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A Methodological Framework for Analyzing Digitally Historical Maps Using Data from Different Sources through an Online Interactive Platform

Keywords: Open data; historical maps; comparative analysis; best fitting process; interactive online platform; Geohistory portal.

Summary: Historical maps are a great resource for many scientists, not only for those dealing with its practice, but also for those of different fields of research, interested in the geographic analysis of the environment. Using historical maps in digital form in conjunction with modern maps or data can offer a variety of benefits to researchers, since it provides to them the opportunity to study the geometric and thematic properties of the maps or to use maps of different time periods to detect and determine changes in the environment, border changes or renaming of toponyms in the area.

Nowadays, the development of new Internet technologies gives the opportunity to experts or the general public to gain web access to information and data, to find maps in digital form and download them with or without cost from digital map libraries or private collections. These maps are usually in high resolution but they are just scanned images, needed to be correctly rectified in order to be compared with modern maps. A solution to this problem is the development of a system where the researcher will have online access to correctly rectified maps and will also have the opportunity to compare historical with modern maps inside the platform and use them in his/her research.

The aim of this paper is to describe analytically the methodology followed in every step of the procedure from the selection of the historical maps and the collection of modern data to the final use of the comparison tools provided by the platform, giving in that way the framework to everybody to analyze digitally historical maps and to compare them with modern data online inside a platform. In order to make the procedure more clear, we have used examples of historical maps and modern data from different sources, obtained free online through the Internet.

Introduction

The comparative study of historical maps coming from different epochs is usually an educative process in mathematical cartography, since the geometric properties of the maps can be studied through modern analytical cartographic tools. Apart from that, studying historical maps is also important and helpful not only to cartographers but also to other scientists dealing with the geographic analysis of terrain and environmental changes and investigating the temporal interaction of human activity with the spatial environment during the years. The digital combination of early maps with modern cartographic data is a very important procedure for researchers, since it pro-

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vides them with the opportunity to study the development of an area and to detect its changes depicted on these maps through time.

Recently, the development of new web technologies gave the opportunity to digital map libraries or private collections to provide maps from their collections in digital form and usually in high resolution online through the internet. This is very helpful for researchers since now they can find easily maps to use in their studies; the only problem is that these maps are just scanned images without having any reference to the maps' coordinates. The wide variety of applications, historical maps can have in different scientific fields, requires a more accurate approach from the simple scanning of historical maps. Most of the times, the historical maps should come in comparison with each other or with modern maps of the same area in order to show changes in the environment or in an area's toponyms, or to study their geometric and projective properties, which is of main interest in the quantitative domain of the history of maps. In order to do that, the researcher is bound to georeference the maps and then to bring them into one to one correspondence, using in both cases best fitting techniques through proper transformations between sets of points, common in both maps. This is sometimes a challenging procedure even to a cartographer due to the inherent properties of the historical maps such as their scale, their projection system and the different standards followed in each case by the cartographer for their construction (Tsorlini et al, 2013a,b).

A solution to this problem is the development of a system where the user - researcher will have online access to properly rectified historical maps which can be easily compared with modern maps. This possibility will save time to the researcher, since he will have historical maps ready to be used in his study without having to care about their correction and reliability. A project developed by the Institute of Cartography and Geoinformation at ETH Zurich to serve these needs is the GeoHistory portal powered by GeoVITe[1]. The GeoHistory portal[2] is developed to provide researchers with online access to historical correctly rectified maps in comparison with modern maps and data giving also the opportunity to compare the maps online through the platform and to download them in the appropriate format and use them in their study.

The aim of this paper is to analytically describe the followed methodology, which consists of a) the collection of the proper historical maps and modern data, b) the correct rectification and transformation of the maps in order to be aligned to vector data and finally, c) their inclusion in an online geo-historical portal, where their comparison will be done using different tools and methods provided by the platform. In this final stage, the correctly transformed maps and the georeferenced vector data will be loaded into a spatial database and managed by a GIS system using visualizing, geocoding and geoprocessing services in order to offer the results online in a web server, through an interface easily accessible and understandable by any user. In such a portal, the comparison of the maps can be done using different tools and methods provided by the platform and described analytically inside it.

For the description of the various steps of the extended methodology described in this paper we have created a specific version of the GeoHistory platform concerning Rome, Italy (also mentioned as GeoHistory4Rome). For this purpose we have been using historical maps and modern data coming from different sources such as libraries, universities, institutes or public services, which were obtained free online through the Internet, covering mainly the area of Rome. These

[1] The GeoVITe portal (https://geodata.ethz.ch/geovite/) is developed by the same Institute of Cartography and Geoinformation in ETH Zurich in cooperation with the ETH Library, to provide employers, students and researchers from ETH access to professional vector and raster geospatial datasets from the Swiss Federal Office of Topography in a simple, convenient and user-friendly environment through the Internet (Iosifescu et al., 2011).

[2] The GeoHistory portal powered by GeoVITe can be accessed in: https://geodata.ethz.ch/geohistory/

data and maps serve only as examples in order to make the methodological framework more clear and to be easily used by anybody interested in this research.

