3D MULTI-TEMPORAL GIS FOR THE MANAGEMENT OF ENVIRONMENTAL RESOURCES

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ABSTRACT
The research done by the Sections of Survey and Mapping, and Environmental Engineering of a DIIAR of the TU of Milan (Italy) about the assessment of aerial volumes in the Lombardia Region of Italy can be here presented as a case study suitable to be applied otherwise. It required the acquisition of: DTM, orthoimage, environmental database both spatial and temporal distributed and subdivided by various categories. The implementation of a Decision Support Oriented GIS needed a complete 3D model of the geometry and a multi-temporal analysis of the environmental data. The paper shows how to model the 3D topology of a geometric information and the way to process the time series of the environmental data, especially concerning the pollution. The multi data integration of this kind of procedures gave the chance to promote international cooperation and technology transfer, considering regional needs and resources.

1. INTRODUCTION

Some years ago, the born of the GIS was the idea that wants to give an answer for the “new representation for the territory” with the humans interact. In the same way, the idea of the “management and planning” is equivalent to mitigate and/or direct the men productive activities to avoid the negative influence into the environment. The National and Regional Authorities are trying not to increase the environmental crisis, using these two tools.

The creation of different “scenarios”, in a GIS to represent the territory with the update and updating cartography in a short time, with the introduction of different thematic or semantic variables, related to the entities that characterize those, makes the “planning actions” and the geomatic instruments the principal tools to make a real analysis for the needs and the activities to apply for the implementation of expected solution in different territories (Buckel D. - 2003).

In this case, it is tried to create different thematic maps to help the public administration to have the control of the different situations. It was opportunely modeled the real time data acquisition of the air pollutant in the Lombardia Region, of Italy, to support global changes, studying them and trying to manage the problems, which are present. After this, there was the need to produce maps, which allow the analysis and the representation of the dynamism in the air basins for the characterization, control and evolution of the air pollutant behavior.

The theme is going to be presented and developed in the present research is the dynamism, which presents the evolution of the air quality over a year, producing some graphics and some relations between measured and modeled data by the application of a “model”, which considers the meteorological and elevation characteristics of the region.

2. GEOCODING AND CREATION OF THE 3D CARTOGRAPHIC BASE

It is important for the management of the information in a GIS the spatial reference of the data for the production of technical and thematic cartography, from remote sensing to photogrammetry and from geodetic data to measured data from environmental and territorial sciences, in order to produce 3D cartography for the analysis of the thematic data.

It is also important the study of the data structures and the implementation of strategies, making possible to use the models present in a geographical information system:

- the external model;
- the conceptual model (following the entity – relation approach);
- the logical model (making use of the structures of the relations between data and the vector system, because of the topology and the metric components, or the raster system, with the compression of the data or continuos models as an alternative);
- the physical model.

The modern research lines give the idea to develop a system considering the time: 3D GIS and time system to allow for the introduction of the dynamic analysis of the scenarios.
It was important to have a DEM for the whole Lombardia region to have a first approach to the real composition of the study area and the boundaries with the other regions and the limit countries (PRQA – 2000). It was decided to get, from a word database, a 1 km x 1 km. DEM called GTOPO30, freely available through internet. The data acquired in this reference system were become into a new cartographic reference system, defined by the Gauss Boaga map projection.

2.1 UTM and GAUSS – BOAGA SYSTEM

If the interest is focused on an small area, it is possible to refer to a local DATUM and consider the ellipsoid of rotation, locally oriented (producing the condition in which, one point is tangent to the geoid, and has in common the same azimuth). In this research, the area involved had as local DATUM the International Ellipsoid of Hayford, oriented to Potsdam, for the UTM – ED50 system (European DATUM 1950) and a second one, oriented to Rome Monte Mario for the Italian Gauss – Boaga system (Rome 1940).

2.2 Systems for the cartographic representation

The local geodetic coordinates, referenced to the zones West and East, in the Gauss – Boaga reference system, and zones 32 and 33, in the UTM reference system, have become in cartographic coordinates E, N, with the elevation referenced to the sea level.

This DATUM transformation gives the possibility to have the data coming from the regular matrix of the DEM GTOPO30 projected in a cartographic plane. These data have been gridding by the software SURFER, with a path 1 km by 1km, producing a matrix with the elevation data, useful for the generation for the DEM of the interest area.

With the data from the DEM were produced some maps with the contour lines and the shade image, which represent the DEM in the Italian Gauss-Boaga reference system (just for the National maps) and in UTM (system in which can be referenced not only Italy but also the France, Austria and Swiss). After the acquisition and geocoding of the altimetric data, it was made the georeference of a DEM (zone West and East together) with a software called ER-Mapper, which gives the possibility to generate a new DEM for the whole Lombardia Region and surrounding area.

