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3D digital maps: New development in cartography for cultural heritage

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Summary

This paper will demonstrate how new technologies in cartographic environment integrate acquisition, management and representation techniques for georefencing data processing. Moreover, there is an ever-growing demand for a more "*representative*" and "*world widespread*" digital cartography. More *representative* means the capabilities in describing physical phenomena but also social, economic and cultural data that are necessarily connected to geographical aspects. More *widespread* derives from the growing use of cartographic products by non-specialized users. Among the different formats of numerical cartography, three-dimensional maps are certainly the more suitable. These represent a cartographic typology corresponding to different levels of accuracy and details to describe reality, such as DTM and city modelling. They provide geometrical and qualitative information coming from the use of historical documents and present-day aerial and terrestrial photo suitably processed: such as orthophotos mapped onto DTM for a more truthful description of territory. Data for 3D map production can be acquired by employing the most advanced and outstanding techniques, normally integrated such as digital photogrammetry and laser scanning, both aerial (aircraft or helicopter) and terrestrial survey. 3D digital cartography seems to be more suitable in different field of applications: to recover the historical maps content, to establish an architectural project in its surroundings, to well deals with town-planning matters, to perform simulations for environmental impact analyses, and so on.

An ever-more pressing need is moving the field toward the study of methods and instruments that make it possible to improve the use of cartography for production and management of current map-making and for conservation of the historical heritage acquired. The trend stems from the need to expand our knowledge required on the role of supports and instruments currently developed, investigate the opportunities and the limits posed by its use, evaluate the potential offered by an evolution that appears closely connected with information technology, and finally, actualize the methods and forms of research in relation to contemporary culture.

Technological innovation, specifically, information technology and telematics, has developed and continues to develop rapidly and at such an accelerated and complex pace that it no longer involves only operating techniques. We are witnessing an interaction between development of the practice and a similarly significant and difficult to predict maturing of the theories. The hope is that one of the objectives of development of the new IT platforms is to become accustomed to this comparison and encourage cooperation, reaffirm specific abilities and prepare qualification of professionalism, in order to achieve an integration of the methods and skills.

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The various forms of representation of information and traditional handling of geometric, alphanumeric and iconographic data - which are in large measure privileged formats for understanding the physical world, its phenomena and its relationships with other social, economic and political realities - have long appeared to be complementary factors, but today, it is conceptually and operationally easier to associate them, handle them, and process them. In this sense, all modern methods of representation that use traditional 2D techniques (planimetries, surveys ...) and 3D techniques (3D aerial surveys, 3D laser scanning of buildings...) enable a cross-over interpretation of the maps and especially, make it possible to integrate the geometric, semantic and symbolic contents of each map.

Since the beginnings

With the development of digital technologies, cartography has demonstrated a great capacity for dialogue and exchange with new technological and scientific instruments. From time to time, it has absorbed the techniques of other disciplines such as image-processing and 2D graphics to use them in its field. The earliest examples of this contamination have emerged with automatic cartography, organized according to the raster or vector model. The former, which arises from optical scanning and acquisitions using a digital camera, uses tools related to image processing and essentially others related to pixels as the minimum unit. In this model, spatial data are discreet elements positioned according to regular sampling, characterized by a certain position and attribute. The latter are more closely related to two-dimensional graphics. It is a way to describe the geographic reality with different types of elements (points, lines and areas) in the vectorial space; each of these is combined with an attribute that distinguishes it from the other elements.

Global or local plane transformations can be applied to each of the models. The most common case is georeferencing. This means converting a map from the original system of representation to the system of coordinates used in the reference maps. There are two steps in the problem to resolve for georeferencing, which is realized by a plane linear transformation:

- converting the geometric coordinates of the map into coordinates of the pixels of the final image;
- creating a correspondence between the geographic coordinates with the map coordinates, the so-called projection.

In addition to the geometric conversion, maps and images also undergo a resampling phase that generates a slight degradation of the image, due to the fact that new pixels are calculated as interpolations between adjacent pixels during every image resampling. This degradation must be added to the aliasing effect of the image prior to rotation and the new one introduced by rotation (on lines that are not diagonal to the axes).

What’s more, digital cartography has turned attention to the third dimension. The interest in three dimensionality has called forth the need for instruments that traditional cartography did not possess and had to borrow from 3D graphics: primitive two and three-dimensional graphics in a vector space, used to represent and communicate the altimetric contents of the map. In numeric cartography, as we have already seen, each of these entities is connected to spatial contents such as the planimetric and altimetric position, as well as symbolic and semantic meanings.