Methodology for analyzing digitally historical maps in an online interactive platform

The methodology for analyzing digitally historical maps in comparison with modern maps and data inside an interactive platform consists of three fundamental stages, in which important steps of the procedure take place (Fig. 1):

Data preparation

1. selection of historical and modern maps and vector data from different sources
2. correct rectification of historical maps
3. transformation of the maps and vector data to the same projection system so that they can be easily compared

Platform design with a "3-tier Architecture"

4. inclusion of all the maps and the data to a spatial database setting the proper symbology to them
5. creation of map services to control the visualization and the geoprocessing of the data included in the spatial database
6. integration of the map data in an interactive graphical user interface

Platform Usage for comparative analysis

7. definition of functionalities and tools to be used for the comparison of historical and modern maps inside the platform.

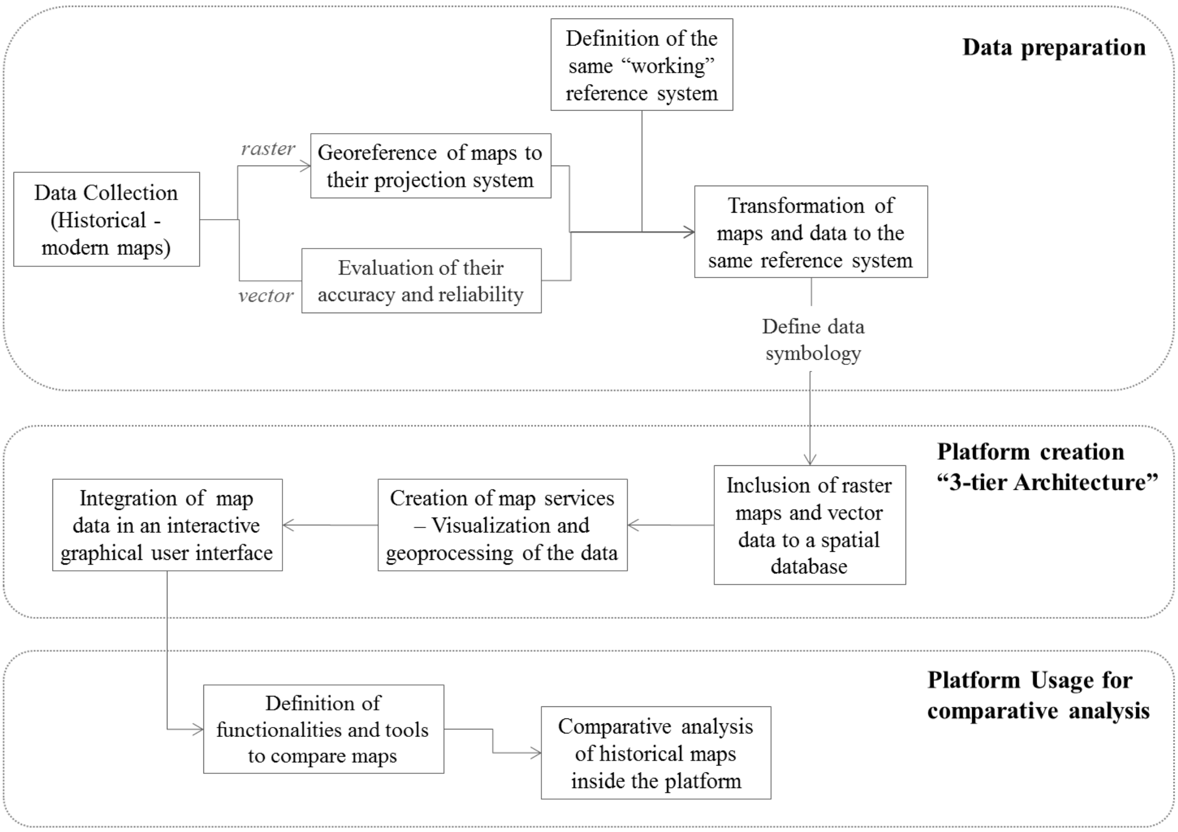

Figure 1: Procedure followed for the digital analysis of historical maps online through a platform developed for this reason.

Selection of historical maps and modern data

The development of new internet technologies gave researchers and general public the opportunity to find historical and modern maps from different sources only by searching on the Internet. These maps are usually in high resolution and can be downloaded with or without cost and used in relevant studies. Important to the selection of historical and modern maps is the area and the characteristics they depict as well as their scale which should be almost similar in all the maps to avoid generalization issues on the maps in small scales.

The collection of modern data depicting the main characteristics of the area (road and hydrological network, settlements) but also its specific characteristics (sites of touristic interest, areas of specific environmental interest) demands to search for maps in analog or digital form and vector files through the Internet or public services. These data should be then combined with each other in order to compose the basemap of the area. Due to the fact that these data are coming from different sources, it is necessary, before their use, to be evaluated mainly for the accuracy of their geometric content but also for the existence of the thematic characteristics they depict. This means that the origin of every file should be known and checked for its consistency, precision and reliability (Boutoura et al, 2013).

Correct rectification of historical and modern maps

The next step in the procedure is the correct rectification of historical and modern maps downloaded in the previous step. In order to do that, it is important first to study the geometric properties of each map in order to define its projection system. The projection system of each map is reconstructed using a grid in which then, each map is georeferenced to its coordinates using as control points the common intersections of the grids (Fig. 2). This procedure is implemented for the georeference of the maps, especially the historical maps, since in this way the map acquires its physical dimensions, eliminating also possible geometric deformations caused mainly by the scanning (Tsorlini et al, 2013b, Iosifescu et al, 2011).