![Figure 1. DEM of the North of Italy](image)

2.3 Georeferencing of the NOAA

Using the DEM as the reference, it was also possible to make the gridding and the georeference of a satellite image (NOAA – RGB). This image is big enough to cover the whole territory of the Lombardia Region, and it could be used as the base map for the data positioning. Those (DEM and NOAA image) will be part of the futures studies, from the present research activity (Malinverni E. et al – 2000).
The image geocoding was made with a linear polynomial function using 11 Ground Control Points. The error is lower than a half of a pixel (the unit of the digital image). After this procedure it was overlayed the image on the DEM to get the DTM (Digital Terrain Model) and to give the possibility to identify the different land uses.

Figure 2. NOAA satellite image with the GCP

Figure 3. GCP and SQM in pixels

Figure 4. Overlay of the NOAA image on the DEM

2.4 Realization of topology for the aerographic basins

The thematic data consisted in the measured and modeled air pollutant values for the Lombardia Region. The idea was to generate a GIS where the possibility of the analysis of different scenarios are developed in the time to study the dynamism and the behavior of this kind of pollutants considering the meteorological conditions. First of all, it was important to define conceptually what an aerographic basin is. It is defined by the Italian CIPE (Comitato Interministeriale per la Programmazione Economica) as: “air mass which has an homogenous behavior, which moves in an area with homogeneous height characteristics as well as homogenous distribution of the emissions meteorological characteristic and diffusive ones” (1993). Considering this kind of definition, it was possible to define more than 60 different areas in three levels in the whole region to characterize the behavior of the territory.

According to the concepts explained in the follows, it was possible to create the topology of the “aerographic basins” for the whole region. It was divided in three different levels:

- **first level**: the canyons of two rivers, which cut the plane territory;
- **second level**: the territory that goes from the sea level to the 2500 m. (with all the valleys, longitudinal and transversal ones);
- **third level**: the bigger geomorphologic areas, which go from the 2500 m. to the 4000 m.

For this objective it was imported a helpful model for the spatial data: a vectorial map (produced by Autocad 14), which has to be updated because simple and it does not respect the real relieve of the region and not even the concept defined in the paragraph before.
From a simple vectorial map, which describes in a large detail the Lombardia Region, it was created the topology of some areal entities for the study of the distribution and diffusion of the pollutant in the region (Mussio L et al. – 1999a).

The **structure of the vector data in a 3D space**, being with major complexity than the ones in a 2D space, has a linear approximation using the polyhedrons, polygon, segments and points. Consequently the shapes are the polyhedrons, the figures are the polygons or are made with polygons, the lines are segments or made by segments. So the topologic relations between the elements in a 3D space show:

- a point with a relation “one – n” with the segments, the polygons and the polyhedrons;
- a segment with a relation “one – two” with points, and one – n with polygons and polyhedrons;
- a polygon with a relation “one – n” with points and segments, “one – two” with polyhedrons;
- a polyhedron with relation “one – n” with points, segments and polygons.

In fact, a polyhedron is close to a surface made by polygons, delimitated by segments, each of them with a start and an end in a point. A polygon is delimited by segments, but it has only one polyhedron on the right and only one on the left. A segment can be in common to lots of polygons (and lots of polyhedrons), but it has its start and its end in a point. A point could belong to the surfaces of different polyhedrons, be the common node to different polygons and different segments.

Using the graph theory, the concept of nodes and arcs can be used and directly connected to points and segments. In other way, using the concept of duality, it is possible to connect the polyhedrons to the nodes (dual) and the polygons to the arcs (dual). Cross – connection table shows the m-n relations among the segments and polygons. This one has two kind of information: the set of segments, which delimited a polygon, and the set of polygons, which have in common the segment. Indeed each of these polygons built, two by two, the faces of a diedric angle with same common segment.

![Figure 5. Topologic relations between the elements considered part of the linear approximation in the 3D space](image)

The **dynamic system or time – variability** can be classified in:

- **constant**: when the process does not have variations;
- **periodic or almost periodic**, when the process has a cycle behavior in the laws of regulation of the process;
- **a–periodic**: when the process does not have a regular temporal fall;
- **mix**: when the a–periodic process shows some periodicity in some period of observations; being generated related only to rare phenomena.

These following categories are related to the time, as:
- **logic time**: when the entity has been modified in the real world;
- **real time**: when the measure surveys the modification of the entity;
- **virtual time**: when simulation operations generates a modification of the entity;
- **physic time**: when the modification has been recorded.

