INTEGRATION OF OLD CADASTRAL MAPS INTO UP-TO-DATE GEODATABASES FOR URBAN PLANNING

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ABSTRACT:

GeoDb are today very important tools to cope efficiently with management and planning of urban areas. On the other hand, very often cities are undergoing a fast transformation process, which could result in changing the specific nature of their districts. The availability of old cadastral maps, although in paper form, allows to reconstruct all steps of land transformation during past years. The integration of such information into digital geodatabases is a complex process, involving their digitization in raster or vector format, georeferencing, integration to the geoDB, publication on the WEB for online access. An example of such applications is the ongoing project Atl@nte in Lombardia region, Italy. Here several cadastral map datasets are available, covering the main land transformations occurred during the last two centuries. Issues under investigation in the project are: quality control of analogue-to-digital transformation; map georeferencing; raster map overlaps along borders; publication of raster maps on WEB-GIS; open layer and open source development tools. The paper will present and discuss the achieved results in the abovementioned items, in terms of already consolidated best practises, products and methods under development, and future trends.

1. INTRODUCTION

Up-to-date geodatabases are today very important tools to efficiently cope with management and planning of urban areas. On the other hand, very often cities have been undergoing a fast transformation process, which could result in changing the specific nature of their districts. During the industrialization period for example, the rural areas in the nearby of a town was occupied by new industrial settlements, which at their turn left place to new residential buildings when farms have been moved out.

The availability of old cadastral maps and historical cartography, although in analogue form, allows to reconstruct all steps of land transformation during past years. The integration of such information into digital geoDB is a complex process, involving digitization in raster or vector format, georeferencing, integration to other archives, publication on the WEB for online access. As it usually happens, in case of wide areas and several map datasets, this process might require a really hard work to be carried out, and a big amount of data to be managed.

The research here presented was developed within the project "Atl@s of historical cadastral and topographic maps of Lombardy (2009-2011)" funded by Fondazione Cariplo, leaded by Politecnico di Milano (B.E.S.T. Dept.), and with the partnership of Archivio di Stato di Milano (national documental archive of Milano – ASMi), Agenzia del Territorio (cadastral administration – AdT), Centro Studi PIM, Regione Lombardia, Comune di Gorgonzola. The project is aimed to built up a geo-portal to make maps available to public (www.atlantestoricolombardia.it). The first release of the geo-portal was presented on the19th January 2010 after the first year of the project. Conceived in the form of a modern Atl@s, it has been designed with a double level access to the historical cadastral series available by ASMi ('Catasto Teresiano', 'Lombardo-Veneto', 'Cessato Catasto'), together with samples of 'Impianto in conservazione' by AdT (see Fig. 1). Besides a catalogue approach level based on classical research keys, an open geographic level was implemented with ongoing functionalities, based on a territorial regional basis. The old cadastral maps, were drawn with respect to a geodetic reference, thus they show a metric content that can be useful exploited. On the other side, they do not have any mapping grid printed on them and, consequently, they need georeferencing. Cadastral maps are organized on the basis of the boundary of each municipality. In particular, here a set of small scale chorographic maps dated 1836 were used to facilitate the web access to the cartographic heritage represented by the cadastral map series. Further considerations on the contribution of little scale historical topographic maps to increase knowledge and consciousness of landscape can be found in Oreni *et al.* (2010).

The paper will discuss about some aspects that have been already considered during the project in order to get the on-line publication of the first datasets. In particular these issues concern: map georeferencing (Sect. 2); raster map overlaps along borders (Sect. 3); publication of raster maps on WEB-GIS (Sect. 4); open layer and open source development tools (Sect. 4). Future work still has to be done especially about control of data quality and automation of the processes involved, as discussed in the conclusions (Sect. 5).

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Figure 1. The access level to the maps on the Atl@nte geo-portal: the descriptive catalographic level (middle), the geographical access based on GeoDB built up on the historical maps (left), and the thematic itineraries (right).

2. GEOREFERENCING OLD COROGRAHPIC MAPS

The project requires the georeferencing of different kinds of historical maps with respect to current geoDB. Indeed, each map was created with its own instruments, purposes and representation methods, and needs a procedural effort to evaluated the more suitable georeferencing technique with the aim of obtaining qualitative, measurable and satisfying results.
In particular here the problem of georeferencing chorographic maps was dealt with, because they were used in Atl@nte to give a geographical framework to the other large scale cadastral maps.
The series of chorographic maps here considered are:

1. 'Corografie delle Province del Regno Lombardo-Veneto'(from 1836, at scale 1:115,000);
2. 'Carta del Territorio del Milanese e Mantovano' (1788-1796, at scale 1:86,400);
3. 'Carta del Regno Lombardo-Veneto' (ITM 1933, at scale 1:86,400).

