

## **Title**

**“Perspectives” on the 3-D analysis through the cadastral map series (XVIII – XX sec.) and the first geodetic large scale map of Milan realized by the ‘Astronomi di Brera’ (Astronomers of Brera): toward an advanced portal**

## **Authors**

C. Monti (\*), C. Achille (\*), R. Brumana (\*), S. Musumeci (\*\*), D. Oreni (\*), M. Signori (\*\*\*)

(\* Politecnico di Milano – DIIAR , (\*\*) Agenzia del Territorio, Direzione Regionale Lombardia, (\*\*\*) Archivio di Stato di Milano, Italy

## **Abstract**

Archivio di Stato di Milano (the State Archive of Milan) has begun the digital archive process of historical cadastral maps few year ago, considered as the first step to support their on-line publications. The portal project ‘Atlas of historical cadastral maps’ was made upon a collaboration between Politecnico di Milano -DIIAR (leader), the two principal owners of the cadastral heritage, Archivio di Stato and Agenzia del Territorio – Direzione Regionale Lombardia (the Agency of Territory – Regional Direction) and Regione Lombardia – Giunta Regionale Presidenza, Patrimonio e Sistema Informativo (Lombardy Region), for the indication activities and those of decentralization of the territory. The main aim was to put together cataloguing approach and to guarantee the spread online presentation and diffusion of the geo-iconographic historical contents in a detailed territorial dimension.

Considering that only for the regional area of Lombardy – interested by the project – there is an extraordinarily huge patrimony, constituted by thousands of sheet units, belonging to different documentaries series, produced during different periods by the cadastral offices devoted to the cadastral generation and conservation. The map documentation, nowadays conserved in the different Archivio di Stato offices decentred within the provinces of the Lombardy region, is statistically the most essential for consulting purposes, correspondent to a wide and variegated research spectrum.

To have an idea of the regional coverage, the current cadastre and its plant (Impianto al vigente catasto, 1937-1958) - owned and conserved by Agenzia del Territorio - is made by about 70.000 sheet for each layer. The Atlas aims to provide for users an agile and intuitive access instruments to the historical cadastres and maps, navigating on currently available maps at different scales (i.e. the technical regional map 1:10000, or the IGM Military Geographic Institute) the territory of yesterday referred to administrative boundaries losing correspondence with the nowadays territorial municipalities. A bond with the actual map can be well constituted by the first cartographic representation at the topographic scale of the Lombard territory anchored at a geodetic reference system: La mappa degli Astronomi di Brera (The map of Astronomi of Brera) and the ITM R LV, adopting an articulated semantics for the anthropic thematic issues of the territorial political-administrative boundaries. The Atlas in a multidisciplinary access networking approach, will be aligned to the international standard for the historic cartography (ISAD, EAD), and to the EU standard for geographic map sharing (INSPIRE); at the same time, being the maps historic geo-iconographic documents, they have to be compared to historic descriptive standard (AACR2\_CM; ICCD for Italy).

## **1. Archivio di Stato di Milano and the portal project ‘The Atl@s of historical cadastral and topographic maps’: towards the geo-iconographic historical content of a detailed territorial dimension**

The Archivio di Stato di Milano aims at publishing in a dedicated WebGIS their digital images of maps series surveyed by government land offices during different surveys done along eighteenth and nineteenth century for all territories of Lombardy region<sup>1</sup>. The goal of this project is to design a metadata-driven and dynamic access tool that will enable users to access scanned and partially geo-referenced map images by querying an easy to use digital gazetteer (a geographical dictionary or directory, an important reference for information about places and their toponomy), to offer qualified access services to public administrations, professional users and researchers.