The object that is characterized by the dynamic variability has to be updated in its representation: this means that it has to be updated without loosing the previous characteristics. An object can be updated in its geometry and in its thematism, indeed the tables representing their topology must be easy to update and obviously complex to archive all the information (the old one and the updated one).

This kind of research is still been studied because it is not possible, for a commercial GIS, to make a constant update of the thematism of all the information archived in the database.

3. CONCEPTUAL MODEL

From the GIS, it is possible the representation of the data (topographic maps, graphs, diagrams draws, etc) using an interface with CAD software which gives the possibility to produce the representation of the territorial data, elaborated and related in the GIS.

The implementation of the data in the GIS has the objective to create a database, to be used to get complex information from simple data. For the creation of the conceptual model, it was used the Entity – Relation Model.

![Conceptual Model](image)

**Figure 6.** The conceptual model used in the present research

Once the conceptual model is defined, the next step is to transform this model to the structure of the database, i.e. the creation of the logical model, defined as relational structure, where the data are represented by tables to define the entities and the relations between all the elements present.

4. CREATION OF THE THEMATIC MAPS

The thematic maps generated by modeled and measured data in the GIS were at the beginning just a file with numeric information, read by any kind of tool that can open an ASCII format.

The modeled data obtained after the AERMOD run (the software used for the comparison of the measured and modeled data) produce the input for the creation of the thematic maps. These data were characterized by the coordinates X, Y and Z, the punctual concentration of the pollutant analyzed in that point and some other information, like time of production of the output and some codes owned to the program.

Once these kind of data are introduced in a GIS, it reads them as a table information; the software is now able to interpolate the information to create the thematic maps. The interpolation used was the **IDW** (Inverse Distance Weight). This method of linear interpolation uses the inverse of the distance; it relates the idea of nearness, owned to the Thiessen polygons, with the gradual variation of the surface.
Therefore the IDW, defined by the nearest 12 points and a cell size equal to 1000 x 1000 meters, permitted the first representation of the data (Mussio L. et al. – 1999b).

Another method is the **Nearest Neighbor: Thiessen Polygons**.

The region is divided in polygons, each of them with a known point. In this way, it is possible to create a regular grid if all the polygons are equal, or an irregular grid if the polygons have different surfaces. The main idea is to give to the whole area of the polygon the value of the known point. Notice that is not an interpolation method because it does not make a mathematical operation.

The **Triangulation** is another method of interpolation used for the generation of the raster maps. The most common procedure is the **TIN (Triangular Irregular Net)** for the calculation of the interpolated values. The most common criteria are the ones defined by Delaunay and a triangulation proposed by the rules of construction of the Polygons of Thiessen.

According to the first case, the circumference among the three points of each triangle does not have any point in it, except for the vertex of the triangle on the boundary of the circumference. The second case considers that the vertex and the center of the circumferences are the same point. Having defined one of them means that it is possible to make a transformation between both.

For the DEM of the Lombardia Region was used the TIN method, because of the complexity of the territory, but once this is obtained the information could be represented by contour lines or a GRID (Polygons of Thiessen)

This method is the most common used in a GIS to create surfaces for the analysis of the thematic maps. It gives the possibility to the user to define the extension of the area to be interpolated and the cell size; in this way, it is very simple to get maps with the same geometric characteristics for the relations between different thematisms coming from different sources (in the present case, the modeled and the measured data).

5. **MODELED DATA COMING FROM AERMOD**

Once the emissions were modeled in AERMOD, the problem of the interface between this software and the GIS to produce the thematic maps for the planning and management of the Lombardia territory has to be solved.

The information, which was useful to import in a GIS, was the data about the values of the behavior of the pollutants modeled in AERMOD. The result was a file made by twenty six networks of receptors for the whole Lombardia territory, where the model calculates the concentration of the pollutant.

![Visualization of the shape file from ISC AERMOD](image)

The visualization of the data in a graphic format covers the Lombardia territory by twenty six different block (made by punctual information) which correspond to the 26 different receptor grids used in AERMOD, where the software modeled the concentration value of the pollutant.

As a consequence, it was modeled the behavior of the CO for the whole year 1999.
5.1 Measured data from the monitoring stations

The data measured by the permanent stations in the Lombardia Region are organized in hourly, dairy and monthly means for each pollutant: CO, NO\textsubscript{X}, SO\textsubscript{2}, O\textsubscript{3}, NO\textsubscript{2}, NO.

As just the values of the CO were modeled and those of the NO\textsubscript{X}, SO\textsubscript{2} limited to January only. The corresponding maps were made the same interpolation method to have a comparable result in the maps produced by the permanets monitoring net and the modeled data.

