GIANT3D: EXPERIMENTATIONS ON A NEW 3D DATA MODEL FOR GIS

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WgS IV/1

KEY WORDS: Cartography, Databases, GIS, Interoperability, Data Structures, Building, Infrastructure

ABSTRACT:

This paper describes phases of the development and results of an experimental structure of numerical cartography, at medium and large scale, to be used in GIS and to be proposed as a national standard. Development and results regarding software for writing and reading this model are reported too.Two of most important issues at the basis of modern cartography for GIS are open data format and three-dimensional content; another important required feature is a full topological structure with a shareable geometrical and semantic content.But the most recent requirement of modern cartography is interoperability: interoperability generally represents the borderline between the older and the newer way of thinking about GIS, and it includes data format, metadata, semantic, application, and service interoperability.So in order to define a new model of numerical cartography, compliant with technical needs mentioned above, 3D capable and interoperable, it's necessary to apply new rules and test the GML format that should grant interoperability.According to this goal, after the analysis of existing cartographic model, like OS MasterMap GML, CityGML, NEN3610, basing the work upon international standards (like ISO and OGC rules) a three-dimensional numerical cartography model has been implemented. This model is called GIANT3D, that means Geographical Interoperable Advanced Numerical Topological 3 Dimensional cartographic model. Software modules for editing and browsing this model has been realized.

1.INTRODUCTION

This work starts from a national research project on numerical cartography for GIS (PRIN 2004 "Strutture evolute della cartografia numerica per I GIS e l'ambiente WEB").

Needs for structuring national cartography come from consideration that international model cannot be used as they are because it's always necessary a conformation process to make them compliant to national rules.

Particularly in Italy GIS data production (including cartography) must be compliant to INSPIRE (Infrastructure for spatial information in Europe) E.U. Directive.

2.CARTOGRAPHY FOR GIS

Today numerical cartography must satisfy a large number of purposes and it has to be provided with specific characteristics to be suitable for certain uses.

Development of CAD technologies for 3D modeling grew up more quickly than tools for 3D GIS. Photorealistic solid models interact with digital terrain models making a representation so-called "City-model". This is useful for browsing and visualization of urban space, but it is not suitable for spatial analysis. So a model of cartography should not be oriented only to the visualization, but to the management of urban transformations and the management of ownership too.

In addition to the above, complying with topological rules can't be considered as optional, because data that aren't topologically structured cannot be used or processed in advanced application, like calculation a route on a graph could be impossible or very difficult without topological rules.

Information's exchange and its revision are carried out by advanced information systems; behind the need of a georeferenced third-dimension information, GIS users very often require tools to handle three-dimensional data.

Briefly, main topics related with handling cartography are:

- a standardized definition of contents of three-dimensional cartography, dealing with nominal scale;
- multi-precision database handling and cartography's generalization;
- a definition of a technical vocabulary or a system to share and unequivocally identify objects, attributes and relationships;
- a definition of a three-dimensional data model to standardize geometrical, topological and thematic aspects;
- the use of the time as an important parameter to evaluate territorial changes and development;
- data exchange and visualization using internet;
- . . . . .

Another very important side of the modern numerical cartography is interoperability; it generally represents the borderline between the older and the newer way of thinking about GIS, and it includes data format, metadata, semantic, application, and service interoperability.

3.BRIEF ANALYSYS OF EXISTING CARTOGRAPHIC MODELS

Before building an own cartographic data model, main existing cartographic model have been reviewed and examined; two of these are the Intesa-GIS Model (made in Italy) and the CityGML Model", made in Germany.

The first main model analyzed, called "Intesa GIS", is a cartographic model built by an italian working group composed of several members of the main public italian bodies.