In particular the case of the provincial chorographic maps (1) is discussed here. This is due to the fact they represent the ideal element of connection between the cadastral maps (Lombardo-Veneto) of the municipalities at the local large scale (1:2,000) and the topographic maps. These maps are without any mapping grid, perhaps considered unnecessary at the time for geographic purpose. Their current use requires a reference system provided for the Cadastral Officers, so that they can be overlapped and compared to current geoDB and cadastral data. This integration is retained really useful to check the different territorial divisions, to focus and to make immediately manifest the political and administrative articulation of the region, through the provincial, municipal and taxable borders. In addition, hydrography and orography were represented with their essential elements.
In this paragraph it is discussed the complex georeferencing operations of the chorographic map sheets obtained so far (7 of the 10 provinces of Lombardia region were completed). Boundaries and other significant physical features that were considered as persistent elements during time were used as stakeholders of this process; in figure 3 GCPs adopted for the area around the city of Milano are shown. Current data were retrieved from up-to-date raster maps at scale 1:100,000 and from vector layers of the regional geoDB (CT50, at scale 1:50,000). This data are referenced to both grid systems adopted in Italy, i.e. Gauss-Boaga (datum "Roma40") and UTM (datum "WGS-84/ETRF89"); in Mugnier (1995) the definition of mapping grids adopted in Italy is reported.
The ground control points (GCP) were carefully chosen after a comparison between the current and the 19th century maps. All points belong to the borders line and are homogeneously distributed in each map sheet.
The first sheet that was georeferenced as test concerned the province of Milan. Here an affine transformation implemented in ArgGIs environment was applied. Different sets of GCPs were selected, made up of a different quantity but all with a homogeneous distribution on the map sheet. The statistics on the residuals on GCPs after estimation of the affine were used to check the quality of the results (see Subsect. 2.1 for numerical details). These appeared to be interesting from both a qualitative and quantitative point of view and have opened the horizon to new possible investigations. On one side, a general excellent result in terms of quality and fruition of the georeferenced maps by researchers, architects, local administrations and citizens has been achieved. On the other, some important distortions of individual sheets were observed, with big anisotropic effects.
It is very difficult to estimate and evaluate the analytical reliability, due to the non homogeneous distribution of the error in the georeferencing process. In case of some profiles, or portion of them, a perfect correspondence of the entire ancient municipality boundary with respect to the actual one were found. Instead, for others there are evident errors, thus local border were shifted along partial traits of the whole close polylines, or totally shifted without a similarity to the adjacent one (see an example in Fig. 2).
In order to evaluate the error distribution (Table 1), we consider the tolerance as a term of comparison. The range error is not always included within a 'virtual' value of tolerance (t), assuming for the ancient maps the same tolerance that would be adopted here for maps at the same scale. In case of maps at 1:100,000, a tolerance t=50 m was considered, corresponding to a 95% confidence range of correctly finding the point positions at the end of georeferencing. The std.-dev. of each point was assumed as the standard graphic error (0.25 mm). In the modern cartography the value of tolerance depends on the production process undergone to achieve the accuracy for a specific scale map generation, from primary data acquisition to plotting.

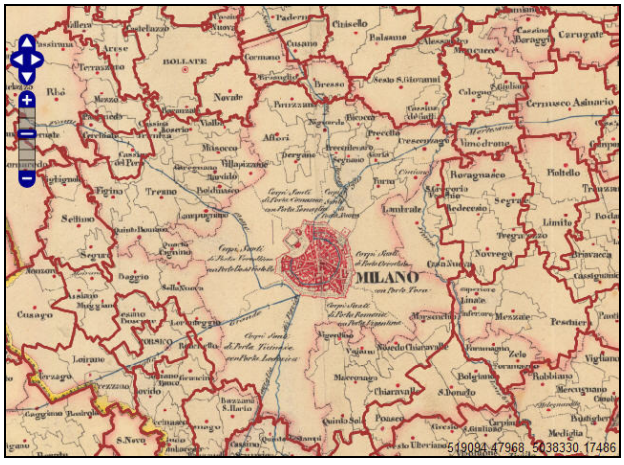

Figure 2. The result of the georeferenced chorographic map (Provincia di Milano) with respect to the current boundaries (in red).