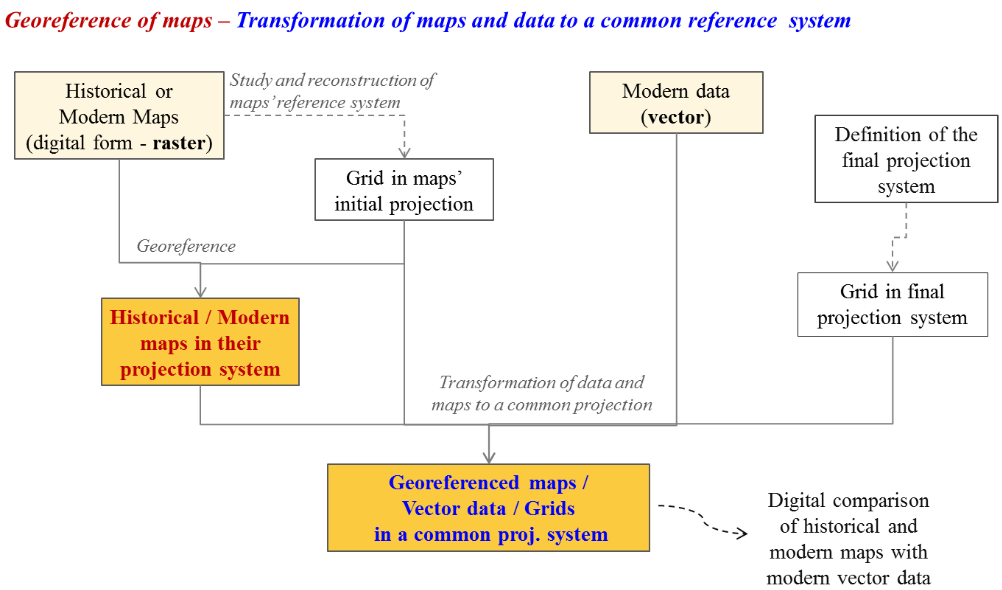

Figure 2: Procedure followed for the correct registration of the scanned historical maps and their digital comparison with other maps (Source: Tsorlini et al. 2013a, b).

Transformation of maps and data to the same reference system

In order to compare the historical maps with the modern maps and data, it is important to bring all the data to a common reference system and in that way to one to one correspondence to each other (Kousoulakou et al. 2010, Tsorlini et al. 2010, 2013a, b). This transformation should be done separately for each map and for each vector file, since the initial reference system may vary from map to map. The procedure including the georeference and the transformation of the maps and the vector data can be summarized in the diagram (see Fig. 2).

Maps and vector data used as examples for this study

For this study, in order to describe the different steps of the methodology, we have downloaded free online historical maps and modern vector data from different sources. These maps and data are first being properly processed and then, transformed to a common reference system in order to proceed to their further digital analysis.

The historical maps downloaded free online from the Digital Map Library of the Cartographic Institute of Catalonia and the online Map Library of the Italian Geographic Society are:

a) *Piano Topografico di Roma e suburbio* by Istituto Geographico Militare, in scale 1:5000, dated to 1907-1924 (Cartoteca, Societa Geographica Italiana). This map series consists of 12 map sheets; six of which are used in our study to show the development of the city during the last century (Fig. 3). This map series is constructed in the modified Flamsteed projection using Bessel Ellipsoid and its Datum is on Monte Mario on geographic longitude λ= 12 27' 8.04" (Baiocchi and Lelo, 2009; Timar et al, 2011).