Main features of the model are:

a. geometrical schema is based on the ISO-19107 standard, that includes solids; notwithstanding this, not every classes of the ISO-19107 standard are adopted, to easily distinguish between 2D and 3D features and to make easier the use of this model by unskilled users;
b. generally it's impossible to directly define objects with three dimensions, or volumes;
c. surface are represented in two dimensions only, but there is an "hybrid" way to model 3D surfaces, using a class of spatial attribute called "B3D surface", that is constituted by a 2D surfaces joined with a 3D ring that is the boundary of the surface;
d. topological constraints are defined separately from the geometry;
e. compound, complex and aggregate objects are defined;
f. levels of detail are not defined, because geometrical information is frequently and strictly linked to the scale of the representation;

This cartographic model is not fully oriented to 3D visualization and analysis, that represent important features to accomplish typical GIS operations.

The "CityGML" model is an information model suitable to represent cartographic and urban objects, mainly oriented to structure 3D models of cities, carried out by a consortium of several German bodies, both public and private.

It encodes a multi-level representation of cities, also including elevation, vegetation, water bodies, city furniture and more. It uses levels of detail, that allow the use cartography at different scale and with different contents, and only one geometric-topological structure. Besides CityGML introduces textures into GML, representing the graphic appearance of objects and making realistic models suitable for virtual reality applications. At present CityGML have undertaken the course to become a real OGC standard.

According to the goal mentioned above, after the analysis of these cartographic model, looking also to OS MasterMap GML, CityGML, NEN3610, basing the work upon international standards (like ISO and OGC rules) a three-dimensional numerical cartography model has been implemented.

4.THE GIANT3D MODEL

In order to allow advanced use of cartography in GIS and WEB-GIS, this model respects well-established rules of numerical cartography and the need of three-dimensional visualization and analysis of urban and out-of-town landscape.

Due to the fact that a unitary data model – collecting semantic, geometric and topological features – is needed, the research has been addressed to take GML rules (version 3.X) in 3D geographic data structuring processes. GIANT3D Model is an application schema based on GML 3.1 profiles.

In the proposed cartographic model entities are classified as 'topological' objects; topological description of spatial relationships speeds up computational processes and allows the description of shared geometric features through simple procedures.

During data collection and processing, therefore, it takes to verify the existence of topological exacteness in the geometric structure of entities, such as shared features and closed polygonals.

In order to ensure the consistency of 3D data, some rules have been set:

- objects' footprints must be surveyed;
- footprints are significant data in Digital Terrain Models processing;
- duplication of elements connecting different objects (shared walls, lines belonging both to road and to building footprint, etc.) must be avoided;
  hidden objects (subways, porches, galleries, etc.) must be surveyed.

Most of existing urban 3D models are suitable for visualization and navigation; objects are often modeled as simple geometric elements (i.e. boxes), whose surface is usually mapped with photos. Such models are not suitable for spatial analysis.

The definition of main classes has been carried out according both to geometrical and thematic features; such classes have been used to define a structure of data that goes beyond the one commonly used in Italy -strictly organized in layers- based on the "recommendations of the Italian Geodetic Committee".

Feature classes are grouped -and linked to each other- into a schema that is split in different smaller schemas, according to the main classes described below:

Real objects	**Modelled objects**
Building	Building part, ground size, maximum size, crowning, terrain-building intersection, horizontal part, accessory perimeter, components of their bound (surfaces 3D)
Artefact	Facility, fence, single, terrain-artefact intersection, accessory perimeter
Transportation infrastructure	Vehicular area, additional area (road-bed, pedestrian areas, parking lots, etc.), terrain-transportation intersection, axis
Infrastructure	Platform, additional area, axis, terrain-infrastructure intersection, accessory perimeter
Vegetation	Accessory perimeter (open space), terrain-open space intersection, green area, additional green area, single plant
Hydrographic entity	Water sheet surface, terrain-water sheet intersection (outlines of rives and lakes)
Terrain	*Under development*

Table 1. Classes of objects in GIANT3D model

Objects' features and relations have been set using a geometric and topological model suited to the theory known as Boundary Representation (Foley, 1995).

Real objects are represented using 0, 1, 2, 3 dimensional primitives (e.g. *node*, *edge*, *face*, *toposolid*); each primitive of a higher order is made of primitives belonging to the previous order.