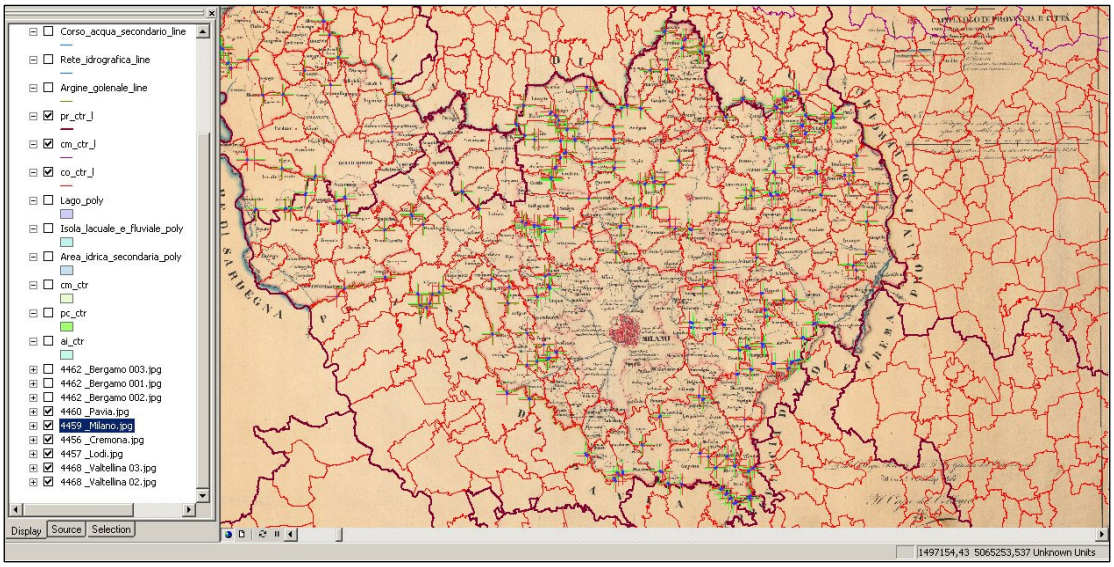

Figure 3. The distribution of GCPs used as stakeholders for the map georeferencing process and the current boundaries from the geoDB (CT50) of Lombardia region.

Obviously those are not the specification of the ancient maps, consequently we are "forcing" the application of this concept to them. However, this assumption is expected to help in the analysis of the georeferencing accuracy.

In addition to possible factors related to the scanning of the maps, to the deformation over the time, and to the individuation of the persistent ground features, it is plausible to attribute these errors to the technique of the Lombardo-Veneto chorographic maps generation process. In fact, it is plausible to suppose that the chorographic maps, lacking in a coordinates reference, were the result of a merging of individual municipal boundaries, derived by several large-scale cadastral maps (scale 1:2,000), prepared for the only purpose of providing a support in tracing the subdivision of cadastral sheets.

This process was carried out by overlapping the single municipal boundaries, deducted directly from the Lombardo-Veneto cadastral maps at scale 1:2,000 (coeval to the chorographic maps), but probably not through a rigorous generalization process. In fact, we have to consider the good results obtained in the georeferencing process carried out on the Lombardo-Veneto cadastral maps at scale 1:2000. The case of Gorgonzola Municipality is shown in Figure 4: , the errors resulted approximately contained in the assumed tolerance (~1.5-2 m).

A test on the geometric accuracy, is on course on one test areas (Gorgonzola), to derive the boundary obtained from the collage of the georeferenced cadastral local map sheets, and comparing it with the provincial map municipalities boundary extracted by the chorographic map by overlapping of the two ancient boundaries.

Georeferencing this typology of maps has required a series of methodological considerations in order to assess preventively the real possibility to obtain compatible results with the scale of representation of the maps, and in order to identify a possible control method during the process.

The need to adapt to this kind of maps a method already tested during other researches, such as the georeferencing of historical cadastral maps, induced the inevitable choice to privilege the final aim (to obtain a continuous and navigable map, georeferenced on current boundaries, still keeping alive the function for which the map was designed and realized), in disadvantage of a lower geometrical accuracy of the final result. Nevertheless, a series of tests on georeferencing individual maps and their union, by using border points, have been made in order to evaluate the goodness of the result, but also to identify any systematic error or rules to predict their punctual showing (Brumana *et al.*, 2009).