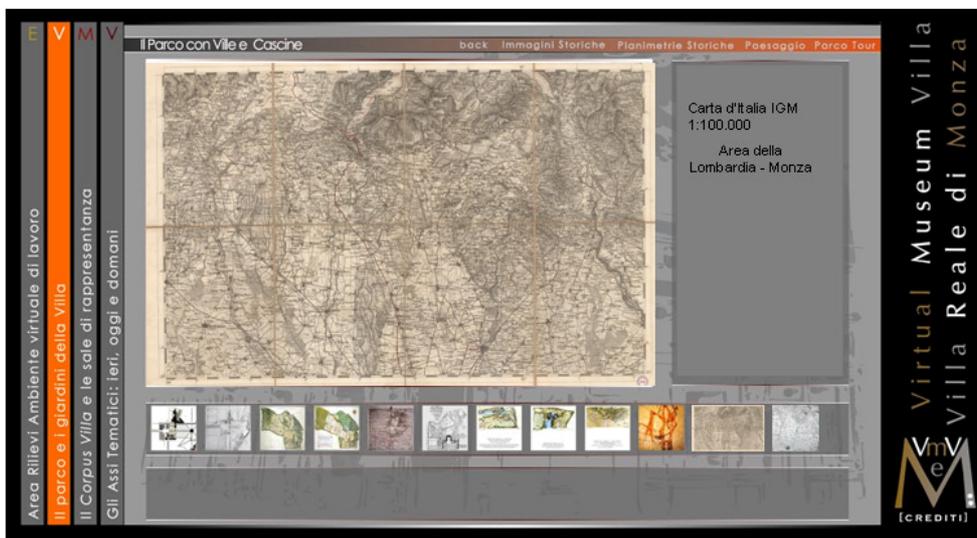
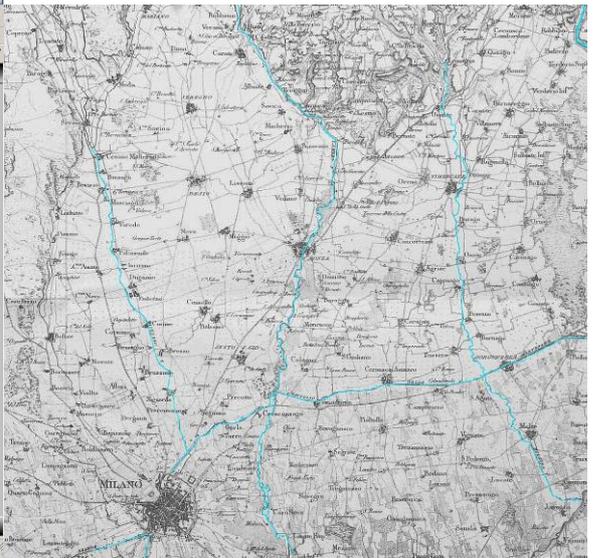
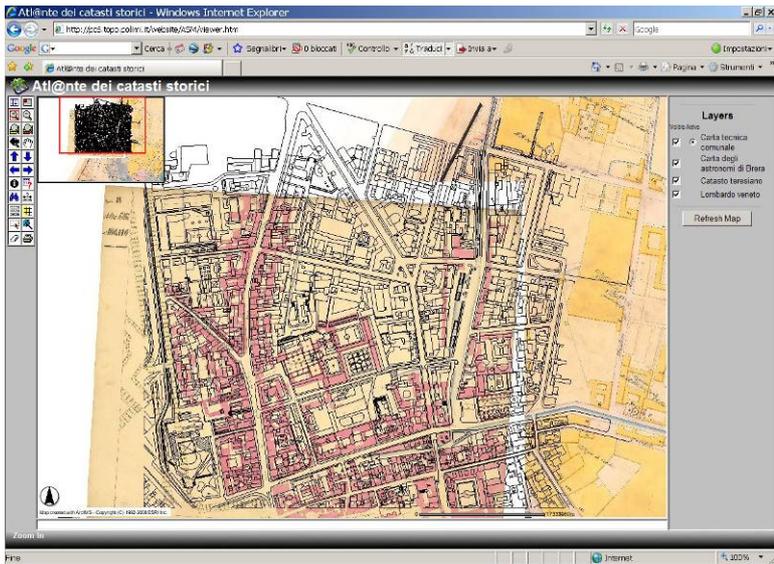
The paper will investigate the digital access methods and the cataloguing approach required to integrate digital gazetteers, standard metadata for archival description and authority file relating the double nature of cadastral maps, which are geometrical scaled drawings produced by technical corps with geographical content referred to specific locations or jurisdictions, and, at the same time, authenticated documents belonging to archival set of fonds and series produced in a bureaucratic context, linked to other documentary series like land-property registers produced by land-offices.

The comparison with coeval topographic maps based on geodetic survey covering the same territories, allows to produce gazetteers regarding settlements, administrative boundaries, hydrographical elements. One of the goals would be the reconstruction of boundaries variations along the period for the whole area covered.

For this aim, the series of maps must be “geo-referenced” to create a continuous layer and digital gazetteer for locating place-names on the map images, in order to relate different chronological maps series. The gazetteer will include both current and historic names referenced to the same geographic location. An Internet Map Server will index the metadata and provide interfaces to the imagery, zooming to the queried place. The interface brings the appropriate images from more sets

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<sup>1</sup> Among the maps used there are those ones with geodetic orientation (carta Astronomi, cessato Catasto, impianto al vigente) and also the ones that lack of these information (catasto teresiano): in both cases, however, the maps used are in scale (1:2000 – 1:1000) and therefore referable using numerous homologous points of the Gauss-Boaga reference system on the presently used cartography and its plant of 1937, the last historical cadastral threshold obtained planimetrically from the previous cadastre.



Atl@nte dei Catasti.  
**Above left:** visualization in ArcIms of georeferred maps.  
**Above right:** 'Carta topografica del Milanese e del Mantovano basata sulle misure effettuate dagli astronomi di Brera fra il 1788 e il 1791' (Topographical map of areas of Milano and Mantova based on the measurements of Brera astronomers 1788-1791)  
**Left:** web page of Villa Reale of Monza. Visualization of Carta d'Italia IGM



Above: The layout of the Milano city walls and internal channels, done by F.B.Ferrari; Carta idrografica di milano (The hydrographic map of Milan) 1866; The map of Milan, Lafreury 1573.  
 Bellow: Rectified image of Milan in scale 1:1000; The georeferenced map of Lafreury; San Marco area, a detail of the map of Lafreury.

of different period maps, classified by map dates and place-names. The project will also investigate image compression formats to build WebGIS application, beginning from the scanned modern format JPG2000.

## 2. A key role within the 'Atlas'<sup>2</sup>: the map of the 'Astronomi di Brera' (1807) at the scale 1:1000

In the year 1806, during Napoleonic period, with a dispatch of 1<sup>st</sup> of April, upon the appeal of the Generale Brossiers, in the frame of the extension of the 'Lombardo-Veneto' to the whole Kingdom of Italy, the astronomers of Brera (De Cesaris Giovanni Angelo, 1749-1832, Reggion Guido Francesco, 1745-1804, Oriani Barnaba, 1752-1832) deliver the original observations: the elements of the reductions (contraction), the results of the first triangles derived from the measurement of the 'Grande Base di Somma Lombardo' (Great Base of Somma Lombardo) - 1788. They answer to the claim with a technical relation, useful to understand the following description of the map at the scale 1:1000 produced a year later (1789) and comparison with the most recent 1:1000 map of the city of Milan (2005).

They answer explaining that the measurement of the base (10km) has been made through forward and backward measures: to each determined value there have been applied the corrections due to the calibration of the double 'tese' applied in the survey campaign, due to the temperature and due to the reduction to the horizon, referred to the starting point of the base. The mean of the two length measures obtained, has been reduced to the sea level, in order to gain the geodetic length between the two extreme points. The difference between forward and backward measures results to be 0.02327 'tese'<sup>3</sup> (less than 5cm on 10km). The initial development has been built on the construction of the two triangles between Nossate (extreme south of the Base), Mezzana (extreme North) and the city of Busto, using the tower bells of the cathedrals.

