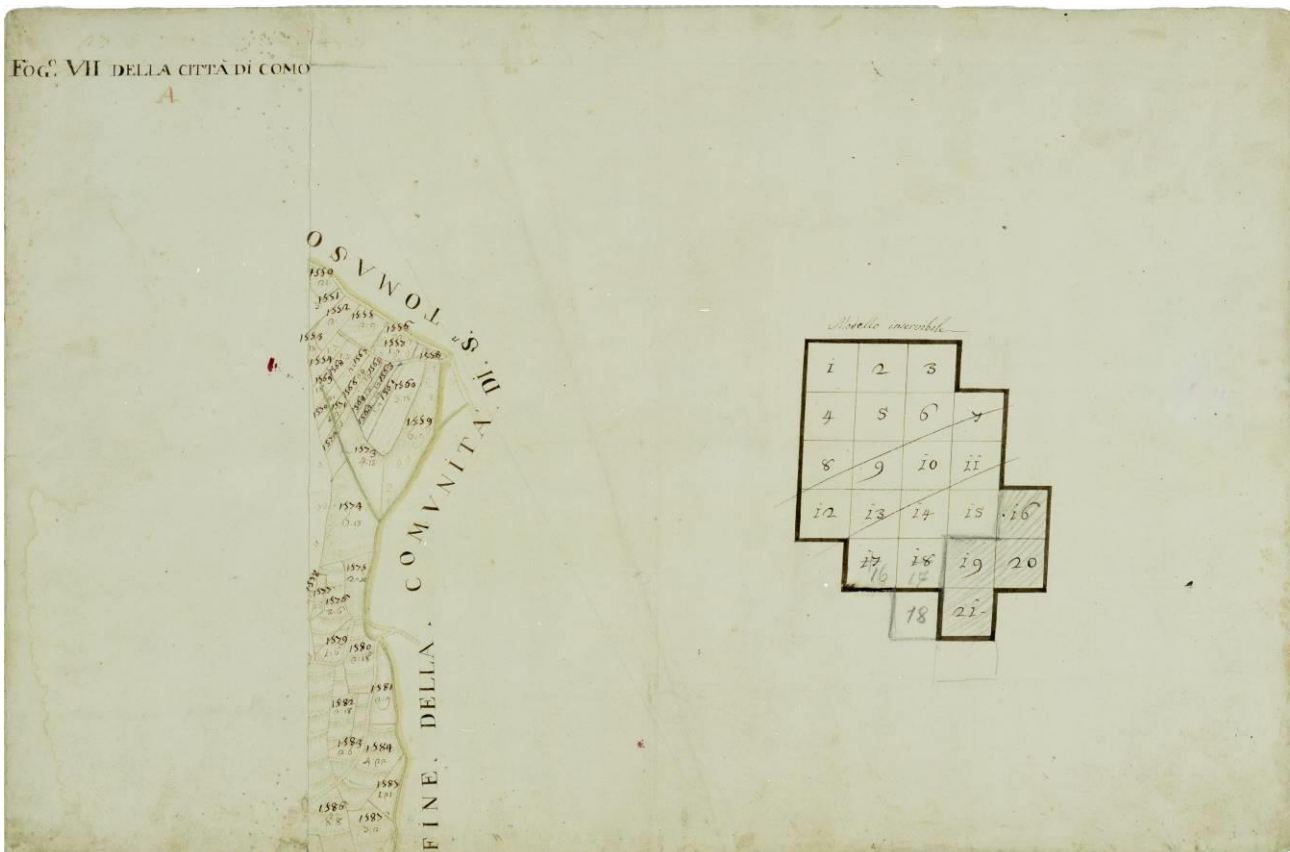


Fig.4.11. Map of the Como from the Teresian cadastre series, sheet VII. Source: Archivio di Stato di Como



Fig.4.12. Map of the Como from the Teresian cadastre series, sheet VIII. Source: Archivio di Stato di Como

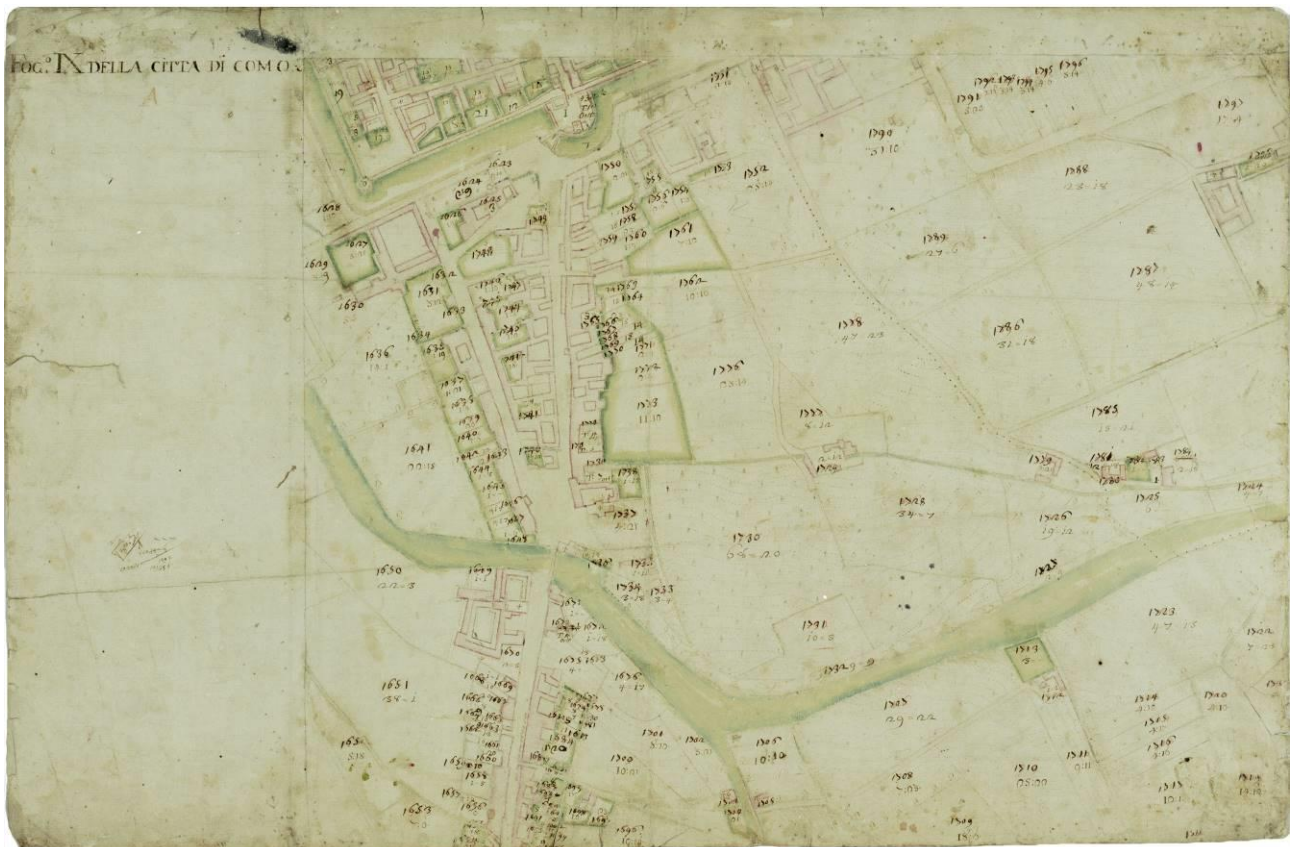


Fig.4.13. Map of the Como from the Teresian cadastre series, sheet IX. Source: Archivio di Stato di Como





Fig.4.14. Map of the Como from the Teresian cadastre series, sheet X. Source: Archivio di Stato di Como

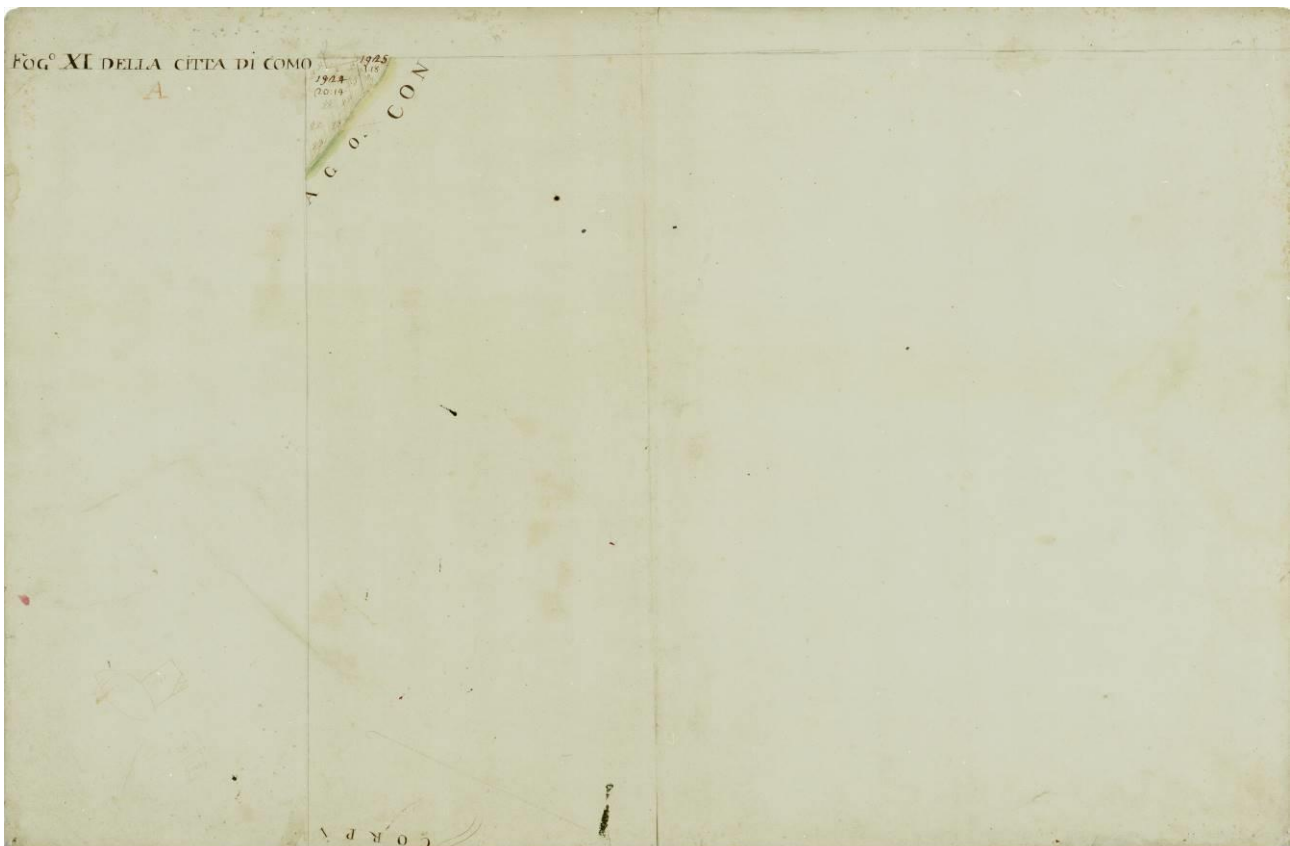


Fig.4.15. Map of the Como from the Teresian cadastre series, sheet XI. Source: Archivio di Stato di Como



Fig.4.16. Map of the Como from the Teresian cadastre series, sheet XII. Source: Archivio di Stato di Como



Fig.4.17. Map of the Como from the Teresian cadastre series, sheet XIII. Source: Archivio di Stato di Como



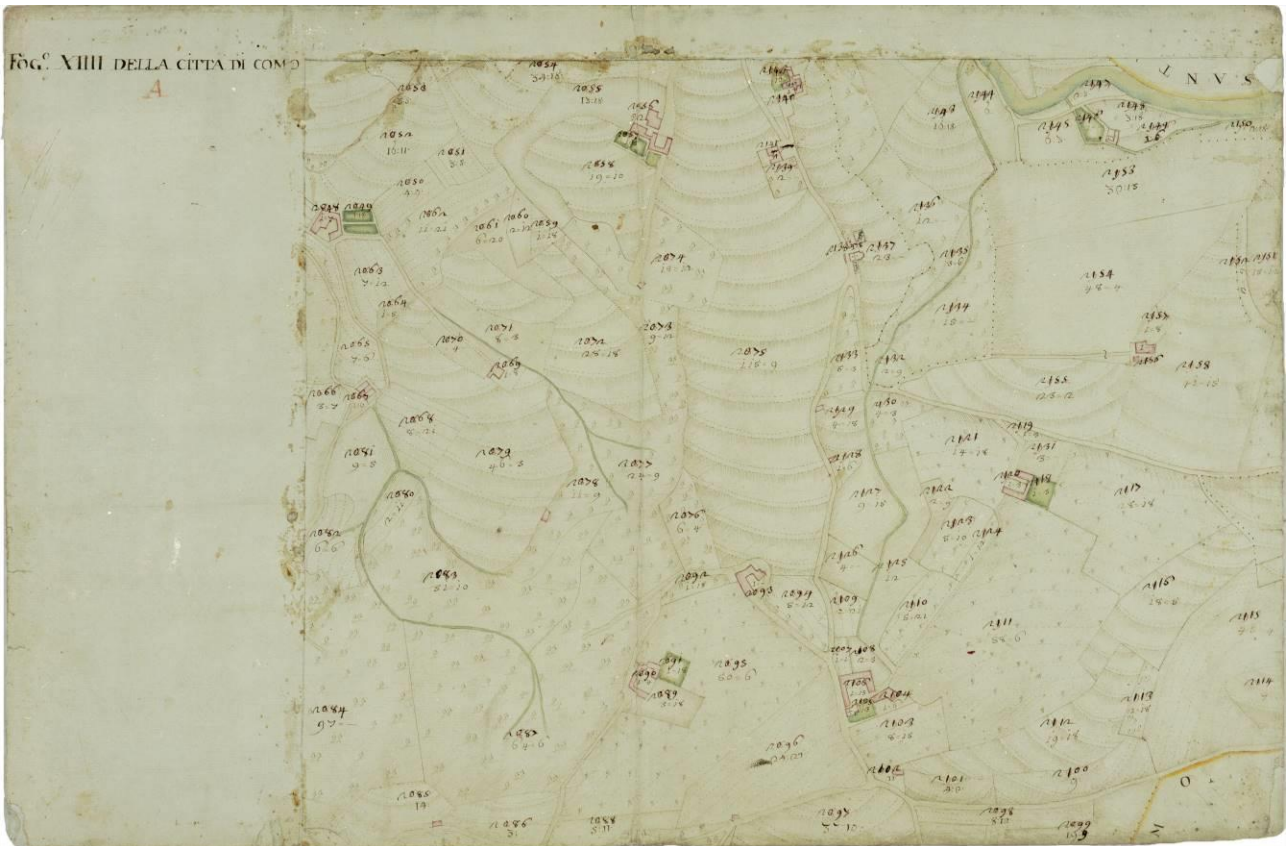


Fig.4.18. Map of the Como from the Teresian cadastre series, sheet XIV. Source: Archivio di Stato di Como



Fig.4.19. Map of the Como from the Teresian cadastre series, sheet XV. Source: Archivio di Stato di Como





Fig.4.20. Map of the Como from the Teresian cadastre series, sheet XVI. Source: Archivio di Stato di Como



Fig.4.21. Map of the Como from the Teresian cadastre series, sheet XVII. Source: Archivio di Stato di Como

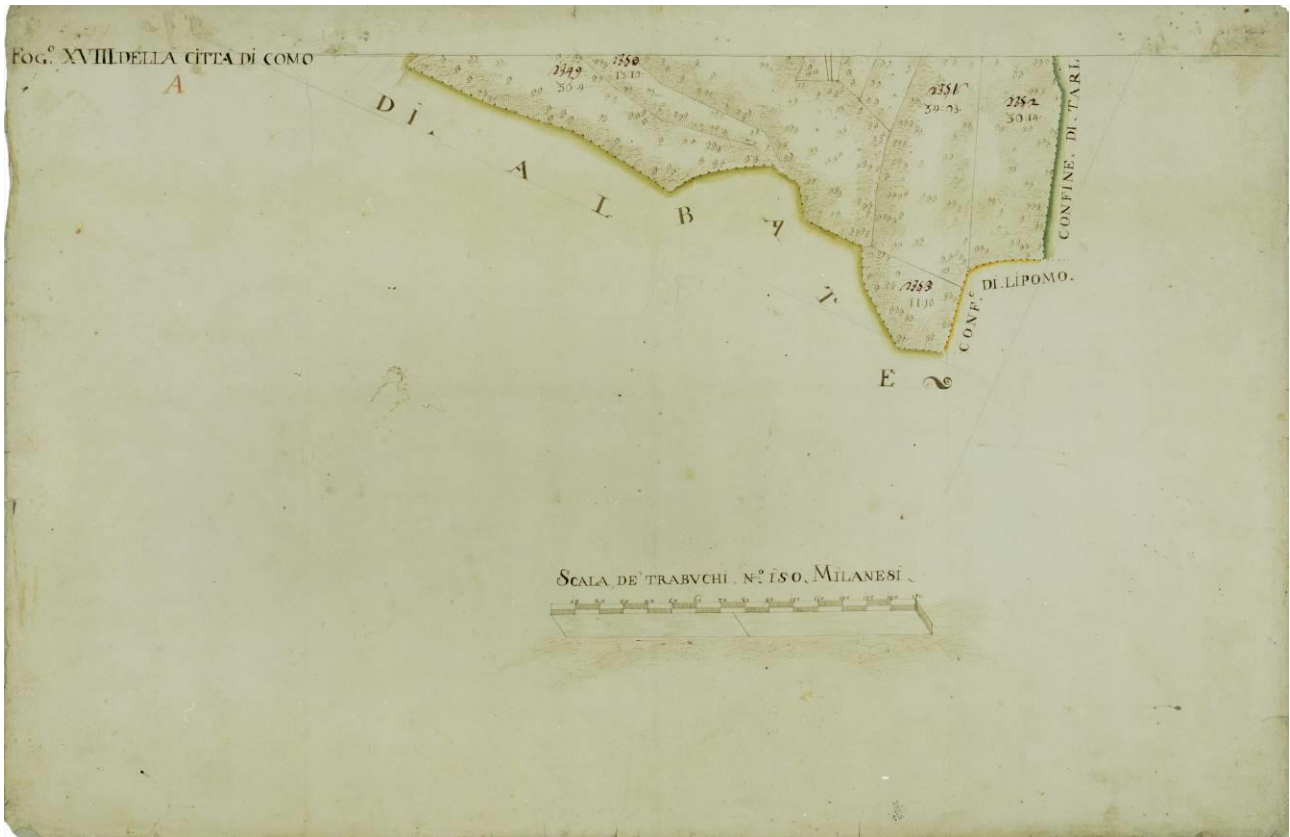


Fig.4.22. Map of the Como from the Teresian cadastre series, sheet XVIII. Source: Archivio di Stato di Como

The whole map, constituted from the previous 18 sheets, together with a careful analysis of each sheet took individually, allowed to experience some of the distinctive features of the Teresian maps. The boundaries between estates are drawn in solid line, while those between different communes are indicated by dotted lines. The map also shows a specific representation code of author which is used to denote the different uses of the soil, forest by a pasture or agricultural land used for different crops. There are even graphics which represent the topography, such as shadows, lines that run along the slopes and wooded slopes, reflecting a strong bond with the perspective representations and decorative arts of the time.

To run the mosaic, again the software Adobe Photoshop has been used: to each sheet was applied a roto-translation and, if necessary, also a scaling (uniform or different in the two directions) to reduce the considerable deformation existing in the border areas. The result, shown in Figure 4.23 shows the non-perfect matching between adjacent sheets, detected independently and errors which gradually increase toward the ends.





The indication of the scale of the map, shown in the Figure 4.24, is contained in the sheet XVIII and centrally located at the lower end of the mosaic of the sheets themselves. What emerges from a simple look at the representation of the scale is that the bar is depicted as a perspective. Beyond of graphical analysis, however, it is important to emphasize that this is the only decoration present on the map that can be attributed to the fantasy and imagination of the author, whose space for the expression of his drawing ability is therefore, when compared with many other maps of Teresian Cadastre, rather limited.

From a point of view more analytical, as shown in a Figure 4.24, the unit of measurement, is presented by the *Scala de trabuchi No. 150 Milanese*. The numerical quantity is then reported, similarly to what already seen the Topographic map of Como, by the length of the scale bar, precisely equal to 150 Milan trebuchets. Repeating the measurement procedure described before to determine the real scale of the chart, remembering now that a Milan trebuchet corresponds to 2.6111 m, we obtain the confirmation of a scale ratio of 1:2000, exactly one chosen for the Teresian maps.

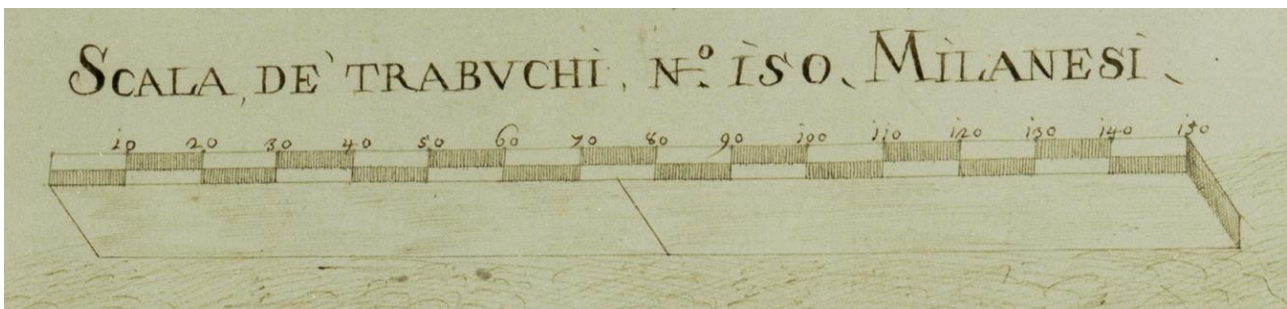


Fig.4.24. Scale Indications Source: Teresian Map of Como, sheet IV

As was found in 1722 during the reign of Emperor Charles VI, the map is classified as "First resort" because it represented the only assets are land, while the estimated buildings (or secondhand goods station) is only performed since 1749, with the appointment of the second council by Maria Theresa. In the map sheets shown by the previous figures, however, it appears evident the presence of buildings, depicted with a discreet detail especially in the Walled City. In fact, the overview of the 18 sheets, shown in Figure 4.23 shows that those buildings of the Walled City are (almost) only ones listed in map: this corresponds to the trend, which is noticed by the analysis of other maps belonging to Teresian cadastre, which represent the maps of the first station: shown buildings are the ones situated in densely built-up and those of particular relevance. It would have been difficult to make a map of the Walled City with no indication in it, ports, the city walls, palaces, churches and monasteries and ordinary residential buildings that three centuries ago, as in much of today, existed in the historical center. A further justification nature of the "first station" map, is seen with the identification of a land by the numbers, while all the buildings are free of it. The only numbers, from 1 to 40, relating to buildings on the map, in fact refers to a kind of legend, included in the Sheet IV (Fig 4.8) of the concerning map, which provides the name or function of those buildings.

### 4.2.3. Map of parishes (Teresian map of Como from 1722)

This map, originating from the 1722, represents the Walled City area of Como. Map used in the project has already been georeferenced, as it was used for the project *Como and its history* realized by the students of Politecnico di Milano.

Being such a diverse city, the history of Como has generated interest among scientists and ordinary people. This project is born within the course of Geographic Information Systems (GIS) in the Master of Science in Environmental and Land planning Engineering at Politecnico di Milano (Como Campus), academic year 2009-2010. The main idea of the project *Como and its history* was to recreate the evolution of the historic center of the town. This work originates from an ancient city-map of 1722, given by Comune di Como to Politecnico di Milano and then georeferenced in UTM coordinates using the PCI OrthoEngine software. The city has been divided into parishes on the base of what that map reported. Each area is characterized by the presence of a church and buildings of high historical and cultural value. Moreover, several parcels were marked by a series of information dating back to the 70s in order to make intelligible the dynamics of historical events that affected the old city.



Fig.4.25. Map of Como parishes. Source: Project *Como and its history*



## 4.3. Maps from the series of Lombardo –Veneto cadaster (1858)

### 4.3.1. Lombardo Veneto cadaster

After the Teresian cadaster in the eighteenth century, successful extension and concretization came in the next century, in which the cadaster of the Kingdom of Lombardy-Venetia acquires a special role among the various tax systems in force in the pre-unification Italian states. In fact, it is designed in order to ensure the equitable distribution of the property tax. It will be essential operating model for the new general cadaster of the Kingdom of Italy implemented in the next period of unification.

A complete analysis of the events related to the formation of the new cadastre can not be considered regardless of, once again, knowing the historical situation which preceded and accompanied its drafting. The starting point must be identified in the Napoleonic wars at the end of 700s, that in the wake of the French Revolution put into question the balance of power on the Old Continent. The victorious campaign of Napoleon Bonaparte in northern Italy, in particular, lays about four centuries after the end of the Duchy of Milan. This state, which formally declared its independence, actually becomes completely under the hegemony of the Alps. The Republic was reconstituted in 1801 with the Treaty of Luneville, that also expands the territories of the former Republic of Venice until the Adige. In 1802 the Cisalpine Republic was renamed the Italian Republic and in 1805, following the French military victories, the Peace of Pressburg marks the birth of the Kingdom of Italy.

Already during the Cisalpine Republic, the incompatibility of forces in the territories that compose it were highlighted: it is stated that there is a need to unify the tax system through the preparation of a new cadaster. The problem becomes more severe after the annexation of large territories under Veneto to the Kingdom of Italy, where the presence of taxation systems based on different instruments involves substantial inequalities in distribution of loads between the various provinces. The tax burden was inevitably less in all areas free of cadaster.

The areas of the former Austrian Lombardy were defined, as a whole, such as the provinces of ancient wealth, and include Milan, Cremona, Lodi, Como, Pavia, Varese, Casalmaggiore, subject to the census Milan activated in 1760, and Mantua, subject to the census that made the model of the previous year, and was activated in 1785. To achieve the objective, a higher tax equalization between the territories of the Kingdom of Italy, the financial administration was moving in two distinct directions. From one side, in order to obtain a reassessment of tax revenue in the different compartments of the kingdom, from the 1808 to 1813 new estimation for the provinces without land registers were provisionally defined, which will remain in force until the activation of the next stable census. At the same time, in 1807, the formation of a new general cadastre in all territories was decreed, in order to achieve a real equalization and an increase in the gross tax receipts, which is necessary to support the budgetary needs of the financial administration of the kingdom.

The operations for the land surveying were conducted on the example of the surveying carried out in the territories of Lombardy from the Teresian period. The territorial map of each municipality is represented in a scale of 1:2000 and contains the reporting data (owner's name, extension and quality of culture). During the Napoleonic period the operation of measurement, often carried out in a state of war and with opposition from some departments, was initiated and brought to a state of advanced realization, but it was not entirely completed.



The continuation of operations on land in the Kingdom of Lombardy-Venetia was then functional to reorganization of the Austrian finances, which judged that the geometrical registers were essential for effective fiscal policy. With the sovereign resolution, on December 23, 1817, signed by the Emperor Francis I of Austria, the general rules for the implementation of registers in the provinces that have not yet reached were established, adopting again the Teresian as a model reference. At the same time they recognized the full validity of the measurement operations initiated in the Napoleonic era and completed it in the same year of 1817. Following the practice of the operational Eighteenth-century England, the results were immediately published in the municipalities and provinces of the kingdom, allowing owners and local representatives to examine the maps in order to, if detect any inaccuracies or omissions, they could present possible complaints. The geographic area in which the work of formation of the new cadastre was carried out, included all the provinces (Venice, Padua, Polesine, Verona, Vicenza, Belluno, Treviso and Friuli) and part of the Lombardy (Brescia, Valtellina, the districts Crema of the province Lodi-Crema, the districts of Asola and Volta of the province of Mantua, Bergamo). But, excluded from the new operations on land were the provinces of ancient wealth: Milan, Lodi, Pavia, Como, Cremona and Mantua, along with some of the common wealthy ancient provinces of Bergamo, belonging to the districts of Almenno, Zogno, Treviglio and the Roman Empire.

Then, the council began to devote itself more to the estimation of the land, which was launched in the provinces in 1826 and ended in 1828. Estimation was based on the average unit rent obtainable in an ordinary and in a year of harvest, according to the crops grown, which is evaluated by the quality and yield of the class. The land estimate refers to the situation of the surveyed property at the date of May 27, 1828.

As was the case for the Teresian Cadastre, the estimation of the land follows that the property to be surveyed include both those lands covered for residential, agricultural, commercial or manufacturing purposes, as well as those lands attached to buildings (courts, courtyards, gardens and orchards), indicated in the land records with the same map number as the one of the buildings. Surveyed, but exempt from tax consideration, were the buildings used for Catholic public religious purposes (such as churches, baptismal fonts, cemeteries) villas and royal palaces, military forts, squares, gates and ramparts of the city. The estimate of buildings, referring also to the state of the buildings on May 27, 1828, is based on the average rent obtainable by individual buildings, to be calculated from the average of the rents charged in the period 1820-1828. For this, in the estimation it was taken into account the location of the buildings, their quality and other specific circumstances which varies from municipality to municipality.

Starting from 1839, in the provinces of Lombardy and Veneto the publication of local registers referred to individual municipalities, where for each land parcel were given the name of the owner and consistency of data, classification and income from land and buildings. The Land Registry was finally activated by the Government in the provinces of the Kingdom of Lombardy-Venetia: Venice, Padua and Polesine in 1846, Treviso, Verona and Belluno in 1849, Vicenza in 1850, Friuli in 1851. During the following years the implementation of the cadaster was also extended to the territories of ancient Lombardy without wealth: in 1852 in Brescia, in the two districts of the province of Lodi-Crema and in the districts of Asola and Volta from the province of

Mantua, in 1853 in Bergamo (excluding the aforementioned territories in which the Teresian Cadastre existed) and in 1854 in the province of Valtellina.