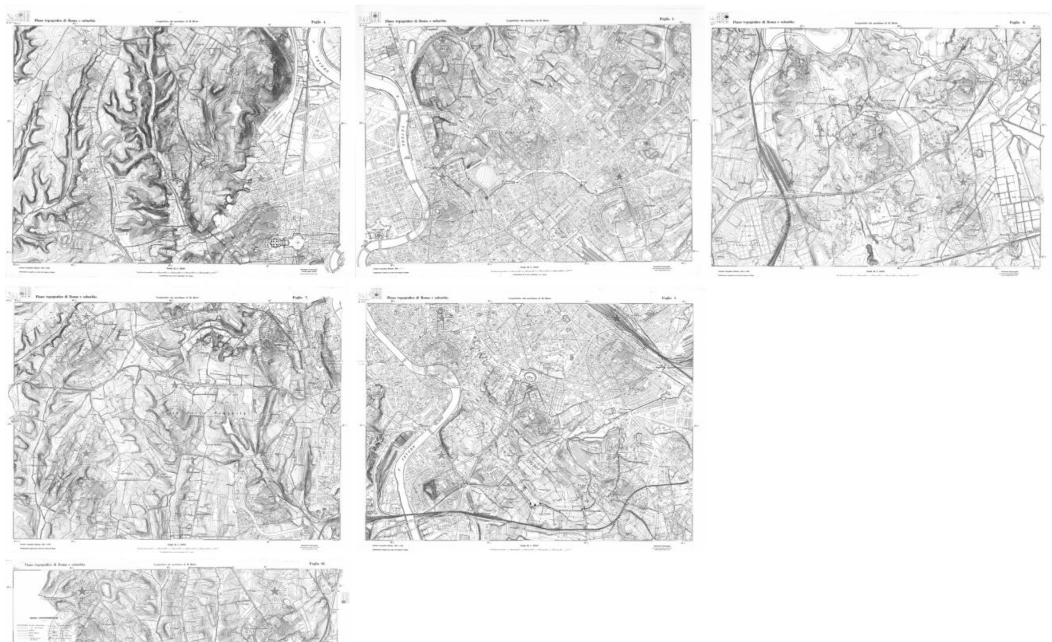

Figure 3: *Piano Topografico di Roma e suburbio* by Istituto Geographico Militare, in scale 1:5000 (1907-1924) [Source: Cartoteca, Societa Geographica Italiana].

b) *Plan of Ancient Rome* by W. B. Clarke, engraved by J. and C. Walker and published by Baldwin and Cradock in London, 1830 (Digital Map Library, Institut Cartografic de Catalunya) (Fig. 4a)

c) *Plan of Modern Rome* by W. B. Clarke, engraved by J. and C. Walker and published by Baldwin and Cradock in London, 1830 (Digital Map Library, Institut Cartografic de Catalunya) (Fig. 4b).

The last two maps constructed by W. B. Clarke do not have an obvious reference system since there is no grid drawn on them or on the frame of the map. These maps are regarded as images and they are best fitted to modern vector data on the common projection system using as control points, characteristic points of the maps such as the river and the wall around the city. In that way, it is possible to see the development of the city inside the wall and to find out similarities and differences.

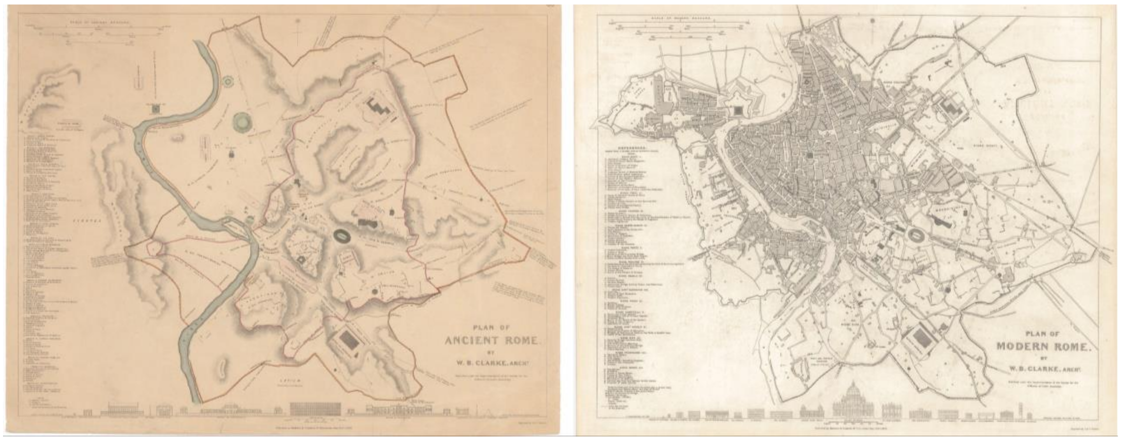

Figure 4: *Plan of Ancient Rome* (left) and *Plan of Modern Rome* (right) by W.B. Clarke (1830) [Source: Cartoteca Digital, Institut Cartografic de Catalunya].

Modern vector data has been found from different sources and due to their accuracy and consistency we have finally used the Openstreetmap (OSM) data in shapefile format downloaded from Geofabrik and CloudMade. This data is available in geographic coordinates in the WGS84 reference system and consists of different layers of information, such as the land use of the area, administrative boundaries, roads, railways, buildings and place names (Fig. 5).

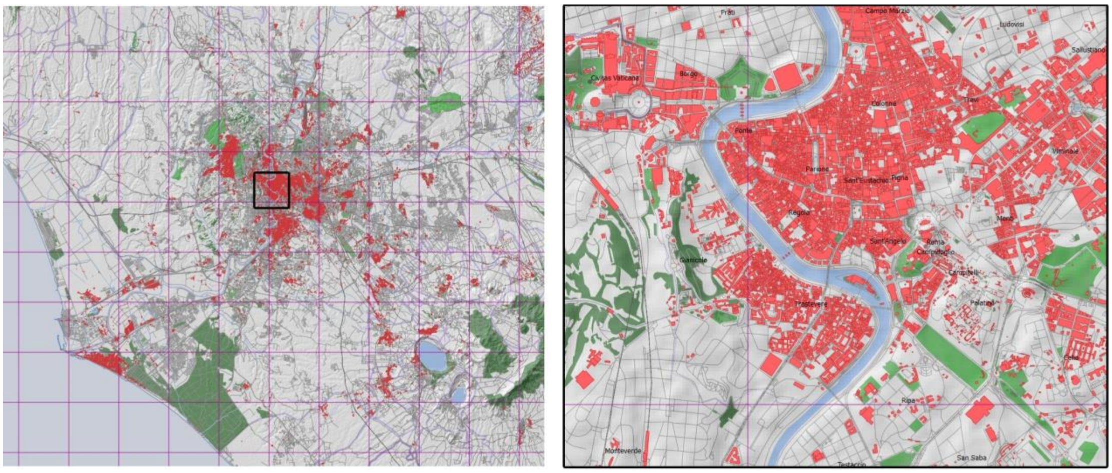

Figure 5: Modern vector data and the relief downloaded free online from different sources in Lazio region (left) and in the city of Rome (right).