For each vertex, the azimuth observation reading 44 times the same direction inside different circus areas, by using 4 'noni' has been made. For each vertex, the zenith distances has been measured for each collimated direction. The stations of Somma and of Busto are off-centre: this aspect has been taken into account. The triangle resolution has been created in a geodetic field considering the spherical excess. The closing error of triangles resulted to be +0",14 and -0",53.

From the new Base Busto-Somma, obtained developing the ones directly measured, the whole series of triangles with spread vertexes in the Lombardo-Veneto territory has derived, among which the city of Milan (Brera's Observatory, Dome). From these vertexes the minor triangles were propagated in order to transfer these new points even over the praetorian tables, in order to build up the most feasible verification of the consequent detail surveyed operations.

Within this operative frame the production of the map of Milan at the scale 1:1000 of 1807 has to be considered. On the 9th of January 1807 (Arch.d'Uff., n. 499, f. 56) "... S.A.I. the Prince Vice King (Eugenio Beauharnais, 1781-1824) approved assisting the survey of the plan of Milan: the duty of being disposal for the survey and progressively informing the Government, was assigned to the astronomers of Brera. The goal was to create the New Urban Plan of Milan.

Here is how the map of Milan of Astronomi di Brera was born. This map, organized in nine coloured sheets, has a great accuracy and it is rich in details, showing even the inside plan of the most important churches and the courtyards. With a great certainty, it has been referred to the vertexes of the 'minor triangles', with distributed measurements of angular directions and direct measurements with long-meters. The topographer Pinchetti was busy being involved in guidance of 'young geometers', under the direction of the Astronomers, in the detailed survey operations. He is also the author of the Carta Topografica di Milano of 1801 (Topographic Plan of Milan), currently conserved at the Biblioteca Trivulziana (Trivulziana Library) of Milan, and many others following ones. The accuracy of the Map of the Astronomi di Brera at the scale 1:1000 is significant both under the semantic aspects and under the quantitative ones.

**Georeferencing process.** First of all the Map of Astronomi di Brera has been georeferenced<sup>4</sup> to the map of Milan of 2005, that during the metric test had an uncertainty in the position of the controlled point largely contained within the graphic error (0,2mm - corresponding to 20cm at the scale 1:1000). The georeferentiation of two sample sheet (8 and 9) of the astronomers' map, for about 100 points used for each sheet georeferencing, has shown, as a mean value, differences on the vector coming from the pair of homologous points, respectively of 1,08m and 1,59m.

These values can appear significant for a map at this scale, but they are actually more than justified for the following reasons:

- 1- the map has undergone certain anisotropic deformations during the 200 years of its life, different events and the conservation methods and restoration techniques adopted
- 2- The precision of the vertexes of the 'minor triangles' can be estimated, in an analogue way to the post-unitary cartography, variable between 0,5m and 1 m.

<sup>2</sup> The origin of the word 'Atlas' derives from the work title "*Atlas sive cosmographicae meditationes de fabrica mundi et fabrica figura*" by Gerard Mercator, where the choice of the title that uses the word 'Atlas', as explained from the author himself, is not referred to the mythological figure of Atlas with the world on the shoulder (a figure often used as logo on successively made atlases), but to mythical Atlas in person, who was a great astronomer and cosmographer during the period of the ancient Greece. It was the first work named Atlas, obtaining an immediate huge commercial success.

<sup>3</sup> The 'tesa' is a Unit of Measure, whose value is equivalent to 6 feet = 1,949036331m; 1 feet = 12 inches = 0,32484m; 1 inch = 12lines = 0,02707 (1 line of the Foot of Paris = 0,002256m). The scale of the map of 'Lombardo Veneto' made by the Astronomer is the same of the 'Map of France' made by 182 sheets (1:86400), known as 'of Cassini or Academy', appeared little before the Revolution, begun by César-Francois Cassini di Thury with Lacaille on 1744 under the Luigi XV (1710-1744), the first map with a geodetic placement network. The origin of this particular scale derives from the fact that one inch ('pollice') on the map correspond to 1200 'tese' on the terrain (6x12x1200=86400).

<sup>4</sup> For the georeferencing methodology, see at the ACHILLE C., BRUMANA R., PRANDI F., ORENI D. (2005). From the guide of georeferencing cultural heritage for the map of risk (Regione Lombardia) to the georeferencing and troubleshooting in historical sites", ISPRS Int. Arch., and CIPA Archives, ISSN 1682 1750, XXXVI-5/C34 and XX-2005 (CIPA), 707- 712.



### 3. Navigating the territory through the third dimension of the past

Each historical map of the selected sample has been georeferenced to the actual technical map of the City of Milan. The opportunities created by publishing on a portal such historical information related to the geographic actual context are evident and vast. Historians, professionals, specialists could compare the different cartographic layers one to another, and make analysis and valuations regarding the transformations of the territorial texture: in this case there have been selected some topics on which to develop the process of analyzing **mutations and permanencies**. The sample considered is the sector 'Corpi Santi' with the vertex in the church of S. Marcus once facing the intersection of the two axes of the canals, closed during the 1930's<sup>5</sup>. The most relevant object coming from this analysis has been managed inside GIS system to be published in future within the portal itself (**Fig.3-5**).

1. WATER. The Water Channel network (Navigli), built up to connect the hydrographic network of the rivers on the North of Lombardy (Lambro, Molgora ecc.) with the external channel 'Martesana' and the urban one.
2. BUILDING aggregation (Churches, Monasteries, Convents, Civil Buildings, Military buildings): the history of the progressive saturation of city blocks.
3. ROAD SYSTEM: streets, gate connection system across the canals and around the city blocks, the principle doors across the defence city walls.