Altimetry, the Z coordinate, has quickly transitioned from a representation by quoted points and level curves to displays that are more complex in terms of IT, but richer and more immediate from a perspective of map legibility. Surfaces and solids are introduced for the representation of diverse objects such as the territory and the building.

The transition to 3D representation of the data poses the question of adherence to the reality, in the graphic translation of information, which implies a new concept in modelling systems, especially when the object of the investigation is a constructed context which presents elements of particular architectonic significance, typical of Italy and other European cities, where the historical evidence is quite significant. The realistic and 3D representation of the natural environment of a territory presents numerous problems of visualization of the natural landscape elements.

The graphic quality of their representation is supported by methods and documents already widely codified, but updated where necessary by the new 3D IT techniques.

These new instruments have been integrated into schemes of representation that are not rigidly static, but able to demonstrate the evolution of an event over time and space. Using 3D animation, it is possible not only to see the characteristics of a map, but especially, it is possible to enter into the virtual center. With introduction of the techniques of virtual reality, it is possible to interact with the model and therefore, with the map.

In the future…

Problems still remain in relation to modelling three-dimensional data, their management in complex databases (GIS 3D) and transmission and use of the cartographic data elaborated in the web service.

The problems that remain open are:

- the correct representation of the natural 3D space of the geographic area object of the survey,
- the capability of realistic movement in the area by the user,
- the significant and reasonable representation of the architectonic characteristics of the area and/or the buildings present.

Case study: the Pelagie Islands south of Sicily

After the systematic collection of existing historical and current maps and the cartographic documents (such as aerial photographs), the essential problem to face was to make these documents usable concurrently, or manage them singly, depending on the purposes of each case. The procedure carried out was to make them uniform from a geometric perspective. This is the classic georeferencing procedure of the maps into a single reference system, which in the case of the work presented, is the national “Gauss-Boaga” system. This was not only an obligatory decision, but it was also extremely convenient since the metrical and geographical information of many of the documents used were expressed in this system. The result was a set of "overlapping" documents, framed in the same reference context; the semantic and metrical differences from map to map are clear. In fact, each map retains its theme content expressed through a system of signs and symbols and preserves the uncertainty of its scale of reduction. Regional technical maps at a scale of 1:10,000 were used as basic metric support for the Islands of Lampedusa and Linosa.

After georeferencing all the maps, historical and current, several comparisons were made. The coastlines shown on 19th-century historical maps were examined by making pixel by pixel comparison operations. To highlight the changes, warping animations were made between the beginning map and the ending map. It was found that the changes present were sometimes the result of survey errors, or at least errors in representation of the territory, while in other cases, the changes corresponded to an actual physical alteration in the coastline. These observations prompted the scientists to make the same control and verification operations, where possible, using altimetric data.

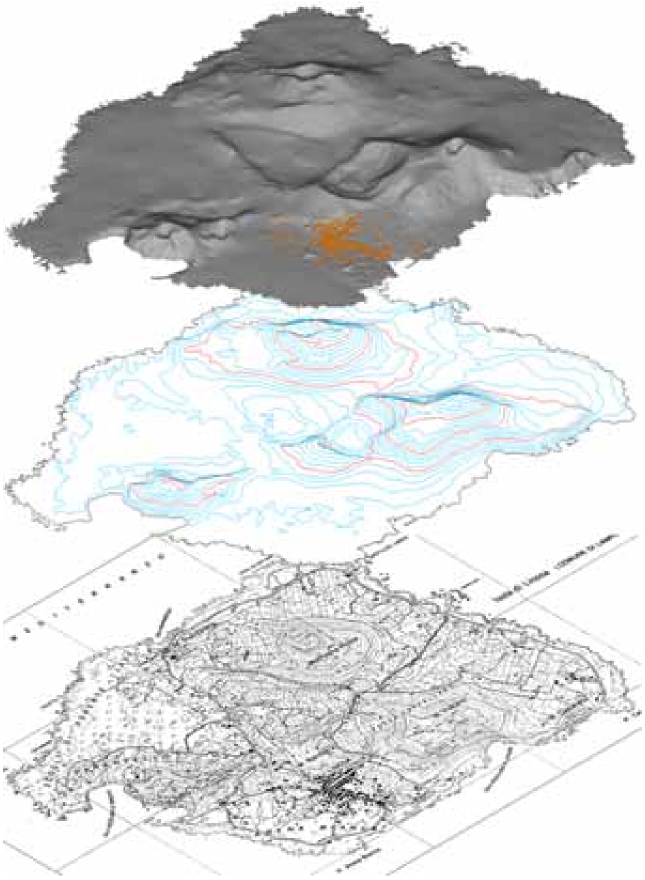

Figure 1. Generation of DTM. From bottom: CTR-traditional map; Boundary map; DTM with buildings