Geometric primitives of 0, 1, 2 dimension (e.g. *point*, *curve*, *surface*) correspond to topological primitives of the same order. Solids are bounded at least with 4 surfaces connected to each other; surfaces must be flat and oriented in order to mark the inner and the outer side of each plane.

Each surface is bounded with an ordered set of edges (outer ring); empty areas are bounded with further inner rings. Each edge must be a straight line, bounded with oriented nodes. Only nodes are defined through x, y, z coordinates.

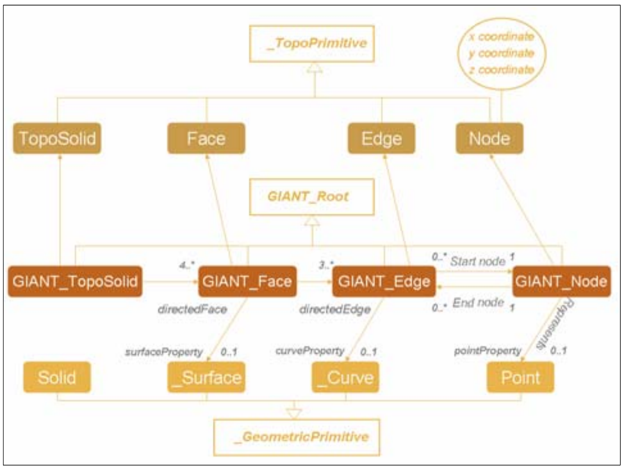

Figure 1. The spatial model

In the development of a spatial model it is necessary to detect a 'main' class, whose properties are transferred to the others; *Giant Root* can restrict properties of geometric and topological classes.

The main class is a subclass of *_TopoPrimitive* and of *_GeometricPrimitive*, due to the constraint assigned to the model that imposes the two classes are coincident. Such structure can manage data and processes both topological and geometric (Figure 1).

In the proposed model objects can be primitives or primitives collections, but not complex objects.

The model uses the '*Xlink*' concept from GML3 specifications. It allows to define the spatial attribute of an object only once: if an attribute is part of a higher order object, or of objects belonging to different thematic classes, it can be linked.

A *'gml:id'* identifier has been attributed to each primitive; such identifier can be recalled using the '*href*' attribute. Such constraint removes redundancies and makes the database simpler.

The model's thematic layers (*GIANT_Theme*) act as the 'composite' geometric classes (*CompositeCurve*, *CompositeSurface*, *CompositeSolid*). Geometric classes collect groups of geometric objects with similar features; thematic layers act in a similar way, since they collect geographical objects linked with same-level relationships (*_Construction*, *_Artefact*, *_Transportation*, *etc*.).

GIANT_Feature is a 'type' class to represent geographical objects in the model.

The purpose is to manage composite geometric objects as if they were geographical objects within the thematic structure of the model (*buildings, rivers, roads, etc.*)

Geographical objects inherit the features of their thematic class and the features of the corresponding geometric class, defined in GML specifications (*CompositePoint*, *CompositeCurve*, *CompositeSurface*, *CompositeSolid*) (Figure 2).

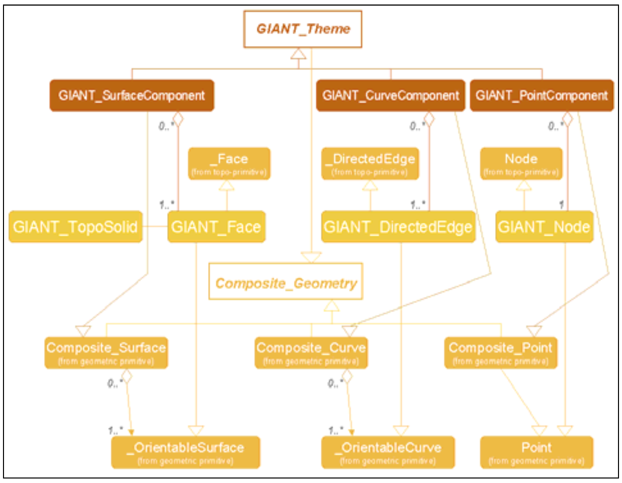

Figure 2. Relations between geometric and thematic classes

'*Construction*' is the class of '*_Building*' and '*_Artefact*'; the objects of this class are objects of the GIANT model, whose properties are defined according to the GIANT Root class.
The '*_Building*' class includes urban objects classified as buildings; his attributes are inherited from the class '*Building*' and from '*BuildingPart*'.