In order to improve map reading of the transformation process of the city in its most significant and relevant topics, a 3D model has been built up from the ground using Digital Terrain Model generated on the actual map, choosing the current building heights: it is obviously possible to modify them associating different heights in function of the different studies and hypothesis by managing the attribute table database.

For this purpose the implementation within the portal of functions and tools will be a priority in order to support interpretation by every subject (user) through the developing of a **remote active user interaction interface**<sup>6</sup>, such as:

- **personalized object digitizing and 2D/3D extraction;**
- **volume generation by height association;**
- **different rasterized layer comparison;**
- **local downloading of manageable format exchange data** (shp, georeferenced map - tfw) within professional and common software (such as CAD, 3DS, GIS)

### 4. 3D perspectives

The research is focusing on the 3-D processing of historical documents characterized by three dimensional contents (such as photos and perspective-axonometric views, which do not allow direct georeferencing procedures) using the metric historical map as a gateway to the interpretation and decryption of non metric views and applying photogrammetric algorithms within internally developed software by the research group of DIAR lab<sup>7</sup> currently in progress.

The research takes place on the contribution of important studies carried out by important historic specialist<sup>8</sup> on the possible approach to decode non metric hybrid 3-d views map with rigorous metric approach mixed to semantic contents. In fact for this map is not possible to apply 'isotropic global transformation' (perhaps from perspective to orthogonal projection), as it is evident due to different aspects and reasons connected to the history of the maps themselves: they are characterized by emphasis on some principle monuments to be politically represented, multiple points of view". This celebrative intentions have generated the 'bird flight map', urban profiles, axonometric views.

#### **Georeferenced map level**

##### **A. Historical Cadastral level (1:2000)**

1. *Catasto Teresiano (XVIII sec.), without topographic (geodetic) placement*
2. *Catasto Lombardo Veneto (1866-67), the first cadastral map with topographic placement*
3. *Cessato Catasto (1902)*
4. *Impianto al Vigente (1937-1958)*

##### **B. Topographic map level**

1. *"Città di Milano" Carta degli astronomi di Brera, 1807 (1:1000)*
2. *Carta topografica del milanese e del Mantovano basata sulle misure effettuate dagli Astronomi di Brera fra il 1788 e il 1791 (1:86400)*

##### **C. Referrent map system for the georeferentiation of historical level**

1. *Catasto Vigente (Vigent Cadastral map level) 1:2000*
2. *Technical Map of the City of Milan (1:1000)*

*"La Grà Città di Milano" Lafréry 1573 (Pianta della Città di Milano), the perspective map of the city of Milan*

<sup>5</sup> Milan's Navigli are artificial canals constructed between 1179 (NaviglioGrande) and sixteenth century (Naviglio Martesana), to allow the arrival to the city from Ticino and Adda. In Milan there were two internal water circles: the first Roman Moat that flowed along the external side of the Walls, fed on the north by the river Seveso, to flow into Vettabbia between Porta Ludovica and Porta Ticinese; the outer water circle, built in 1387, represented the defence moat out of Spanish Wall, used for the transportation of marble from Condoggia (Maggiore Lake) to the Duomo. Connected to the Naviglio Martesana around 1497, the outer circle maintained its function of passing the waters between Ticino and Adda until the 30's of the twentieth century, when it was fully covered. Today, the urban part of the waterway of Martesana, covered in the 60's until Cassina dè Pomm, flows in Milan into Seveso.

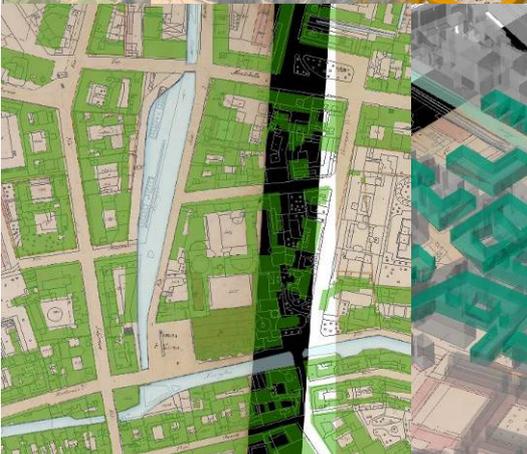
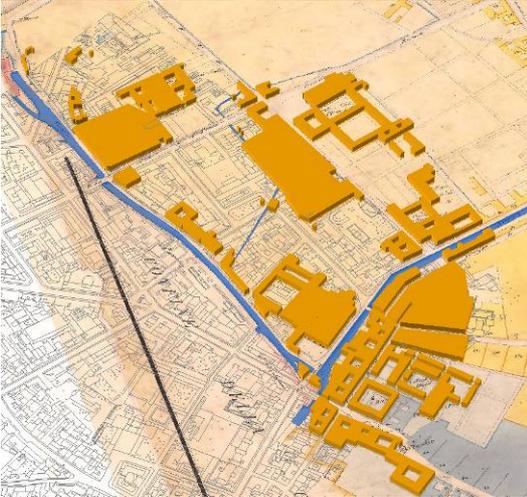
<sup>6</sup> Cfr. BRUMANA R., PRANDI F. (2005). *E-historical Site. Documentation and Protecting Sharing 3D geobase*, in 'The e-volution of Information Communication Technology in Cultural Heritage', eds. M. Ioannides, D. Arnold, F. Niccolucci, K. Mania, Budapest ARCHAEOLOGIA, ISBN-10:963 8046 75, pp. 293-300

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<sup>7</sup> <http://rilev5.topo.polimi.it/elab>, Elab3DPOLI, Laboratori di Photogrammetry, Survey, Cartography, GIS POLIMI-DIAR