Given that modern management of cartography is totally digital, all the documents collected had to be digitalized. Digitalization was done in the vectorial format, by manual digitalization, for Linosa (Lampedusa was already in the digital format), and in raster form for the other documents, such as historical cartography. The vectorial cartographic basis was enriched with information from other maps in order to complete the semantic content. The two numeric maps obtained from the most recent data were used as a basis for creation of a 3D digital model of the two islands. As spatial support of every other territorial information, 3D digital cartography was used. The 3D model is based on the altimetric contents already present in the vectorial maps in the classic forms of the quoted plane of representation at level curves. The model produced was realized by constructing a DTM (digital terrain model) with a square grid with estimated and prediction algorithms (kriging); afterwards, the DTM was triangulated to enable a correct modelling of the surface of the terrain around the buildings.
This operation was reproduced for all the maps in which it was possible to recognize the altimetric content. In this case, comparisons were made between the DTM obtained, in order to highlight the changes between the maps using simple Boolean operations. Consequent to the creation of the 3D model of the morphology of the territory, the constructed area and the road network were modelled in 3D. Another result obtained from the DTM is the "mapped" model of the islands which enables a virtual exploration of the island. This is a vesting of the model with aerial photographs, historical aerial photographs, and historical maps of the islands in order to afford the maximum

description quality. In the case of aerial photo projections, the operations were the orientation of the various photographic shots on points extracted from numeric cartography and subsequently, their ortho-projection (with digital techniques) on the cartographic plan using the heights of the DTM realized from present-day maps as a model. The result was an orthophoto of the islands that links the correct scale representation of the cartography with the replicating and descriptive ability of photography. The last step was to project the orthophoto back onto the model so that each point of the model is "coloured" with the contents of the orthophoto.

Figure 2. Lampedusa DTM, shaded representation

Figure 3. Lampedusa orthophoto.

The final step in the reprojection can also be made with historical maps, in order to obtain the current geometric content, the 3D model, connected to the semantic content deriving from the map.

Figure 4. Lampedusa DTM mapped by orthophoto.

In this operation, the warpings of the historical cartography with respect to present-day cartography are clear. The final model lends itself to every type of representation, including representations realized for demonstrational purposes of film clips of virtual flights on the islands. Beyond the spectacular qualities of the cartography, there remains the fact that the information demonstrated is a comprehensive example of what can be achieved with sophisticated processing, but all feasible, cartographic material that is generally present for the Italian landscape.

Figure 5. Island of Lampedusa, Sanvisente, Marvuglia, 1846.

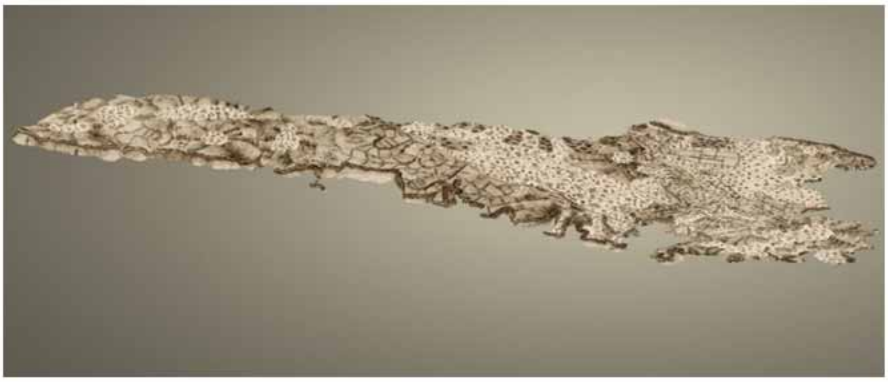

Figure 6. DTM drapped with historical map.

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