The sovereign resolution on August 18, 1854, which features the resurveying of the Lombardy of ancient wealth, outlines different operating modes for the formation of the new cadaster in the provinces the upper part of Lombardy (including that of Como), corresponding to mountainous areas, hilly and that part of the plain with a less intense development of infrastructure for irrigation and reclamation operations. In the territories of ancient wealth of the lower part of Lombardy, where it is more widespread presence of irrigation canals and drainage, it is established that the work must currently be limited to only resurvey of the buildings. For the "equalization" of the estimated land is instead applied a re-evaluation of the rates of the old estimates, based on a fixed coefficient given by the value of the ratio 1:2.64, while maintaining the quality and classes found from the records of Teresian cadastre.

As regards the province of Como, jobs of surveying started in 1856 and ended in 1858, and the campaign of 1857 marks the beginning of the estimation of land and buildings. In 1859, the provinces, with the exception of Mantua, were aggregated temporarily to the Kingdom of Sardinia, before flowing into the Kingdom of Italy in 1861. The genesis of the new state after the Italian unification forcefully recalls the problem of differences in systems of distribution and collection of taxes in force in the various territories of the kingdom. In this regard, the Law of 14 July 1864 the so-called "Adjustment of provisional tax", defines the land of the United compartments (including the Lombardy) and the respective quotas. In the aggregation in the Kingdom of Italy, Venetian provinces (1866), noticed the urgency of the problem equalization between the various registers active in the pre-unification states. Hence the need, after the activation of cadaster in 1873 in the municipalities of the upper part of Milan, and in 1876 the entire province of Como, to group the territories of Lombardy and Veneto, counted on the basis of finally being homogeneous, in a single cadastral compartment. Meanwhile, resurveying work continued in the lower part of the region, still in progress when the law was enacted on March 1, 1886 governing the implementation of the new general cadaster throughout the kingdom. Land inequality has finally passed in 1905 with the activation of the New Land Cadastre (NCT), which accepted the law of 1886 and appears to be the first geometrical cadaster, one for the whole country. The Land Registry of Lombardy-Venetia therefore remained active, stable in the provinces of wealth and in those affected by resurvey until the beginning of the XX century.

The cartographic production in the Lombardo-Venetio Cadaster, despite having been made in a wide time interval and for a geographically vast and heterogeneous area, keeps surprising elements of uniformity. The universal nature of the measure had already been stressed in the Teresian era the need for common patterns charts, as well as its aim at equalization of tax and objective representation of the territory is what characterize it.

The majority of the map sheets, in fact, is detected at the same scale of 1:2000 which had marked the Teresian work, but they are rare parts of the territory represented on a larger scale (1:1000 or 1:500), both in the substitution and in addition to the previous sheets in scale 1:2000. While maps can be considered indicative of the Teresian urban reality not only in the eighteenth century, but also one or two centuries earlier, new maps of the Lombardo-Venetio must represent a

territory in the process of change. From this comes the need to adopt a higher degree of detail in the representation of the territory, which results in the choice of a larger scale to reproduce densely built urban centers. For the relief is used again, the plane table, the instrument which has become customary in the field of surveying. The formation of cadastral maps, therefore, is not even connected in this case to geodetic operations, despite the knowledge in this field were established and recognized for some time now. Even in the relief operations for the Cadaster of Lombardo-Veneto it is believed, obviously, that the practical benefits derived from the use of plane table are higher than the graphic inaccuracies themselves. Regarding the units of measurement used in the New Land Cadastre, the new unit of measure for length is the meter, defined as the ten millionth part of a of the terrestrial meridian, while the square meter is therefore adopted as the unit for the measurement of the surface. Teams in charge of the measure had again to use chains and metal rods (of length equal to a predetermined number of meters) and the maps, based on the model of Teresian ones, must be oriented to the north.

One last item of interest from the Land Registry from the Lombardy-Venetia is related to the content and to those drawings on produced maps and their comparison with the previous Teresian ones. In the cadastral production of the nineteenth century emerges clearly the establishment of professional bodies specialized in topographic survey, an investment rather impersonal by which the taste of the authors of the cartographic representations goes into history. In this century, the link with the traditional decorative arts, was lost completely. Landscapes, mythological figures, animals, wind roses, classical and medieval ruins and all other decorations found in the Teresian Cadaster disappear. The different cultures practiced are no longer distinguished by icons and backgrounds directly on the card (for which, as mentioned, a certain freedom was left to the designer), but are shown with the corresponding numbering mentioned in catalogue and land registers, with an indication of the quality and class of the soil. As regards buildings, instructions for their representation in the maps were provided directly by the Government. All the buildings subject to the payment of taxes were shown in plain view with colored backgrounds in pink and numbered with the cadastral map identifiers, and exempt buildings are represented with backgrounds of crimson dark and identified with the letters in the uppercase. An example of application of these conventions is given in Fig 4.26 below, in which it is easy to distinguish the exempted from the taxes: Duomo di Como (Como Cathedral), la Basilica di S.Giacomo and Porta Portello (access from the east to the Walled City).

The maps of Lombardo-Venetio also differ from Teresian in other graphics relating to the representation of the territory. It is to be noted, however, that the content of any cadastral map will always be included in the context of the purpose for which it essentially It is not surprising, therefore, the absence or lack of detail in the representation of some characters of the municipalities surveyed. The maps of the cadaster of Lombardo-Venetio not bear any traces of shading, profiles and wooded slopes systematically used in Teresian maps for the representation of relief. Also notable is the attention given by the maps of the Cadaster of Lombardo-Veneto to the road and hydrographic networks, which now allow to draw a more complete and realistic state of territory at the time of the surveys.



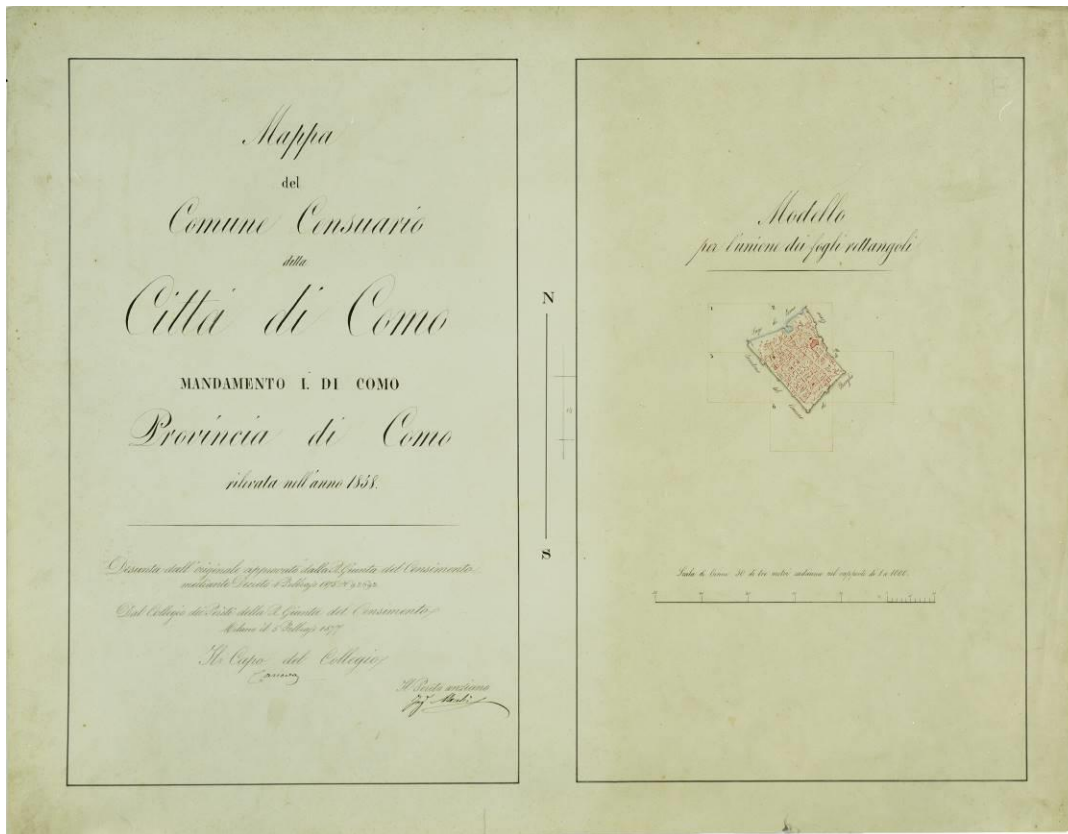


Fig.4.27. Map of Cadaster Lombardo -Veneto of City of Como (1958), sheet: together. Source: Archivio di Stato di Como.

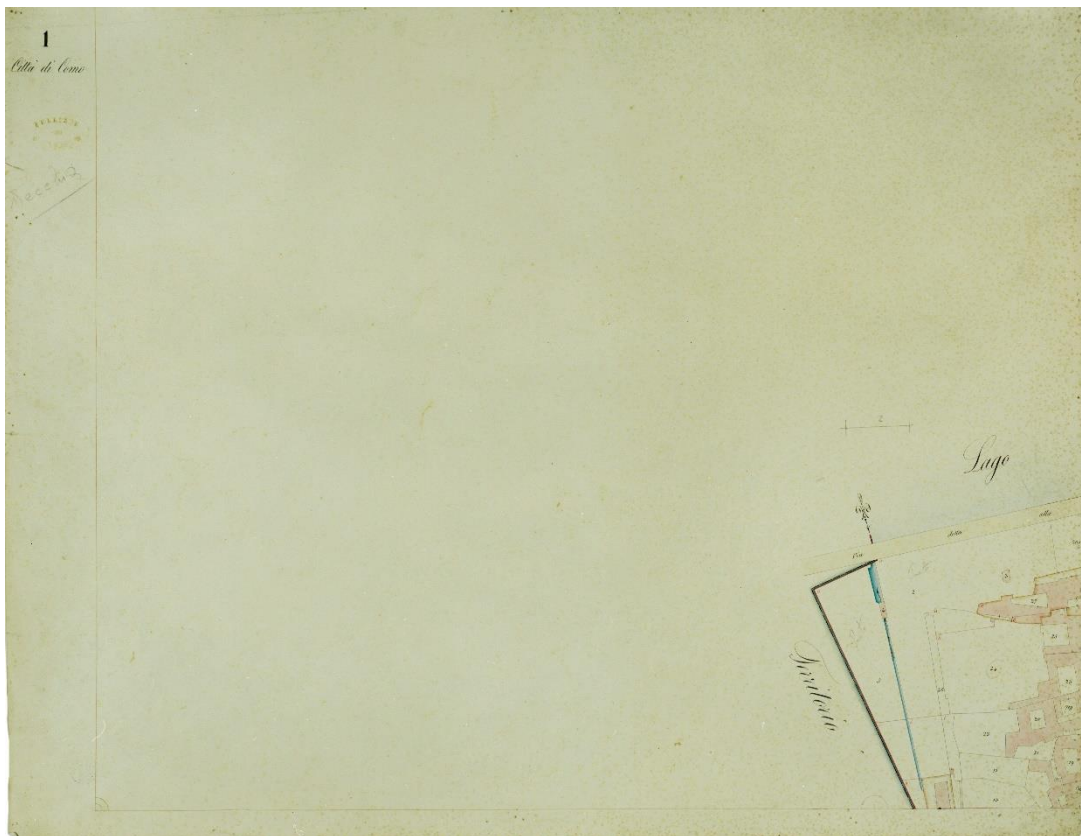


Fig.4.28. Map of Cadaster Lombardo -Veneto of City of Como (1958), sheet: I. Source: Archivio di Stato di Como.





Fig.4.29. Map of Cadaster Lombardo -Veneto of City of Como (1958), sheet: II. Source: Archivio di Stato di Como.

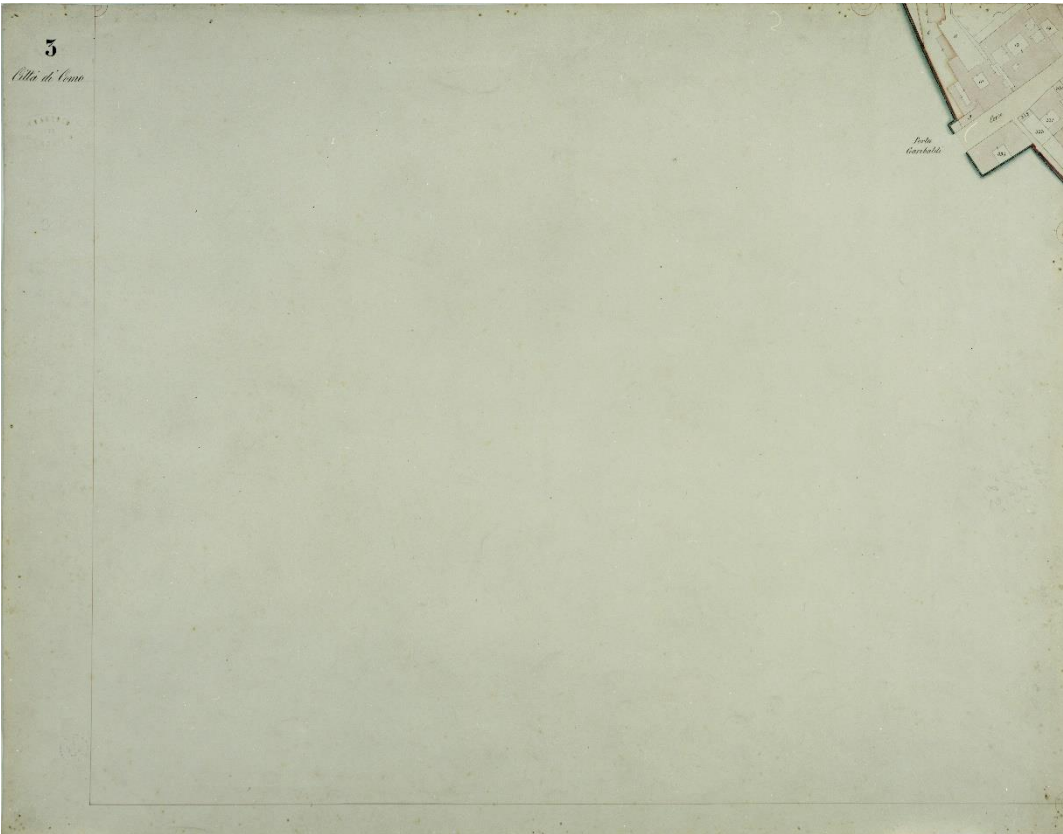


Fig.4.30. Map of Cadaster Lombardo -Veneto of City of Como (1958), sheet: III. Source: Archivio di Stato di Como.

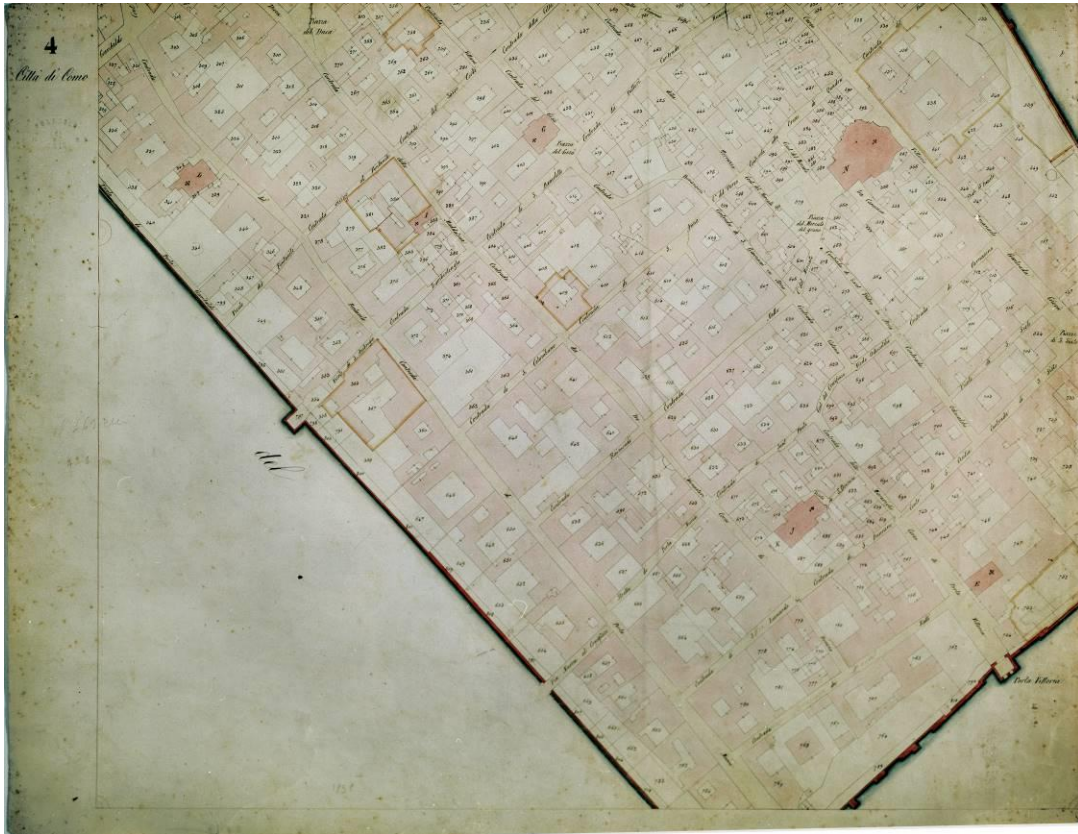


Fig.4.31. Map of Cadaster Lombardo - Veneto of City of Como (1958), sheet: IV. Source: Archivio di Stato di Como.

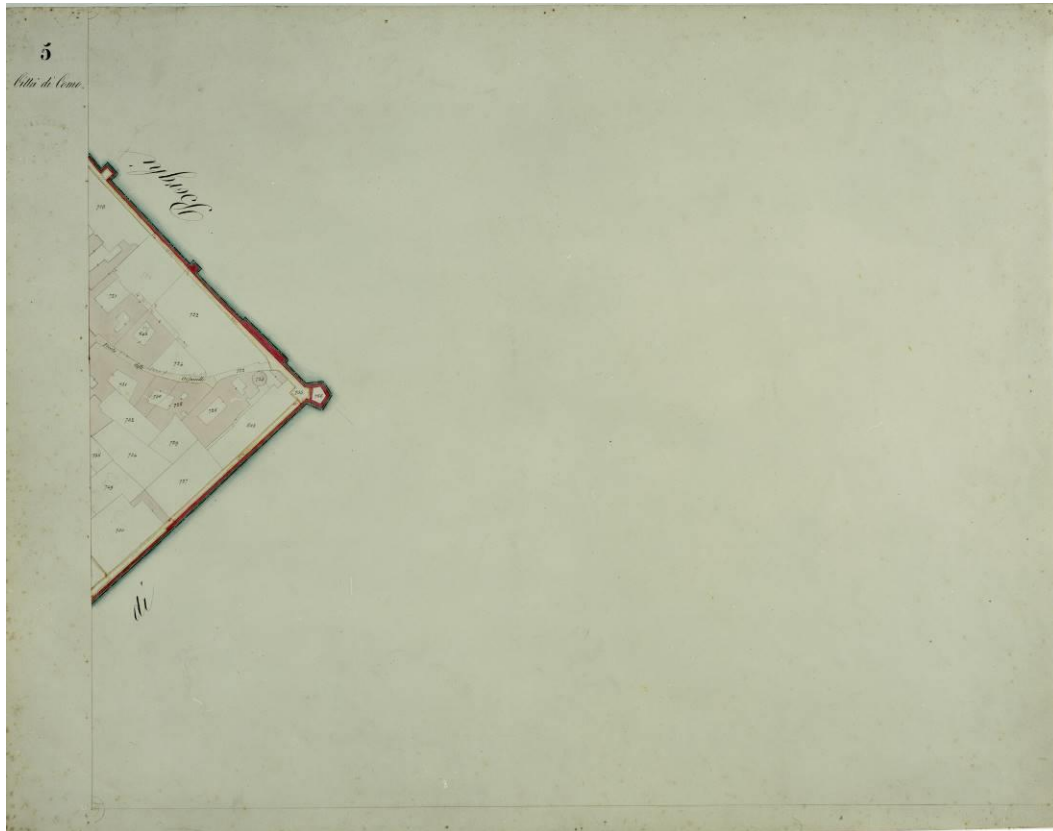


Fig.4.32. Map of Cadaster Lombardo - Veneto of City of Como (1958), sheet: V. Source: Archivio di Stato di Como.



Fig.4.33. Map of Cadaster Lombardo -Veneto of City of Como (1958), sheet: VI. Source: Archivio di Stato di Como.

Even in the map of the City of Como in the Lombardo-Veneto Cadastre you may encounter, such as already in that of the Teresian, all aspects of graphics production characteristic of the entire register. It is evident first of all that the paper is written, like the Teresian but differently from the topographic map from the seventeenth century, guiding the sheets so that you have the vertical direction coincident with the north, as was expressly required in the work of eighteenth-century registers. A quick glance at the map sheets of the previous Teresian ones and the Lombardo-Veneto, however, it is sufficient to understand the profound difference from the graphical point. The nineteenth-century maps immediately appear sharper and geometricly similar in appearance to the strict modern maps and very far from the artistic taste and decoration which is well established, however, in the production of Charles VI. Therefore, shadows and other graphical means for the representation of orography, symbols and icons for identification of crops and any other item disappear from the map. The use of color is reduced to the essentials and respond to very specific needs: all buildings subject to taxes are shown in pink and identified by a cadastral number, those exempt (such as walls and gates to the city, churches and monasteries) are colored in dark carmine and indicated in the map with a capital letter. Backgrounds in blue, as seen, are also used for representation of the main water supply, which is still pretty poor in the Walled City and detectable only in a small detail in sheet I (Figure 4.28).



The indication of the scale of the map is located on the right side of the sheet of header shown in Fig 4.27, and it is presented magnified in Figure 4.34. The unit of measurement, consistent with the provisions of the Land Registry for the Lombardo-Veneto cadaster, is the meter. The extension of the scale bar is not, however, expressed directly in meters, but in rods of three meters each. This is clearly the operating mode in which the direct measurement was performed by comparing the length to be measured with a series of lengths, namely rods and chains of length equal to a number of trabucchi Milanese. The choice of using the meter as a unit of measurement in the Cadastre of Lombardo-Veneto had not changed the criteria for relief, now based on the use of instruments of extension equal to a certain number of meters (for example, in this case, three meters long rods). The other interesting aspect that you can see in the indication of the scale is the fact that, unlike the previous maps, the scale factor is now explicitly stated, thus allowing you to save the procedure described above for the determination of its value. The choice of scale 1:1000, however, is part of customary Lombardo-Veneto Cadaster to represent in a scale greater than the traditional (1:2000) the most important territories or the territories that are more densely built.

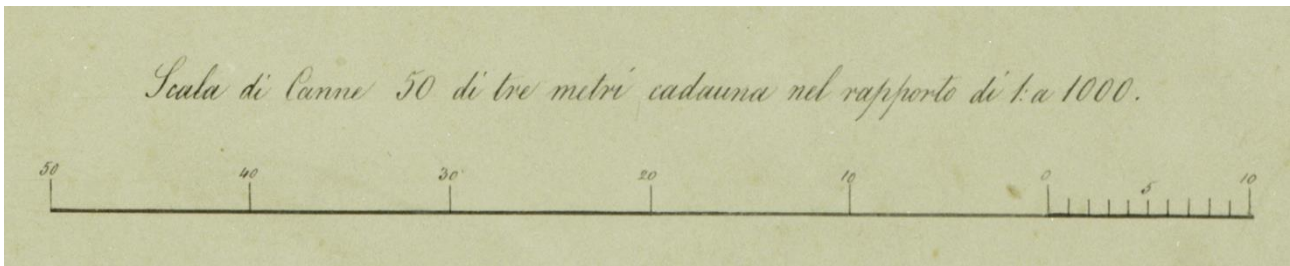


Fig.4.34. Indication of a scale. Source: Map of Cadaster Lombardo -Veneto of City of Como (1958)

The sheets of paper-based maps have dimension of 69.7 x 53.8 cm. Their digital images are provided by the State in TIFF format, derived from scans performed again with the scanner Epson Perfection V700 Photo with the sampling density of 600 dpi. Since the original sheets are of dimension slightly greater than those of the previous Teresian map, the area of edge together with scanned paper documents was rather small and, in this case, the insertion of the scale of the colors and of the ruler was not allowed. The digital images were cropped with respect to area of the interest, acquiring an extension of 16465 x 12709 pixels and a space on a disk of 75 MB. By using the RGB model for color representation, the images have again radiometric resolution of 24 bits.

The 6 sheets were finally mosaicked using the Adobe Photoshop software with the same procedure already followed in the previous maps (Fig. 4.35). The comparison with the mosaic of the Teresian Cadastre is observed in the near-perfect correspondence between the details located on the border between adjacent sheets (as a result of the nineteenth-century refinement of the techniques of measurement). Also, the merged map of Lombardo-Veneto Cadastre has no obvious chromatic jumps within transitions between different sheets, which shows various processes of conservation and aging that sheets themselves have suffered.



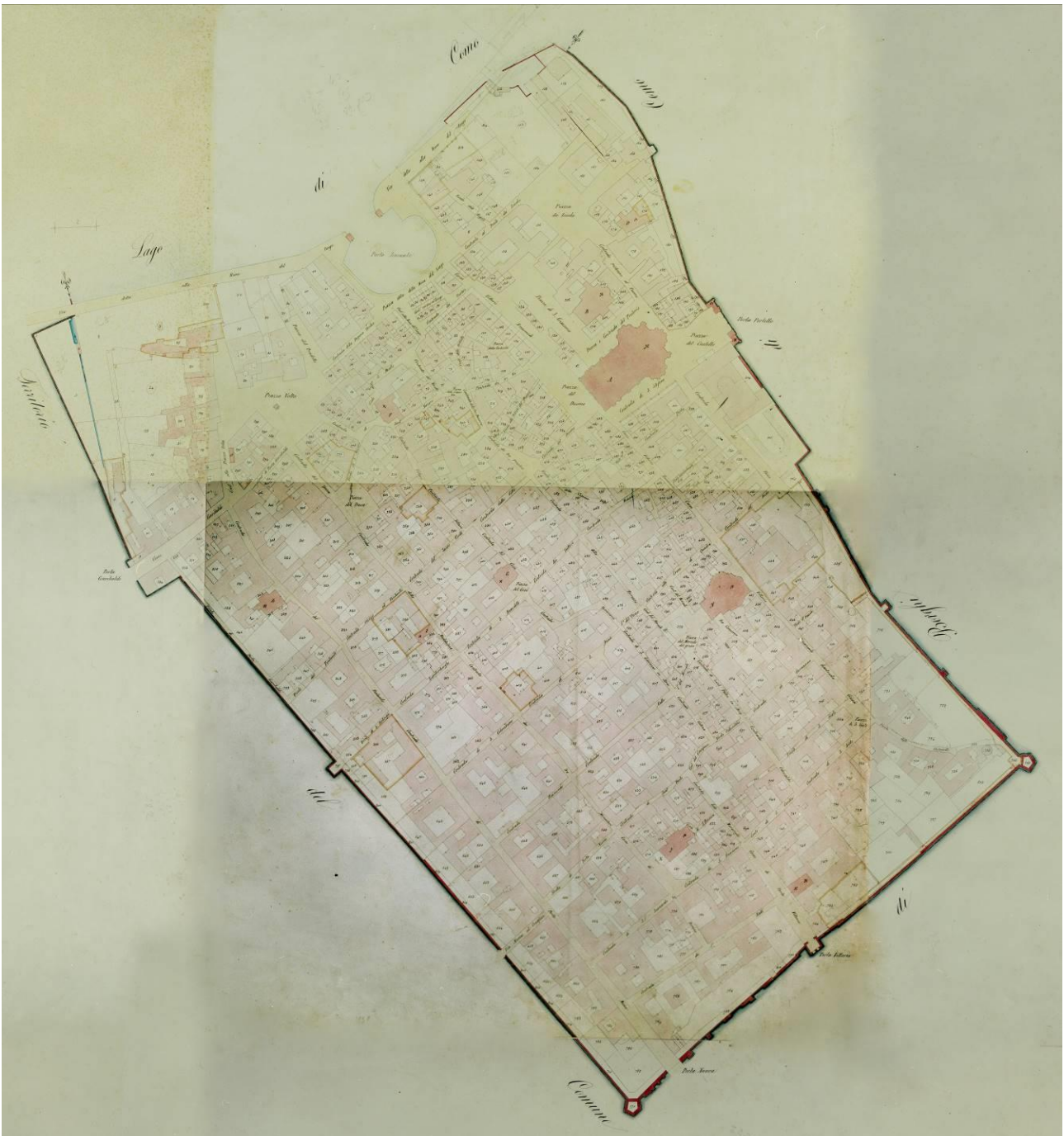


Fig.4.35. Map of Cadaster Lombardo -Veneto of City of Como (1958), complete

### 4.3.3. Lombardo Veneto cadaster map of Como Borghi from 1861

This map also has all the characteristics of the Lombardo\_Veneto cadastral maps. Therefore, shadows and other graphical means for the representation, identification of crops and any other item disappear from the map. The use of color is again reduced to the essentials and respond to already explained needs: all buildings subject to taxes are shown in pink and identified by a cadastral number, those exempt (such as walls and gates to the city, churches and monasteries) are colored in dark carmine and indicated in the map with a capital letter. Backgrounds in blue, as seen, are also used for representation of the main water supply, which is on this map more obvious than on that of the Walled City map.