A similar method was studied in order to get georeferenced the two other important historical cartographic layers of Lombardia listed as items 2 and 3 at the beginning of this section. They were essential to integrate the information represented in provincial chorographies with orography, roads, shape and precious 'toponima' of urban and rural centres, system of cultivations, and the like.

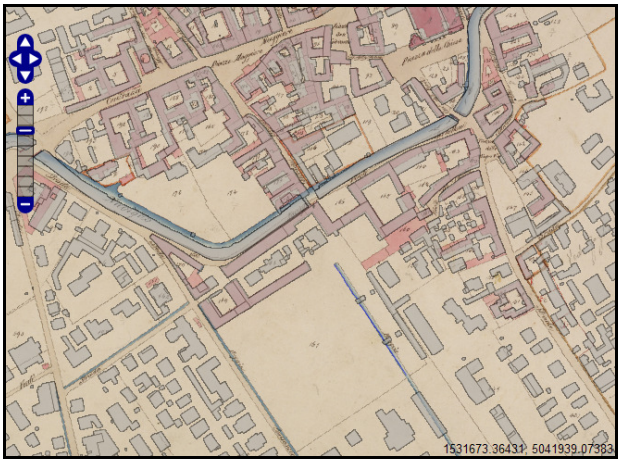

Figure 4. One of the cadastral map sheet georeferenced on the current technical maps, belonging to the Lombardo-Veneto series (1:2000) of the Municipality of Gorgonzola, and the results obtained

2.1 Analysis of statistics on georeferencing

By looking at the residuals shown in table 1, a progressive growth of the RMSE according to increase of GCP number can

be noticed. The analysis performed on the sheet 'Milano' revealed that this behaviour neither was constant and linear as function of the GCP number, nor it depended on their distribution. In addition, only with the smallest datasets the assumed tolerance was respected.
On the other hand, the decision about the choice of the number of GCPs to be used fell on the larger datasets. Indeed, this option, that apparently worsened the accuracy of the result, was however functional to the aim of the research. It was therefore wrong, from the point of view of the historical information contained in the document, to avoid the points that were manifestly different from the tolerance value of the map.
Therefore, the need to find a compromise led to continuous improvements in the applied method, even though this meant to privilege the semantic and geographic content of the map, instead of the geometric one. Further information can be found in Oreni *et al.* (2010).

Sheet	# GCPs	Residuals		
		RMSE [m]	Min [m]	Max [m]
Bergamo 1	73	218 m	49 m	410 m
Bergamo 2	120	506 m	80 m	1244 m
Valtellina 3	17	211 m	78 m	449 m
Valtellina 2	57	315 m	55 m	734 m
Cremona	151	300 m	34 m	622 m
Milano	6	22 m	2 m	34 m
Milano	9	35 m	14 m	56 m
Milano	30	169 m	57 m	255 m
Milano	35	196 m	48 m	367 m
Milano	52	307 m	33 m	546 m
Milano	203	178 m	27 m	297 m
Milano	232	210 m	41 m	440 m

Table 1. The residuals on GCPs obtained after georeferencing; in case of the sheet 'Milano', different sets of GCPs were tried.