The relief used as the background of the map (Fig. 5) is the ASTER Global Digital Elevation Model. This is a product of the Ministry of Economy, Trade, and Industry (METI) of Japan and the United States National Aeronautics and Space Administration (NASA) and it is provided by U.S. Geological Survey[3]. The GDEM is produced with 30 meter postings, and is formatted in 1 x 1 degree tiles as GeoTIFF files, covering the region of Lazio.

Inclusion to a spatial database

For our system, we employ a three-tier-architecture: a database (the data tier), the services (the logic tier) and the graphical user interface (the presentation tier) as shown in Figure 6.

Figure 6: Modern three-tier architecture used in our system.

In order to organize, store and manage various geospatial datasets for online use, it is important to have a database management system. In our case the geodata are stored in a PostgreSQL 9.1 database, which manages the spatial data using the PostGIS 2.0 spatial database extension (*Geohistory, About*). A spatial database offers a wide range of advantages; the most important in this case is the increased performance of geodata rendering when many users in an online platform access the same data concurrently. Moreover, a geodatabase offers obvious advantages in the organization and the management of the spatial data, since it can store raster and vector data in a centralized location while insuring data consistency, integrity and fault-tolerance. It inherently prevents data redundancy and updating errors, it can define advanced geospatial relational models (e.g., topologies, networks) and it offers independence of a specific GIS data format. Finally, it offers, through SQL, a well-known query language for efficient spatial data retrieval (with geometry data types and spatial functions) or for applying sophisticated rules and relationships to the data. In other words, having all the data in a database gives the opportunity to maintain integrity of spatial data with a consistent, accurate database while performing within a multiuser access and editing environment.

Creating map services - Visualization and Geoprocessing of the data

Since the database offers accurate procedures for data organization and retrieval, it is possible to design and create a service oriented architecture (SOA) offering a wide range of services based on this data. Services, or more exactly Web Services are the central elements in developing any kind of software applications in our architecture. A Web service is a type of service that can be identi-

[3] The elevation model was downloaded for the area of Rome through the EarthExporer website of U.S. Geological Survey (http://earthexplorer.usgs.gov/).

fied unambiguously by an URL and uses Web standards such as HTTP for transport. It works on top of the basic concept underlying the Web, namely the concept of request-response (Fig. 7).

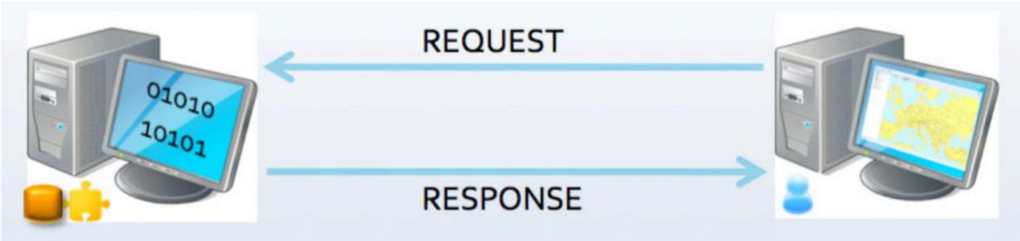

Figure 7: The concept of request-response used by the platform for accessing the Web services that were set up on top of the data [Source: Iosifescu 2011].

A client simply sends a service request to a service and the service returns an appropriate response to the client containing the desired results. This means that every user interaction (such as map visualization or download) in the platform is translated into requests that can be fulfilled by the corresponding services of the logic tier. Therefore any software application, including a geohistorical online portal, can be flexibly composed from interconnected services such as visualization, geoprocessing and geocoding services that are provided to the users through a *Graphical User Interface* (Iosifescu et al, 2011).

Integration of the services in an interactive Graphical User Interface

Our graphical user interface (GUI) is encapsulated in Java Servlets and JSP technology and hosted on a Tomcat Servlet Container (reference Tomcat). The GUI itself, which is the presentation / interaction tier in our architecture, was created using JavaScript and Scalable Vector Graphics (SVG) based on the carto.net framework (Neumann and Winter, 2003), that we further developed and adapted to the needs of the Geovite project. The user interface interacts with the visualization and download services by using the request-response mechanism detailed above. The integration of services in the platform is done though a configuration file in XML format, thus, decoupled of any code. This configuration file contains, in a human-readable format, the necessary information such as the service location, the type of service, the layers to be displayed or the icon and legend information. As a consequence, no programming skills are required for editing this file and for connecting the available service to the corresponding GUI elements since the interface elements are created programmatically based on the XML file.