The important difference, obviously, with respect to the previous map, is that this map represents the whole area of the municipality of Como, but excludes the area of the Walled City. Here, there are 10 sheets (Figures: 4.37, 4.38, 4.39, 4.40, 4.41, 4.42, 4.43, 4.44, 4.45, 4.46) that later merged represent the whole map of Como Borghi (Figure 4.47).

In the header of the map, reported on Figure 4.36 only an indication of area is represented: Como Borghi, District I. Como, Como Province. Below this header there is the specification of the of the year 1861. There is also an indication that the map is recognized as the original, followed by the date (February 4, 1875), and the signature of the designer. On the right, there is an indication of the scale. The choice of scale is 1:2000, which is a part of customary Lombardo-Veneto Cadaster, as explained before.

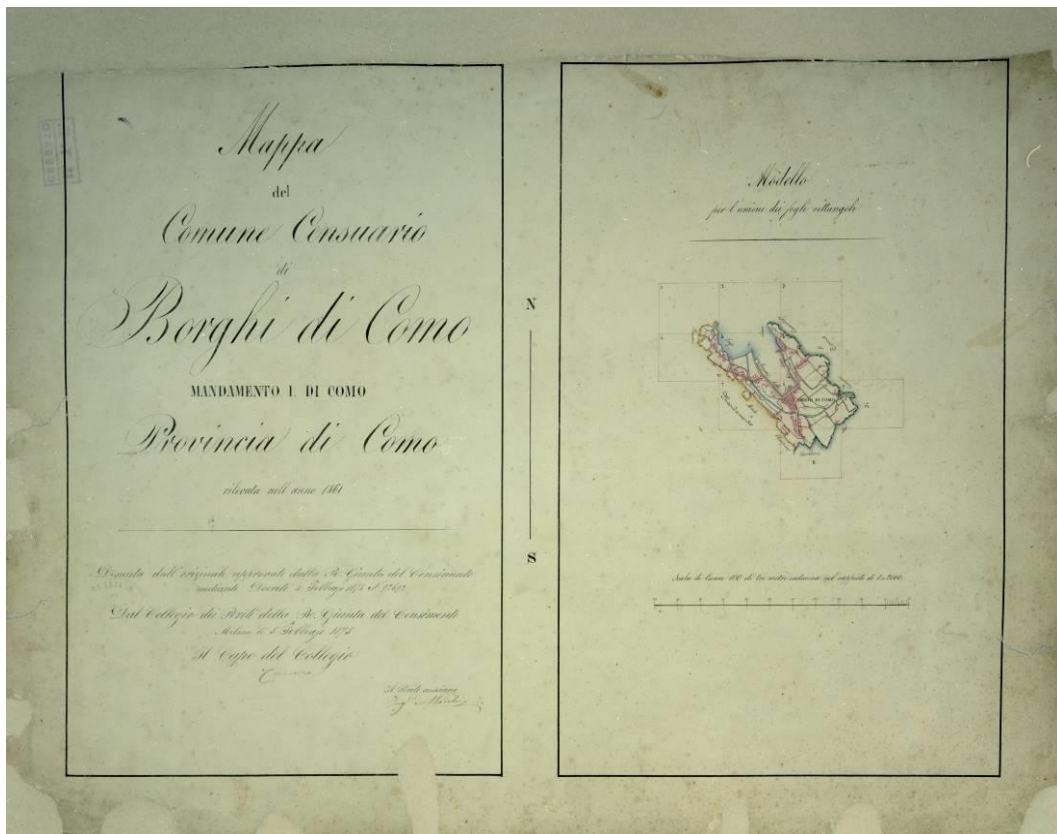


Fig.4.36. Map of Cadaster Lombardo -Veneto of Como Borghi (1861), header. Source: Archivio di Stato di Como

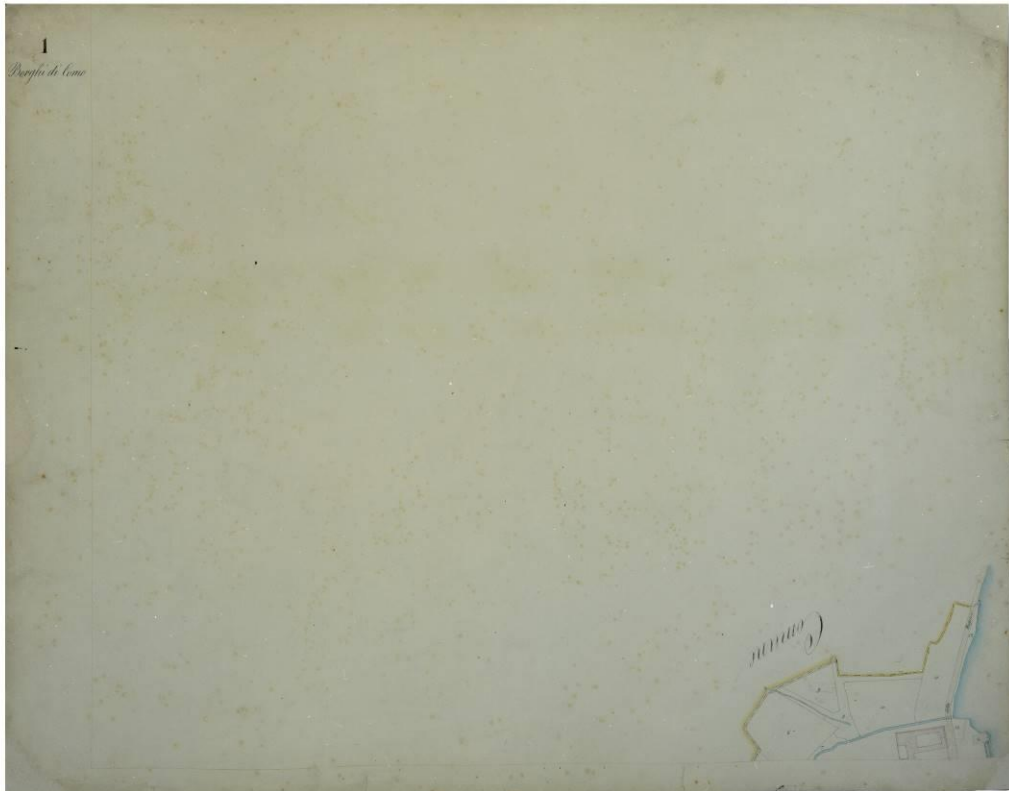


Fig.4.37. Map of Cadaster Lombardo -Veneto of Como Borghi (1961), sheet I. Source: Archivio di Stato di Como



Fig.4.38. Map of Cadaster Lombardo -Veneto of Como Borghi (1961), sheet II. Source: Archivio di Stato di Como



Fig.4.39. Map of Cadaster Lombardo -Veneto of Como Borghi (1961), sheet III. Source: Archivio di Stato di Como



Fig.4.40. Map of Cadaster Lombardo -Veneto of Como Borghi (1961), sheet IV. Source: Archivio di Stato di Como





Fig.4.41. Map of Cadaster Lombardo -Veneto of Como Borghi (1961), sheet V. Source: Archivio di Stato di Como



Fig.4.42. Map of Cadaster Lombardo -Veneto of Como Borghi (1961), sheet VI. Source: Archivio di Stato di Como



Fig.4.43. Map of Cadaster Lombardo -Veneto of Como Borghi (1961), sheet VII. Source: Archivio di Stato di Como



Fig.4.44. Map of Cadaster Lombardo -Veneto of Como Borghi (1961), sheet VIII. Source: Archivio di Stato di Como



Fig.4.45. Map of Cadaster Lombardo -Veneto of Como Borghi (1961), sheet IX. Source: Archivio di Stato di Como



Fig.4.46. Map of Cadaster Lombardo -Veneto of Como Borghi (1961), sheet X. Source: Archivio di Stato di Como





*Fig.4.47. Map of Cadaster Lombardo -Veneto of Como Borghi (1961), complete*



#### 4.3.4. Update of the Lombardo Veneto map of the City of Como (1873)

Taken in the year of 1873 this map updates and replaces the previous Cadaster Lombardo-Veneto map of a City of Como, dated in 1858. This map is similar to the preceding, divided again into 6 sheets having exactly the same size (69.7 x 53.8 cm) and strictly containing the same portion of the territory of the corresponding sheets they replace. Interestingly, performed in 1873, this map precedes the activation of the stable wealth in the province of Como (which took place in 1876) of well three years. From this we can deduce that the previous map of 1858 has not been ever used for the cadastral purpose, precisely because it has been replaced with this from 1873, even before the cadaster was activated in the Como area.

In the header of the map, reported on Figure 4.48, this time an official designation of the map does not appear, but only an indication of area is represented: City of Como, District I. Como, Como Province. Below this header there is the specification of the update of year 1873, and below, the stamp of the Internal Finances of Como and the signature of the Intendant. There is also an indication that the map is recognized as the original, followed by the date (Como August 10, 1875), and the signiture of the designer. The 6 map sheets are depicted in Figures: 4.49, 4.50, 4.51, 4.52, 4.53, and 4.54.

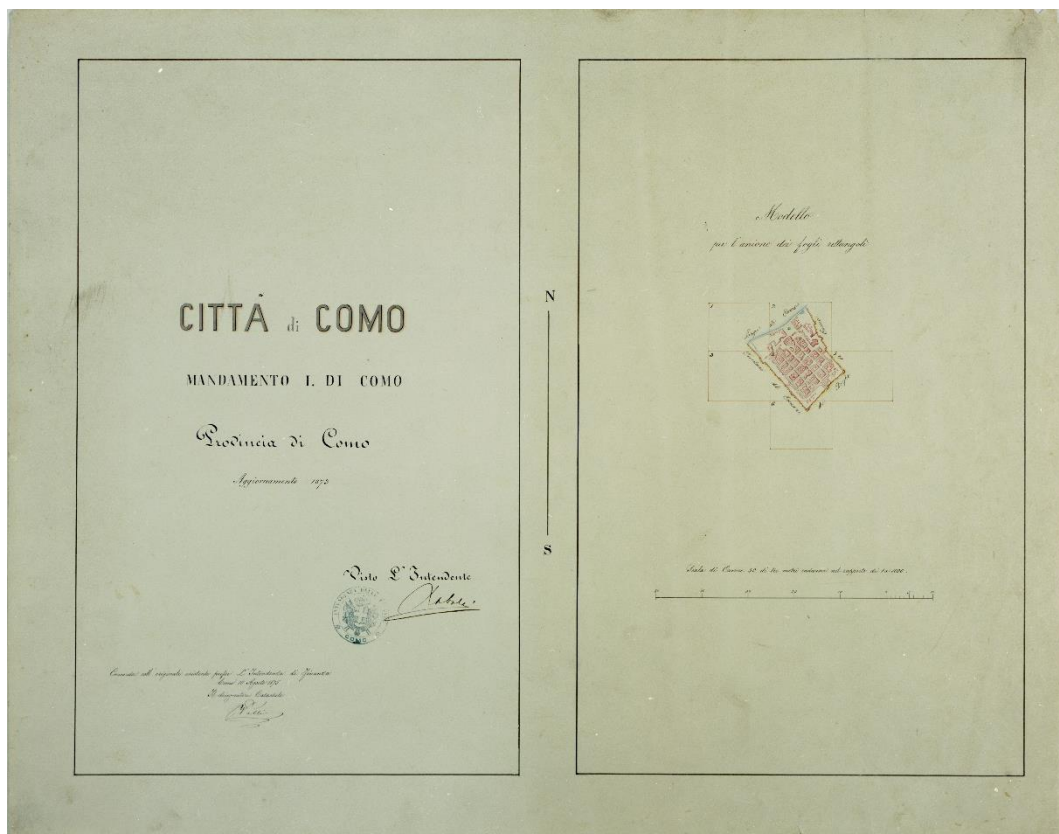


Fig.4.48. Map of Cadaster Lombardo -Veneto of City of Como (1873), sheet: header. Source: Archivio di Stato di Como.

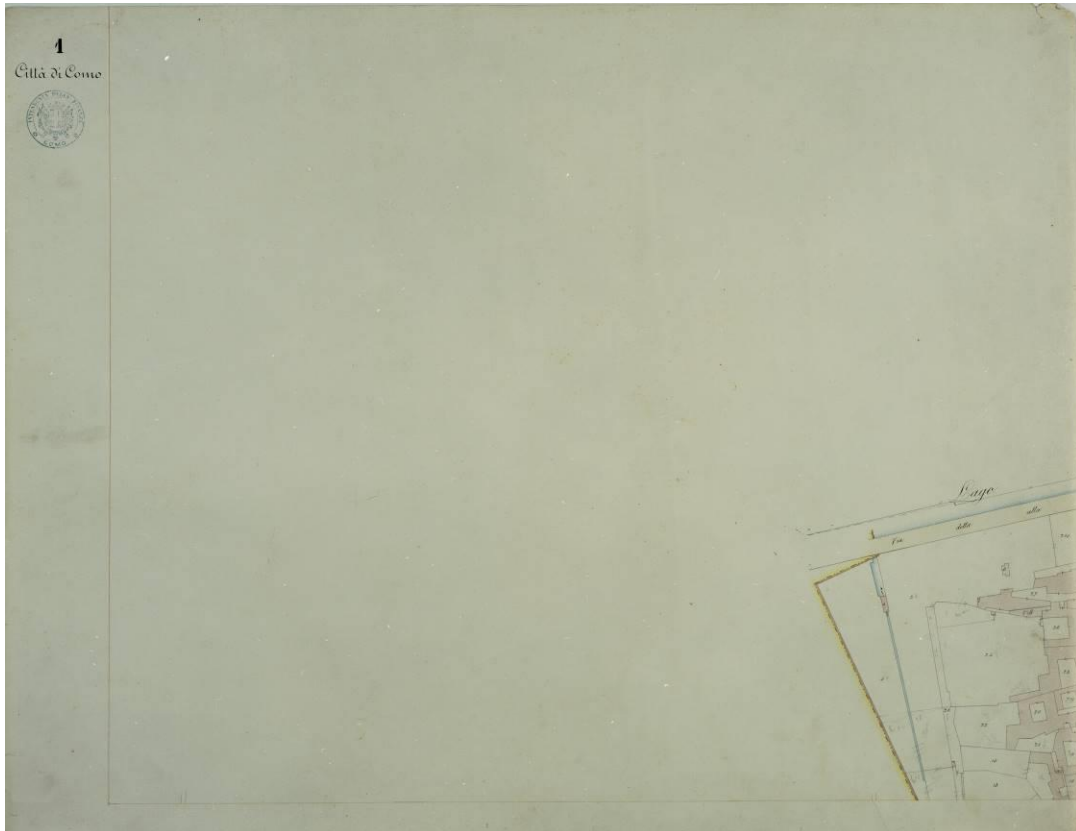


Fig.4.49. Map of Cadaster Lombardo -Veneto of City of Como (1973), sheet: I. Source: Archivio di Stato di Como.



Fig.4.50. Map of Cadaster Lombardo -Veneto of City of Como (1973), sheet: II. Source: Archivio di Stato di Como.



Fig.4.51. Map of Cadaster Lombardo -Veneto of City of Como (1973), sheet: III. Source: Archivio di Stato di Como.



Fig.4.52. Map of Cadaster Lombardo -Veneto of City of Como (1973), sheet: IV. Source: Archivio di Stato di Como.



Fig.4.53. Map of Cadaster Lombardo -Veneto of City of Como (1973), sheet: V. Source: Archivio di Stato di Como.



Fig.4.54. Map of Cadaster Lombardo -Veneto of City of Como (1973), sheet: VI. Source: Archivio di Stato di Como.



The changes that occurred in the urban structure of the Walled City in the 15 years from 1858 do not naturally appear with respect to considering the duration of the millennial history of the old town of Como. But, careful comparison of the corresponding sheets of the two maps, however, reveals that some significant changes of entities actually happened. This is obvious because the need for providing the update (with all the difficulties and costs that it entails) can only be born from the changes in the urban configuration in no small measure. The change was probably more significant than as it can be seen from maps, and in particular from the sheet II of both periods (Figs. 4.29 and 4.50), is the transformation of the Port Lacuale that appears in the map of 1858 in today's Piazza Cavour present in that of 1873. The characteristics and graphic contents of the map, are entirely geared to those of cartography of previous years, in line with the entire production of the Cadaster Lombardo-Veneto orientation to the north, the absence of ornamentation, the same meaning of the colors and the presence of numerous annotations in pencil. On the latter point is to be noted that the map remained in force for more than two decades, and it is replaced by a later update dating back to 1900. The long period in which the map was used justifies such a great wealth of detail added, drawings of the buildings and of the rear building and cancellations of those that no longer exist.

The scale at which the map is made is still in continuity with the previous one from 1858, 1:1000. The indication, shown in the sheet with header (Figure 4.48) is magnified below, at Figure 4.55. It shows that both the unit of measurement, and the extension of the bar, have been aligned with those used 15 years earlier.

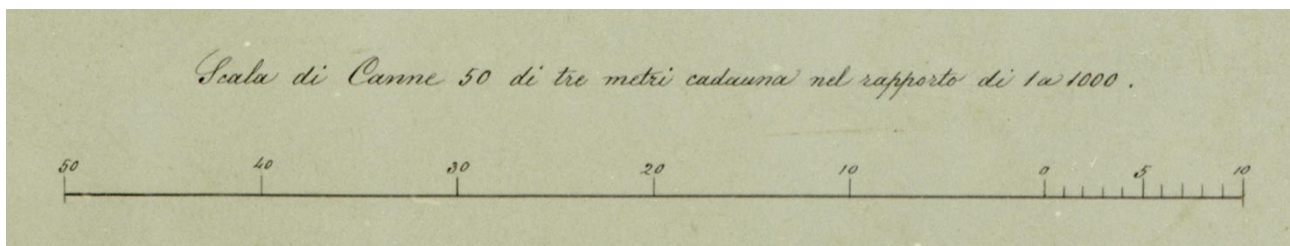


Fig.4.55. Indications of the scale. Source: Map of Cadaster Lombardo -Veneto of City of Como (1973)

Even the technical characteristics of the images of map sheets, provided by the State of Como after scanning with the same scanner Epson Perfection V700 Photo, coincide with those of the map of 1858. As with previous maps, Adobe Photoshop software has allowed the generation of a mosaicked map useful for further processing. The image, shown in Fig 4.56 shows a remarkable quality from the point of view of geometric correspondence, and from that of the overall graphic performance.



Fig.4.56. Update of the map of Lombardo –Veneto Cadaster of City of Como (1973), complete

#### 4.3.5. Update of the Lombardo Veneto map of the Como Borghi (1900-1902)

Taken in the years from 1900 to 1902, this map updates and previous Cadaster Lombardo-Veneto map of a Como Borghi, dated in 1861. This map is similar to the preceding, divided again into 10 sheets having exactly the same size (69.7 x 53.8 cm) and strictly containing the same portion of the territory of the corresponding sheets they replace. The difference is that for this map, there is no sheet that represents the header. There is the info about the end date of surveying (25. Settembre 1900) and the name of responsible surveyor, on the left side of each of the sheets. Also, there is the indication of a place (Como) and the stamp of the Finance Office, dated on 23.09.1902.

The 10 map sheets are depicted in Figures: 4.57, 4.58, 4.59, 4.60, 4.61, 4.62, 4.63, 4.64, 4.65 and 4.66.

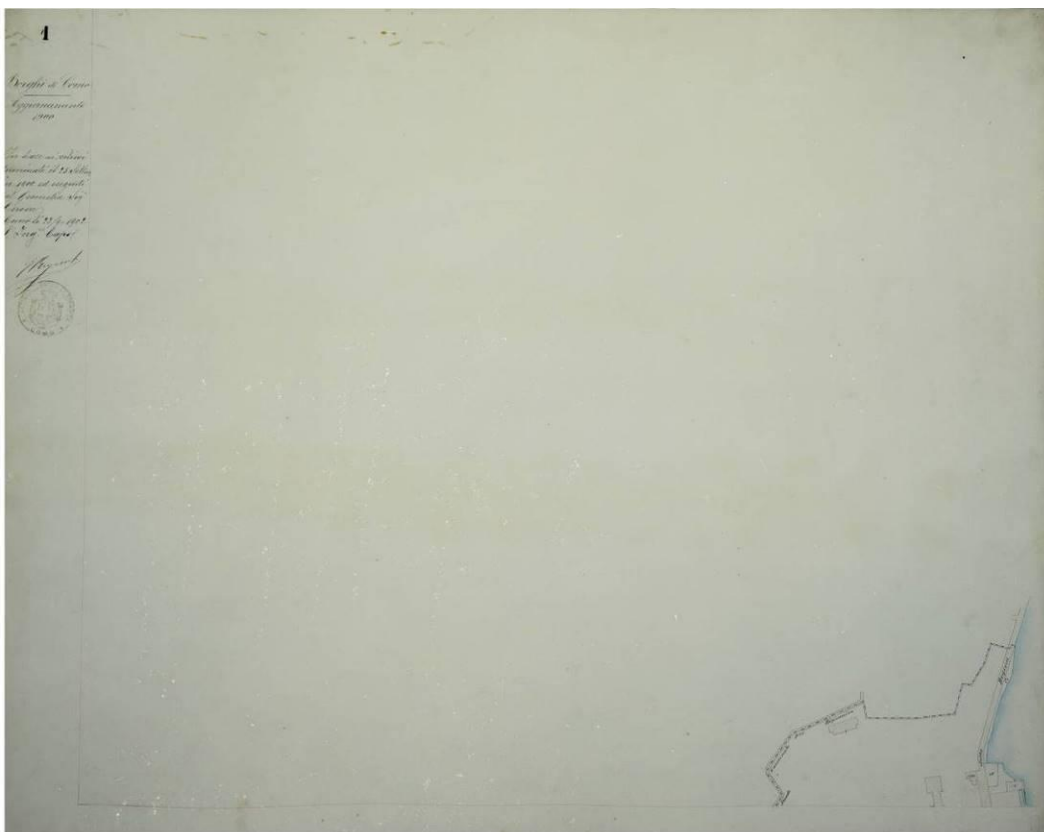


Fig.4.57. Map of Cadaster Lombardo -Veneto of Como Borghi (1900), sheet: I. Source: Archivio di Stato di Como.



Fig.4.58. Map of Cadaster Lombardo - Veneto of Como Borghi (1900), sheet: II. Source: Archivio di Stato di Como.



Fig.4.59. Map of Cadaster Lombardo - Veneto of Como Borghi (1900), sheet: III. Source: Archivio di Stato di Como.



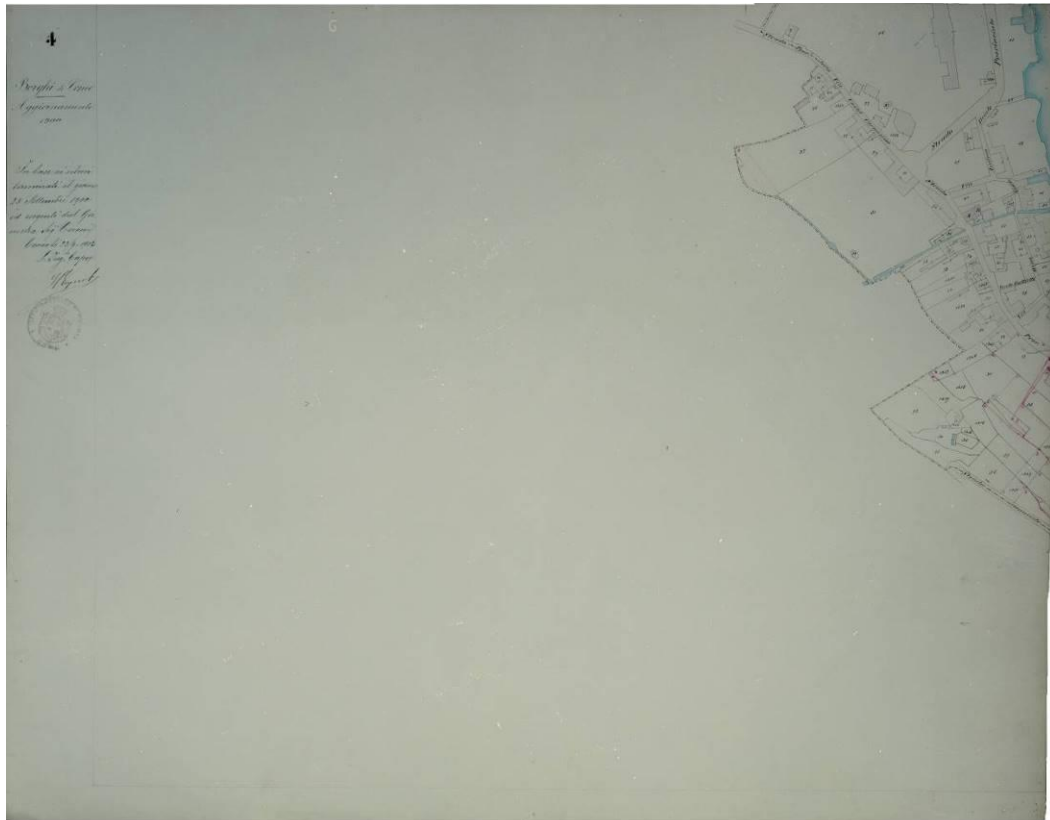


Fig.4.60. Map of Cadaster Lombardo -Veneto of Como Borghi (1900), sheet: IV. Source: Archivio di Stato di Como.



Fig.4.61. Map of Cadaster Lombardo -Veneto of Como Borghi (1900), sheet: V. Source: Archivio di Stato di Como.



Fig.4.62. Map of Cadaster Lombardo -Veneto of Como Borghi (1900), sheet: VI. Source: Archivio di Stato di Como.



Fig.4.63. Map of Cadaster Lombardo -Veneto of Como Borghi (1900), sheet: VII. Source: Archivio di Stato di Como.



Fig.4.64. Map of Cadaster Lombardo -Veneto of Como Borghi (1900), sheet:VIII. Source: Archivio di Stato di Como.



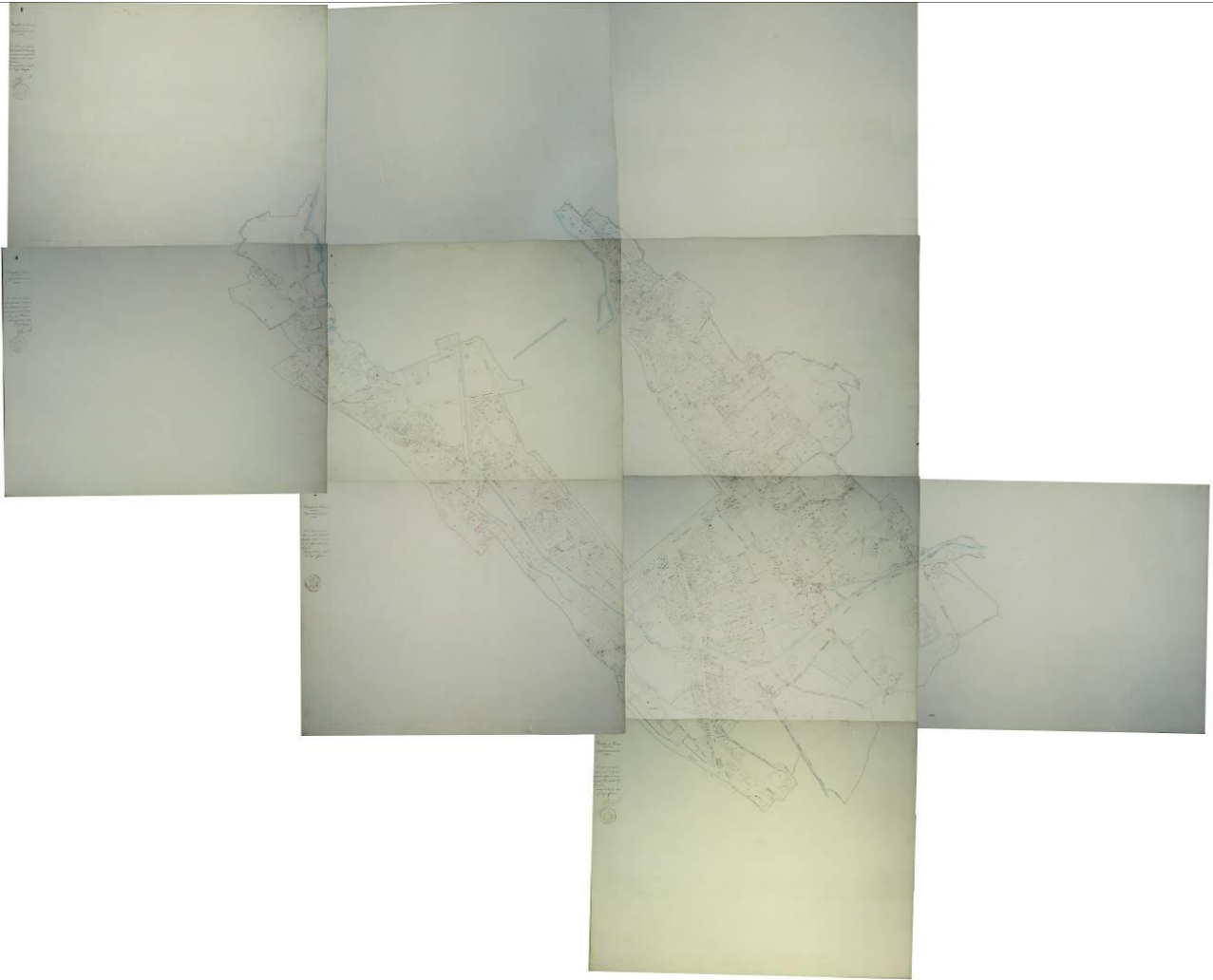
Fig.4.65. Map of Cadaster Lombardo -Veneto of Como Borghi (1900), sheet: IX. Source: Archivio di Stato di Como.