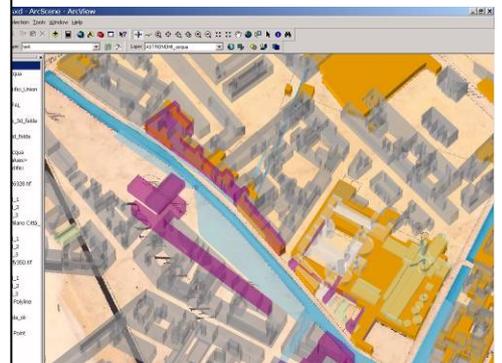
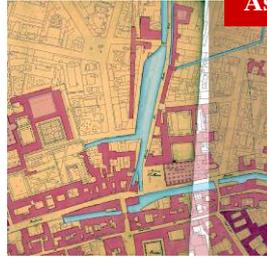
<sup>8</sup> DE SETA C. (1996), *Città d'Europa. Iconografia e vedutismo dal XV al XVIII secolo*, Electa, Napoli, 1996, pp.183-189

Teresian Calastre Level 2-D 3-D



The 'Lombardo Veneto' cadastral Level 2D, 3D

Astronomi's Topographic Map Level 2-D 3-D



Teresian and Astronomi's level on the Actual Map Level 3-D

Permanencies and mutations on the sample area of San Marco (Porta Nuova).

*From the upper left:* views of the actual map of the buildings and of the Navigli network coming from digitalization of the georeferenced Teresian Cadastre (2D and 3D view)

In grey the volumes of the **today present buildings**, from the Technical City Map 1:1000.

In **yellow (buildings) and dark blue (channel)** the elements of Teresian map.

*From the upper right:* On the purple level the permanencies on the Topographic map of Astronomi di Brera. On the cyan level the variation comparing to the Teresian channel (dark blue) is represented. The enlargement of the channel can be seen.

*On the bottom side:* The green level concerns the current cadastral map and to the plant to the current cadastre, with the progressive saturation of the city blocks.

The State of Art Cadastral Level used as gate to the 'Impianto al Vigente' and to the historical cadastral levels



## Legenda

- BUILDING *Cadastra* of *Teresiano*
- BUILDING *Carta* *Astronomi di Brera*
- BUILDING *Cadastra* of *Lombardo Veneto*
- CTC Milano 1:1000
- WATER network

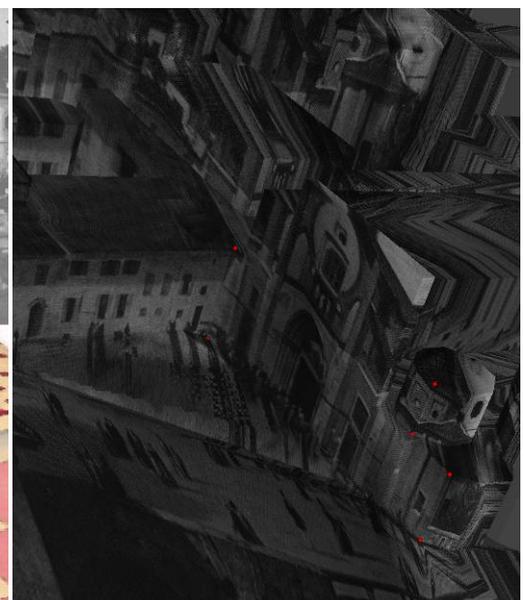
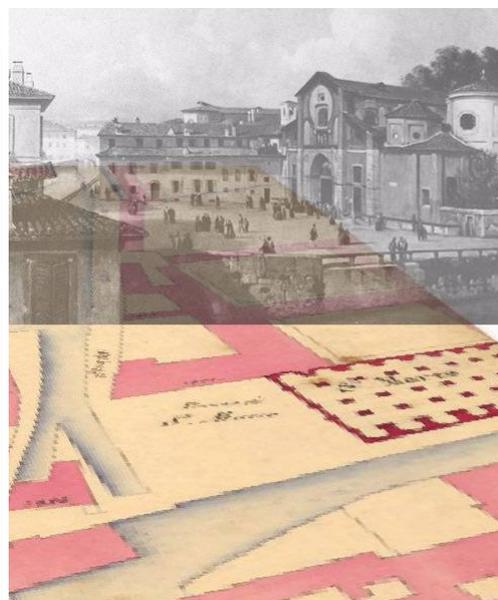


The canals network at the correspondence of the node in S. Marco square. The sequence of three georeferenced historical cadastral series and the topographic maps: Catasto Teresiano, Carta degli Astronomi; Catasto Lombardo Veneto, Technical Map of Milan (2004).



Left: an ancient painting of the area in front of the church of San Marco (end of 19<sup>th</sup> century). The intersection between Naviglio Martesana and internal water circle can be seen.