Tools and methods to compare maps inside the platform

From the user interface perspective, various tools are offered to give a researcher the opportunity to have online access to historical maps, to select those correctly rectified to the region he needs, to study and compare them online and finally to download them in an appropriate format for offline use.
The GeoHistory portal, part of which is the GeoHistory for Rome developed for demonstration purposes, uses the basic functionalities developed for GeoVITe portal, but there are also additional tools useful for the digital comparison of historical and modern maps. The online digital comparison of the maps in this portal is allowed though an overlay of maps and a variable transparency technique or for better results, it is possible to invert one of the maps in order to make differ-

ences more obvious (Fig. 8) or to use the modern vector data included in the platform to compare specific characteristics of the map (Fig. 9).

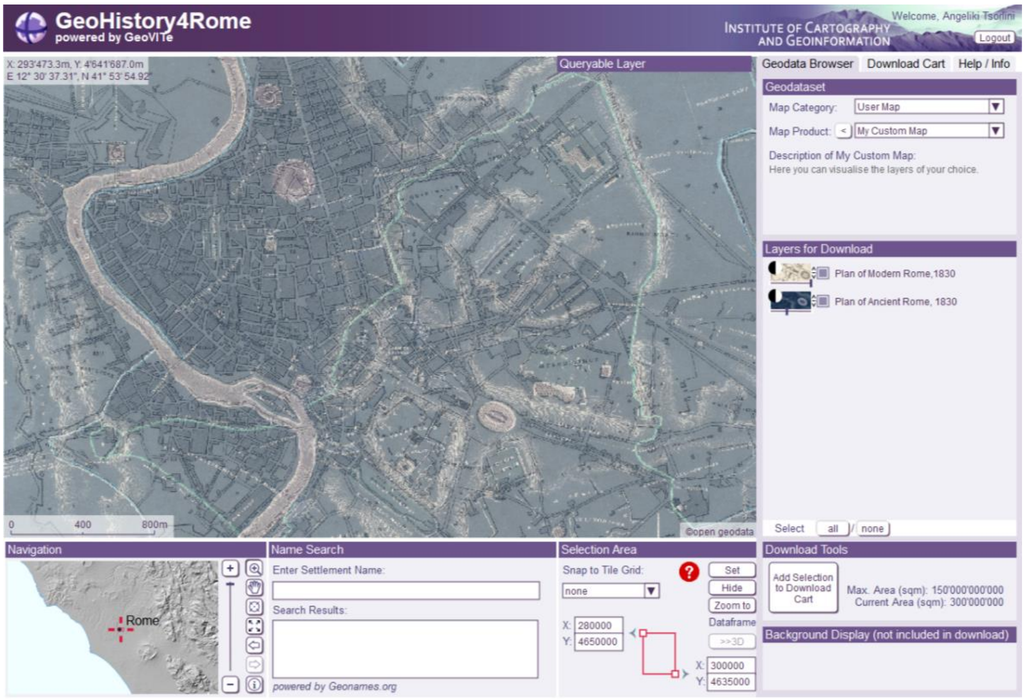

Figure 8: Comparing ancient and modern Rome constructed by Clarke, using inverted colors and transparency to detect the historical monuments of the city.

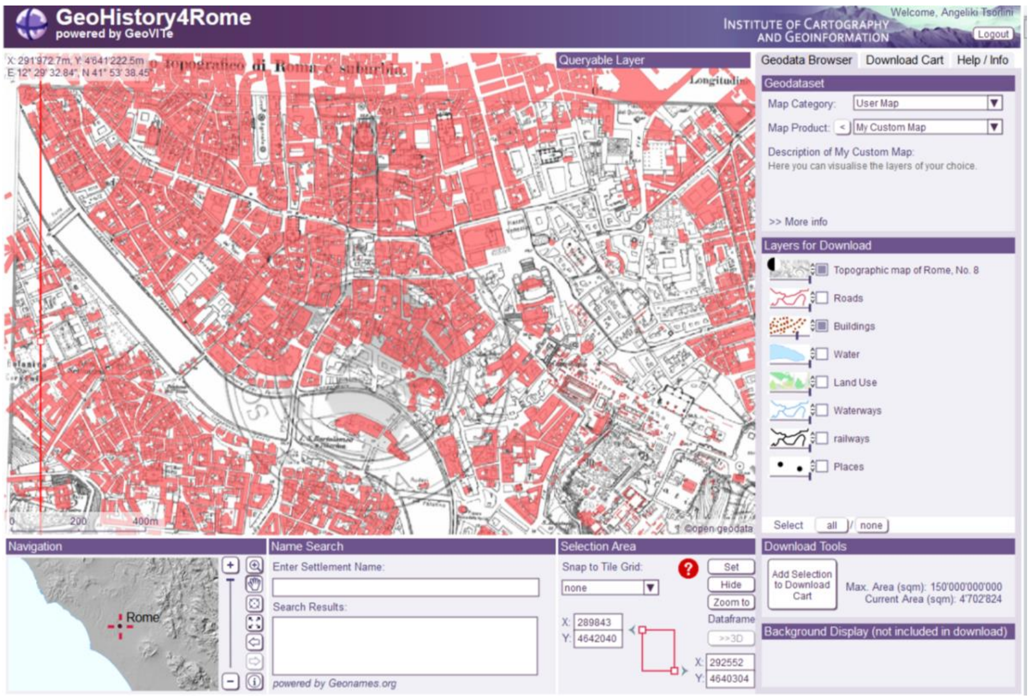

Figure 9: Comparing the buildings on the topographic map of Rome with the modern buildings in vector form (red polygons in transparency).