Fig.4.66. Map of Cadaster Lombardo -Veneto of Como Borghi (1900), sheet: X. Source: Archivio di Stato di Como.

Interestingly, there is no scale indication in any of the sheets of this map. This is maybe due to the fact that there is no sheet with the header, where the scale was indicated usually for the previous maps. But, the technical characteristics of the images of map sheets, provided by the State of Como after scanning with the same scanner Epson Perfection V700 Photo, coincide with those of the map of 1861. As with previous maps, Adobe Photoshop software has allowed the generation of a mosaicked map useful for further processing. The image, shown in Fig 4.67 shows a mosaicked image got by combining all the 10 sheets.





*Fig.4.67. Map of Cadaster Lombardo -Veneto of Como Borghi (1900), complete*

## 5. Georeferencing of the historical maps of Como

### 5.1. Basics of georeferencing

The georeferencing is applied here as the process, which assigns to the historical maps a metric reference from the actual geospace or its mappings. When the metric reference is related to the system of earth coordinates or their map-projection counterparts, it is called georeference. This assignment is done with the use of geometric transformations applied to points of the historical map with known or given coordinates. These points are called control points. The result of the transformation is that all the other points of the historical map are then getting coordinates which are predicted (through proper interpolation functions) from the known or given coordinates of the control points. Georeferencing involves correctly aligning a raster image with a map coordinate system. If a raster image does not contain correct positional information, or if the information is not available, we need to align it to a spatially referenced vector. So, the goal of georeferencing is to find the right transformation from a raster image to a vector representing the corresponding area. In order to define this link, Ground Control Points (GCPs) are needed. Ground Control Points are point features identified on the historical map, for which cartographic coordinates (i.e. coordinates expressed into a current reference and projection system) are also available. These coordinates can be directly obtained from a topographic or GPS survey, but typically they are derived from current digital cartography, such is in this case. Once GCPs have been collected, a georeferencing transformation can be applied.

The typical georeferencing process includes the following steps: (1) identifying a set of control point pairs (CPPs) that link locations on a raster image with corresponding locations in a correctly positioned vector dataset; (2) calculating a transformation function from the raster image to the vector map based on CPPs; (3) transforming and resampling the image. Steps (2) and (3) normally are implemented by software. Step (1) is mainly a manual process. It requires the user to have substantial knowledge about the geographic allocation of the raster image in order to manually establish CPPs.

It is called global the transformation due to which the best possible metric reference is assigned to the ungeoreferenced map, without keeping unaltered, after the transformation, the coordinates of the control points. The main characteristics of global transformations can be summarized in the next few steps: The transformation is based on parameters which are calculated before the transformation, with the aid of the known coordinates of the control points; the parameters are valid for any point of the map, in other words they concern the map globally; the larger is the number of the control points used for the computation of the parameters the better statistical solution is achieved; a statistical estimate of the transformation results is among the output of the process in terms of regular statistical quantities.

The global transformations are derived from the well-known full polynomial system of equations

$$X_k = \sum_{i=0}^m \sum_{j=0}^n a_{ij} x_k^i y_k^j, Y_k = \sum_{i=0}^m \sum_{j=0}^n b_{ij} x_k^i y_k^j$$

where the summation convention in  $i, j$  is applied up to the order of the polynomial  $m, n$ . This system relates the coordinates of the control points  $X_k$  and  $Y_k$  in the geospace (or its mappings) with their coordinates  $x_k$  and  $y_k$  on the map to be georeferenced, where  $k$  ( $k=1,2,3,\dots$ ) is the control point involved in the transformation. For each point  $k$  a set of two equations are taken and the required value of  $k$  for the solution of the system, depends on the order of the polynomial used. Today these coordinates  $x_k$  and  $y_k$  are obtained digitally from the map to be georeferenced. The quantities  $a_{ij}$  and  $b_{ij}$ , are the unknown parameters which are obtained by the transformation process and are valid all over the area. In a computational process the number of the control points should be always more than the unknown parameters. In the case in which only linear terms are taken into consideration, the above system is providing the linear transformations commonly used in mapping disciplines, known as conformal, affine and projective. The use of non-linear terms provides the higher order polynomial transformations with most used that of the second order.

## 5.2. Process of georeferencing of historical maps

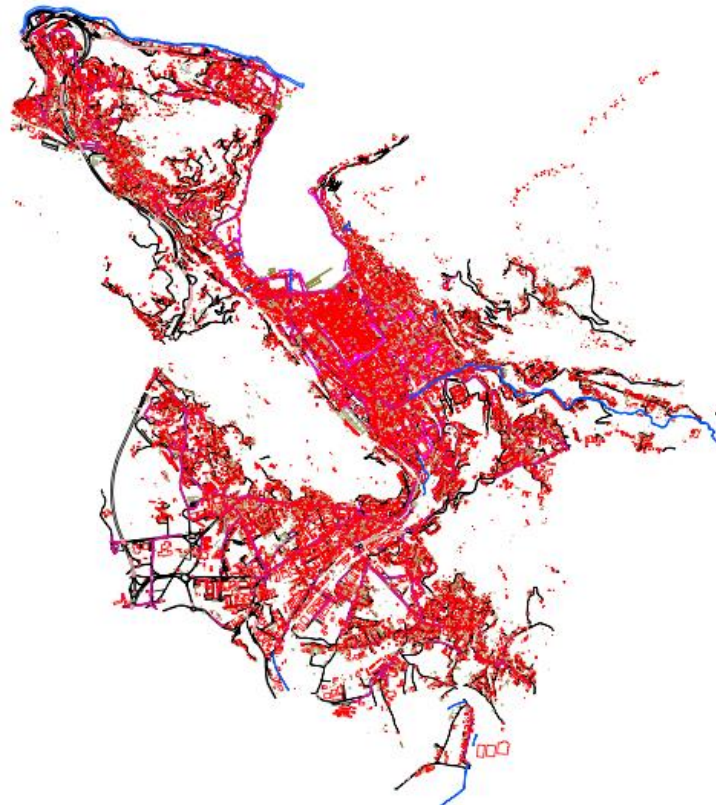
The georeferencing of historical maps was done using the software Quantum GIS for the work within collecting the Control Points, software MatLab for determining the optimal order of the polynomial function that will be used for the transformation, and the software OrthoEngine from the package PCI Geomatics for the process of geometrical correction of the images.

### 5.2.1. Collecting homologous points in Quantum GIS

As mentioned, for collecting the Control Points, the Quantum GIS software was used. Quantum GIS (QGIS) was initially created in 2002 as a simple GIS viewer, but has evolved into one of the premier FOSS (Free and Open source Software) GIS packages. It runs on GNU/Linux, Unix, Mac OSX, and MS Windows. QGIS is a cross-platform free and open source desktop geographic information systems (GIS) application that provides data viewing, editing, and analysis capabilities. It is licensed under the GNU General Public License. Similar to other software GIS systems, QGIS allows users to create maps with many layers using different map projections. Maps can be assembled in different formats and for different uses. It supports vector, raster and database formats, including ESRI shapefiles, spatial data in PostgreSQL/PostGIS, GRASS vectors and rasters, or GeoTiff. Typical for this kind of software is that the vector data is stored as either point, line, or polygon-feature. Different kinds of raster images are supported and the software can perform georeferencing of images.

Having in mind that Control Points are point features identified on the historical map, for them, cartographic coordinates (i.e. coordinates expressed into a current reference and projection system) need to be available. In this project these coordinates have been derived by using digital cartography, more precisely, the shapefiles of the Como Municipality from 2006, which was provided by the Municipality of Como. This is the Semi-implementation of the project "Topographic Database of the Municipality of Como" updated to 2006, not tested positive and therefore unofficial and free of certified guarantees of accuracy and fairness. It can be used exclusively as mere "background" useful for the preparation of thematic maps. The data can only be used for technical/scientific and educational purposes and not for commercial purposes. The data is in the WGS 84, UTM zone 32N reference system (EPSG: 32632). Even do this database has 49 layers, for this project, for the purpose of collecting the homologous points, 10 layers was used:

1. A010101 Area of vehicular circulation
2. A010102 Area of pedestrian circulation
3. A020102 Building
4. A020106 Minor Building
5. A020301 Bridge/Viaduct/Overpass
6. A020505 Harbor or Coastal defense work
7. A040101 River areas
8. A040102 Water bodies
9. A020210 Wall or Thickness division
10. L010105 Pathway



*Fig.5.1.* Shapefiles of the Como Municipality (QGIS; scale 1:65000) Source: Municipality of Como





Fig.5.2. Shapefiles of the Como Municipality zoomed to the walled city of Como (QGIS; scale 1:8100)

By using the functionality of the raster plug in called Georeferencer, in the QGIS, it is possible to collect homologous points, get the standard deviations for the selected transformation function, and finally, georeference the image. It is possible to check the residuals whenever adding a new point, and also to get a mean one. The next table (Fig. 5.3) is an example of the individual residuals of the points (Example of Teresian map, 170 points).

id	srcX	srcY	dstX	dstY	dx[map units]	dy[map units]	residual[map units]
0	4946.63	4712.55	506617.20	5072567.85	-0.06	1.21	1.21
1	4990.60	4648.12	506624.89	5072585.48	-0.14	1.91	1.92
2	4131.76	5072.67	506434.01	5072439.61	-3.27	-3.56	4.83
3	4837.99	4225.65	506561.75	5072681.37	1.33	2.55	2.88
4	4756.34	3932.25	506524.09	5072752.42	2.33	-0.16	2.33
5	4426.76	4030.58	506446.58	5072708.96	1.86	1.24	2.23
6	4064.30	4196.71	506370.03	5072649.32	-4.17	0.24	4.18
7	4166.64	4474.19	506411.61	5072586.37	-4.73	-0.11	4.73
8	4590.21	4549.95	506515.39	5072586.80	2.74	3.43	4.39
9	5977.72	4285.58	506848.65	5072726.12	5.92	4.14	7.22
10	5454.25	3953.56	506702.07	5072779.74	2.00	4.71	5.11
11	5137.56	4047.32	506630.70	5072741.08	-1.60	3.13	3.51
12	4540.37	4365.70	506491.96	5072633.58	3.51	-0.35	3.53
13	5307.25	3668.96	506650.19	5072844.46	1.16	2.64	2.89
14	5007.88	3780.38	506579.62	5072800.53	2.11	2.88	3.57
15	4905.79	3492.54	506536.72	5072864.21	3.48	5.07	6.15
16	5236.94	3480.50	506620.44	5072887.61	2.84	2.43	3.74
17	4331.74	3797.62	506411.60	5072764.57	0.09	-1.73	1.73
18	3975.25	3957.13	506333.46	5072704.76	-3.21	-0.60	3.27
19	4219.35	3542.95	506366.92	5072821.99	2.44	-2.06	3.20
20	4559.38	3443.09	506449.18	5072866.72	0.71	-3.78	3.85
21	4419.07	3278.93	506404.48	5072899.75	0.97	-3.65	3.78
22	5112.73	3267.24	506578.96	5072935.38	1.26	0.86	1.53
23	4757.01	2886.17	506471.71	5073007.71	-2.25	3.89	4.49
24	4321.30	3128.72	506374.48	5072934.38	-1.95	-6.30	6.60
25	4020.77	3245.52	506307.05	5072887.42	-4.15	-4.43	6.07
26	3782.15	3372.23	506248.06	5072839.16	1.42	-0.38	1.47
27	3884.76	3667.15	506293.28	5072769.38	-1.75	1.80	2.51
28	3610.11	2927.92	506179.87	5072938.48	1.85	1.19	2.20
29	3964.63	2882.60	506271.23	5072972.28	-2.34	-2.34	3.31
30	4272.62	2805.99	506347.30	5073004.84	-4.71	0.62	4.75
31	4555.14	2647.55	506408.23	5073057.55	-2.84	2.35	3.69

Fig.5.3. Example of the individual residuals of control points for the Teresian map (QGIS)

As mentioned before, here, in the QGIS, only the step of collecting the points was done and for the other steps (finding an optimal order of a polynomial function and geometric correction) different software have been used. In the next image, Figure 5.4, the functionality Georeferencer of the QGIS is shown with the example of 170 collected control points on the Teresian map.

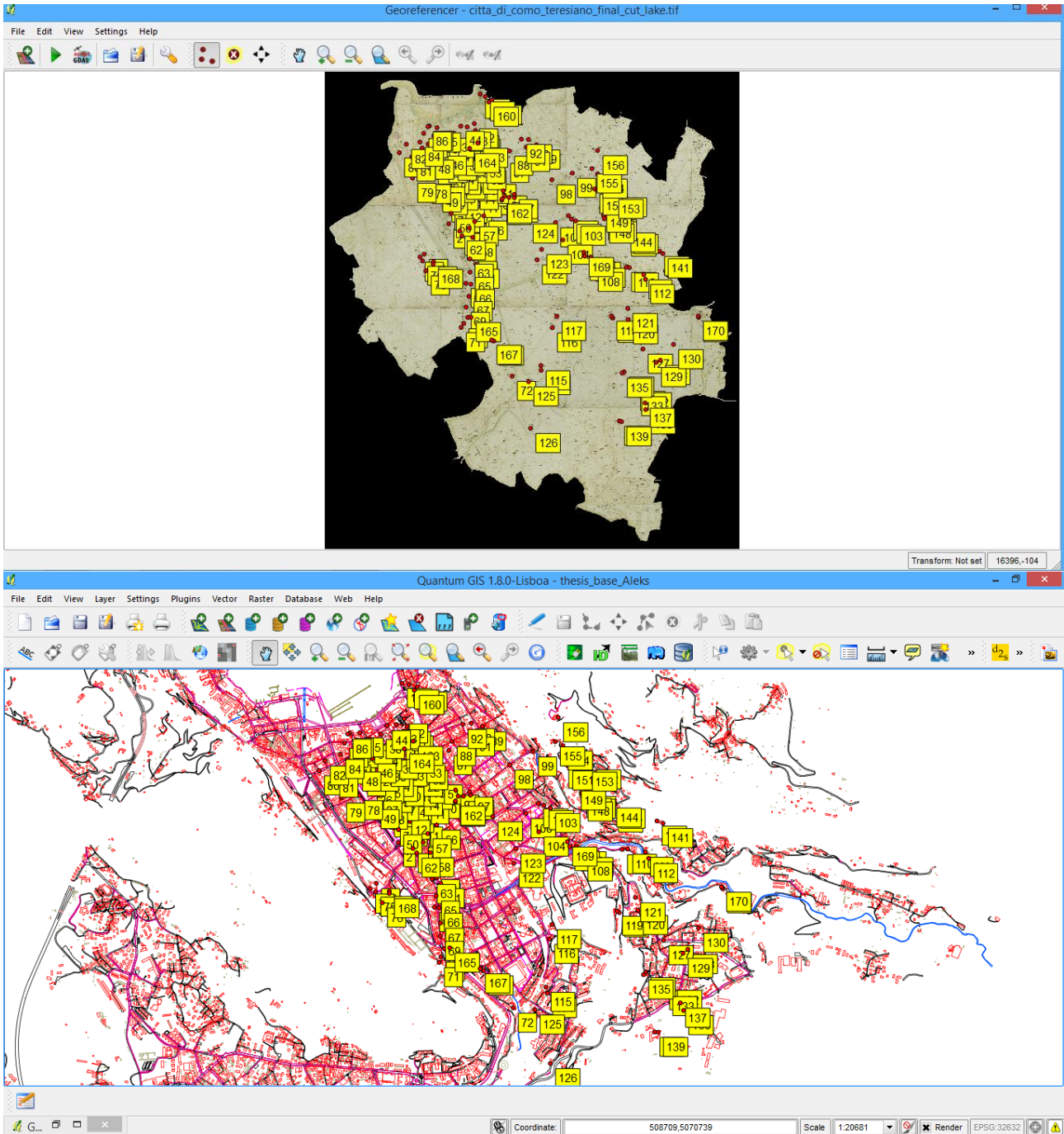


Fig.5.4. Collecting homologous points on for the Teresian map (QGIS)

### 5.2.2. Finding an optimal polynomial order of the transformation function

Unknown parameters which define the mathematical equation between the image coordinate system and the geographic coordinate system should be determined by using the collected homologous points. This is exactly what is done in a process of later geometric correction in the OrthoEngine. But in order to see which of the polynomial orders is best suitable to be used for the process of correction, first the determination of polynomial order has to be assessed. To do this, 20% of a collected points for each of the maps was chosen regularly distributed on the map area, to be excluded from the process of transformation, but to serve as a checking points, for the assessment of accuracy.

Then, the already generated MatLab script<sup>6</sup> (*Anex 1*) was used. This script takes as an input a text file containing, in the 4 columns, the map and image coordinates (X,Y,x,y) of the GCPs and check points (CPs), implements polynomial transformations of order 1,2,3,4,5, and for each of them computes the statistics (mean, standard deviation, minimum, maximum, and RMSE) of the residuals on the X and Y components and on the module, on both the GCPs and CPs. Finally, a statistical procedure is implemented which, on the basis of the computed residuals of GCPs and CPs, determines the optimal order of the polynomial model to be used for georeferencing the map.

This determination of the optimal polynomial order is done on the basis of least squares adjustment. The application of the least-squares solution for the polynomial case can help to understand the two different possibilities that exist for the evaluation of the quality of a transformation model or interpolation, consisting of the concepts of precision and accuracy, often wrongly confused, but in reality very different in the meaning:

The precision defines, in general, the proximity of repeated measurements of the same value; in the specific case of georeferenced images using mathematical models based on known points on the ground, the precision is determined by the proximity of the estimated position of the GCP (points that are used for the calculation of the solution of the model) to the "true" positions of the same points. The accuracy instead expresses, in general, the proximity of a measured value to its real value; in the specific case of georeferenced images using mathematical models based on known points on the ground, the accuracy depends on the proximity of the estimated position of the CP (Check Points, or points where you know the real coordinates, but are not used to compute the solution of the model) to the "real" positions of the same points.

The resulted values for each of the map, given by running the aforementioned script (*Anex 1*) are given in the *Anex 2*.

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<sup>6</sup> By Marco Minghi, Phd Student at Politecnico di Milano

### 5.2.3. Geometric correction of images (OrthoEngine)

OrthoEngine is a powerful photogrammetric tool designed to handle small and large production workloads to efficiently produce quality geospatial products. OrthoEngine's interface is organized along logical workflows to produce orthorectified or geometrically corrected images, digital elevation models (DEMs), three-dimensional vectors, and mosaics.

To be able to execute the geometrical correction, some parameters have to be given to the software:

- Having in mind that the collecting of homologous points was done in the QGIS by using the WGS 84 UTM zone 32 reference system, the geometrical correction of the maps was done exactly referring to it.
- The math modeling method was different for each of the maps, as calculated from the previous step.
- The output pixel spacing (output resolution) differed from map to map depending on a scale and on the scanning quality. The equation connecting the two parameters is:  
 $1 \text{ cm} : \text{Scale factor cm} = 1 \text{ pixel} : x$  (the first part of the proportion means the map has scale 1:Scale factor; the second part means that x (in cm) is the unknown, that is the dimension of an output pixel). Being the resolution of all the scanned maps 600 dpi = 600 pixel/inch = 600 pixel / 2.54 cm, it derives that the proportion is  $1 \text{ cm} * 600 \text{ pixel} / 2.54 \text{ cm} : \text{Scale factor cm} = 1 \text{ pixel} : x$ , from which  $x = \text{Scale factor cm} * 1 \text{ pixel} / (1 \text{ cm} * 600 \text{ pixel} / 2.54 \text{ cm}) = \text{Scale factor} / 234$ . By using this proportion, we get the approximate output resolutions 9cm for the maps at scale 1:2000, and 5cm for the maps at scale 1:1000.
- The resampling method was chosen the same for all the maps- bilinear resampling.
- The output file is in the Geotiff format

After defining all the parameters needed for the geometrical correction, the correction is done by the software in a reasonable amount of time (15 min to 1 hour). The georeferenced images of the historical maps used are shown in the *Anex 3* of this project.

## 6. WebGIS

Geographic Information Systems (GIS) are now widely accepted as powerful and integrated tools for storing, manipulating, visualizing and analyzing spatial data. As a new and emerging technology in the early 1970s, GIS had a profound influence on the capabilities of geographic analysis, and in retrospect marked a turning point in the reinforcement of geography as an explicitly spatial discipline.



With a short history, the integration of the internet and GIS technology has produced an expanding area of research referred to as Web based GIS, Internet GIS, On-line GIS, and Internet distributed GIS-services. Early implementations were mainly dissemination of static maps. Then interactive maps with pan-identify-zoom features, support for client/server designs, and advanced cartographic and geovisualization tool were developed. Out of this progression, Internet based GIS emerged and expanded to yield Internet distributed GIS services with the capabilities to interact with multiple and heterogeneous systems and servers that support more advanced GIS functions.

Geographic Information Systems are characterized by the ability to integrate geospatial data from a wide variety of sources. The nature of these operations is often based on application models, the current disciplinary approach to the problem at hand. Obviously, maps play an important roles in GIS. Not only do they present the final results of the spatial analysis but they are also critical during the whole iterative process of geospatial data handling. Many maps have been created and used, but during the beginning of the GIS era, map quality was not always acceptable. This is partly due to the fact that not all the people involved in GIS mapmaking were skilled in this process, and partly due to the limited resolution of screens and plotter.

The rise of internet, and particularly WWW, was another stimulant to map use. However the web has also brought specific changes and opportunities due to the characteristics of this medium. These changes are related to the look and function of maps and their dissemination. As such, the use of Web had much wider implications than the rise of a GIS. Today, millions of maps are being used by the audience that earlier on would not necessarily have thought of creating maps themselves.

The expansion of internet based GIS created many new research opportunities in Geographic Information Science. Web based GIS has enhanced the open use of GIS in three main directions: (1) spatial data access and dissemination, (2) spatial data exploration and geovisualization, and (3) spatial data processing, analysis and modeling.

Distributing geospatial information on the Internet is an enforcing factor for information providers. Internet allows all levels of society to access geospatial information, and provides a media for processing geo-related information with no location restrictions. Web-based GIS is evolved from different Web maps and client-server architecture to distributed ones. As such, Internet reshapes all functions of information systems including: gathering, storing, retrieving, analyzing, and visualizing data. The high cost of GIS system, the release of system specific databases, and the enormous software developer efforts on upgrading the system are fading with the introduction of Web-based GIS.

GIS software has enabled users to view spatial data in its proper format. As a result, the interpretation of spatial data has become easy and increasingly simple to understand. Unfortunately, everyone does not have access to GIS, nor would he be able to spend the time necessary to use it efficiently. Web GIS becomes a cheap and easy way of disseminating geospatial data and processing tools. Many organizations are interested to distribute maps and processing tools without time and location restriction to users. Internet technology has made its way to many government organizations as well as numerous households. The ability to get information through Internet made spatial data providers to explore the Internet resources for disseminating spatial information.

Development of the Web and expansion of the Internet provide two key capabilities that can greatly help geoscientists. First, the Web allows visual interaction with data. By setting up a Web

Server, clients can produce maps. Since the maps and charts are published on the Internet, other clients can view these updates, helping to speed up the evaluation process. Second, because of the nature of the Internet, the geospatial data can be widely accessible. Clients can work on it from almost any location.

## 6.1. Web GIS Architectures

In performing the GIS analysis tasks, Web GIS is similar to the client/server typical three-tier architecture. The geo-processing is breaking down into server-side and client-side tasks. A client typically is a Web browser. The server-side consists of a Web Server, Web GIS software and Database (Figure 6.1.).

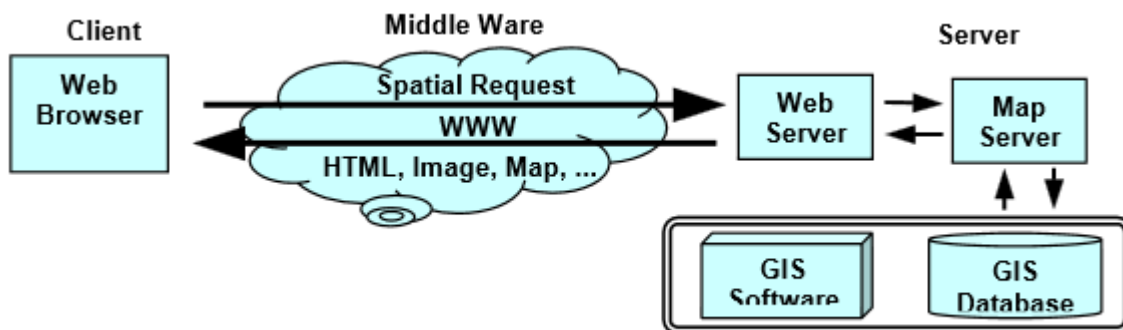


Fig.6.1.. How a typical WebGIS model works Source: Helali 2001

This model of network widely exists within enterprises, in which some computers act as servers and others act as clients. Server simply have the proprietary GIS running, and add a client interface at the client side and a middleware at the server side to communicate between the client and the proprietary GIS software. Recent development in object oriented programming make it possible to produce software components, and send them to the client before running it in the client machine, such as Java classes, ActiveX components and plug-ins.

## 6.2. Open source Web Server used in the Project: GeoServer

The GeoServer project was started in 2001 by The Open Planning Project, a non-profit company based out of New York. The initial target for GeoServer was to be the first open source implementation of the Web Feature Service (WFS) specification. WFS is one of the many standards published by the Open Geospatial Consortium (OGC), an organization mad eup of industry of experts who publish specifications for open geospatial web services. The WFS specification defines a web service used to publish geospatial data in vector format. Since its inception GeoServer has been closely tied to OGC web services. In 2002 GeoServer became an implementation of the OGC Web Map Service (WMS). WMS is a standard which describes how to publish maps in image format. In 2005 the Web Coverage Service (WCS), a web service for publishing data in raster or coverage format came. Today, GeoServer is the reference implementation of the WFS 1.0, WFS

1.1, and WCS 1.1 specifications. It also a fully OGC compliant implementation of the WMS 1.1 and WCS 1.0 standards.

A primary directive of the GeoServer project has always been to make geospatial data as widely available as possible. Providing a robust and reliable implementation of open standards has been crucial in achieving this goal. Equally important has been the effort to support as wide variety of data storage formats as possible. Since its birth GeoServer has been closely tied to the Geotools project, the underlying toolkit providing much of the GIS functionality used in GeoServer. Among other things, Geotools provides the drivers for a variety of different spatial data formats ranging from vector file formats such as Shapefile, GML, and VPF, to relational databases such as PostGIS, Oracle Spatial, and MySQL to raster formats such as GeoTIFF, GTOPO30 etc. With the arrival of major players such as Google, Microsoft, and Yahoo, the landscape of the geospatial world has changed. Google, armed with a friendly exchange format, a powerful desktop client, and an easy to use API for building web applications has successfully provided a way for users who know nothing about GIS to create maps. They have successfully marketed web mapping to the average consumer.

GeoServer has been quick to adopt the new technologies and the new ways of exposing geospatial information that come along with them. In 2007 support for both KML and GeoRSS as output formats for the GeoServer WMS were added. Geographic JavaScript Object Notation (GeoJSON), a simple lightweight vector format, was added to the GeoServer WFS. Support for these technologies and formats is yet another part of achieving the GeoServer vision. They provide alternative ways for pushing data out to the wider web that go beyond the audiences targeted by OGC web services.

### 6.3. Open source JavaScript library used in the project: OpenLayers

OpenLayers is an Open Source map viewing framework, written in pure JavaScript. The OpenLayers framework provides a JavaScript application programming interface (API) which makes it easy to incorporate maps from a variety of sources into your webpage or application, similar to Google Maps and Bing Maps. OpenLayers currently has support for OGC WMS, WFS, GML and many other layers, navigation, icons, markers, and layer selection. As open source code with a practical respect for standards, OpenLayers offers an open market for all geographic data. OpenLayers is agnostic of server-side technologies. It allows anyone to rapidly construct applications using layers from different providers of georeferenced data.

Nowadays, OpenLayers is the most complete and powerful open source JavaScript library to create any kind of web mapping application. In addition to offering a great set of components, such as maps, layers, or controls, OpenLayers offers access to a great number of data sources using many different data formats, implements many standards from *Open Geospatial Consortium* (OGC), and is compatible with almost all browsers.

## 6.4. Implementation of a WebGIS

### 6.4.1. Publishing data on GeoServer

As said, for the implementation of this WebGIS, two main keywords are GeoServer and OpenLayers. First of all, to be able to publish the data via internet, it is needed to put them on some server, which is in this case the GeoServer of version 2.5.1. Installed as a service, on the local disk of a computer, it allows us to store on it all the data needed for this project. In the WebBrowser (Mozilla Firefox used), on the localhost: 8080 port, it is possible to access the GeoServer installed on the computer. In the Figure 6.2., the start page of Geoserver is shown.

