PROPOSAL OF 3D GIS FOR SPATIAL DATA VISUALIZATION AND ANALYSIS OVER INTERNET

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ABSTRACT

Nowadays, sharing and querying spatial data through Internet has been become ubiquitous and easier in term of visualization and analysis. Thus, GIS (Geographic Information System) is no more an isolated application used by a limited number of users, but essentially a worldwide shared set of complex geo-applications. Any more, many concepts combining both GIS and Internet have been occurred, i.e. WebGIS, Internet-Based GIS, GIS Web mapping, etc. Nowadays, the application of the 3rd dimension in Internet-based GIS, with rare exceptions, is restricted and limited to research work. Thus, this paper proposes a contribution in 3D GIS deployment over Internet. After a discussion of the advantages and limits of current Internet-based GIS, this work highlights a proposal of a multilevel spatial database structure implemented in PostgreSQL/PostGIS. Then, the paper gives details about data integration in spatial database from different types of data sources. Finally, it proposes a set of functionalities to visualize and query 3D spatial data within Internet. Spatial data visualization and analysis is based on layer management. The layers are defined dynamically by users through spatial and semantic queries. Hence, the GIS is composed of a set of superposed layers. Each layer structure can be stored for further use and can be shared by different users. Java applets provide to each distant client connected to the spatial databases the possibility to design his own set of layers, visualize and analyze 3D geometric and semantic data in an Internet viewer.

INTRODUCTION

The concept of WebGIS (Web based Geographical Information System) is nowadays very widespread (Uchoa *et al*, 2009). The GIS application is shared by many users for different purposes. Since the application areas of GIS are now very diversified, Internet has been become a main tool to supply a large number of users with spatial services. The ability to get information through Internet made spatial data providers to explore the Internet resources for disseminating spatial information (Alsheikh *et al*, 2002). Despite the continuous progress of Internet in term of data access, performance of online applications including visualization API (Application Programming Interface), data security, etc. the application of the 3rd dimension in Internet-based GIS is not yet common. Therefore, this work discusses the existing web based tools including WebGIS providing spatial services over Internet. It proposes an alternative approach to visualize and analyze spatial data over Internet.

This paper is organized as follows: It starts by an overview of the existing WebGIS and spatial data tools and discusses their advantages and limits. Then, our proposal of a 3D GIS deployment over Internet is described. Finally, a conclusion is drawn.

RELATED WORK

More and more, local governments in charge of the management of cities look for services providers to share and distribute geospatial data to all their technical departments and users. GIS could be a rich data source for geographic phenomena management, simulation and analysis. Since Internet allows transferring and accessing data in a short time, spatial data and particularly GIS interrogation via Internet has become well-known and many Web sites have been established to provide online services to manipulate such data. This section presents an overview of the existing tools which take advantage of Internet to supply users with “spatial” services providing suitable representation and quick access time.

Spatial Data within Internet

In the early days of GIS, spatial data tools take advantage of the prevalence of Internet users for data provision, administration and service delivery. Today, the tendency of GIS is no longer their exploitation as a local and isolated application in an organization. It is rather their integration in the development process and their deployment through Internet. The Internet facilitates data sharing through standards, and distributed public geo-spatial data sources (Iwerks *et al*, 2003). Thus, many standards are created to make data exchange easier. The ISO (International Standardization Organization) and OGC (Open Geospatial Consortium) contribute in the definition of such standards (Koussa *et al*, 2009). The ISO191**, defined by the TC211 (Technical committee 211), is a set of standards for geographic information. It includes the methods, the tools and the services for the acquisition, the analysis, the access, the presentation and the exchange of geographic information. In particular, ISO19107 defines a conceptual schema for the spatial features of geographic entities through geometric and topological objects. Otherwise, GML (Geography Markup Language) is a modelling language for geographic information. It is an OGC specification. It supports spatial and non spatial properties and implements the concepts of ISO19100. GML contains a set of primitives which includes features, geometry, coordinates, reference system, etc. GML distinguishes between geometry and feature (a feature represents physical entities, i.e. buildings, bridges, etc.). CityGML (City Geography Markup Language), an OGC specification, is a recent open model for the representation of 3D city objects. It is intended to become an open standard for the storage and the exchange of virtual 3D city models. It defines the properties of many topographic objects such as geometric, topological, semantic and appearance properties (OGC, 2007).

Recently, a set of new concepts has been appeared and allows data exploitation and exchange by means of Internet. Web service is a process which allows data communication and exchange between heterogeneous applications. It consists in a set of functionalities executed in real time without human intervention. Spatial Web Services is a fast developing concept in Web-based GIS application development and data delivery services. The main intention is to minimize the costs and efforts associated with application development, data, hardware and GIS software. In last few years concept of Web services has been gaining attention and appreciation as a powerful and efficient technology for connected and distributed computing (Sundaram *et al*, 2005). In the field of spatial data, many standardized Web services are recently defined, i.e. WMS (Web Map Service), WFS (Web Feature Service), SWS (Semantic Web service), etc.