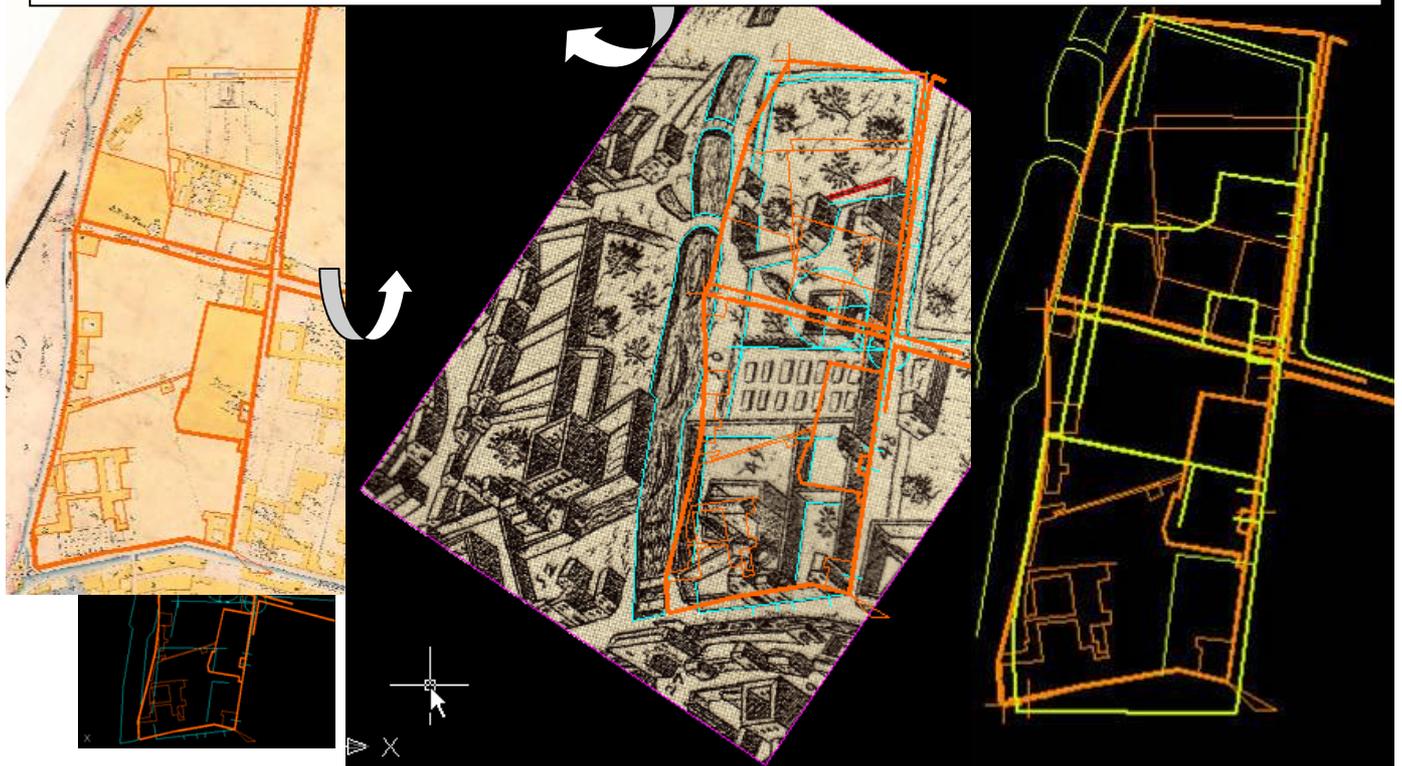
Center: overlapping between the georeferenced 3D Carta degli Astronomi di Brera and the painting.

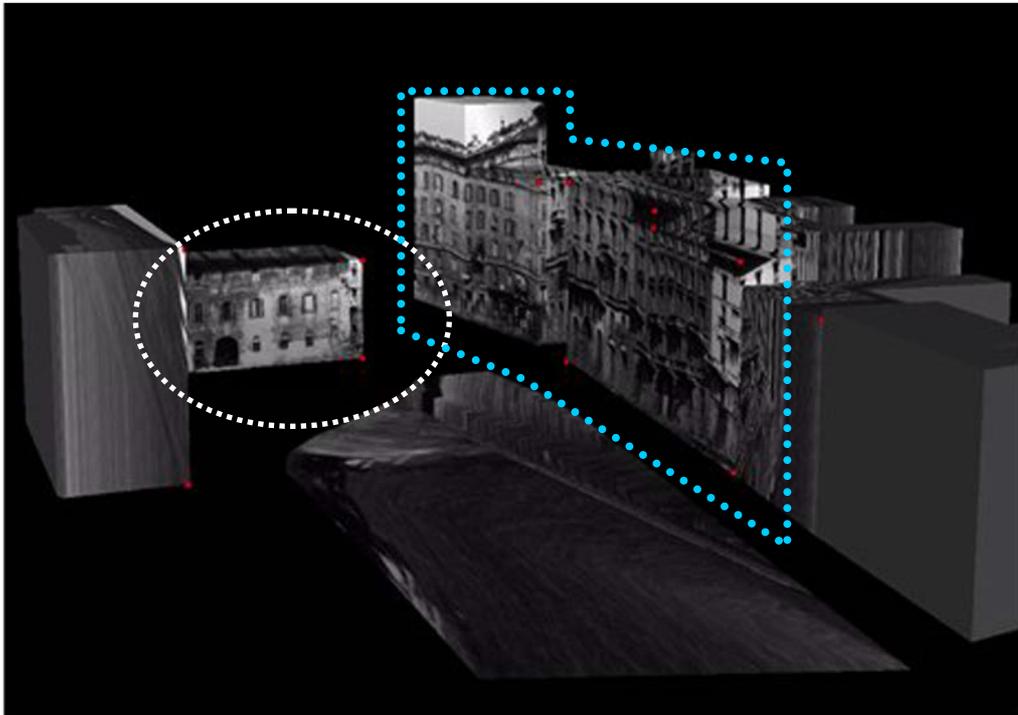
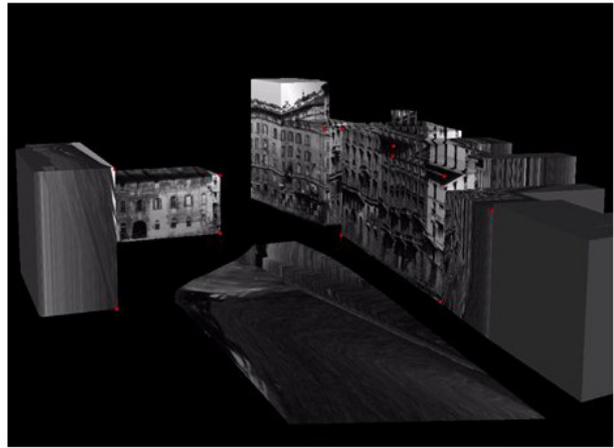




Above: planimetric evolution of the city block included between the church of San Marco and the city door of Porta Nuova: the permanence and the transformations of the built up environment at different historic thresholds considered can be seen.

Below: the anisotropic deformations of the representation used in 16<sup>th</sup> century can be easily noticed from the comparison between the georeferenced historical map and the Lafrey's three-dimensional map. However, the permanent elements are easily recognizable, in particular near the streets tracks.