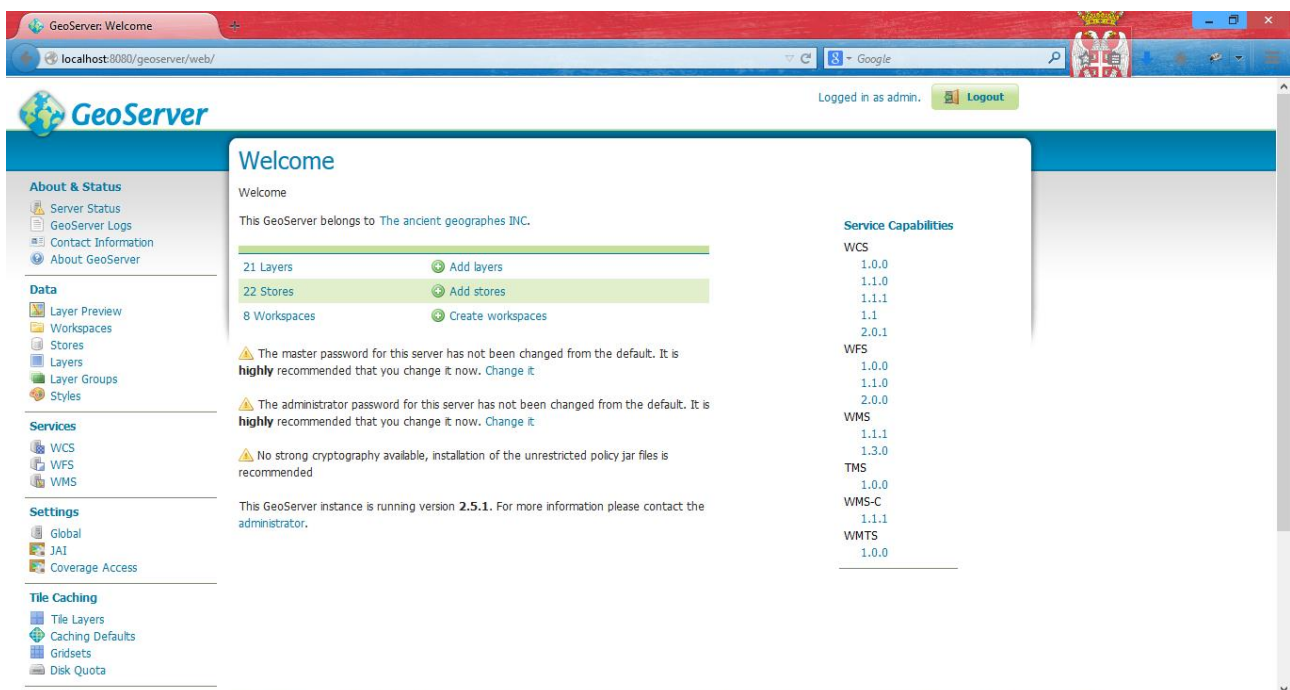


Fig.6.2. Starting page of the Geoserver

At the very beginning of starting a project on GeoServer, it is needed to define the workspace linked to it, where all the data will be stored. A workspace is a container which organizes all other items. In GeoServer, a workspace is often used to group similar layers together. Individual layers are often referred to by their workspace name, then store. Two different layers with the same name can exist as long as they exist in different workspaces. The workspace name is limited of ten characters and may not contain space. In this project, the workspace is referred as Thesis\_Aleks.

Then, the next step is to add the stores needed for storing all the layers. A store connects to a data source that contains raster or vector data. A data source can be a file or group of files, a table in a database, a single raster file, or a directory, for example a Vector Product Format library. Using the store construct means that connection parameters are defined once, rather than for each piece of data in a source. As such, it is necessary to register a store before loading any data. While there are



many potential formats for data source, there are only four types of stores. For raster data, a store can be a file. For vector data, a store can be a file, database, or server. While connection parameters will vary depending on data format, some of the basic information is common across formats. The Workspace menu lists all registered workspaces. The store is assigned to the selected workspace). Data Source Name is the store name as listed on the view page. GeoServer natively supports many formats (with more available via extensions) as shown on the Figure 6.3.

To be able to add the dataset as a store, the data has to be in the root folder of the GeoServer. In this case, all the data is stored at the GeoServer default data directory, subfolders maps or shapefiles, depending whether we are storing the historical maps, or the layers of the digital cartography of Municipality of Como.

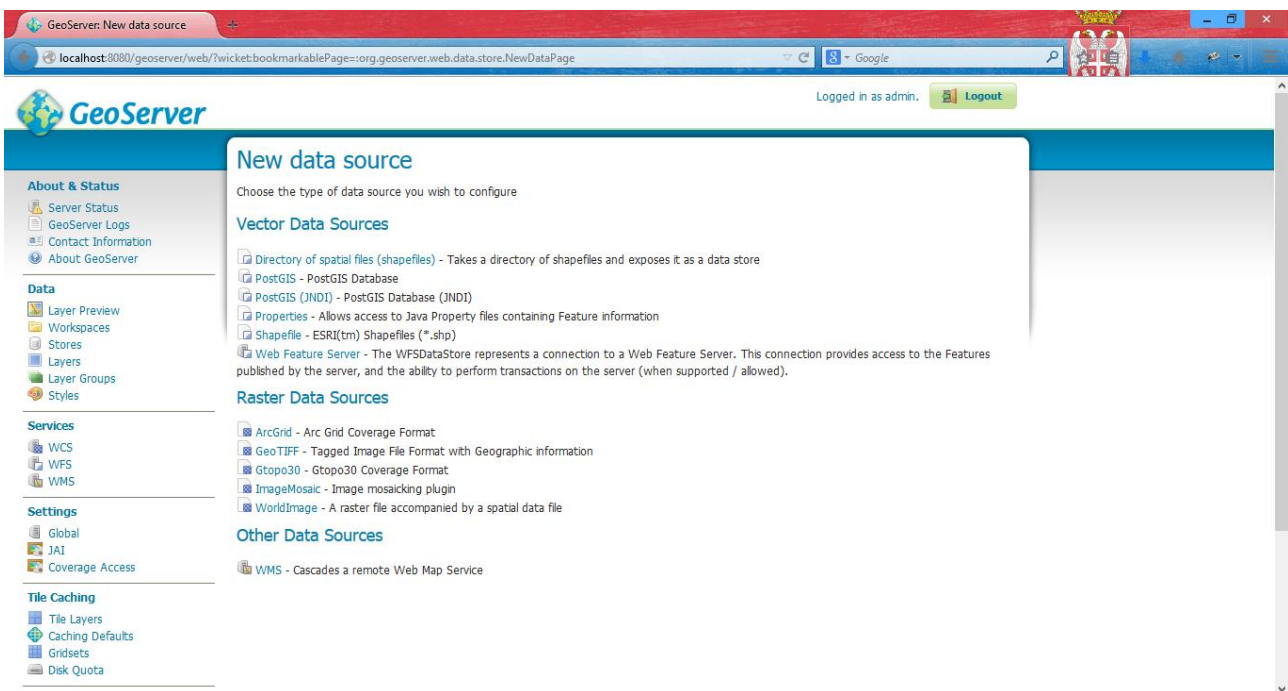


Fig.6.3. Available data sources formats in GeoServer

Next and final step for adding the data on the server is the layer publishing. In Geoserver, the term layer refers to raster or vector data that contains geographic features. Vector layers are analogous to feature types and raster layers are analogous to coverages. Layers represent each feature that needs to be shown on a map. All layers have a source of data, known as a Store. In the layers section, it is possible to view and edit an existing layers, add a new layer, or delete a layer. The Layers View page displays relevant dependencies, that is, the layer within the store within the workspace. The View page also displays the layer's status and native SRS.

The layers added for this project are (all in the workspace Thesis\_Aleks):

- Shapefiles: Area of vehicular circulation, Area of pedestrian circulation, Buildings, Minor Buildings, Bridge, Harbor, River areas, Water bodies, Thickness division, Pathway
- GEOTiff: geoTopo, geoTeresian, geoParishes, geo1858, geo1861, geo1873, geo1900

The shapefiles added are the layers of the Como Municipality database from 2006, already mentioned before. The GeoTiff data represents the historical maps georeferenced in this project.

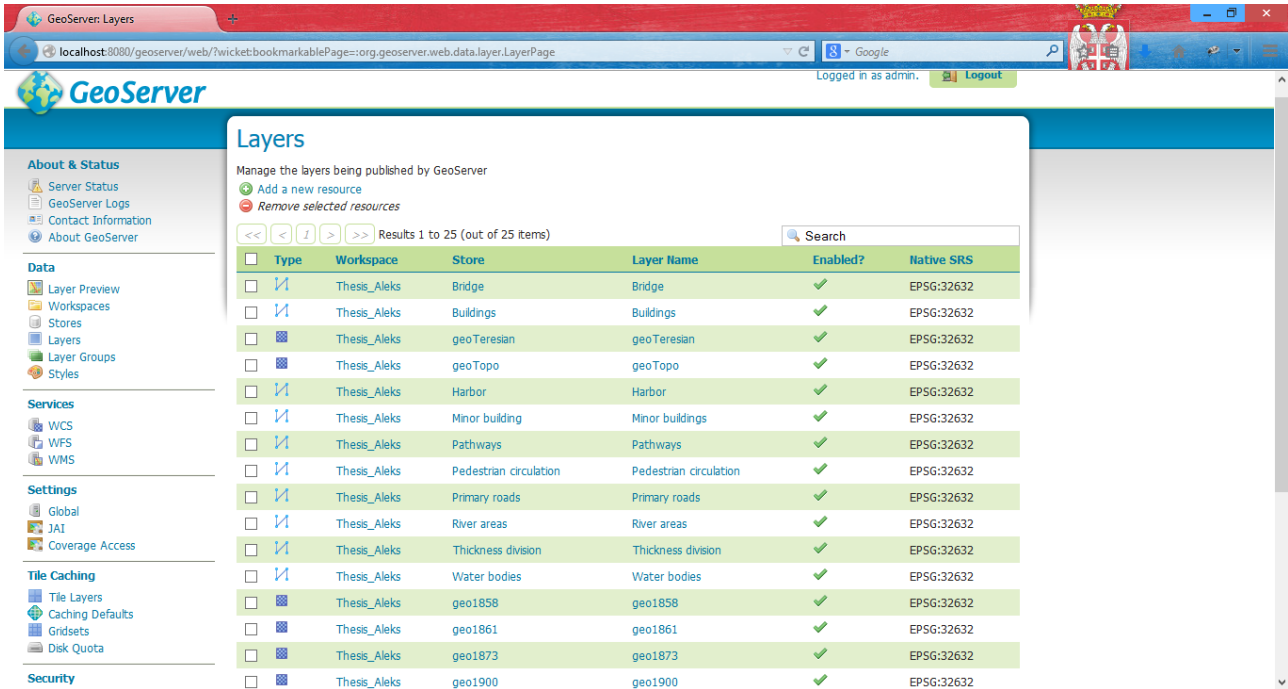


Fig.6.4. Layers stored in GeoServer

Using the layer preview, it is possible to visualize all the layers, to check them. In this project, the existing styles of the layers weren't satisfactory for showing all the layers, so some new styles were added, to represent each of them:

- Roads: black line 1px wide
- Pedestrian circulation: dark green line 1px wide
- Buildings, Minor buildings: red line 1px wide
- Bridge/Viaduct/Overpass: light gray line 1px wide
- Harbor: light blue line 1px wide
- River areas, water bodies: blue line 1px wide
- Wall/Thickness division: light pink line 1px wide
- Pathway: dark gray line 1px wide

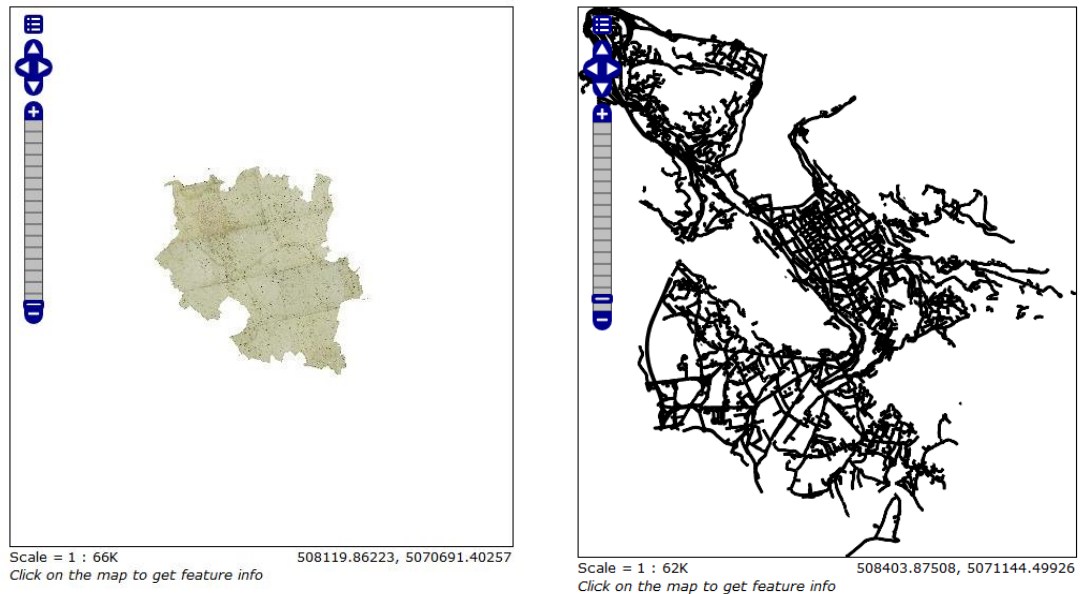


Fig.6.5. Layers preview in GeoServer (Left: geoTeresian layer; Right: roads layer)

#### 6.4.2. Developing a simple WebGIS with use of Open Layers

Apart from the OpenLayers library, *GeoExt* is also used. This is a JavaScript toolkit for building powerful Web mapping applications using JavaScript. It is based on the integration of: OpenLayers for geospatial data management and Ext JS for the GUI customization. The *Ext JS* is the leading JavaScript library for developing desktop-style interactive Web applications. It is released with a dual license: GNU GPL v. 3 for open source applications, and two licenses for commercial applications. Regarding this project, the GeoExt 1.1 with OpenLayers 2.13.1 and Ext JS 3.4.0 is used.

In order to develop WebGIS based on the aforementioned libraries, the development of an HTML code is needed. The important thing is that the HTML code has to refer to the java scripts needed for its development.

Next important thing was to define the map and to add a layers. For this, layers have to be separated into the Base layers and Overlay layers. In this project as base layers, the widely known ones are used (Figure 6.6):

- Google layers: Hybrid, Streets and Physical
- Bing layers: Roads and Aerial with labels
- Open Street Map,

And additionally, as a base layer, also it is made as possibility to choose the database of the Municipality of Como from 2006 (all already mentioned layers together), given as WMS service provided by the GeoServer.

For the overlay layers, two groups have been separated. The first one represents the layers of the Como Municipality database from 2006 (Roads, Pedestrian circulation, Buildings, Minor buildings, Bridge/Viaduct/Overpass, Harbor, River areas, Water bodies, Wall/Thickness division and Pathway. Here, the layers Buildings and Minor buildings is merged into one, as it was the case also for the Rivers and Water areas. All the overlay layers are given as a WMS service provided by the GeoServer (as explained in the chapter 6.4.1.). The other group is the group of Historical maps, Georeferenced (Chapter 5.2.) and also published via GeoServer. Here the layers are: Topographic map XVII century, Theresian map from 1722, Theresian mp from 1722-City perishes, Walled City of Como(1858), Como Borghi (1861), Walled City of Como (1873) and Como Borghi (1900).

Then, additionally, the layer editing, shown at the bottom of the layers represents the empty vector layer, available for storage of the drawings, possibly made by the user.

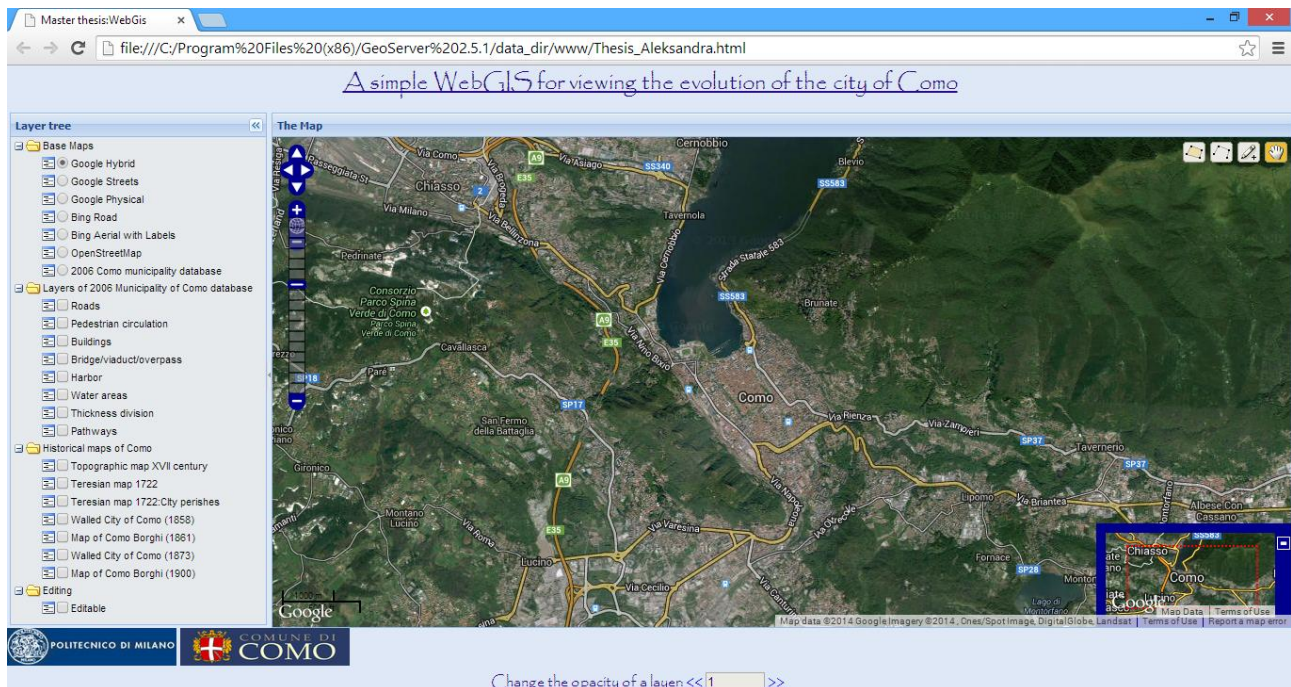


Fig.6.6. Default Base layer of the WebGIS with showing all layers extended

This Layer tree look, wouldn't be possible without the added GeoExt and Ext Jt. Actually, the whole map area, tree layer area and the banners for the title and references are made by using those libraries.

Some basic controls are added on the map as it can be seen on the Figure 6.6. There is a Pan and Zoom Bar on the upper left corner of the map and also the Scale Line for better understanding of the current scale of the map, added at the lower left corner. Then, on the right lower corner, there is an Overview map, showing the area visible on the main map inside of the red rectangle. This Overview map always represents the Default Base layer: Google Hybrid. In the right upper corner there are the editing functionalities, which allow users to draw lines, polygons or points which are then stored in the layer Editable.



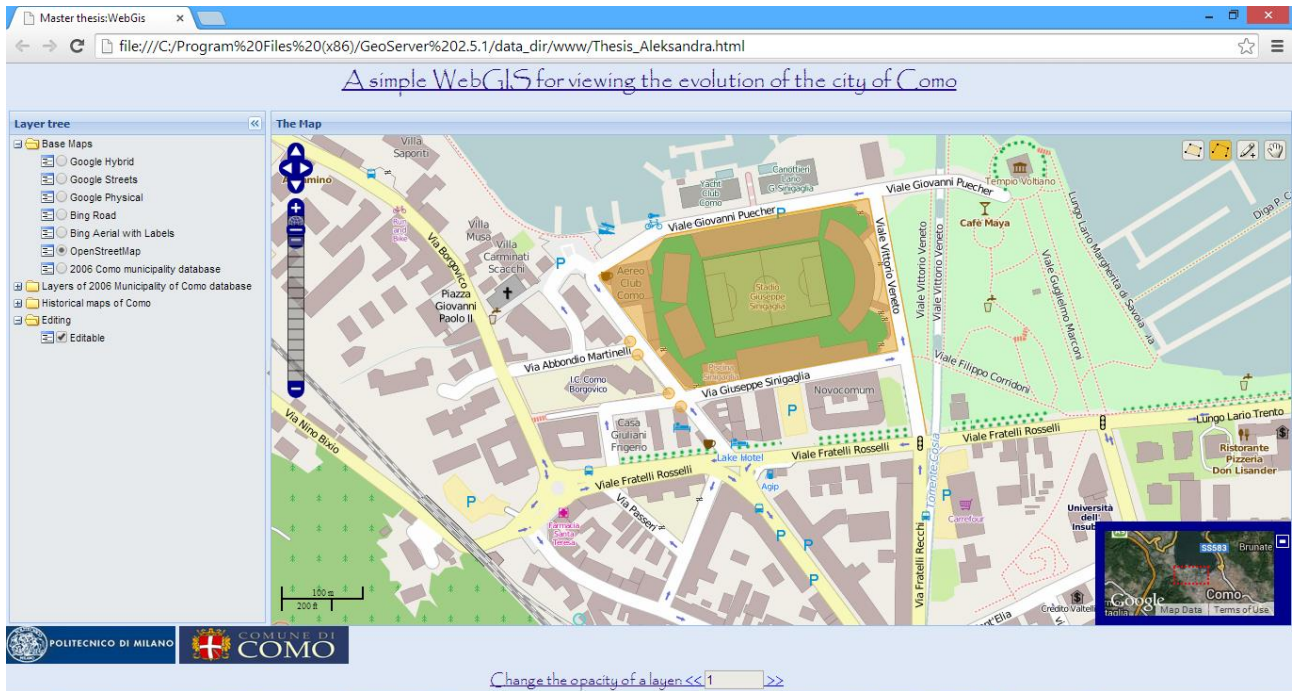


Fig.6.7. Drawing of a point, line and polygon by using the Editing tools (Stadium of Como)

Apart from the important links to the Poltecnico di Milano and Municipality of Como, in the lower banner, there is a tool for changing the opacity of the maps. This has its purpose especially with the historical maps, because in this way, when overlapping the maps, it is possible to compare different periods and to see the evolution of the Como Municipality, as it was the purpose of this simple WebGIS.

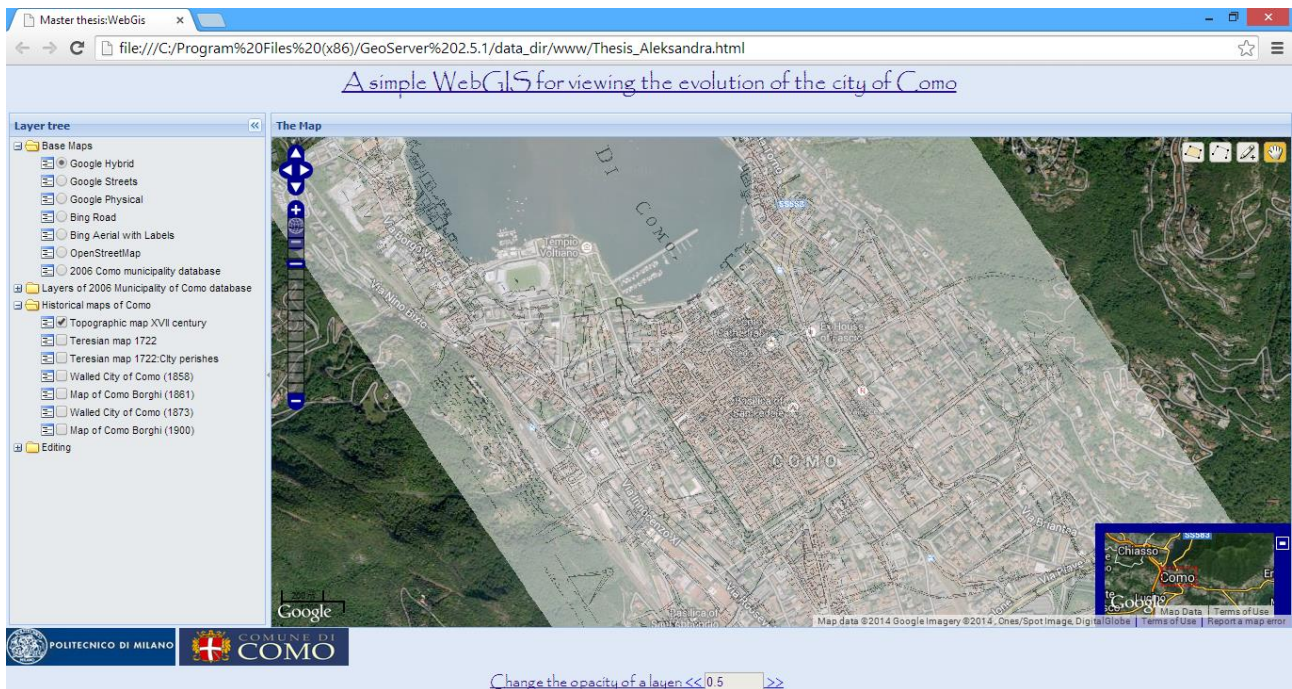


Fig.6.8. Topographic Map of Como (XVIIc.); Opacity: 0.5





Fig.6.9. Topographic Map of Como (XVIIc.); Opacity:0.5

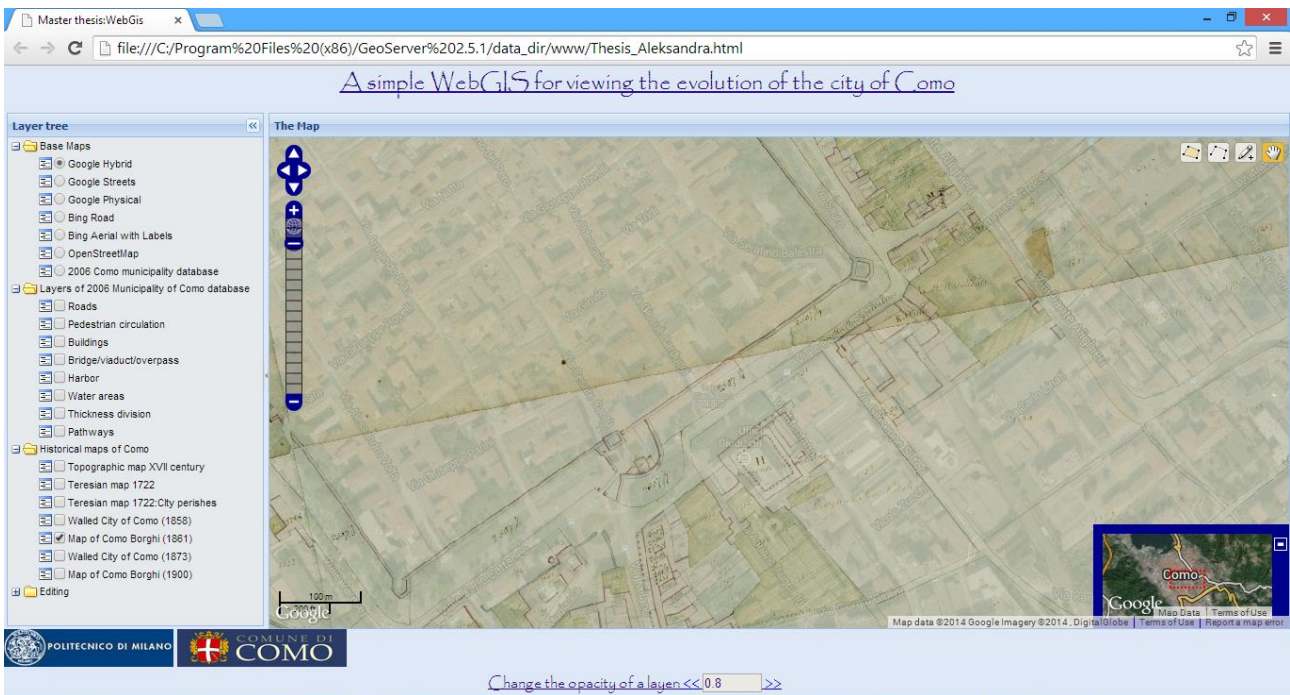


Fig.6.10. Map of Como Borghi (1861); Opacity:0.8





Fig.6.11. Maps of Como Borghi (1861) and Walled city (1858) together

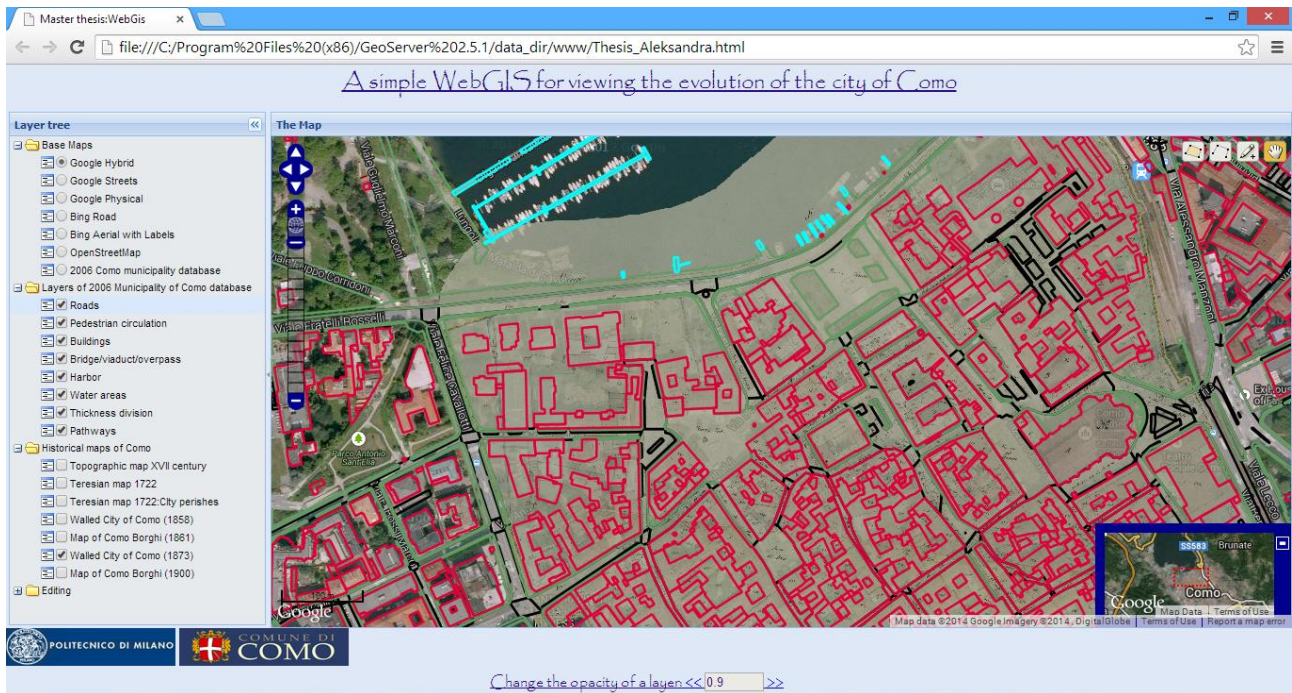


Fig.6.12. Walled city of Como (1873) overlaid with layers of Como Municipality database; Opacity:0.9

## 7. Conclusion

We live in the century of information and a lot of this information is susceptible to being represented geographically. This is probably the main feature that has made Geographic Information System (GIS) become one of the most important aspects of many companies. GIS-related technologies are a growing industry and, because of this, GIS has become a desired skill for many professionals. Recent developments in digital technologies have opened new possibilities for the exploitation of cartographic heritage. The usage of historical maps in such applications gained a new dimension thanks to the latest advancements in the fields of digital technologies and Geographic Information Systems (GIS), which allowed to study ancient cartography no longer as pure archival documentation, but as real geographic information. The universality of the Web and the improvement on the browsers' performance has made it possible for the Web to become a main part of the current GIS and has subtracted the importance of desktop applications because of its capabilities: the browsers allow us to show data visualizations to the masses, create online data editors, and so on.