3. WEB PUBLICATION

Once generated the geoDB storing the georeferenced old maps, an open geographic platform was implemented to make them available to all end-users through the geo-portal Atl@nte. The concept was to create a powerful instrument for documenting the transformations of the territorial administration boundaries, recording the history of changes and aggregation of areas up to the current political asset, with a strong impact on the identity roots and cultural issues. The result is a bird flight on the territory of the Lombardia region, with the possibility to navigate with continuity along the municipalities and the provinces in the asset of 19th century.
A further application of the geo-portal will enable the geographic query access to the cadastral maps in case not yet georeferenced (this functionality will be exploited and experimented during the second year of the project activities). Indeed, the availability of areas corresponding to different municipalities in the old cadastral maps, will enable a geocoding process where each cadastral sheet is identified by an attribute that links it to the municipality it once belonged to.
GIS technologies have evolved, towards an increasingly distributed model based on independently provided and interoperable GIS Web Services. It is possible to dynamically assemble applications from multiple GIS Web services for use in a variety of client applications. During the last years, Open Geospatial Consortium (OGC) has successfully executed efforts for GIS interoperability. The OGC Web Services (OWS) initiative has undergone multiple phases – including the Web Map Service (WMS), Web Feature Service (WFS), Web Coverage Service (WCS), and OGC Web Service Architecture, which support application developers in integrating a variety of online geo-processing and location services (Lieberman, 2003).
As the result, end-users can take advantage from the Web-GIS that is WMS compliant to publish and access geospatial information from many sources and systems. By supporting the WMS Server, any WMS client able to view information published by any WMS compliant server. WMS layers are added to maps published by the WMS compliant server and a map layer may be a combination of one or more WMS layers. This makes it possible to take advantage of the wealth of information publicly available through WMS service.
Access to geospatial data from the consumers point of view, is a part of a process of what goes from discovery to evaluation, to access and finally to exploitation. Discovery (find, locate) involves the use of services such as metadata catalogues to find data of particular interest over a specific geographic region. Evaluation involves detailed reports, sample data and visualisation to help the consumer determining whether the data is of interest. Access involves the order, packaging and delivery, offline or online, of the data specified (coordinate and attributes according to the form of the data). Finally exploitation (use, employ) is what the consumer does with the data for their own purpose.
In order to assure access to historical map the Geoportal has been developed using Geoserver, which is an open source OGC standard compliant. In this way we can assure interoperability through different system.
The historical maps once georeferenced, has been tiled and then exposed through Geoserver such as WMS service (Fig. 5). In this way is possible both to consult the map into the Geoportal and to access the map using desktop GIS solution through the map services exposed by Geoserver. Further using on the fly datum transformation, the map can be exposed in the available projections (see Sect. 2). As it can be seen in figure 5, the different sheets could be mosaicked within the geoportal in order to allow the navigation of the territory with continuity.
In figure 6 some details on the navigation of the geo-portal Atl@nte at different scales are shown.

4. EXAMPLE OF APPLICATION: THE THEME OF 'WATER'

With the aim of valorise the Cartographic Heritage shared in the geo-portal, and suggest some possible use of the published documents, some cultural axes on the theme of 'Water' were selected in Atl@nte. This further possibility to access to data still survive in parallel with the construction of a geoDB of historical maps.
The choice of this axis is related to a peculiar characteristic of this region: among the EU regions , Lombardia is one of the most characterised by an early and long lasting construction of an articulated hydraulic infrastructure. Its presence has influenced the economy of the irrigated plains and determined new or faster commercial routes. The territories of Lombard municipalities are still characterised from both the presence of rivers and lakes, creeks and other natural elements of the hydrographic network, and from canals, ditches and fountains, referable to the artificial networks of irrigation and reclamation.

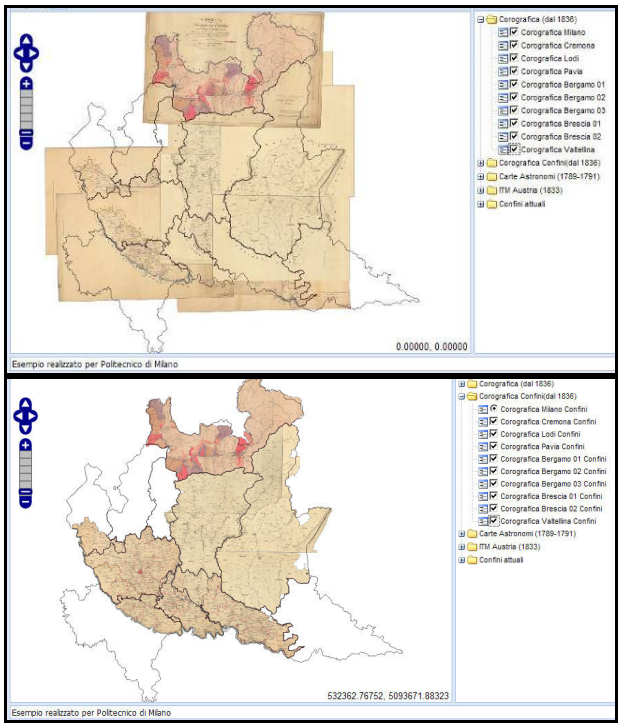

Figure 5. The maps sheets data management within the geoportal and the mosaic obtained on all the chorographic sheets georeferenced