A building can be divided in several parts (*Building Part*) having their own identity.

A block represents an element of town planning scheme, but several parts (buildings) usually constitute a block (Figure 3). Building units inside each construction are defined through the class '*orizzontal_partitioning*', which is an attribute of the abstract class '*_Building*'.

The abstract class '*_Building*' allows the representation of 3D geometric elements that constitute buildings' bound. The model uses the '*bounded*' geometric attribute, that is a

'*_BoundedbyType*'.

```
<!-========================================= -->
<xs:complexType name="_BuildingType" abstract="true">
<xs:complexContent>
        <xs:extension base="_ConstructionType">
          <xs:sequence>

                    <xs:element name="bounded"
type="_BoundedbyType" minOccurs="0"/>
          </xs:sequence>
```

```
        </xs:extension>
</xs:complexContent>
</xs:complexType>
<!-========================================== -->
```

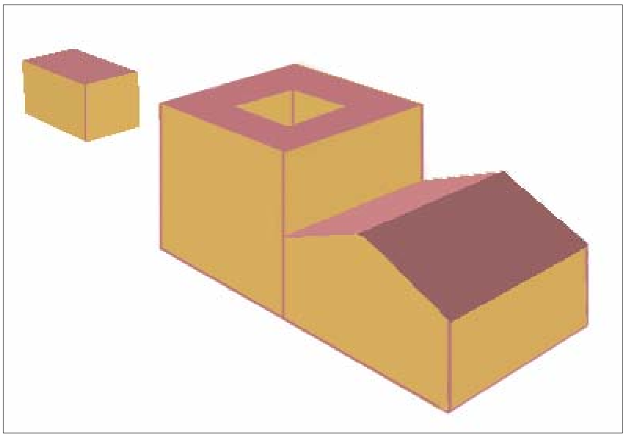

Figure 3. 3D Surfaces build up a block

Surfaces represent walls, roofs, base closure of real buildings; these elements are geometric attributes of *_Boundedby* class.

```
<!-- ==================================== -->
<xs:complexType name="_BoundedbyType" abstract="false">
    <xs:complexContent>
        <xs:extension base="GIANT3DObjectType">
            <xs:sequence>
                <xs:element name="Wall"
type="BuildingsurfacecomponentType" minOccurs="3"
maxOccurs="unbounded"/>
                <xs:element name="Roof"
type="BuildingsurfacecomponentType"
maxOccurs="unbounded"/>
                <xs:element name="Buildingplug"
type="BuildingsurfacecomponentType"
maxOccurs="unbounded"/>
            </xs:sequence>
        </xs:extension>
    </xs:complexContent>
</xs:complexType>
<!-- ==================================== -->
<xs:element name="Boundedby" type="_BoundedbyType"
substitutionGroup="GIANT3DObject"/>
<!-- ==================================== -->
```

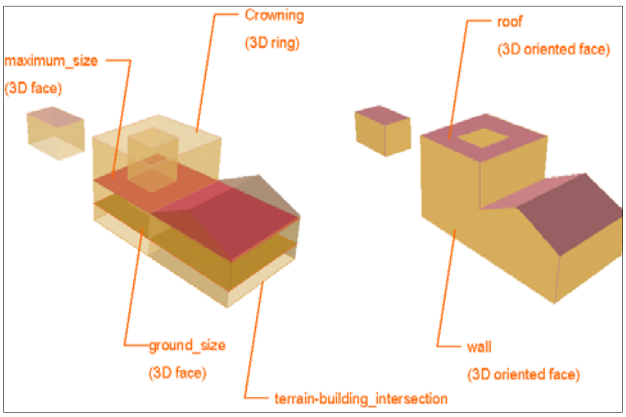

Figure 4. '*Building*' geometric attributes

Ground_size, *maximum_size*, *crowning*, *terrain-building_intersection*, *bounded*, *property_lands* are further geometric attributes of the class (Figure 4). These attributes provide useful informations for disaster management, town planning, navigational purpose connected to GPS-GIS technologies, etc.