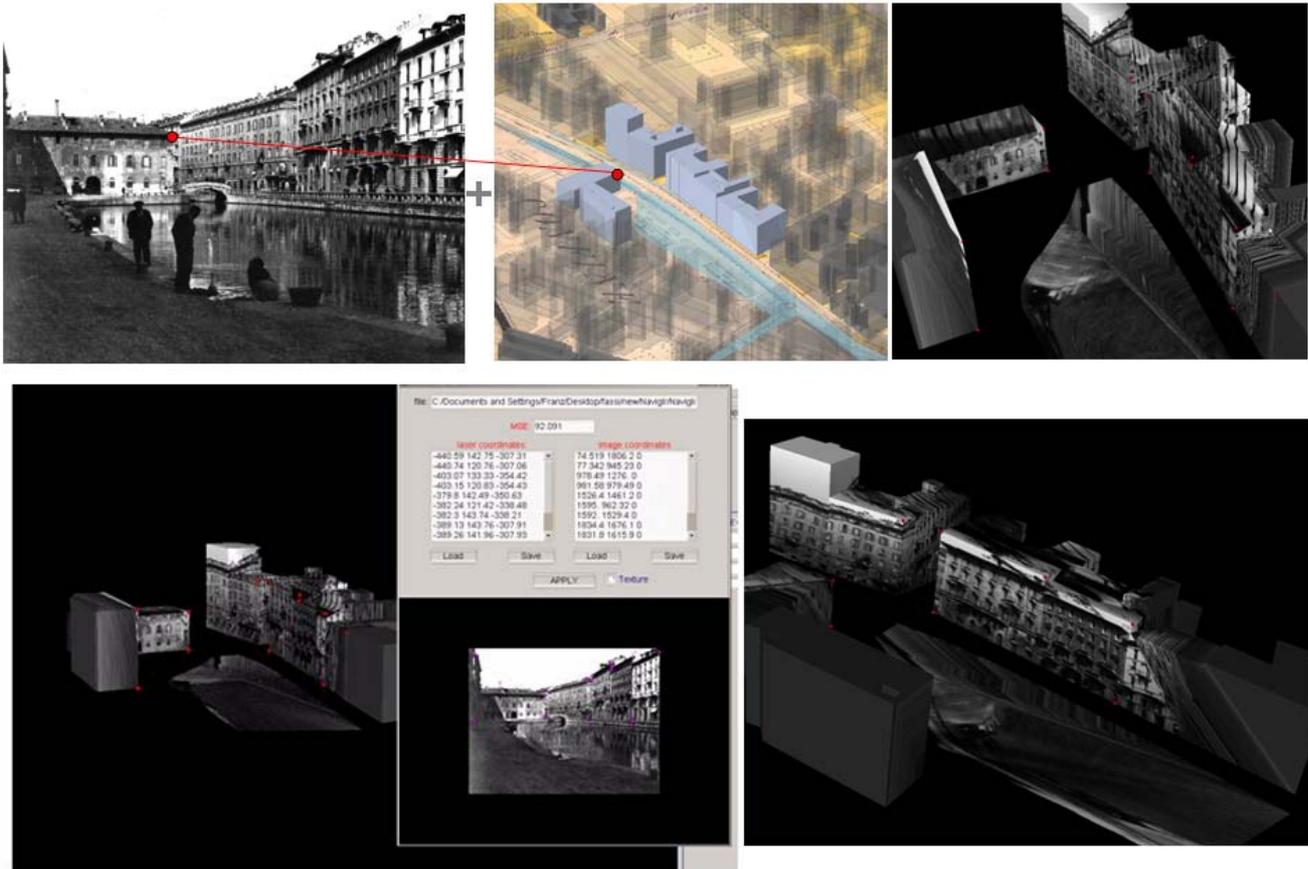


The first result obtained from the photogrammetric processing of the historic photo on the 3D city model: the 3D transformation of the 2D image to the 3D image. The profile of the channel has been integrated on the 3D model in order to reconstruct the perception of the place with surrounding buildings, gate and at different chronological sequences:

- the building evidenced with the dotted elliptical line is one of the permanencies of the place coming from the Teresian level registered on the map of Astronomi di Brera;
- the dotted polygon represents the progressive saturation block evidenced in the previous illustrations along the different historical sequences.

Metric result and anisotropic error within the global bundle adjustment:

- the photogrammetric transformation of the portion evidenced by the ellipse is more precise due to the relevant number of homologous point on the ground level to fix the global bundle used for all the photo transformation;
- the polygon puts in evidence the transformation error (on the parallel skirt roof): there are not enough homologous point number; it is required to implement within the software with external orientation tool so as to allow the insertion of measured points.



**Fig. 4** The step of the internally developed software in order to support the photogrammetric projection of the historic photo on the 3D-model extracted from the correspondent chronological map (in this case the Lombardo Veneto cadastral level). For the future there will be implemented a tool to relate the homologous point with ground point coming from laser scanner measurements, or topographic point, in order to remove the noise derived from not well fixed points at the ground level (point not visible on the photo, to be integrated by new points on the facades at the correspondence of the different floors so as to improve the result).

In the beginning basic projection algorithm of DLT has been developing the bundle adjustment tool and co-linearity constrain for internal and external orientation and parameter estimation.

The internally developed MIMO<sup>9</sup> software developed in C++ with supporting OpenGL and DirectX (for visualizing), will allow to compare results coming from different photogrammetric algorithms known in literature and today in use known in literature, with unconventional ones, in order to support management of digital shot acquired in the past with an oblique direction. The volume reconstruction of the 3D scene need to be improved respect the simplified one built up on the technical map of the city (1:1000), in order to support the photogrammetric projection as a textured rigorous model. For this aim it would be useful to test the results obtained by importing more detailed and refined models coming from different data source (laser scanner, TIN, NURBS approximated to the precision requested mesh) and 3D format modern standards, developing Level of Detail representation (LOD) applied to the surface (mesh pyramid).