![Visualization of the permanent stations and the CO concentration values for the whole year 1999](image1)

Figure 8. Visualization of the permanent stations and the CO concentration values for the whole year 1999

![Distribution of the modeled data of the concentration of the CO in µg/m3](image2)

Figure 9. Distribution of the modeled data of the concentration of the CO in µg/m3

5.2 Comparison between the thematic maps produced by modeled and measured data

A comparison between the modeled data and the direct measured data from the permanent station net has been performed. This operation was made with the tools of “spatial analyst” of the GIS chosen for the comparison and for the elaboration of thematic maps: in this present case, it was used one of the commercial products of the ESRI: Arc View 3.2 and Arc GIS 8.1 and 8.2.

6. CONCLUSIONS AND FUTURE DEVELOPMENTS
6.1 Dynamism in a GIS: the forth dimension

Data management and modeling capabilities of GIS coupled with Remote Sensing data, but also with all kind of surveying sources, provide powerful tools to track landscape conditions and to conceptualize spatial relationships (Crippa B. et al. –1995). The traditional 2D planimetric maps have been effective, across disciplines, to display the outcomes of GIS analysis. However a truly effective means to visualize GIS results and to communicate aesthetic concerns are steeped in using 3D visualization and multimedia techniques.

In recent years, there have been strong advances in 3D simulation and visualization, as it is possible to see through entertainment. This techniques can be apply in the spatial analysis and to relate thematic data. Map animation is used to represent temporal data for 2D or 3D maps. Multi – media mapping is the integration of video and imagery with maps to describe “what currently is”, as opposed to 3D visualization, which typically reflects “what could be”.

As a consequence map data are generated from GIS using analytical models, or from external simulation models, they are sequenced all together to build a “movie” or frames, each frame is a map for a specific time period. The main idea was interface with a DSS model for the multi - evaluation criteria, in order to manage and plan the activities, and political decisions (Malinverni E. et al. – 2003).

6.2 Visualization data requirements

For the visualization of the 3D scene, there are lots of software. The data models employed can be very different, from commercial softwares offering more advanced capabilities, but more complex interfaces, to public domain, tending to use very simple “data file” approach. For this research work, it was utilized the ARC SCENE from ARC GIS. It can be analyzed in three different components:

- **Image Draping**: in this case, it was needed the GIS coverages (points, lines, polygons), which is going to be the Base map and the Thematic (vector or raster format), the DEM for the terrain representation and optionally the Imagery.
- **Geometric Modeling**: it is represented by the GIS data (DEM for terrain; base map features for draping (e.g. roads, rivers and lakes), thematic layers for the identification and localization of the objects to be represented in 3D, (like trees and buildings).
- **Real Time Simulation**: in this case for the representation, it is needed the base map with the features and the typical landmarks and the imagery, which moderate the resolution of the landscape scale and give the high resolution for detailed scale.

Most of the visualization software includes a specific interface to generate the rendered 3D scene like fly or animation. In some cases, the interface is in real time (VRML interface), but typically the user defines view parameters and then the static image is rendered (this was the case applied).

6.3 General remarks

The subdivision of Lombardia territory in aerographic basins for the study of the diffusion of the pollutant is very important. This kind of subdivision makes the spatial – temporal analysis easier: it was the most important of the objectives of this research.

These basins represent the entities where the behavior of the air pollutants have to be studied and the areas where the authorities have the possibility to plan and manage the activities, to implement according to the evolution of the pollutants’ behavior.

When the study of the diffusion of the pollutant, considering the new aerographic basins, was suggested, the first thing noticed was that the monitoring network was not present in all the basins. It is obvious that the missing information produced the blanks in the applied methodology. The future idea is to offer in a GIS different options to make this kind of system more powerful to select, catalogue and analyze the data about the pollution of the air basins in the Lombardia Region.

The technology for a SDSS can be summarized in the acronym DDM, which means Dialog, Data Modeling according to Sprague and Watson (1996).

The SDSS must be very good organized and it needs three main components:

- **Data Base Management System (DBMS)**: a part of the software for the management of the geographic data,
their logical relations and their control, like update, acquisition, modification, etc.;

- Model Base Management System (MBMS): is the machine that generates the decision (modeling); it has an analyze function (research of the problem, optimization, simulation and selection of the best solution);
- Dialog Generation and Management System (DGMS): is made by the interface between the operator and the components of the software.

![Figure 10. The relation between GIS and SDSS](image)

This system constitutes one of the main lines to create a simple and efficient SDSS, based on measurements easily to be updated and to produce different scenarios for the study and the research of the air quality in all over the Region.

REFERENCES


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