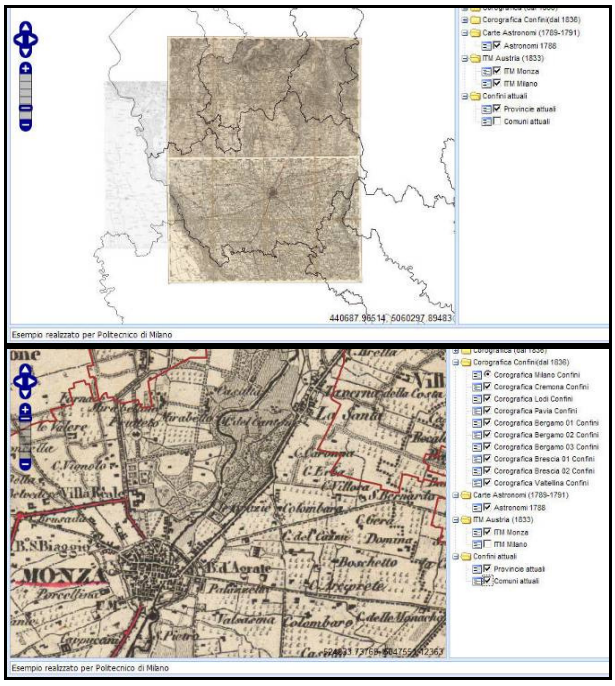

Figure 6. Details of the geo-portal navigation at different scales.

For centuries the water paths, the rights of their use in agriculture and the demarcation of borders have been the causes for an enormous production of maps, now preserved in various archives but often inaccessible and rarely known, except to the technicians. Therefore, the aim of this research is to show how the theme of the water can be used as a key to comprehend the dynamics of the transformation of the landscape and can become an advantaged point of observation of the territory, with its peculiarities.

Among the investigated thematic axes during the first year of activity (which will continue during the second year), interest was focused on the path of Martesana canal, an ancient way of connection between Milano canals network and Adda river. This attention was motivated by the fact that Martesana flowed across an area full of villas, parks and gardens, agricultural landscape and historical cultivations typical of that region.

In figure 7 an example of one of the maps included in this thematic section is reported.

Starting from the inner circle of Milano city canals (different cartographic layers covering this area were been previously already georeferenced; see Oreni *et al.*, 2010), the reconstruction of the Martesana environment at the time of 'Catasto Lombardo-Veneto' (1835-1865) were completed by georeferencing all the maps that included this Canal (originally designed by Leonardo da Vinci).

Through the identification of still persistent homologous points to be adopted as GCPs for georeferencing (building corners, land parcels, irrigation canals, etc.), and using border points of different sheets, it was possible to setup a continuous and navigable map of the whole canal, between Adda river and the circle of Milano Canals. The aim of this research is to allow a virtual tour useful both for an historical and cultural analysis of the area, and for the landscape protection and planning.

The decision of publishing historical metrics maps in the Atl@nte was made with the aim to provide a synthetic and continuous vision of the territory, at different historical levels, in order to allow to different end-users an immediate comparisons between the shapes and the characteristics of the landscape of yesterday and today.

In order to achieve this goal, a phase of georeferencing of old maps on the current ones was necessary. Georeferencing historical maps did not naturally mean to alter the qualitative and quantity contents of the maps, in order to fit them on the current cartography, but it meant to make a series of scientifically rigorous operations of processing of the maps, by using algorithms, control parameters and methodological standards, shared by the international scientific community. Therefore, this technique allows to correlate, among its geographic reference system, historical map by "overlapping" it to the current ones.

It should further be noted that the georeferencing of the individual maps does not, in any way, invalidate the future possibility of extracting the original map at any time, regardless by the different map layers which were overlapped.

The choice of using the Provincial Chorographic Maps such as geographic access to the single municipal cadastral maps, was also dictated by the functional need to allow a future connection between the databases of current official boundaries and the ones of 19th century. This link will enable an easy access to all the information associated to every municipality, which borders have now changed, geographically and administratively (municipalities combinations, subdivisions, etc.).

The subsequent extraction of the actual borders and those of mid 19th century, will also allow to setup a geographical access tool to individual cadastral maps at scale 1:2,000.

It is therefore evident that the local offset of the shapes of the georeferenced boundaries are almost irrelevant for their readability over the centuries, while the analysis of the problem and the origin of the error obtained is important and still open, in order to a gradual improvement of techniques and tools for georeferencing the historical maps.