## 5. Conclusive considerations

Nowadays it is possible to have a web-portal that enables the consultation of cartographic information georefered to different historic periods, the elaboration of diachronized and synchronized cognitive processes regarding the use and the transformations of the built environment over time. The opportunity of this virtual space is an important support to the analysis of the past transformations and the management of the future interventions in different parts of the historic city. An instrument conceived in this way could be an auxiliary tool to the traditional techniques for the of the built environment analysis, aiming at the preservation and conservation of the environment heritage: the basic cartography, the historic one and evidences collected *in situ*, using the stratigraphic permanence reading, could be cross-related, interrogated and available to all technicians that work, at different levels, in the context of the built environment (ex. it is possible to work in local systems using mapping functions on the georefered maps), in order to guaranty city transformations that would be more respectful towards the historic tracks and complexes, still recognizable within the urban structure.

This does not mean that the georeferencing process is the final goal as far as the knowledge of the stratifications and historical transformations is concerned. It offers an important auxiliary tool for the analysis prior to any intervention, defining possible places of particular attention to be verified during site visits or excavations. It is also indisputable how the

<sup>9</sup> Cfr. Elab3DPOLI with the contribution of informatics competences (Ing. Parri) and photogrammetric one (Ing. Fassi and Ing. Prandi).

overlapping of different cartographic layers, in some cases apparently difficult to compare (the Plan of Milan done by Lafrery), could allow to identify entities that would open new research prospective.

This was the case of the georeferencing procedure of the Lafrery's three-dimensional map, done in planimetric perspective but with the third dimension very similar to an axonometric representation (the prospective point of view is at infinity): although it is an anisotropic map with a representation technique that favours some important urban elements (churches, Sforzesco Castle), and thus deforms some parts of the city, it is however possible to identify easily recognisable permanent elements (streets, water flow, lot shape ect). The current research should therefore concern the development of algorithms that would transform the map (geo-morfing-warping), using not so much the homologous points of the single buildings but the global dimensions of the urban structure drawn from already georefered tracks.

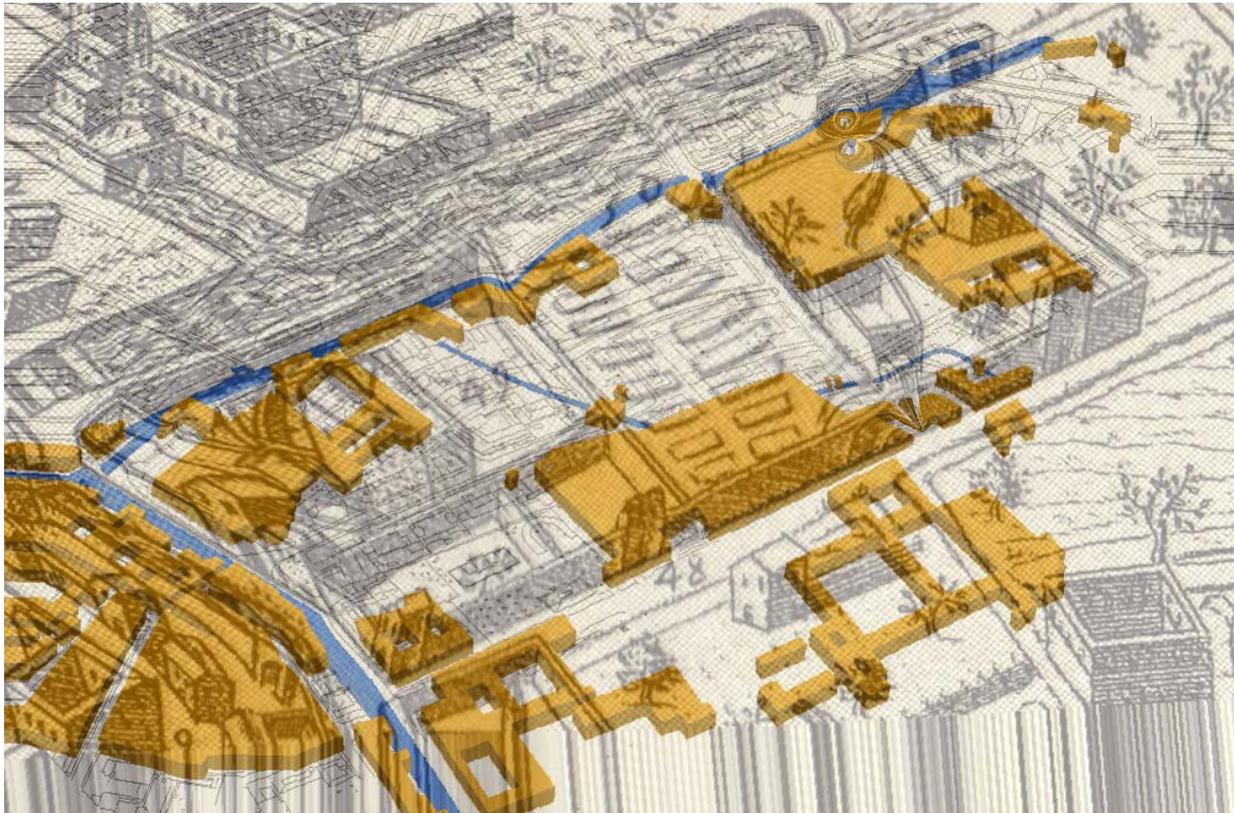


Fig. 5 Geomorfing of buildings represented within catasto Teresiano (3D symbolic representation) on georefered Lafrery's map of Milan

This aspect opens up some parallel research activities, currently in development, on the complex problem on the transformation of the historic views of the digital three-dimensional cartography, implementing the correlation algorithm - three-dimensional prospective georeferencing among the internally developed software MiMO.

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