The usage of historical maps in such applications gained a new and revolutionary dimension thanks to the latest advancements in the fields of digital technologies and Geographic Information Systems (GIS), which allowed to study ancient cartography no longer as pure archival documentation, but as real geographic information. Georeferencing provides thus an opportunity, allowing to directly integrate historical cartography with every kind of current spatially referenced product and perform on them all the desired GIS analysis.

The open source license guarantees the freedom to read, redistribute, modify and use Software freely (OSI). This license plays an important role in breaking down barriers where the cost limits the use of public spatial data and the access to GIS tools. With an effort, the open source GIS has grown its popularity in geo-informatics community. The purpose of this thesis was to make use of free and open source software to conceive a Web based system able to access georeferenced historical maps and provide their visualization.



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<http://www.herpnet.org/herpnet/Gazetteer/GeorefSteps.html>

<http://en.wikipedia.org/wiki/Como>

<http://www.archeologicacomo.it/storiadicomo/index.asp>

<http://www.comune.como.it/citta/conoscere-como/storia>

<http://www.lakecomoguide.com/lake-como-history.html>

<http://www.britannica.com/EBchecked/topic/129450/Como>

<http://motherearthtravel.com/italy/como/history.htm>

[http://webgis.como.polimi.it/como\\_hist](http://webgis.como.polimi.it/como_hist)

<http://www.archivi.beniculturali.it/ASCO>

<http://www.archeologicacomo.it>

<http://www.pcigeomatics.com>

<http://www.geoserver.org>

<http://www.openlayers.org>

<http://www.geoExt.org>

[http://webgis.como.polimi.it/GIScourse10/como\\_hist\\_utente08/html/en\\_aboutproject.html](http://webgis.como.polimi.it/GIScourse10/como_hist_utente08/html/en_aboutproject.html)

## Anex 1: MatlabScript for determining the optimal polynomial order

```
% This script takes as input a text file containing, on the 4 columns, the map and image coordinates (X,Y,x,y)
of the GCPs and

% CPs, implements polynomial transformations of order 1,2,3,4,5, and for each of them computes the
statistics (mean, standard

% deviation, minimum, maximum, and RMSE) of the residuals on the X and Y components and on the
module, on both the GCPs and CPs.

% Finally, a statistical procedure is implemented which, on the basis of the computed residuals of GCPs and
CPs, determines the

% optimal order of the polynomial model to be used for georeferencing the map.

% In order to use the script, you need to specify:

% - the name of the text file containing the coordinates of the points (lines 22,25,27);

% - the number of GCPs (line 33);

% - the indexes of the points used as CPs (line 39);

% - the name of the output text file you want to generate (lines 240,442,660,898,1160,1209,1239): choose
a name which identifies the map, ends with "_output" and has an extension .txt;

clear all;

close all;

% caricamento del file di testo contenente, sulle 4 colonne, le coordinate carta (X,Y)
% e le coordinate immagine (x,y) dei punti a terra da utilizzare per la trasformazione:

load -ascii Orsenigo_con_Parzano_teresiano_catasto_matlab.txt;

% cambiamento del nome della variabile:

matrice_punti = Orsenigo_con_Parzano_teresiano_catasto_matlab;

clear Orsenigo_con_Parzano_teresiano_catasto_matlab;

% definizione del numero totale di punti (GCP+CP) utilizzati nella trasformazione:

N = length(matrice_punti);

% definizione del numero di GCP utilizzati nella trasformazione:
```

```
N_GCP = ...;

% definizione del numero di CP utilizzati nella trasformazione:

N_CP = N-N_GCP;

% definizione del vettore contenente l'indice dei punti utilizzati come CP:

id_CP = [...];

% estrazione, dalla matrice iniziale dei punti, in una nuova matrice, delle sole
% righe corrispondenti ai CP:

matrice_CP = zeros(N_CP,4);

for i = 1:N_CP
    matrice_CP(i,:) = matrice_punti(id_CP(i),:);
end

% creazione della matrice dei GCP per eliminazione, dalla matrice iniziale dei punti,
% delle righe corrispondenti ai CP (estratte in precedenza):

matrice_GCP = matrice_punti;

for i = 1:N_CP
    matrice_GCP(id_CP(i),:) = [];
    if i ~= N_CP
        id_CP(i+1) = id_CP(i+1)-i;
    else
        end
    end
end

% definizione dei vettori contenenti coordinate carta e coordinate immagine di
% GCP e CP:

X_GCP = matrice_GCP(:,1);
Y_GCP = matrice_GCP(:,2);
x_GCP = matrice_GCP(:,3);
y_GCP = matrice_GCP(:,4);
```



```
X_CP = matrice_CP(:,1);
Y_CP = matrice_CP(:,2);
x_CP = matrice_CP(:,3);
y_CP = matrice_CP(:,4);

% -----

%           MODELLO POLINOMIALE DI ORDINE 1

% -----

% Stima a minimi quadrati dei parametri del modello polinomiale di ordine 1, calcolo
% dei residui sui GCP e CP ed estrazione delle statistiche su tali residui.

% definizione del vettore delle osservazioni, che contiene (incolonnate) le coordinate
% carta (X,Y) dei GCP:

oss = zeros(2*N_GCP,1);

for i=1:N_GCP
    oss(2*i-1) = X_GCP(i);
    oss(2*i) = Y_GCP(i);
end

% definizione della matrice disegno:

A = zeros(2*N_GCP,6);

for i=1:N_GCP
    A(2*i-1,1) = x_GCP(i);
    A(2*i-1,2) = y_GCP(i);
    A(2*i-1,3) = 1;
    A(2*i,4) = x_GCP(i);
    A(2*i,5) = y_GCP(i);
    A(2*i,6) = 1;
end

% Calcolo della matrice normale:
```

```
matrice_normale = A'*A;

% Stima a minimi quadrati del vettore dei parametri incogniti:

parametri = matrice_normale\A'*oss;

% Stima a posteriori del vettore delle osservazioni (coordinate carta):

oss_stimate = A*parametri;

% Stima del sigma zero quadro:

sigma_zero_quadro = (oss-oss_stimate)'*(oss-oss_stimate)/(2*N_GCP-6);

% Calcolo della matrice di covarianza dei parametri stimati:

C_xx = sigma_zero_quadro*inv(matrice_normale);

% Calcolo del vettore dei residui sui GCP:

residui_GCP = oss_stimate-oss;

% Estrazione del vettore dei residui sulla componente X dei GCP:

residui_GCP_X = residui_GCP(1:2:2*N_GCP-1);

% Estrazione del vettore dei residui sulla componente Y dei GCP:

residui_GCP_Y = residui_GCP(2:2:2*N_GCP);

% Calcolo della somma dei quadrati dei residui sulle componenti X e Y dei GCP

% (utili a posteriori per il test-F):

S_X_pol(1) = sum(residui_GCP_X.^2);

S_Y_pol(1) = sum(residui_GCP_Y.^2);

% Calcolo del modulo del residuo di ogni GCP:

residui_GCP_modulo = zeros(N_GCP,1);

for i=1:N_GCP

    residui_GCP_modulo(i) = sqrt((residui_GCP_X(i))^2+(residui_GCP_Y(i))^2);

end

% definizione del vettore, che contiene (incolonnate) le coordinate carta (X,Y) dei CP:

oss_CP = zeros(2*N_CP,1);

for i=1:N_CP
```

```
oss_CP(2*i-1) = X_CP(i);
oss_CP(2*i) = Y_CP(i);
end
% definizione della matrice, per l'implementazione della trasformazione sui CP:
A_CP = zeros(2*N_CP,6);
for i=1:N_CP
    A_CP(2*i-1,1) = x_CP(i);
    A_CP(2*i-1,2) = y_CP(i);
    A_CP(2*i-1,3) = 1;
    A_CP(2*i,4) = x_CP(i);
    A_CP(2*i,5) = y_CP(i);
    A_CP(2*i,6) = 1;
end
% Stima del vettore delle coordinate carta (X,Y) dei CP:
oss_stimate_CP = A_CP*parametri;
% Calcolo del vettore dei residui sui CP:
residui_CP = oss_stimate_CP-oss_CP;
% Estrazione del vettore dei residui sulla componente X dei CP:
residui_CP_X = residui_CP(1:2:2*N_CP-1);
% Estrazione del vettore dei residui sulla componente Y dei CP:
residui_CP_Y = residui_CP(2:2:2*N_CP);
% Calcolo del modulo del residuo di ogni CP:
residui_CP_modulo = zeros(N_CP,1);
for i=1:N_CP
    residui_CP_modulo(i) = sqrt((residui_CP_X(i))^2+(residui_CP_Y(i))^2);
end
% plot, in colore diverso, dei GCP e CP:
% imm_mosaicata = imread('Bellagio_Teresiano_merged_300dpi.tif','tif');
```

```
% figure;

% imagesc(imm_mosaicata); axis image; colormap(gray);

% hold on;

figure;

plot(x_GCP,y_GCP,'.g'); legend('GCP');

axis equal; axis([0 max(x_GCP)+3000 min(y_GCP)-1000 max(y_GCP)+1000]); grid on;

set(gca,'xTickLabel',{}); set(gca,'yTickLabel',{});

hold on; plot(x_CP,y_CP,'.r'); legend('GCP','CP');

% La coordinata NORD, in cui è espresso il residuo in Y (in metri), va dal basso verso l'alto,
% mentre la coordinata Y dell'immagine va dall'alto verso il basso: perciò, per rappresentare
% correttamente i residui dei CP in direzione Y, è necessario cambiare il loro segno:

residui_CP_Y_corretti = -residui_CP_Y;

% visualizzazione grafica del modulo dei residui sui CP:

hold on; quiver(x_CP,y_CP,residui_CP_X,residui_CP_Y_corretti);
legend('GCP','CP','residuo','Location','NorthWest');

title('Posizioni di GCP e CP e visualizzazione del modulo del residuo sui CP per modello polinomiale di
ordine 1');

% Estrazione delle statistiche (media, deviazione standard, minimo, massimo e RMSE)

% dei residui sulle componenti X,Y e del modulo, sui GCP e sui CP:

statistiche_GCP_X(1) = mean(residui_GCP_X);

statistiche_GCP_X(2) = std(residui_GCP_X);

statistiche_GCP_X(3) = min(residui_GCP_X);

statistiche_GCP_X(4) = max(residui_GCP_X);

statistiche_GCP_X(5) = sqrt(mean(residui_GCP_X.^2));

statistiche_GCP_Y(1) = mean(residui_GCP_Y);

statistiche_GCP_Y(2) = std(residui_GCP_Y);

statistiche_GCP_Y(3) = min(residui_GCP_Y);
```







```
fprintf(statistiche,' ');
for i = 1:length(statistiche_CP_modulo)
    fprintf(statistiche,'%8.3f ',statistiche_CP_modulo(i));
end
fclose(statistiche);
% -----
%           MODELLO POLINOMIALE DI ORDINE 2
% -----
% Stima a minimi quadrati dei parametri del modello polinomiale di ordine 2, calcolo
% dei residui sui GCP e CP ed estrazione delle statistiche su tali residui.

% definizione della matrice disegno:
A = zeros(2*N_GCP,12);
for i=1:N_GCP
    A(2*i-1,1) = 1;
    A(2*i-1,2) = x_GCP(i);
    A(2*i-1,3) = y_GCP(i);
    A(2*i-1,4) = x_GCP(i)^2;
    A(2*i-1,5) = x_GCP(i)*y_GCP(i);
    A(2*i-1,6) = y_GCP(i)^2;
    A(2*i,7) = 1;
    A(2*i,8) = x_GCP(i);
    A(2*i,9) = y_GCP(i);
    A(2*i,10) = x_GCP(i)^2;
    A(2*i,11) = x_GCP(i)*y_GCP(i);
    A(2*i,12) = y_GCP(i)^2;
end
% Calcolo della matrice normale:
```

```
matrice_normale = A'*A;

% Stima a minimi quadrati del vettore dei parametri incogniti:

parametri = matrice_normale\A'*oss;

% Stima a posteriori del vettore delle osservazioni (coordinate carta):

oss_stimate = A*parametri;

% Stima del sigma zero quadro:

sigma_zero_quadro = (oss-oss_stimate)'*(oss-oss_stimate)/(2*N_GCP-12);

% Calcolo della matrice di covarianza dei parametri stimati:

C_xx = sigma_zero_quadro*inv(matrice_normale);

% Calcolo del vettore dei residui sui GCP:

residui_GCP = oss_stimate-oss;

% Estrazione del vettore dei residui sulla componente X dei GCP:

residui_GCP_X = residui_GCP(1:2:2*N_GCP-1);

% Estrazione del vettore dei residui sulla componente Y dei GCP:

residui_GCP_Y = residui_GCP(2:2:2*N_GCP);

% Calcolo della somma dei quadrati dei residui sulle componenti X e Y dei GCP

% (utili a posteriori per il test-F):

S_X_pol(2) = sum(residui_GCP_X.^2);

S_Y_pol(2) = sum(residui_GCP_Y.^2);

% Calcolo del modulo del residuo di ogni GCP:

residui_GCP_modulo = zeros(N_GCP,1);

for i=1:N_GCP

    residui_GCP_modulo(i) = sqrt((residui_GCP_X(i))^2+(residui_GCP_Y(i))^2);

end

% definizione del vettore, che contiene (incolonnate) le coordinate carta (X,Y) dei CP:

oss_CP = zeros(2*N_CP,1);

for i=1:N_CP
```



```
oss_CP(2*i-1) = X_CP(i);
oss_CP(2*i) = Y_CP(i);

end

% definizione della matrice, per l'implementazione della trasformazione sui CP:
A_CP = zeros(2*N_CP,12);

for i=1:N_CP

    A_CP(2*i-1,1) = 1;
    A_CP(2*i-1,2) = x_CP(i);
    A_CP(2*i-1,3) = y_CP(i);
    A_CP(2*i-1,4) = x_CP(i)^2;
    A_CP(2*i-1,5) = x_CP(i)*y_CP(i);
    A_CP(2*i-1,6) = y_CP(i)^2;

    A_CP(2*i,7) = 1;
    A_CP(2*i,8) = x_CP(i);
    A_CP(2*i,9) = y_CP(i);
    A_CP(2*i,10) = x_CP(i)^2;
    A_CP(2*i,11) = x_CP(i)*y_CP(i);
    A_CP(2*i,12) = y_CP(i)^2;

end

% Stima del vettore delle coordinate carta (X,Y) dei CP:
oss_stimate_CP = A_CP*parametri;

% Calcolo del vettore dei residui sui CP:
residui_CP = oss_stimate_CP-oss_CP;

% Estrazione del vettore dei residui sulla componente X dei CP:
residui_CP_X = residui_CP(1:2:2*N_CP-1);

% Estrazione del vettore dei residui sulla componente Y dei CP:
residui_CP_Y = residui_CP(2:2:2*N_CP);

% Calcolo del modulo del residuo di ogni CP:
```

```
residui_CP_modulo = zeros(N_CP,1);

for i=1:N_CP

    residui_CP_modulo(i) = sqrt((residui_CP_X(i))^2+(residui_CP_Y(i))^2);

end

% plot, in colore diverso, dei GCP e CP:

figure; plot(x_GCP,y_GCP,'g'); legend('GCP');

axis equal; axis([0 max(x_GCP)+3000 min(y_GCP)-1000 max(y_GCP)+1000]); grid on;

set(gca,'xTickLabel',{}); set(gca,'yTickLabel',{});

hold on; plot(x_CP,y_CP,'r'); legend('GCP','CP');

% La coordinata NORD, in cui è espresso il residuo in Y (in metri), va dal basso verso l'alto,

% mentre la coordinata Y dell'immagine va dall'alto verso il basso: perciò, per rappresentare

% correttamente i residui dei CP in direzione Y, è necessario cambiare il loro segno:

residui_CP_Y_corretti = -residui_CP_Y;

% visualizzazione grafica del modulo dei residui sui CP:

hold on; quiver(x_CP,y_CP,residui_CP_X,residui_CP_Y_corretti);

legend('GCP','CP','residuo','Location','NorthWest');

title('Posizioni di GCP e CP e visualizzazione del modulo del residuo sui CP per modello polinomiale di

ordine 2');

% Estrazione delle statistiche (media, deviazione standard, minimo, massimo e RMSE)

% dei residui sulle componenti X,Y e del modulo, sui GCP e sui CP:

statistiche_GCP_X(1) = mean(residui_GCP_X);

statistiche_GCP_X(2) = std(residui_GCP_X);

statistiche_GCP_X(3) = min(residui_GCP_X);

statistiche_GCP_X(4) = max(residui_GCP_X);

statistiche_GCP_X(5) = sqrt(mean(residui_GCP_X.^2));

statistiche_GCP_Y(1) = mean(residui_GCP_Y);

statistiche_GCP_Y(2) = std(residui_GCP_Y);

statistiche_GCP_Y(3) = min(residui_GCP_Y);
```







```
for i = 1:length(statistiche_CP_modulo)

    fprintf(statistiche,'%8.3f ',statistiche_CP_modulo(i));

end

fclose(statistiche);

% -----

%           MODELLO POLINOMIALE DI ORDINE 3

% -----

% Stima a minimi quadrati dei parametri del modello polinomiale di ordine 3, calcolo
% dei residui sui GCP e CP ed estrazione delle statistiche su tali residui.

% definizione della matrice disegno:

A = zeros(2*N_GCP,20);

for i=1:N_GCP

    A(2*i-1,1) = 1;

    A(2*i-1,2) = x_GCP(i);

    A(2*i-1,3) = y_GCP(i);

    A(2*i-1,4) = x_GCP(i)^2;

    A(2*i-1,5) = x_GCP(i)*y_GCP(i);

    A(2*i-1,6) = y_GCP(i)^2;

    A(2*i-1,7) = x_GCP(i)^3;

    A(2*i-1,8) = x_GCP(i)^2*y_GCP(i);

    A(2*i-1,9) = x_GCP(i)*y_GCP(i)^2;

    A(2*i-1,10) = y_GCP(i)^3;

    A(2*i,11) = 1;

    A(2*i,12) = x_GCP(i);

    A(2*i,13) = y_GCP(i);

    A(2*i,14) = x_GCP(i)^2;
```

```
A(2*i,15) = x_GCP(i)*y_GCP(i);
A(2*i,16) = y_GCP(i)^2;
A(2*i,17) = x_GCP(i)^3;
A(2*i,18) = x_GCP(i)^2*y_GCP(i);
A(2*i,19) = x_GCP(i)*y_GCP(i)^2;
A(2*i,20) = y_GCP(i)^3;

end

% Calcolo della matrice normale:
matrice_normale = A'*A;

% Stima a minimi quadrati del vettore dei parametri incogniti:
parametri = matrice_normale\A'*oss;

% Stima a posteriori del vettore delle osservazioni (coordinate carta):
oss_stimate = A*parametri;

% Stima del sigma zero quadro:
sigma_zero_quadro = (oss-oss_stimate)'*(oss-oss_stimate)/(2*N_GCP-20);

% Calcolo della matrice di covarianza dei parametri stimati:
C_xx = sigma_zero_quadro*inv(matrice_normale);

% Calcolo del vettore dei residui sui GCP:
residui_GCP = oss_stimate-oss;

% Estrazione del vettore dei residui sulla componente X dei GCP:
residui_GCP_X = residui_GCP(1:2:2*N_GCP-1);

% Estrazione del vettore dei residui sulla componente Y dei GCP:
residui_GCP_Y = residui_GCP(2:2:2*N_GCP);

% Calcolo della somma dei quadrati dei residui sulle componenti X e Y dei GCP
% (utili a posteriori per il test-F):
S_X_pol(3) = sum(residui_GCP_X.^2);
```

```
S_Y_pol(3) = sum(residui_GCP_Y.^2);

% Calcolo del modulo del residuo di ogni GCP:

residui_GCP_modulo = zeros(N_GCP,1);

for i=1:N_GCP
    residui_GCP_modulo(i) = sqrt((residui_GCP_X(i))^2+(residui_GCP_Y(i))^2);
end

% definizione del vettore, che contiene (incolonnate) le coordinate carta (X,Y) dei CP:

oss_CP = zeros(2*N_CP,1);

for i=1:N_CP
    oss_CP(2*i-1) = X_CP(i);
    oss_CP(2*i) = Y_CP(i);
end

% definizione della matrice, per l'implementazione della trasformazione sui CP:

A_CP = zeros(2*N_CP,20);

for i=1:N_CP
    A_CP(2*i-1,1) = 1;
    A_CP(2*i-1,2) = x_CP(i);
    A_CP(2*i-1,3) = y_CP(i);
    A_CP(2*i-1,4) = x_CP(i)^2;
    A_CP(2*i-1,5) = x_CP(i)*y_CP(i);
    A_CP(2*i-1,6) = y_CP(i)^2;
    A_CP(2*i-1,7) = x_CP(i)^3;
    A_CP(2*i-1,8) = x_CP(i)^2*y_CP(i);
    A_CP(2*i-1,9) = x_CP(i)*y_CP(i)^2;
    A_CP(2*i-1,10) = y_CP(i)^3;
    A_CP(2*i,11) = 1;
    A_CP(2*i,12) = x_CP(i);
    A_CP(2*i,13) = y_CP(i);
```

```
A_CP(2*i,14) = x_CP(i)^2;
A_CP(2*i,15) = x_CP(i)*y_CP(i);
A_CP(2*i,16) = y_CP(i)^2;
A_CP(2*i,17) = x_CP(i)^3;
A_CP(2*i,18) = x_CP(i)^2*y_CP(i);
A_CP(2*i,19) = x_CP(i)*y_CP(i)^2;
A_CP(2*i,20) = y_CP(i)^3;

end

% Stima del vettore delle coordinate carta (X,Y) dei CP:

oss_stimate_CP = A_CP*parametri;

% Calcolo del vettore dei residui sui CP:

residui_CP = oss_stimate_CP-oss_CP;

% Estrazione del vettore dei residui sulla componente X dei CP:

residui_CP_X = residui_CP(1:2:2*N_CP-1);

% Estrazione del vettore dei residui sulla componente Y dei CP:

residui_CP_Y = residui_CP(2:2:2*N_CP);

% Calcolo del modulo del residuo di ogni CP:

residui_CP_modulo = zeros(N_CP,1);

for i=1:N_CP

    residui_CP_modulo(i) = sqrt((residui_CP_X(i))^2+(residui_CP_Y(i))^2);

end

% plot, in colore diverso, dei GCP e CP:

figure; plot(x_GCP,y_GCP,'g'); legend('GCP');

axis equal; axis([0 max(x_GCP)+3000 min(y_GCP)-1000 max(y_GCP)+1000]); grid on;

set(gca,'xTickLabel',{}); set(gca,'yTickLabel',{});

hold on; plot(x_CP,y_CP,'r'); legend('GCPs','CPs');

% La coordinata NORD, in cui è espresso il residuo in Y (in metri), va dal basso verso l'alto,
```



```
% mentre la coordinata Y dell'immagine va dall'alto verso il basso: perciò, per rappresentare
% correttamente i residui dei CP in direzione Y, è necessario cambiare il loro segno:

residui_CP_Y_corretti = -residui_CP_Y;

% visualizzazione grafica del modulo dei residui sui CP:

hold on; quiver(x_CP,y_CP,residui_CP_X,residui_CP_Y_corretti);
legend('GCPs','CPs','residual','Location','NorthWest');

title('Posizioni di GCP e CP e visualizzazione del modulo del residuo sui CP per modello polinomiale di
ordine 3');

% Estrazione delle statistiche (media, deviazione standard, minimo, massimo e RMSE)

% dei residui sulle componenti X,Y e del modulo, sui GCP e sui CP:

statistiche_GCP_X(1) = mean(residui_GCP_X);
statistiche_GCP_X(2) = std(residui_GCP_X);
statistiche_GCP_X(3) = min(residui_GCP_X);
statistiche_GCP_X(4) = max(residui_GCP_X);
statistiche_GCP_X(5) = sqrt(mean(residui_GCP_X.^2));
statistiche_GCP_Y(1) = mean(residui_GCP_Y);
statistiche_GCP_Y(2) = std(residui_GCP_Y);
statistiche_GCP_Y(3) = min(residui_GCP_Y);
statistiche_GCP_Y(4) = max(residui_GCP_Y);
statistiche_GCP_Y(5) = sqrt(mean(residui_GCP_Y.^2));
statistiche_GCP_modulo(1) = mean(residui_GCP_modulo);
statistiche_GCP_modulo(2) = std(residui_GCP_modulo);
statistiche_GCP_modulo(3) = min(residui_GCP_modulo);
statistiche_GCP_modulo(4) = max(residui_GCP_modulo);
statistiche_GCP_modulo(5) = sqrt(mean(residui_GCP_modulo.^2));
statistiche_CP_X(1) = mean(residui_CP_X);
statistiche_CP_X(2) = std(residui_CP_X);
statistiche_CP_X(3) = min(residui_CP_X);
```





% dei residui sui GCP e CP ed estrazione delle statistiche su tali residui.