5.EDITING AND BROWSING SOFTWARE

In order to edit and handle data structured according to the GIANT3DModel, two software modules have been realized: the first attends to structure the three dimensional urban model, the second attends to explore the model.

5.1 GML3 editor

The module by which it is possible to structure the model provides also to export it in GML3 format (OGC compliant); it has been implemented with commercial software (Autocad®) that, today, is the most suitable solution for data editing.

Starting from simple objects in CAD environment and using a suitable software application running in a CAD environment, geographical objects can be defined both geometrically and topologically; attributes can be stored in a relational database, so really carrying out a 3D city model.

Using the editor plugin data can structured based on rules belonging to GIANT3DModel; at the end, data can be exported in GML3 format, OGC compliant.

This editor-modeler is an Autocad®® plugin, developed using SDK Object ARX: it allows you to assign tag and attributes to objects, that are saved in a database. Once the plugin is loaded, it opens a toolbox over main window of Autocad®: many tabs (like *Building*, *Artefact*, *Infrastructure*, *Vegetation*, *Orography*, *Services*, *Hydrographical*, *Building group*) with text fields and check buttons allow to choose what elements of drawing combine to bring about objects and their attributes (Figure 5).

As an example, information like class, typology, function, floors, etc. can be loaded for a building, according to limitations and parameters of cartographic model.

Finally, after that data set has been structured, information can be exported using the application schema of the model to write a GML3 file.

This modeler can be used with several version of Autocad®, including "Map" versions too.

Defining application schema, used by the modeller, a constraint regarding the use of only straight segments and only flat surfaces has been imposed. This constraint considerably simplifies three-dimensional triangulation.

5.2 GML3 Browser

To explore and query files made by plugin described above, representing a three-dimensional model of territorial objects, a viewer has been developed.

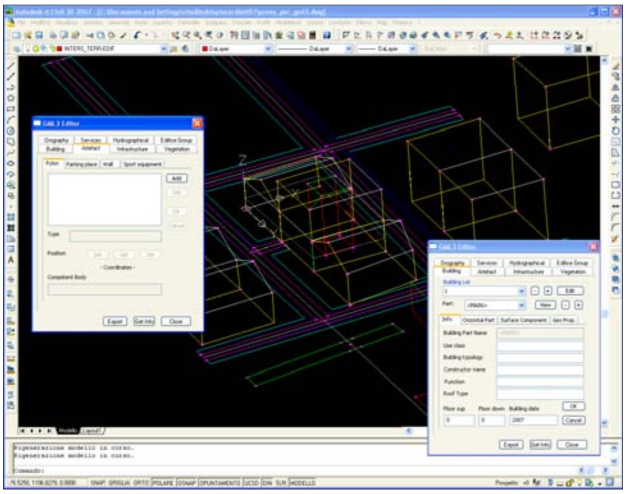

Figure 5. GML3 Editor (*Plug in* for Autocad®)

With this software you can browse the dataset previously exported, querying it to know attributes of objects, as well as their hierarchical composition.

This browsing module, that allows opening and browsing the model in GML3 format, has been built using open source libraries, like IRRLICTH (graphical engine) and WX widget (display framework), and MingW as compiler.

The Irrlicht Engine is an open source high performance realtime 3D engine written and usable in C++. It is completely cross-platform (Windows, Linux, Mac), using D3D, OpenGL and its own software renderer, and has powerful features for 3D rendering. It supports many kinds of illuminations and shade's representations; its mathematic matrix subsystem can make high speed matrix computations.

Software allows you to optimize lines' visualization (Figure 6), using each line just once; this is due to the structure of the file, written in GML3 format by the modeler inside Autocad®, with points and edges identified unequivocally. The lack of double lines simplifies a lot the rendering operations; besides it avoids the annoying visual effect due to overlapping lines.