Another way to identify the changes in the natural characteristics of an area close to the mountains or close to the route of a river is to use satellite images or a 3D digital model (Fig. 10) to see if the depiction of these specific areas corresponds with the modern relief (Tsorlini et al, 2013a).

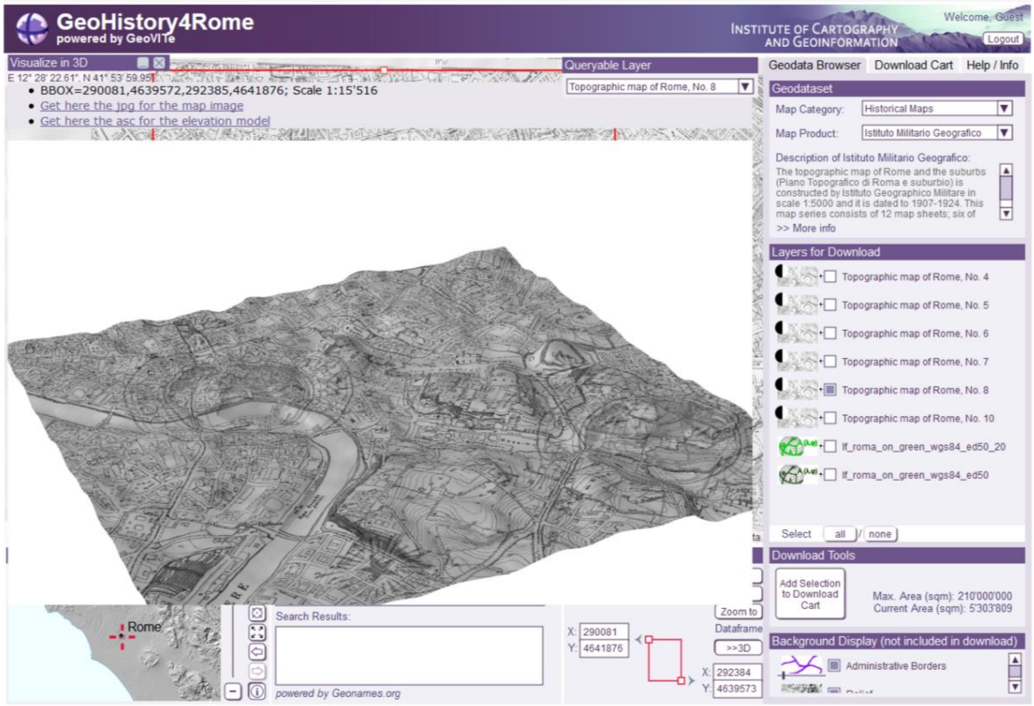

Figure 10: Topographic map of Rome presented on the 3d model of the area.

Through the platform, it is also possible for a researcher to study the geometric and thematic content of a historical map and find more details about its reference system and the relevant grids (geographic or projected) drawn on it (Fig. 11). For instance, it is possible to see the coordinates of a grid's intersection on the map's projection system and on the final working projection system which is usually the modern one used in the area.

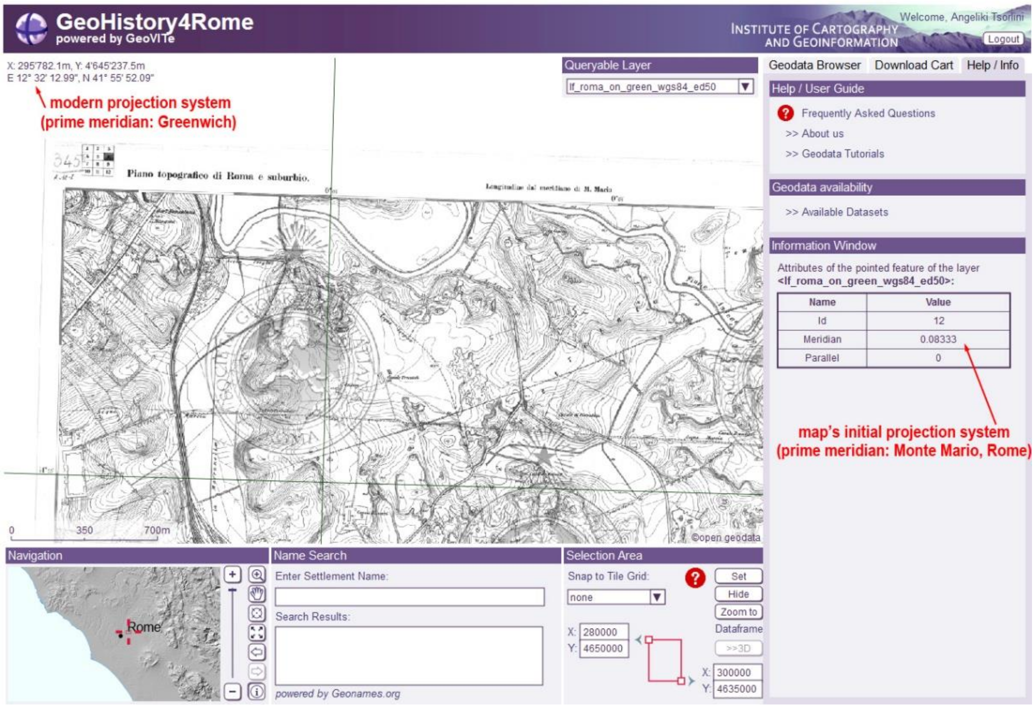

Figure 11: Clicking on the meridian, it is possible to see the coordinates of the map's initial projection system on the attribute table on the link and the coordinates of the meridian on the modern projection system.