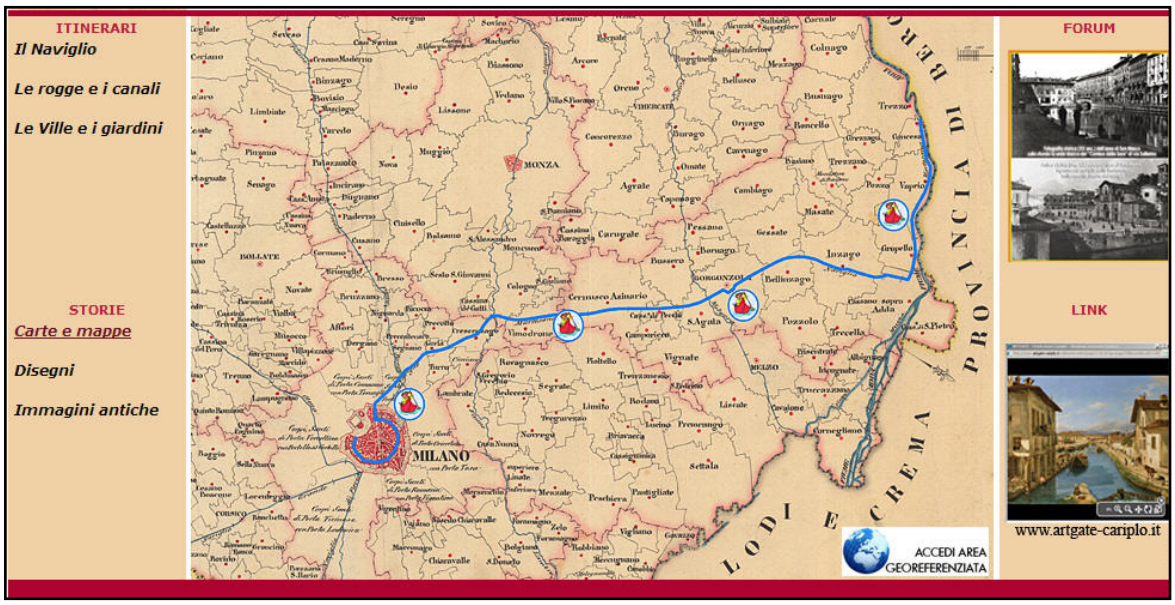

Figure 7. One page of the thematic axis "Water" focusing on the Martesana canal.

5. FINAL CONSIDERATIONS AND FUTURE WORK

The decision of publishing historical metrics maps in the Atl@nte geo-portal, was made with the aim to provide a synthetic and continuous vision of the territory at different historical levels. This tool will allow different end-users to make immediate comparison between shapes and characteristics of the landscape of yesterday and today.

After one year of project work, different results have been achieved. First of all, the geo-portal was setup and published on-line with first datasets. An important issue of the project consisted in georeferencing some sets of chorographic maps at small scale. This task enables a web diffusion of large scale cadastral maps (1:2,000) with two different strategies. In case of georeferenced maps, chorographies have helped in mosaicking single sheets. In case of non georeferenced maps, they however helped during geocoding, because sheets can be linked to a geographical feature. Georeferencing chorographic maps was a harsh task, due to either the difficulty of looking for persistent elements during time to be used as GCPs, either for their intrinsic deformations, probably due to their generation process. It is therefore evident that the local offset of the shapes of the georeferenced boundaries are almost irrelevant for their readability over the centuries, while the analysis of the problem and the origin of the error obtained is important and still open. Furthermore, the analysis of the data quality and the automation of the georeferencing procedure are two fundamental issues in order to cope with large map datasets. Due to the high number of historical cadastral sheets, the generation of a systematic geoDB on the local cadastral series - with a rigorous georeferencing method - shall be faced by government policies and by algorithms automation, to become sustainable in the next years in terms of time and costs. Indeed, ASMi is going to share through WMS developed on the little scale map more than 28,000 sheet units.

Furthermore procedures capable to extract sets of corresponding points between maps sheets which differ in scale and kind of representation are required (see e.g. Zamboni, 2006).

Flying the territory of the past with the little scale synthesis, its political assets and physical elements, such as the hydrographical network, can offer interesting thematic cultural opportunities to the knowledge dissemination of 'our territory' and its preservation.

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