Main features of the software are:

- loading of the cartographic structure with its attributes, using the GML3 format;
- browsing of the model, with pan and zoom functions available both by mouse or by keyboard;
- querying cartographic objects;
- tree-visualization of each component of cartographic elements, with graphic highlighting of selected elements, and vice-versa;
- solid or wireframe visualization mode;
- dependently on the kind of element, the visualization color can be chosen from a palette;
- the point of view can be modified by the user;

At this stage of development, this browser cannot load texture for every object, but this feature is under further development.

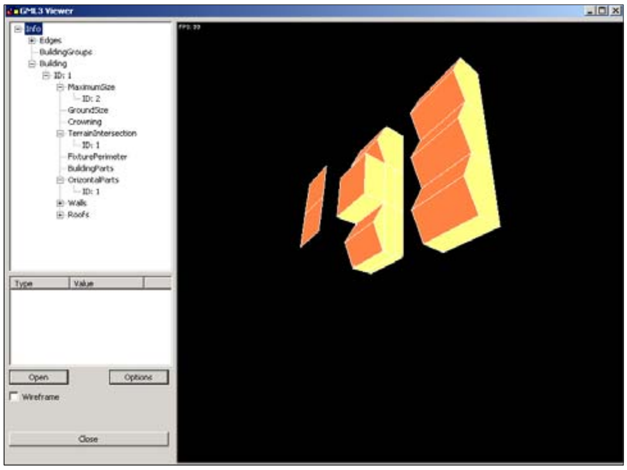

Figure 6. Tree structure of dataset

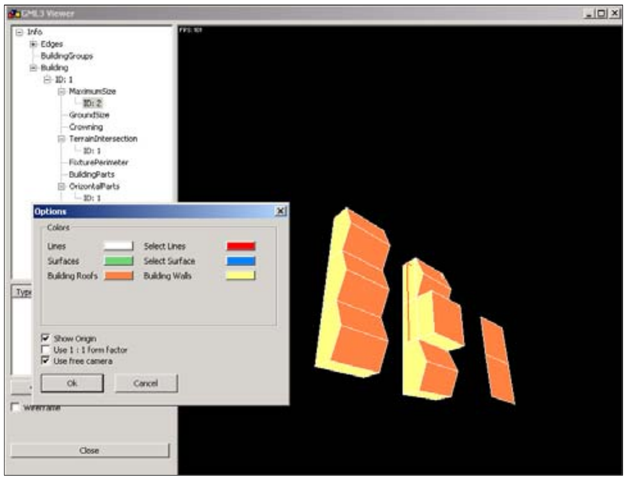

Figure 7. Visualization's options

Browser allows the assignment of different colours to different surfaces, like walls or roofs of a building, so distinct elements cab be easily detected (Figure 7).

This plugin is still under development, to improve the final-user interface and importing features.

6.CONCLUSIONS

Cartography needs are considerably growing day by day; so, starting off with this requirements and on the basis of studies carried out on existing cartographic models, a new cartographic model has been defined and called GIANT3D. Cartography structured according to this model is geometrically and topologically correctly structured, and it's suitable to be used in GIS.

Main features of this model are:
•structure according to indication of rules coming from OGC and ISO 19100 series;
•topological constraints defined together with the geometry;
•features structured using 0, 1, 2, 3 dimensional primitives, with the constraint that each higher primitive derives from the lower;
•aggregate objects not defined;
•edges composed by straight lines and planar faces;

•orientation of faces stored explicitly, using the rule of the right hand;
•terrain modeled using contour lines and spot elevations.
An editing module, built as an Autocad® plugin, has been developed: through this module it is possible to structure cartography and to export structured data in GML 3 format.

As further development, digital terrain model has to be improved, like so transportation infrastructure have to be structured with a more complex model. Finally, the independent module, that allows full 3D browsing and exploring of objects “GIANT3D compliant”, should be developed as an Internet browser plugin to allow object browsing on the web.

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