Finally, it is also possible to study the deformations of the historical maps in comparison to modern data. These deformations can be shown through a grid adjusted to the map and transformed likewise or through arrows showing the magnitude of the deformation on specific places of the map. In our case, in order to visualize the deformations of the historical maps, we have added on them an arbitrary rectangular grid, which was transformed in the same way the map did (Fig. 12).

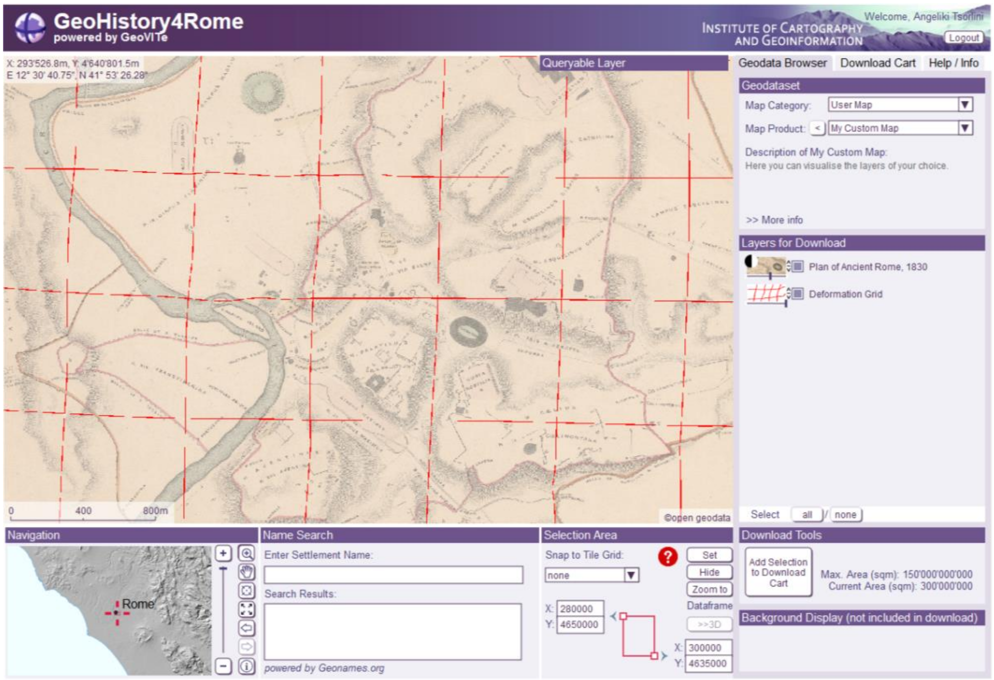

Figure 12: The deformation grid of the plan of ancient Rome adjusted to modern data.

Researchers from different scientific fields can benefit from all these techniques applied to historical maps through the GeoHistory platform, since the latter offer them the freedom to decide on their own which technique is the most appropriate to be used for better showing visually the result of their study. Moreover, they have the opportunity to save and download the maps they have used for their comparative analysis in order to use them offline, giving them also ideas and providing them with the necessary instructions for applying the same techniques offline on other software.

Conclusions - Future Plans

The use of historical maps to study the development of an area and to detect changes in the environment is very important for researchers of different scientific fields. The development of new technologies and the implementation of new techniques give free online access to historical and modern maps and vector data and allow new approaches in the digital comparative analysis of historical maps providing also the opportunity to users who are not well experienced on this field to use historical maps in their studies or to work on them through platforms developed to serve these needs.

In this paper, we demonstrate all the methodological steps necessary to correctly georeference and integrate historical and modern data in an online platform for the purpose of comparative analysis. The online platform offers various advantages such as a user-friendly environment where the comparison of maps can be done using various tools such as overlay and transparency on maps or inversion of colors in order to make differences more obvious. Another advantage of an online platform is its flexibility based on web services. In our case, we have created a specific version of the GeoHistory platform and we have adapted this platform to use data and projections from Rome, Italy instead of Zurich, Switzerland. We can therefore use this methodology on any region and any projection using historical and modern data coming from different sources, either in raster or vector form.

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Cartoteca Digital, Institut Cartografic de Catalunya, http://cartotecadigital.icc.cat/

U.S. Geological Survey, http://earthexplorer.usgs.gov/

Il Portale Opendata della Provincia di Roma, http://www.opendata.provincia.roma.it/

Commons4EU project, http://commonsforeurope.net/province-of-rome/

Natural Earth, http://www.naturalearthdata.com/features/^

CloudMade, http://downloads.cloudmade.com/

OpenStreetMap - The Free Wiki World Map, http://www.openstreetmap.org

SINAnet, Rete del Sistema Informativo Nazionale Ambientale – ISPRA, Istituto Superiore per la Protezione e la Ricerca Ambientale, http://www.sinanet.isprambiente.it/it/sia-ispra/download-mais/

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