% definizione della matrice disegno:

```
A = zeros(2*N_GCP,30);
```

```
for i=1:N_GCP
```

```
    A(2*i-1,1) = 1;
```

```
    A(2*i-1,2) = x_GCP(i);
```

```
    A(2*i-1,3) = y_GCP(i);
```

```
    A(2*i-1,4) = x_GCP(i)^2;
```

```
    A(2*i-1,5) = x_GCP(i)*y_GCP(i);
```

```
    A(2*i-1,6) = y_GCP(i)^2;
```

```
    A(2*i-1,7) = x_GCP(i)^3;
```

```
    A(2*i-1,8) = x_GCP(i)^2*y_GCP(i);
```

```
    A(2*i-1,9) = x_GCP(i)*y_GCP(i)^2;
```

```
    A(2*i-1,10) = y_GCP(i)^3;
```

```
    A(2*i-1,11) = x_GCP(i)^4;
```

```
    A(2*i-1,12) = x_GCP(i)^3*y_GCP(i);
```

```
    A(2*i-1,13) = x_GCP(i)^2*y_GCP(i)^2;
```

```
    A(2*i-1,14) = x_GCP(i)*y_GCP(i)^3;
```

```
    A(2*i-1,15) = y_GCP(i)^4;
```

```
    A(2*i,16) = 1;
```

```
    A(2*i,17) = x_GCP(i);
```

```
    A(2*i,18) = y_GCP(i);
```

```
    A(2*i,19) = x_GCP(i)^2;
```

```
    A(2*i,20) = x_GCP(i)*y_GCP(i);
```

```
    A(2*i,21) = y_GCP(i)^2;
```

```
    A(2*i,22) = x_GCP(i)^3;
```

```
    A(2*i,23) = x_GCP(i)^2*y_GCP(i);
```

```
    A(2*i,24) = x_GCP(i)*y_GCP(i)^2;
```

```
A(2*i,25) = y_GCP(i)^3;
A(2*i,26) = x_GCP(i)^4;
A(2*i,27) = x_GCP(i)^3*y_GCP(i);
A(2*i,28) = x_GCP(i)^2*y_GCP(i)^2;
A(2*i,29) = x_GCP(i)*y_GCP(i)^3;
A(2*i,30) = y_GCP(i)^4;

end

% Calcolo della matrice normale:
matrice_normale = A'*A;

% Stima a minimi quadrati del vettore dei parametri incogniti:
parametri = matrice_normale\A'*oss;

% Stima a posteriori del vettore delle osservazioni (coordinate carta):
oss_stimate = A*parametri;

% Stima del sigma zero quadro:
sigma_zero_quadro = (oss-oss_stimate)'*(oss-oss_stimate)/(2*N_GCP-30);

% Calcolo della matrice di covarianza dei parametri stimati:
C_xx = sigma_zero_quadro*inv(matrice_normale);

% Calcolo del vettore dei residui sui GCP:
residui_GCP = oss_stimate-oss;

% Estrazione del vettore dei residui sulla componente X dei GCP:
residui_GCP_X = residui_GCP(1:2:2*N_GCP-1);

% Estrazione del vettore dei residui sulla componente Y dei GCP:
residui_GCP_Y = residui_GCP(2:2:2*N_GCP);

% Calcolo della somma dei quadrati dei residui sulle componenti X e Y dei GCP
% (utili a posteriori per il test-F):
S_X_pol(4) = sum(residui_GCP_X.^2);
S_Y_pol(4) = sum(residui_GCP_Y.^2);
```



```
% Calcolo del modulo del residuo di ogni GCP:
residui_GCP_modulo = zeros(N_GCP,1);
for i=1:N_GCP
    residui_GCP_modulo(i) = sqrt((residui_GCP_X(i))^2+(residui_GCP_Y(i))^2);
end

% definizione del vettore, che contiene (incolonnate) le coordinate carta (X,Y) dei CP:
oss_CP = zeros(2*N_CP,1);
for i=1:N_CP
    oss_CP(2*i-1) = X_CP(i);
    oss_CP(2*i) = Y_CP(i);
end

% definizione della matrice, per l'implementazione della trasformazione sui CP:
A_CP = zeros(2*N_CP,30);
for i=1:N_CP
    A_CP(2*i-1,1) = 1;
    A_CP(2*i-1,2) = x_CP(i);
    A_CP(2*i-1,3) = y_CP(i);
    A_CP(2*i-1,4) = x_CP(i)^2;
    A_CP(2*i-1,5) = x_CP(i)*y_CP(i);
    A_CP(2*i-1,6) = y_CP(i)^2;
    A_CP(2*i-1,7) = x_CP(i)^3;
    A_CP(2*i-1,8) = x_CP(i)^2*y_CP(i);
    A_CP(2*i-1,9) = x_CP(i)*y_CP(i)^2;
    A_CP(2*i-1,10) = y_CP(i)^3;
    A_CP(2*i-1,11) = x_CP(i)^4;
    A_CP(2*i-1,12) = x_CP(i)^3*y_CP(i);
    A_CP(2*i-1,13) = x_CP(i)^2*y_CP(i)^2;
```

$$A\_CP(2*i-1,14) = x\_CP(i)*y\_CP(i)^3;$$

$$A\_CP(2*i-1,15) = y\_CP(i)^4;$$

$$A\_CP(2*i,16) = 1;$$

$$A\_CP(2*i,17) = x\_CP(i);$$

$$A\_CP(2*i,18) = y\_CP(i);$$

$$A\_CP(2*i,19) = x\_CP(i)^2;$$

$$A\_CP(2*i,20) = x\_CP(i)*y\_CP(i);$$

$$A\_CP(2*i,21) = y\_CP(i)^2;$$

$$A\_CP(2*i,22) = x\_CP(i)^3;$$

$$A\_CP(2*i,23) = x\_CP(i)^2*y\_CP(i);$$

$$A\_CP(2*i,24) = x\_CP(i)*y\_CP(i)^2;$$

$$A\_CP(2*i,25) = y\_CP(i)^3;$$

$$A\_CP(2*i,26) = x\_CP(i)^4;$$

$$A\_CP(2*i,27) = x\_CP(i)^3*y\_CP(i);$$

$$A\_CP(2*i,28) = x\_CP(i)^2*y\_CP(i)^2;$$

$$A\_CP(2*i,29) = x\_CP(i)*y\_CP(i)^3;$$

$$A\_CP(2*i,30) = y\_CP(i)^4;$$

end

% Stima del vettore delle coordinate carta (X,Y) dei CP:

oss\_stimate\_CP = A\_CP\*parametri;

% Calcolo del vettore dei residui sui CP:

residui\_CP = oss\_stimate\_CP-oss\_CP;

% Estrazione del vettore dei residui sulla componente X dei CP:

residui\_CP\_X = residui\_CP(1:2:2\*N\_CP-1);

% Estrazione del vettore dei residui sulla componente Y dei CP:

residui\_CP\_Y = residui\_CP(2:2:2\*N\_CP);

% Calcolo del modulo del residuo di ogni CP:

residui\_CP\_modulo = zeros(N\_CP,1);

```
for i=1:N_CP
    residui_CP_modulo(i) = sqrt((residui_CP_X(i))^2+(residui_CP_Y(i))^2);
end

% plot, in colore diverso, dei GCP e CP:
figure; plot(x_GCP,y_GCP,'g'); legend('GCP');
axis equal; axis([0 max(x_GCP)+3000 min(y_GCP)-1000 max(y_GCP)+1000]); grid on;
set(gca,'xTickLabel',{}); set(gca,'yTickLabel',{});
hold on; plot(x_CP,y_CP,'r'); legend('GCP','CP');

% La coordinata NORD, in cui è espresso il residuo in Y (in metri), va dal basso verso l'alto,
% mentre la coordinata Y dell'immagine va dall'alto verso il basso: perciò, per rappresentare
% correttamente i residui dei CP in direzione Y, è necessario cambiare il loro segno:
residui_CP_Y_corretti = -residui_CP_Y;

% visualizzazione grafica del modulo dei residui sui CP:
hold on; quiver(x_CP,y_CP,residui_CP_X,residui_CP_Y_corretti);
legend('GCP','CP','residuo','Location','NorthWest');

title('Posizioni di GCP e CP e visualizzazione del modulo del residuo sui CP per modello polinomiale di
ordine 4');

% Estrazione delle statistiche (media, deviazione standard, minimo, massimo e RMSE)
% dei residui sulle componenti X,Y e del modulo, sui GCP e sui CP:
statistiche_GCP_X(1) = mean(residui_GCP_X);
statistiche_GCP_X(2) = std(residui_GCP_X);
statistiche_GCP_X(3) = min(residui_GCP_X);
statistiche_GCP_X(4) = max(residui_GCP_X);
statistiche_GCP_X(5) = sqrt(mean(residui_GCP_X.^2));
statistiche_GCP_Y(1) = mean(residui_GCP_Y);
statistiche_GCP_Y(2) = std(residui_GCP_Y);
statistiche_GCP_Y(3) = min(residui_GCP_Y);
statistiche_GCP_Y(4) = max(residui_GCP_Y);
```







```
for i = 1:length(statistiche_CP_modulo)

    fprintf(statistiche,'%8.3f ',statistiche_CP_modulo(i));

end

fclose(statistiche);

% -----

%           MODELLO POLINOMIALE DI ORDINE 5

% -----

% Stima a minimi quadrati dei parametri del modello polinomiale di ordine 5, calcolo
% dei residui sui GCP e CP ed estrazione delle statistiche su tali residui.

% definizione della matrice disegno:

A = zeros(2*N_GCP,42);

for i=1:N_GCP

    A(2*i-1,1) = 1;

    A(2*i-1,2) = x_GCP(i);

    A(2*i-1,3) = y_GCP(i);

    A(2*i-1,4) = x_GCP(i)^2;

    A(2*i-1,5) = x_GCP(i)*y_GCP(i);

    A(2*i-1,6) = y_GCP(i)^2;

    A(2*i-1,7) = x_GCP(i)^3;

    A(2*i-1,8) = x_GCP(i)^2*y_GCP(i);

    A(2*i-1,9) = x_GCP(i)*y_GCP(i)^2;

    A(2*i-1,10) = y_GCP(i)^3;

    A(2*i-1,11) = x_GCP(i)^4;

    A(2*i-1,12) = x_GCP(i)^3*y_GCP(i);

    A(2*i-1,13) = x_GCP(i)^2*y_GCP(i)^2;

    A(2*i-1,14) = x_GCP(i)*y_GCP(i)^3;

    A(2*i-1,15) = y_GCP(i)^4;
```

$A(2*i-1,16) = x\_GCP(i)^5;$   
 $A(2*i-1,17) = x\_GCP(i)^4*y\_GCP(i);$   
 $A(2*i-1,18) = x\_GCP(i)^3*y\_GCP(i)^2;$   
 $A(2*i-1,19) = x\_GCP(i)^2*y\_GCP(i)^3;$   
 $A(2*i-1,20) = x\_GCP(i)*y\_GCP(i)^4;$   
 $A(2*i-1,21) = y\_GCP(i)^5;$   
 $A(2*i,22) = 1;$   
 $A(2*i,23) = x\_GCP(i);$   
 $A(2*i,24) = y\_GCP(i);$   
 $A(2*i,25) = x\_GCP(i)^2;$   
 $A(2*i,26) = x\_GCP(i)*y\_GCP(i);$   
 $A(2*i,27) = y\_GCP(i)^2;$   
 $A(2*i,28) = x\_GCP(i)^3;$   
 $A(2*i,29) = x\_GCP(i)^2*y\_GCP(i);$   
 $A(2*i,30) = x\_GCP(i)*y\_GCP(i)^2;$   
 $A(2*i,31) = y\_GCP(i)^3;$   
 $A(2*i,32) = x\_GCP(i)^4;$   
 $A(2*i,33) = x\_GCP(i)^3*y\_GCP(i);$   
 $A(2*i,34) = x\_GCP(i)^2*y\_GCP(i)^2;$   
 $A(2*i,35) = x\_GCP(i)*y\_GCP(i)^3;$   
 $A(2*i,36) = y\_GCP(i)^4;$   
 $A(2*i,37) = x\_GCP(i)^5;$   
 $A(2*i,38) = x\_GCP(i)^4*y\_GCP(i);$   
 $A(2*i,39) = x\_GCP(i)^3*y\_GCP(i)^2;$   
 $A(2*i,40) = x\_GCP(i)^2*y\_GCP(i)^3;$   
 $A(2*i,41) = x\_GCP(i)*y\_GCP(i)^4;$   
 $A(2*i,42) = y\_GCP(i)^5;$

end

```
% Calcolo della matrice normale:
matrice_normale = A'*A;

% Stima a minimi quadrati del vettore dei parametri incogniti:
parametri = matrice_normale\A'*oss;

% Stima a posteriori del vettore delle osservazioni (coordinate carta):
oss_stimate = A*parametri;

% Stima del sigma zero quadro:
sigma_zero_quadro = (oss-oss_stimate)'*(oss-oss_stimate)/(2*N_GCP-42);

% Calcolo della matrice di covarianza dei parametri stimati:
C_xx = sigma_zero_quadro*inv(matrice_normale);

% Calcolo del vettore dei residui sui GCP:
residui_GCP = oss_stimate-oss;

% Estrazione del vettore dei residui sulla componente X dei GCP:
residui_GCP_X = residui_GCP(1:2:2*N_GCP-1);

% Estrazione del vettore dei residui sulla componente Y dei GCP:
residui_GCP_Y = residui_GCP(2:2:2*N_GCP);

% Calcolo della somma dei quadrati dei residui sulle componenti X e Y dei GCP
% (utili a posteriori per il test-F):
S_X_pol(5) = sum(residui_GCP_X.^2);
S_Y_pol(5) = sum(residui_GCP_Y.^2);

% Calcolo del modulo del residuo di ogni GCP:
residui_GCP_modulo = zeros(N_GCP,1);

for i=1:N_GCP
    residui_GCP_modulo(i) = sqrt((residui_GCP_X(i))^2+(residui_GCP_Y(i))^2);
end

% definizione del vettore, che contiene (incolonnate) le coordinate carta (X,Y) dei CP:
oss_CP = zeros(2*N_CP,1);
```

```
for i=1:N_CP
    oss_CP(2*i-1) = X_CP(i);
    oss_CP(2*i) = Y_CP(i);
end

% definizione della matrice, per l'implementazione della trasformazione sui CP:
A_CP = zeros(2*N_CP,42);

for i=1:N_CP
    A_CP(2*i-1,1) = 1;
    A_CP(2*i-1,2) = x_CP(i);
    A_CP(2*i-1,3) = y_CP(i);
    A_CP(2*i-1,4) = x_CP(i)^2;
    A_CP(2*i-1,5) = x_CP(i)*y_CP(i);
    A_CP(2*i-1,6) = y_CP(i)^2;
    A_CP(2*i-1,7) = x_CP(i)^3;
    A_CP(2*i-1,8) = x_CP(i)^2*y_CP(i);
    A_CP(2*i-1,9) = x_CP(i)*y_CP(i)^2;
    A_CP(2*i-1,10) = y_CP(i)^3;
    A_CP(2*i-1,11) = x_CP(i)^4;
    A_CP(2*i-1,12) = x_CP(i)^3*y_CP(i);
    A_CP(2*i-1,13) = x_CP(i)^2*y_CP(i)^2;
    A_CP(2*i-1,14) = x_CP(i)*y_CP(i)^3;
    A_CP(2*i-1,15) = y_CP(i)^4;
    A_CP(2*i-1,16) = x_CP(i)^5;
    A_CP(2*i-1,17) = x_CP(i)^4*y_CP(i);
    A_CP(2*i-1,18) = x_CP(i)^3*y_CP(i)^2;
    A_CP(2*i-1,19) = x_CP(i)^2*y_CP(i)^3;
    A_CP(2*i-1,20) = x_CP(i)*y_CP(i)^4;
    A_CP(2*i-1,21) = y_CP(i)^5;
```

```
A_CP(2*i,22) = 1;  
A_CP(2*i,23) = x_CP(i);  
A_CP(2*i,24) = y_CP(i);  
A_CP(2*i,25) = x_CP(i)^2;  
A_CP(2*i,26) = x_CP(i)*y_CP(i);  
A_CP(2*i,27) = y_CP(i)^2;  
A_CP(2*i,28) = x_CP(i)^3;  
A_CP(2*i,29) = x_CP(i)^2*y_CP(i);  
A_CP(2*i,30) = x_CP(i)*y_CP(i)^2;  
A_CP(2*i,31) = y_CP(i)^3;  
A_CP(2*i,32) = x_CP(i)^4;  
A_CP(2*i,33) = x_CP(i)^3*y_CP(i);  
A_CP(2*i,34) = x_CP(i)^2*y_CP(i)^2;  
A_CP(2*i,35) = x_CP(i)*y_CP(i)^3;  
A_CP(2*i,36) = y_CP(i)^4;  
A_CP(2*i,37) = x_CP(i)^5;  
A_CP(2*i,38) = x_CP(i)^4*y_CP(i);  
A_CP(2*i,39) = x_CP(i)^3*y_CP(i)^2;  
A_CP(2*i,40) = x_CP(i)^2*y_CP(i)^3;  
A_CP(2*i,41) = x_CP(i)*y_CP(i)^4;  
A_CP(2*i,42) = y_CP(i)^5;
```

```
end
```

```
% Stima del vettore delle coordinate carta (X,Y) dei CP:
```

```
oss_stimate_CP = A_CP*parametri;
```

```
% Calcolo del vettore dei residui sui CP:
```

```
residui_CP = oss_stimate_CP-oss_CP;
```

```
% Estrazione del vettore dei residui sulla componente X dei CP:
```

```
residui_CP_X = residui_CP(1:2:2*N_CP-1);
```



```
% Estrazione del vettore dei residui sulla componente Y dei CP:
residui_CP_Y = residui_CP(2:2:2*N_CP);

% Calcolo del modulo del residuo di ogni CP:
residui_CP_modulo = zeros(N_CP,1);

for i=1:N_CP
    residui_CP_modulo(i) = sqrt((residui_CP_X(i))^2+(residui_CP_Y(i))^2);
end

% plot, in colore diverso, dei GCP e CP:
figure; plot(x_GCP,y_GCP,'.g'); legend('GCP');
axis equal; axis([0 max(x_GCP)+3000 min(y_GCP)-1000 max(y_GCP)+1000]); grid on;
set(gca,'xTickLabel',{}); set(gca,'yTickLabel',{});
hold on; plot(x_CP,y_CP,'.r'); legend('GCP','CP');

% La coordinata NORD, in cui è espresso il residuo in Y (in metri), va dal basso verso l'alto,
% mentre la coordinata Y dell'immagine va dall'alto verso il basso: perciò, per rappresentare
% correttamente i residui dei CP in direzione Y, è necessario cambiare il loro segno:
residui_CP_Y_corretti = -residui_CP_Y;

% visualizzazione grafica del modulo dei residui sui CP:
hold on; quiver(x_CP,y_CP,residui_CP_X,residui_CP_Y_corretti);
legend('GCP','CP','residuo','Location','NorthWest');

title('Posizioni di GCP e CP e visualizzazione del modulo del residuo sui CP per modello polinomiale di
ordine 5');

% Estrazione delle statistiche (media, deviazione standard, minimo, massimo e RMSE)
% dei residui sulle componenti X,Y e del modulo, sui GCP e sui CP:
statistiche_GCP_X(1) = mean(residui_GCP_X);
statistiche_GCP_X(2) = std(residui_GCP_X);
statistiche_GCP_X(3) = min(residui_GCP_X);
statistiche_GCP_X(4) = max(residui_GCP_X);
statistiche_GCP_X(5) = sqrt(mean(residui_GCP_X.^2));
```

```
statistiche_GCP_Y(1) = mean(residui_GCP_Y);
statistiche_GCP_Y(2) = std(residui_GCP_Y);
statistiche_GCP_Y(3) = min(residui_GCP_Y);
statistiche_GCP_Y(4) = max(residui_GCP_Y);
statistiche_GCP_Y(5) = sqrt(mean(residui_GCP_Y.^2));
statistiche_GCP_modulo(1) = mean(residui_GCP_modulo);
statistiche_GCP_modulo(2) = std(residui_GCP_modulo);
statistiche_GCP_modulo(3) = min(residui_GCP_modulo);
statistiche_GCP_modulo(4) = max(residui_GCP_modulo);
statistiche_GCP_modulo(5) = sqrt(mean(residui_GCP_modulo.^2));
statistiche_CP_X(1) = mean(residui_CP_X);
statistiche_CP_X(2) = std(residui_CP_X);
statistiche_CP_X(3) = min(residui_CP_X);
statistiche_CP_X(4) = max(residui_CP_X);
statistiche_CP_X(5) = sqrt(mean(residui_CP_X.^2));
statistiche_CP_Y(1) = mean(residui_CP_Y);
statistiche_CP_Y(2) = std(residui_CP_Y);
statistiche_CP_Y(3) = min(residui_CP_Y);
statistiche_CP_Y(4) = max(residui_CP_Y);
statistiche_CP_Y(5) = sqrt(mean(residui_CP_Y.^2));
statistiche_CP_modulo(1) = mean(residui_CP_modulo);
statistiche_CP_modulo(2) = std(residui_CP_modulo);
statistiche_CP_modulo(3) = min(residui_CP_modulo);
statistiche_CP_modulo(4) = max(residui_CP_modulo);
statistiche_CP_modulo(5) = sqrt(mean(residui_CP_modulo.^2));
RMSE_CP_modulo_pol(5) = statistiche_CP_modulo(5);
% Continuazione del precedente file di output contenente i valori calcolati delle statistiche:
statistiche = fopen('Orsenigo_con_Parzano_teresiano_catasto_output.txt','a');
```





```
% i = 1;

%

% while ((i < 5) && (ForceOut == false))

%   if RMSE_CP_modulo_pol(i) < RMSE_CP_modulo_pol(i+1)

%     fprintf(statistiche,'Il polinomio che produce il minimo RMSE dei moduli dei residui sui CP è quello di
grado %1.0f, ',i);

%     fprintf(statistiche,'con un valore %6.3f m.',RMSE_CP_modulo_pol(i));

%     ForceOut = true;

%   else i = i+1;

%   end

% end

%

% if i == 5

%   fprintf(statistiche,'Il polinomio che produce il minimo RMSE dei moduli dei residui sui CP è quello di
grado 5, con un valore %6.3f.',RMSE_CP_modulo_pol(5));

% end

fclose(statistiche);

% Continuazione del precedente file di output con la determinazione del grado del polinomio

% derivato da un test di Fisher sui residui sulle coordinate X e Y dei GCP:

statistiche = fopen('Orsenigo_con_Parzano_teresiano_catasto_output.txt','a');

forceOut = false;

k = 2;

while ((k < 6) && (forceOut == false))

    F_emp_X = ((S_X_pol(k-1)-S_X_pol(k))/(k+1))/(S_X_pol(k)/(N_GCP-(k+1)*(k+2)/2));

    F_emp_Y = ((S_Y_pol(k-1)-S_Y_pol(k))/(k+1))/(S_Y_pol(k)/(N_GCP-(k+1)*(k+2)/2));

    F_teor = finv(0.95,k+1,N_GCP-(k+1)*(k+2)/2);

    if F_emp_X <= F_teor && F_emp_Y <= F_teor

        fprintf(statistiche,'\n\nIl polinomio risultante dal test di Fisher sui residui sulle coordinate X e Y dei GCP
è quello di grado %1.0f. ',k-1);
```



```
    forceOut = true;

else k = k+1;

end

end

if k == 6

    k = 5;

    fprintf(statistiche,'\n\nIl polinomio risultante dal test di Fisher sui residui sulle coordinate X e Y dei GCP è quello di grado 5. ');

end

ordine_ottimale = min(grado_ottimale,k-1);

fprintf(statistiche,'\n\nGlobalmente, il polinomio ottimale per georiferire la mappa è quello di grado %1.0f. ',ordine_ottimale);

fclose(statistiche);
```

## Anex 2: Results of determination of the polynomial order for transformation (RMSE)

### Topographic Map:

#### GEOREFERENZIAZIONE CON POLINOMIO DI ORDINE 1

Statistiche dei residui sui GCP

COMPONENTE X												
COMPONENTE Y						COMPONENTE X						
MODULO			COMPONENTE Y			COMPONENTE X			COMPONENTE X			
media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
max	RMSE											
-0.000	9.836	-22.625	24.677	9.788	-0.000	9.235	-21.893	23.767	9.190	12.020	6.011	
1.232	28.610	13.426										

Statistiche dei residui sui CP

COMPONENTE X												
COMPONENTE Y						COMPONENTE X						
MODULO			COMPONENTE Y			COMPONENTE X			COMPONENTE X			
media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
max	RMSE											
0.201	9.568	-19.126	15.757	9.377	-3.009	9.048	-20.016	17.052	9.362	12.421	4.710	
1.921	21.095	13.250										

GEOREFERENZIAZIONE CON POLINOMIO DI ORDINE 2

Statistiche dei residui sui GCP

COMPONENTE X												
COMPONENTE Y						COMPONENTE X						
MODULO			COMPONENTE Y			COMPONENTE X			MODULO			
media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
max	RMSE											
-0.000	8.407	-21.235	23.551	8.367	0.000	9.167	-22.023	23.358	9.123	11.071	5.564	
0.974	28.129	12.378										

Statistiche dei residui sui CP

COMPONENTE X												
COMPONENTE Y						COMPONENTE X						
MODULO			COMPONENTE Y			COMPONENTE X			MODULO			
media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
max	RMSE											
-0.313	10.821	-19.799	22.520	10.607	-3.045	9.082	-19.398	14.112	9.405	12.736	6.353	
1.497	26.017	14.176										

GEOREFERENZIAZIONE CON POLINOMIO DI ORDINE 3

Statistiche dei residui sui GCP

COMPONENTE X												
COMPONENTE Y						COMPONENTE X						
MODULO			COMPONENTE Y			COMPONENTE X			MODULO			
media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
max	RMSE											

-0.000 8.098 -21.937 18.406 8.058 0.000 8.190 -24.289 22.347 8.150 10.253 5.147  
 1.194 26.160 11.461

Statistiche dei residui sui CP

COMPONENTE X  
 COMPONENTE Y  
 MODULO

media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
-0.343	9.795	-19.552	21.022	9.603	-1.877	8.184	-13.513	17.369	8.235	11.440	5.511	
max	RMSE											
2.706	23.472	12.651										

GEOREFERENZIAZIONE CON POLINOMIO DI ORDINE 4

Statistiche dei residui sui GCP

COMPONENTE X  
 COMPONENTE Y  
 MODULO

media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
-0.000	7.320	-16.801	19.751	7.284	-0.000	7.888	-24.883	22.005	7.850	9.524	4.920	
max	RMSE											
0.785	24.919	10.709										

Statistiche dei residui sui CP

COMPONENTE X  
COMPONENTE Y  
MODULO

media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
-0.364	8.584	-18.699	12.830	8.419	-1.229	7.507	-12.776	18.176	7.457	10.270	4.678	
2.855	23.549	11.246										

GEOREFERENZIAZIONE CON POLINOMIO DI ORDINE 5

Statistiche dei residui sui GCP

COMPONENTE X  
COMPONENTE Y  
MODULO

media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
-0.000	6.832	-16.709	21.468	6.799	0.000	6.563	-18.660	26.934	6.531	8.070	4.899	
1.287	29.719	9.428										

Statistiche dei residui sui CP

COMPONENTE X  
COMPONENTE Y  
MODULO

media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
2.053	8.643	-19.349	14.191	8.714	-3.894	11.684	-34.343	13.859	12.092	12.853	7.702	
2.499	34.640	14.905										

## DETERMINAZIONE DEL POLINOMIO DI GRADO OTTIMALE

Il polinomio che produce il minimo RMSE dei moduli dei residui sui CP è quello di grado 4, con un valore 11.246 m.

Il polinomio risultante dal test di Fisher sui residui sulle coordinate X e Y dei GCP è quello di grado 5.

Globalmente, il polinomio ottimale per georiferire la mappa è quello di grado 4.

## **Theresian Map (1722):**

### GEOREFERENZIAZIONE CON POLINOMIO DI ORDINE 1

Statistiche dei residui sui GCP

COMPONENTE X												
COMPONENTE Y						COMPONENTE X						
MODULO			COMPONENTE Y			COMPONENTE X			COMPONENTE X			
media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
max	RMSE											
-0.000	4.569	-10.400	11.325	4.553	-0.000	4.437	-10.899	12.709	4.421	5.678	2.844	
0.573	12.992	6.346										

Statistiche dei residui sui CP

COMPONENTE X												
COMPONENTE Y						COMPONENTE X						
MODULO			COMPONENTE Y			COMPONENTE X			COMPONENTE X			
media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
max	RMSE											



0.174 5.077 -8.297 12.367 5.007 -0.219 4.642 -10.136 10.066 4.581 5.883 3.432  
 0.770 13.120 6.786

GEOREFERENZIAZIONE CON POLINOMIO DI ORDINE 2

Statistiche dei residui sui GCP

COMPONENTE X												
COMPONENTE Y						COMPONENTE X						
MODULO												
media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
max	RMSE											
-0.000	4.250	-8.621	11.390	4.234	-0.000	4.161	-9.299	10.325	4.146	5.332	2.596	
0.445	11.749	5.926										

Statistiche dei residui sui CP

COMPONENTE X												
COMPONENTE Y						COMPONENTE X						
MODULO												
media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
max	RMSE											
-0.301	4.728	-10.122	11.427	4.669	0.024	4.497	-10.881	10.485	4.432	5.697	3.042	
0.636	11.581	6.438										

GEOREFERENZIAZIONE CON POLINOMIO DI ORDINE 3

Statistiche dei residui sui GCP

COMPONENTE X												
COMPONENTE Y						COMPONENTE X						
MODULO												
media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
max	RMSE											
0.000	3.999	-7.647	9.657	3.984	-0.000	3.517	-8.732	9.582	3.504	4.809	2.250	0.652
11.119	5.306											

Statistiche dei residui sui CP

COMPONENTE X												
COMPONENTE Y						COMPONENTE X						
MODULO												
media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
max	RMSE											
-0.537	4.490	-10.992	8.778	4.458	0.360	4.560	-7.038	11.326	4.509	5.719	2.777	0.757
11.362	6.340											

GEOREFERENZIAZIONE CON POLINOMIO DI ORDINE 4

Statistiche dei residui sui GCP

COMPONENTE X												
COMPONENTE Y						COMPONENTE X						
MODULO												
media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
max	RMSE											

0.000 3.775 -7.667 10.785 3.762 0.000 3.410 -10.007 8.836 3.398 4.515 2.313 0.564  
 10.847 5.069

Statistiche dei residui sui CP

COMPONENTE X												
COMPONENTE Y						COMPONENTE X						MODULO
media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
max	RMSE											
-0.365	4.739	-9.930	12.501	4.685	0.437	4.575	-7.352	10.986	4.531	5.752	3.108	1.180
13.756	6.517											

GEOREFERENZIAZIONE CON POLINOMIO DI ORDINE 5

Statistiche dei residui sui GCP

COMPONENTE X												
COMPONENTE Y						COMPONENTE X						MODULO
media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
max	RMSE											
-0.000	3.331	-8.212	8.760	3.319	0.000	3.211	-10.986	8.446	3.199	4.002	2.295	0.054
10.988	4.609											

Statistiche dei residui sui CP

COMPONENTE X  
COMPONENTE Y  
MODULO

media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
-0.466	4.700	-9.143	10.805	4.656	0.410	4.783	-7.473	12.603	4.732	5.867	3.151	1.233
12.783	6.638											

DETERMINAZIONE DEL POLINOMIO DI GRADO OTTIMALE

Il polinomio che produce il minimo RMSE dei moduli dei residui sui CP è quello di grado 3, con un valore 6.340 m.

Il polinomio risultante dal test di Fisher sui residui sulle coordinate X e Y dei GCP è quello di grado 5.

Globalmente, il polinomio ottimale per georiferire la mappa è quello di grado 3.

## **Walled City of Como (1858):**

GEOREFERENZIAZIONE CON POLINOMIO DI ORDINE 1

Statistiche dei residui sui GCP

COMPONENTE X  
COMPONENTE Y  
MODULO

media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min

0.000 1.035 -2.659 3.061 1.030 -0.000 1.695 -4.288 3.334 1.686 1.760 0.904 0.104  
 4.429 1.976

Statistiche dei residui sui CP

COMPONENTE X												
COMPONENTE Y												
MODULO												
media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
max	RMSE											
-0.539	1.068	-2.396	1.248	1.176	0.293	1.678	-4.072	3.496	1.669	1.818	0.949	0.334
4.097	2.042											

GEOREFERENZIAZIONE CON POLINOMIO DI ORDINE 2

Statistiche dei residui sui GCP

COMPONENTE X												
COMPONENTE Y												
MODULO												
media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
max	RMSE											
0.000	0.968	-2.747	2.931	0.964	0.000	1.078	-2.230	2.552	1.073	1.306	0.614	0.171
2.931	1.442											

Statistiche dei residui sui CP

COMPONENTE X  
COMPONENTE Y  
MODULO

media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
-0.493	1.086	-2.991	1.653	1.172	0.419	1.078	-2.067	2.328	1.135	1.474	0.714	0.187
max	RMSE											
3.017	1.631											

GEOREFERENZIAZIONE CON POLINOMIO DI ORDINE 3

Statistiche dei residui sui GCP

COMPONENTE X  
COMPONENTE Y  
MODULO

media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
-0.000	0.955	-2.569	2.833	0.950	0.000	1.034	-2.253	2.475	1.029	1.281	0.568	0.254
max	RMSE											
2.836	1.400											

Statistiche dei residui sui CP

COMPONENTE X  
COMPONENTE Y  
MODULO

media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
-0.461	1.150	-2.813	1.959	1.216	0.388	0.883	-1.757	2.078	0.948	1.381	0.699	0.127
max	RMSE											
2.824	1.542											



## GEOREFERENZIAZIONE CON POLINOMIO DI ORDINE 4

Statistiche dei residui sui GCP

COMPONENTE X														
COMPONENTE Y						COMPONENTE X						COMPONENTE Y		
MODULO			COMPONENTE X			COMPONENTE Y			MODULO			COMPONENTE X		
media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min		
max	RMSE													
0.000	0.926	-2.190	2.573	0.921	-0.000	1.003	-2.368	3.028	0.998	1.234	0.571	0.106		
3.029	1.358													

Statistiche dei residui sui CP

COMPONENTE X														
COMPONENTE Y						COMPONENTE X						COMPONENTE Y		
MODULO			COMPONENTE X			COMPONENTE Y			MODULO			COMPONENTE X		
media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min		
max	RMSE													
-0.441	1.121	-2.431	1.933	1.183	0.335	0.896	-1.793	2.126	0.939	1.384	0.617	0.101		
2.438	1.510													

## GEOREFERENZIAZIONE CON POLINOMIO DI ORDINE 5

Statistiche dei residui sui GCP

COMPONENTE X												
COMPONENTE Y												
MODULO												
media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
max	RMSE											
-0.000	0.912	-2.031	2.620	0.908	0.000	0.986	-2.315	2.943	0.981	1.209	0.572	0.118
2.943	1.337											

Statistiche dei residui sui CP

COMPONENTE X												
COMPONENTE Y												
MODULO												
media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
max	RMSE											
-0.390	1.125	-2.173	2.150	1.168	0.366	0.857	-1.038	1.920	0.916	1.358	0.613	0.188
2.443	1.484											

#### DETERMINAZIONE DEL POLINOMIO DI GRADO OTTIMALE

Il polinomio che produce il minimo RMSE dei moduli dei residui sui CP è quello di grado 5, con un valore 1.484 m.

Il polinomio risultante dal test di Fisher sui residui sulle coordinate X e Y dei GCP è quello di grado 2.

Globalmente, il polinomio ottimale per georiferire la mappa è quello di grado 2.

### **Como Borghi (1861):**

## GEOREFERENZIAZIONE CON POLINOMIO DI ORDINE 1

Statistiche dei residui sui GCP

COMPONENTE X													
COMPONENTE Y						COMPONENTE X						COMPONENTE Y	
MODULO			COMPONENTE X			COMPONENTE Y			MODULO			COMPONENTE X	COMPONENTE Y
media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min	
max	RMSE												
-0.000	4.607	-12.605	9.646	4.595	0.000	4.534	-9.879	11.915	4.522	5.877	2.657	0.533	
13.650	6.447												

Statistiche dei residui sui CP

COMPONENTE X													
COMPONENTE Y						COMPONENTE X						COMPONENTE Y	
MODULO			COMPONENTE X			COMPONENTE Y			MODULO			COMPONENTE X	COMPONENTE Y
media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min	
max	RMSE												
0.678	4.471	-10.588	14.621	4.475	-0.240	5.604	-11.637	9.690	5.549	6.449	3.071		
2.277	15.669	7.129											

## GEOREFERENZIAZIONE CON POLINOMIO DI ORDINE 2

Statistiche dei residui sui GCP

COMPONENTE X  
COMPONENTE Y  
MODULO

media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
0.000	4.419	-10.731	9.404	4.407	-0.000	4.169	-8.938	12.420	4.158	5.401	2.753	0.402
13.150	6.059											

Statistiche dei residui sui CP

COMPONENTE X  
COMPONENTE Y  
MODULO

media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
0.577	4.447	-7.739	15.081	4.437	-0.262	5.307	-12.175	10.651	5.257	6.029	3.347	
0.119	15.857	6.879										

GEOREFERENZIAMENTO CON POLINOMIO DI ORDINE 3

Statistiche dei residui sui GCP

COMPONENTE X  
COMPONENTE Y  
MODULO

media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
0.000	4.232	-11.582	10.051	4.221	0.000	4.127	-8.953	12.132	4.116	5.211	2.764	
0.284	12.823	5.895										

Statistiche dei residui sui CP

COMPONENTE X												
COMPONENTE Y						COMPONENTE X						
MODULO			COMPONENTE Y			COMPONENTE X			MODULO			
media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
max	RMSE											
0.731	4.369	-7.208	13.579	4.384	-0.142	5.487	-12.271	12.406	5.430	6.258	3.122	
0.294	14.294	6.979										

GEOREFERENZIAZIONE CON POLINOMIO DI ORDINE 4

Statistiche dei residui sui GCP

COMPONENTE X												
COMPONENTE Y						COMPONENTE X						
MODULO			COMPONENTE Y			COMPONENTE X			MODULO			
media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
max	RMSE											
-0.000	4.010	-12.093	10.511	4.000	0.000	3.769	-11.165	12.263	3.759	4.796	2.677	
0.223	14.032	5.489										

Statistiche dei residui sui CP

COMPONENTE X												
COMPONENTE Y						COMPONENTE X						
MODULO			COMPONENTE Y			COMPONENTE X			MODULO			
media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
max	RMSE											

0.655 4.571 -7.421 12.996 4.569 0.015 4.979 -12.744 9.492 4.926 5.931 3.192 0.319  
 13.761 6.719

GEOREFERENZIAZIONE CON POLINOMIO DI ORDINE 5

Statistiche dei residui sui GCP

COMPONENTE X												
COMPONENTE Y						COMPONENTE X						
MODULO												
media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
max	RMSE											
0.000	3.971	-13.100	10.303	3.960	-0.000	3.715	-11.037	10.947	3.705	4.731	2.658	
0.637	14.831	5.423										

Statistiche dei residui sui CP

COMPONENTE X												
COMPONENTE Y						COMPONENTE X						
MODULO												
media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
max	RMSE											
0.690	4.431	-6.437	12.828	4.437	0.076	4.972	-12.729	9.613	4.919	5.863	3.118	0.536
13.297	6.625											

DETERMINAZIONE DEL POLINOMIO DI GRADO OTTIMALE



Il polinomio che produce il minimo RMSE dei moduli dei residui sui CP è quello di grado 5, con un valore 6.625 m.

Il polinomio risultante dal test di Fisher sui residui sulle coordinate X e Y dei GCP è quello di grado 4.

Globalmente, il polinomio ottimale per georiferire la mappa è quello di grado 4.

## **Walled City of Como (1873):**

### GEOREFERENZIAZIONE CON POLINOMIO DI ORDINE 1

Statistiche dei residui sui GCP

COMONENTE X												
COMONENTE Y						COMONENTE X						
MODULO						MODULO						
media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
max	RMSE											
0.000	1.120	-2.370	2.507	1.114	0.000	1.061	-2.015	2.560	1.056	1.386	0.664	0.118
2.608	1.535											

Statistiche dei residui sui CP

COMONENTE X												
COMONENTE Y						COMONENTE X						
MODULO						MODULO						
media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
max	RMSE											
-0.510	0.831	-1.930	0.818	0.960	0.134	1.023	-2.060	2.359	1.011	1.252	0.627	0.178
2.490	1.394											

## GEOREFERENZIAZIONE CON POLINOMIO DI ORDINE 2

Statistiche dei residui sui GCP

COMPONENTE X												
COMPONENTE Y												
MODULO												
media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
max	RMSE											
-0.000	1.039	-2.493	2.598	1.034	0.000	1.023	-2.012	2.868	1.018	1.315	0.616	0.105
2.870	1.451											

Statistiche dei residui sui CP

COMPONENTE X												
COMPONENTE Y												
MODULO												
media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
max	RMSE											
-0.480	0.879	-1.891	0.936	0.985	0.119	0.969	-1.791	2.122	0.956	1.261	0.555	0.159
2.146	1.373											

## GEOREFERENZIAZIONE CON POLINOMIO DI ORDINE 3

Statistiche dei residui sui GCP

COMPONENTE X  
COMPONENTE Y  
MODULO

media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
0.000	1.018	-2.316	2.874	1.013	-0.000	0.948	-2.377	2.747	0.943	1.248	0.602	0.087
max	RMSE											
2.875	1.384											

Statistiche dei residui sui CP

COMPONENTE X  
COMPONENTE Y  
MODULO

media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
-0.454	0.855	-1.768	0.909	0.952	0.158	1.054	-1.992	1.876	1.044	1.321	0.511	0.262
max	RMSE											
2.183	1.412											

GEOREFERENZIAZIONE CON POLINOMIO DI ORDINE 4

Statistiche dei residui sui GCP

COMPONENTE X  
COMPONENTE Y  
MODULO

media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
0.000	0.992	-2.117	2.780	0.987	-0.000	0.932	-2.421	2.582	0.927	1.217	0.596	0.088
max	RMSE											
2.866	1.354											

Statistiche dei residui sui CP

COMPONENTE X												
COMPONENTE Y						COMPONENTE X						
MODULO												
media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
max	RMSE											
-0.369	0.869	-1.595	1.015	0.927	0.181	1.057	-1.865	2.061	1.050	1.326	0.460	0.267
2.091	1.401											

GEOREFERENZIAZIONE CON POLINOMIO DI ORDINE 5

Statistiche dei residui sui GCP

COMPONENTE X												
COMPONENTE Y						COMPONENTE X						
MODULO												
media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
max	RMSE											
0.000	0.947	-2.174	2.548	0.942	-0.000	0.886	-2.407	2.199	0.881	1.157	0.572	0.096
2.559	1.290											

Statistiche dei residui sui CP

COMPONENTE X												
COMPONENTE Y						COMPONENTE X						
MODULO												

media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
-0.337	0.862	-1.741	1.112	0.909	0.242	1.054	-1.569	2.456	1.059	1.285	0.555	0.115
2.458	1.396											

#### DETERMINAZIONE DEL POLINOMIO DI GRADO OTTIMALE

Il polinomio che produce il minimo RMSE dei moduli dei residui sui CP è quello di grado 2, con un valore 1.373 m.

Il polinomio risultante dal test di Fisher sui residui sulle coordinate X e Y dei GCP è quello di grado 3.

Globalmente, il polinomio ottimale per georiferire la mappa è quello di grado 2.

### **Como Borghi (1900):**

#### GEOREFERENZIAZIONE CON POLINOMIO DI ORDINE 1

Statistiche dei residui sui GCP

COMONENTE X												
COMONENTE Y						COMONENTE X						
MODULO												
media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
-0.000	4.607	-12.605	9.646	4.595	0.000	4.534	-9.879	11.915	4.522	5.877	2.657	0.533
13.650	6.447											

Statistiche dei residui sui CP

COMPONENTE X												
COMPONENTE Y						COMPONENTE X						
MODULO												
media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
max	RMSE											
0.678	4.471	-10.588	14.621	4.475	-0.240	5.604	-11.637	9.690	5.549	6.449	3.071	
2.277	15.669	7.129										

GEOREFERENZIAZIONE CON POLINOMIO DI ORDINE 2

Statistiche dei residui sui GCP

COMPONENTE X												
COMPONENTE Y						COMPONENTE X						
MODULO												
media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
max	RMSE											
0.000	4.419	-10.731	9.404	4.407	-0.000	4.169	-8.938	12.420	4.158	5.401	2.753	0.402
13.150	6.059											

Statistiche dei residui sui CP

COMPONENTE X												
COMPONENTE Y						COMPONENTE X						
MODULO												
media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
max	RMSE											



0.577 4.447 -7.739 15.081 4.437 -0.262 5.307 -12.175 10.651 5.257 6.029 3.347  
 0.119 15.857 6.879

GEOREFERENZIAZIONE CON POLINOMIO DI ORDINE 3

Statistiche dei residui sui GCP

COMPONENTE X												
COMPONENTE Y						COMPONENTE X						
MODULO												
media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
max	RMSE											
0.000	4.232	-11.582	10.051	4.221	0.000	4.127	-8.953	12.132	4.116	5.211	2.764	
0.284	12.823	5.895										

Statistiche dei residui sui CP

COMPONENTE X												
COMPONENTE Y						COMPONENTE X						
MODULO												
media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
max	RMSE											
0.731	4.369	-7.208	13.579	4.384	-0.142	5.487	-12.271	12.406	5.430	6.258	3.122	
0.294	14.294	6.979										

GEOREFERENZIAZIONE CON POLINOMIO DI ORDINE 4

Statistiche dei residui sui GCP

COMPONENTE X												
COMPONENTE Y						COMPONENTE X						
MODULO												
media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
max	RMSE											
-0.000	4.010	-12.093	10.511	4.000	0.000	3.769	-11.165	12.263	3.759	4.796	2.677	
0.223	14.032	5.489										

Statistiche dei residui sui CP

COMPONENTE X												
COMPONENTE Y						COMPONENTE X						
MODULO												
media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
max	RMSE											
0.655	4.571	-7.421	12.996	4.569	0.015	4.979	-12.744	9.492	4.926	5.931	3.192	0.319
13.761	4.719											

GEOREFERENZIAZIONE CON POLINOMIO DI ORDINE 5

Statistiche dei residui sui GCP

COMPONENTE X												
COMPONENTE Y						COMPONENTE X						
MODULO												
media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
max	RMSE											

0.000 3.971 -13.100 10.303 3.960 -0.000 3.715 -11.037 10.947 3.705 4.731 2.658  
 0.637 14.831 5.423

Statistiche dei residui sui CP

COMPONENTE X												
COMPONENTE Y						COMPONENTE X						MODULO
media	dev.st.	min	max	RMSE	media	dev.st.	min	max	RMSE	media	dev.st.	min
max	RMSE											
0.690	4.431	-6.437	12.828	4.437	0.076	4.972	-12.729	9.613	4.919	5.863	3.118	0.536
13.297	4.665											

#### DETERMINAZIONE DEL POLINOMIO DI GRADO OTTIMALE

Il polinomio che produce il minimo RMSE dei moduli dei residui sui CP è quello di grado 5, con un valore 4.665 m.

Il polinomio risultante dal test di Fisher sui residui sulle coordinate X e Y dei GCP è quello di grado 4.

Globalmente, il polinomio ottimale per georiferire la mappa è quello di grado 4.

## Anex 3: Georeferenced Historical Maps

Topographic map of Como, XVII century



## Theresian map of Como, 1722



Theresian map of Como city parishes, 1722





## Map of Walled City of Como, 1858

---





## Map of Como Borghi, 1861



## Map of Walled City of Como, 1873



## Anex 4: WebGIS HTML file

```
<html>
<head>
  <title>Master thesis:WebGis</title>
  <script src="OpenLayers-2.13.1/OpenLayers.js" type="text/javascript"></script>
  <script src="ext-3.4.0/adaptor/ext/ext-base.js" type="text/javascript"></script>
  <script src="ext-3.4.0/ext-all.js" type="text/javascript"></script>
  <link rel="stylesheet" type="text/css" href="ext-3.4.0/resources/css/ext-all.css"></link>
  <link rel="stylesheet" type="text/css" href="ext-3.4.0/resources/css/xtheme-blue.css"></link>
  <script src="GeoExt/lib/GeoExt.js" type="text/javascript"></script>
  <link rel="stylesheet" type="text/css" href="GeoExt/resources/css/geoext-all-debug.css"></link>
  <script src="http://maps.google.com/maps/api/js?v=3&sensor=false"></script>
  <meta http-equiv="Content-Type" content="text/html; charset=utf-8"></meta>
  <h1 align="center" id="title" style="color: #29088A"><u><strong><font face="Papyrus" size="5">
    A simple WebGIS for viewing the evolution of the city of Como </font></strong></u></h1>
</head>
<style type="text/css">
.olControlOverviewMap {
  background:#0040ff;
  top: 300px
  width:200px;
};
#opacity {
  padding: 0;
  float:center;
  right: 500px
  text-align: center;
```

```
width: 20px;

font-family: Papyrus;

background: transparent;

color: #29088A;

border: 0;

};

</style>

<body >

<script type="text/javascript">

    var map = null;

    var topo = null;

    var teresian = null;

    var teresian_perishes = null;

    var geo1858 = null;

    var geo1861 = null;

    var geo1873 = null;

    var geo1900 = null;

    var maxOpacity = 1;

    var minOpacity = 0;

    function changeOpacity(byOpacity) {

        var newOpacity = (parseFloat(OpenLayers.Util.getElement('opacity').value) + byOpacity).toFixed(1);

        newOpacity = Math.min(maxOpacity,

            Math.max(minOpacity, newOpacity));

        OpenLayers.Util.getElement('opacity').value = newOpacity;

            topo.setOpacity(newOpacity);

            teresian.setOpacity(newOpacity);
```

```
        teresian_perishes.setOpacity(newOpacity);

        geo1858.setOpacity(newOpacity);

        geo1861.setOpacity(newOpacity);

        geo1873.setOpacity(newOpacity);

        geo1900.setOpacity(newOpacity); }

    var apiKey = "AqTGBsziZHIJYxgivLBf0hVdrAk9mWO5cQcb8Yux8sW5M8c8opEC2lZqKR1ZZXf"; // for
Bing layers

    Ext.onReady(function() {

        var map = new OpenLayers.Map('map',{ controls: [new OpenLayers.Control.PanZoom()],

            projection: 'EPSG:900913', displayProjection: 'EPSG: 32632', units: "m"});

// Google layers:

        var gphy = new OpenLayers.Layer.Google("Google Physical",

            {type: google.maps.MapTypeId.TERRAIN} );

        var gmap = new OpenLayers.Layer.Google("Google Streets",

            {numZoomLevels: 20} );

        var ghyb = new OpenLayers.Layer.Google("Google Hybrid",

            {type: google.maps.MapTypeId.HYBRID,

            numZoomLevels: 20} );

        map.addLayers([ghyb,gphy,gmap]);

// Bing layers:

        var bingroads = new OpenLayers.Layer.Bing({

            key: apiKey,

            type: "Road",

            name: "Bing Road",

            wrapDateLine: true });

        var bingaeriallab = new OpenLayers.Layer.Bing({

            key: apiKey,

            type: "AerialWithLabels",
```

```
    name: "Bing Aerial with Labels",
    wrapDateLine: true });

map.addLayers([bingroads, bingaeriallab]);

// OSM layer:

var mapnik = new OpenLayers.Layer.OSM();

map.addLayer(mapnik);

// shapefiles

roads = new OpenLayers.Layer.WMS( "Roads",

"http://localhost:8080/geoserver/wms/Thesis_Aleks", {layers: 'Thesis_Aleks:Primary roads',
transparent:"true", style: "color: black"}, {isBaseLayer:false} );

roads.setVisibility(false);

pedestrian = new OpenLayers.Layer.WMS( "Pedestrian circulation",

"http://localhost:8080/geoserver/wms/Thesis_Aleks", {layers: 'Thesis_Aleks:Pedestrian circulation',
transparent:"true", style: "color: black"}, {isBaseLayer:false} );

pedestrian.setVisibility(false);

buildings = new OpenLayers.Layer.WMS( "Buildings",

"http://localhost:8080/geoserver/wms/Thesis_Aleks", {layers:
'Thesis_Aleks:Buildings,Thesis_Aleks:Minor buildings', transparent:"true"}, {isBaseLayer:false} );

buildings.setVisibility(false);

bridge = new OpenLayers.Layer.WMS( "Bridge/viaduct/overpass",

"http://localhost:8080/geoserver/wms/Thesis_Aleks", {layers: 'Thesis_Aleks:Bridge', transparent:"true"},
{isBaseLayer:false} );

bridge.setVisibility(false);

harbor = new OpenLayers.Layer.WMS( "Harbor",

"http://localhost:8080/geoserver/wms/Thesis_Aleks", {layers: 'Thesis_Aleks:Harbor', transparent:"true"},
{isBaseLayer:false} );

harbor.setVisibility(false);

river = new OpenLayers.Layer.WMS( "Water areas",

"http://localhost:8080/geoserver/wms/Thesis_Aleks", {layers: 'Thesis_Aleks:River
areas,Thesis_Aleks:Water bodies', transparent:"true"}, {isBaseLayer:false} );
```



```
river.setVisibility(false);

thickness = new OpenLayers.Layer.WMS( "Thickness division",

"http://localhost:8080/geoserver/wms/Thesis_Aleks", {layers: 'Thesis_Aleks:Thickness division',
transparent:"true"}, {isBaseLayer:false} );

thickness.setVisibility(false);

pathway = new OpenLayers.Layer.WMS( "Pathways",

"http://localhost:8080/geoserver/wms/Thesis_Aleks", {layers: 'Thesis_Aleks:Pathways',
transparent:"true"}, {isBaseLayer:false} );

pathway.setVisibility(false);

together = new OpenLayers.Layer.WMS( "2006 Como municipality database",

"http://localhost:8080/geoserver/wms/Thesis_Aleks",

{layers: 'Thesis_Aleks:Thickness division,Thesis_Aleks:Pathways,Thesis_Aleks:River
areas,Thesis_Aleks:Water
bodies,Thesis_Aleks:Harbor,Thesis_Aleks:Bridge,Thesis_Aleks:Buildings,Thesis_Aleks:Minor
buildings,Thesis_Aleks:Primary roads,Thesis_Aleks:Pedestrian circulation', transparent:"true"},
{isBaseLayer:true} );

map.addLayer(together);

//historical maps

topo = new OpenLayers.Layer.WMS( "Topographic map XVII century",

"http://localhost:8080/geoserver/wms/Thesis_Aleks", {layers: 'Thesis_Aleks:geoTopo',
transparent:"true"}, {isBaseLayer:false} );

topo.setVisibility(false);

teresian = new OpenLayers.Layer.WMS( "Teresian map 1722",

"http://localhost:8080/geoserver/wms/Thesis_Aleks", {layers: 'Thesis_Aleks:geoTeresian',
transparent:"true"}, {isBaseLayer:false} );

teresian.setVisibility(false);

teresian_perishes = new OpenLayers.Layer.WMS( "Teresian map 1722:Clty perishes",

"http://localhost:8080/geoserver/wms/Thesis_Aleks", {layers: 'Thesis_Aleks:geoPerishes',
transparent:"true"}, {isBaseLayer:false} );
```

```
teresian_perishes.setVisibility(false);

geo1858 = new OpenLayers.Layer.WMS( "Walled City of Como (1858)",
"http://localhost:8080/geoserver/wms/Thesis_Aleks", {layers: 'Thesis_Aleks:geo1858',
transparent:"true"}, {isBaseLayer:false} );

geo1858.setVisibility(false);

geo1861 = new OpenLayers.Layer.WMS( "Map of Como Borghi (1861)",
"http://localhost:8080/geoserver/wms/Thesis_Aleks", {layers: 'Thesis_Aleks:geo1861',
transparent:"true"}, {isBaseLayer:false} );

geo1861.setVisibility(false);

geo1873 = new OpenLayers.Layer.WMS( "Walled City of Como (1873)",
"http://localhost:8080/geoserver/wms/Thesis_Aleks", {layers: 'Thesis_Aleks:geo1873',
transparent:"true"}, {isBaseLayer:false} );

geo1873.setVisibility(false);

geo1900 = new OpenLayers.Layer.WMS( "Map of Como Borghi (1900)",
"http://localhost:8080/geoserver/wms/Thesis_Aleks", {layers: 'Thesis_Aleks:geo1900',
transparent:"true"}, {isBaseLayer:false} );

geo1900.setVisibility(false);

map.addLayer(topo);
map.addLayer(teresian);
map.addLayer(teresian_perishes);
map.addLayer(geo1858);
map.addLayer(geo1861);
map.addLayer(geo1873);
map.addLayer(geo1900);
map.addLayer(roads);
map.addLayer(pedestrian);
map.addLayer(buildings);
```

```
map.addLayer(bridge);  
map.addLayer(harbor);  
map.addLayer(river);  
map.addLayer(thickness);  
map.addLayer(pathway);  
map.addLayer(together);
```

```
map.addControl(new OpenLayers.Control.MousePosition(  
    {prefix: "X: ",  
    separator: ", Y: ",  
    numDigits: 2}  ));
```

```
map.addControl(new OpenLayers.Control.Scale());  
map.addControl(new OpenLayers.Control.ScaleLine());  
map.addControl(new OpenLayers.Control.Navigation());  
map.addControl(new OpenLayers.Control.PanZoomBar());  
map.addControl(new OpenLayers.Control.Attribution());
```

```
var vlayer = new OpenLayers.Layer.Vector( "Editable" );  
var container = document.getElementById("panel");  
var panel = new OpenLayers.Control.EditingToolbar(  
    vlayer, {div: container} );  
map.addControl(panel);  
    map.addLayer(vlayer);  
    vlayer.setVisibility(false);
```

```
var overview1 = new OpenLayers.Control.OverviewMap({
    maximized: true });
map.addControl(overview1);

var mapPanel = new GeoExt.MapPanel({
    region: 'center',
    title: 'The Map',
    xtype: 'mapcomponent',
    width: '80',
    map: map,
    frame: false,
    border: true,
    margins: '0 0 0 0'
});

var LayerNodeUI = Ext.extend(GeoExt.tree.LayerNodeUI, new GeoExt.tree.TreeNodeUIEventMixin());
var treeConfig = [{
    text: "Base Maps",
    leaf: false,
    expanded: true,
    children: [{
nodeType: 'gx_layer',
layer: ghyb },
    {  nodeType: 'gx_layer',
layer: gmap },
    {  nodeType: 'gx_layer',
layer: gphy },
    {  nodeType: 'gx_layer',
layer: bingroads },
```

```
{  nodeType: 'gx_layer',
layer: bingaeriallab },
{  nodeType: 'gx_layer',
layer: mapnik },
{  nodeType: 'gx_layer',
layer: together }
}],
{text: "Layers of 2006 Municipality of Como database",
  leaf: false,
  expanded: false,
  children: [{
nodeType: 'gx_layer',
layer: roads},
{nodeType: 'gx_layer',
layer: pedestrian},
{  nodeType: 'gx_layer',
layer: buildings },
{  nodeType: 'gx_layer',
layer: bridge },
{  nodeType: 'gx_layer',
layer: harbor },
{  nodeType: 'gx_layer',
layer: river },
{  nodeType: 'gx_layer',
layer: thickness },
{  nodeType: 'gx_layer',
layer: pathway }
}],
```

```
{text: "Historical maps of Como",
  leaf: false,
  expanded: false,
  children: [{
nodeType: 'gx_layer',
layer: topo},
 {  nodeType: 'gx_layer',
layer: teresian  },
 {  nodeType: 'gx_layer',
layer: teresian_perishes  },
 {  nodeType: 'gx_layer',
layer: geo1858  },
 {  nodeType: 'gx_layer',
layer: geo1861  },
 {  nodeType: 'gx_layer',
layer: geo1873  },
 {  nodeType: 'gx_layer',
layer: geo1900  }
]},
{text: "Editing",
  leaf: false,
  expanded: false,
  children: [{
nodeType: 'gx_layer',
layer: vlayer}
]}
];

var tree = new Ext.tree.TreePanel({
```

```
    region: 'west',
xtype: 'layertree',
    title: 'Layer tree',
    border: true,
width: '20%',
    split: true,
    collapsible: true,
    collapseMode: "mini",
frame: false,
autoScroll: true,
    bodyStyle: 'background-color: #e6eaec',
    margins: '0 0 3 3',
    loader: new Ext.tree.TreeLoader({
applyLoader: false,
uiProviders: {"layernodeui": LayerNodeUI}
    }),
root: {
nodeType: "async",
children: treeConfig
    },
rootVisible: false,
lines: false
    });

banner = new Ext.BoxComponent({
    region: 'north',
    border: true,
    layout: 'fit',
    margins: '0 0 0 0',
```



```
        el: 'banner',
        height: 50
    });

    banner2 = new Ext.BoxComponent({
        region: 'south',
        border: true,
        layout: 'fit',
        margins: '0 0 0 0',
        el: 'banner2',
        height: 70
    });

    viewport = new Ext.Viewport({
        layout: 'border',
        items: [
            banner,
            mapPanel,
            tree, banner2]
    });

    map.setCenter(new OpenLayers.LonLat(9.09, 45.81).transform(
        new OpenLayers.Projection("EPSG:4326"),
        new OpenLayers.Projection("EPSG:900913")), 13);
});

</script>
</body>
<div id="banner"></div>
<div id="banner2">
```

```
<a href="http://www.polimi.it/en/english-version/"><img src='polimi.jpg', style="width:180px; height:40px; float: left padding: 5px"/></a>
```

```
<a href="http://www.comune.como.it/"><img src='como.gif', style="width:180px; height:40px"/></a>
```

```
<div style="width:1340px; height:10px" id="docs">
```

```
<p align= 'center' style= "color: #29088A; float: center"><u><strong><font face="Papyrus" size="3">Change the opacity of a layer:
```

```
<a title="Decrease opacity" href="javascript: changeOpacity(-0.1);">&lt;&lt;</a>
```

```
<input id="opacity" type="text" value="1" size="5" align="center" style= "color: #29088A;" disabled="true" />
```

```
<a title="Increase opacity" href="javascript: changeOpacity(0.1);">&gt;&gt;</a>
```

```
</p> </div>
```

```
</div>
```

```
</html>
```