Data Visualization Over Internet

Data visualization is an essential task in a GIS. It allows representing graphically both spatial data and their querying results. Over Internet, spatial data are visualized with 2D, 2.5D and 3D representation. Thus, there are many tools allowing geo-referenced data visualization through Internet. GoogleMaps (Maps, 2009) is a free online service representing geographic maps and plans. It combines two basic types of visualization: 2D plans and satellites images. By zooming, it allows representing data from city scale to road scale. Many other Websites propose similar services, i.e. Michelin routing (Viamichelin, 2009), yellow pages (Pagesjaunes, 2009), national geographic (Nationalgeographics, 2009), French IGN (French National Geographic Institute) (Ign, 2009), etc.

At the present time, 3D is no longer limited to satellite images. Thus, many Web sites proposes 3D models of cities, i.e. IGN's GeoPortail (Geoportail, 2009), Pages jaunes 3D (3D yellow pages) (Pagesjaunes, 2009b), etc. Another type of 3D visualization has recently been proposed by GoogleMaps called "Street view". It is not a 3D representation of buildings but a 360 degrees view of street at any given point in the street. It uses the technology of Immersive Media Company which films 360 degrees videos with high resolution. GoogleMaps "Street View" works in the same way but it uses images instead of videos. This technique is not yet available in all cities around the world and is limited to main streets.

The tools mentioned above allow showing spatial data via Internet but they are not GIS. A GIS exceeds the simple visualization of spatial data. Thus, many 2D WebGIS are now available over internet, i.e. Pasco Internet GIS (Hirano *et al*, 2009), Main Street GIS (Mainstreetgis, 2009), etc. Such 2D Web GIS represent spatial data by some map layers, DTM (Digital Terrain Model), etc. The majority of WebGIS are 2D and there are a few WebGIS with 3D visualization, i.e. O3DG (Open3DGIS) (Open3dgis, 2009), GRASS (Grass, 2009), OSSIM (Ossim, 2009), etc.

Both of 2D and 3D Web GIS use the basic navigation and zooming methods. Nearly all of them use the computer mouse as a main interaction device. For 2D maps, user can move in four directions: north, south, east and west. By zooming, user can move from the globe scale to the street scale. For 3D models, in addition to navigation and zooming, user can rotate the scene on the X, Y and Z axis. Depending on the WebGIS, other functionalities can be possible. In addition to data visualization, data analysis is a main task for all GIS. An overview of some existing spatial data analysis functionalities are described in the next section.

Data Analysis Over Internet

More and more, GIS demonstrate their large usefulness to solve many kinds of problems and supply users with quickly understood data. GIS are no longer isolated application in an organization. They could be integrated into the IS (Information System) of public or private organization. In the early days of GIS, Internet have been become an axial vector for spatial data exchange and communication. The main task of a GIS consists in data analysis. A few years ago, this task has become well-known through Internet. It is very difficult to list all WebGIS analysis functionalities because each GIS is designed to meet specific needs. However, there are some main functionalities which are provided by the most of WebGIS, i.e. routing, finding addresses, coordinates identification, etc. These functionalities are provided also by non-GIS tools, i.e. Google Maps, Michelin, Mappy (Mappy, 2009), etc. For example, GoogleMaps shows also the direction of roads and calculates an estimation of the time between two addresses for both vehicles and persons. Mappy calculates also an estimation of the price of gasoline consumption and the motorway toll between two addresses.

WebGIS.com (Webgis, 2009) is an example of 2D Web GIS which contains extensive map coverage for technical applications including Air Dispersion Modelling, Human Health & Ecological Risk Assessment and Terrain Processing. It proposes many types of maps, i.e. Digital Terrain, Land Use, Digital Line, etc.

DGO (Wallonie, 2009) defines a 2D WebGIS which allows the visualization of cartographic data, its associated documentary data and an interactive visualization of statistics.

3D WebGIS use generally VRML (Virtual Reality Markup Language), X3D (eXtensible 3D), etc. to model and visualize buildings. But, 3D WebGIS are not yet widespread through Internet. Apia Antica Project (Appia, 2009) is a WebGIS for the Archaeological Park in Rome. It provides a 3D model for buildings projected on a DTM. Mantova 3D terrain and buildings (Abacogroup, 2009) is a WebGIS which shows textured 3D buildings projected on a DTM. It provides some functionalities of measurement of distance, area and volume and users can choose a point of interest (buildings, monuments), etc. There are several other WebGIS around the world which provide a variety of services in different domains.

This section gives a non exhaustive overview of some WebGIS and non-GIS tools which provide very interesting services for the net surfers. The advantages and limits of such tools are discussed in the next section.

Discussion

Due to the large number of Internet users around the world, spatial data querying via Internet can be very useful in terms of time saving. WebGIS are now rife and provide several services to meet different needs. Such WebGIS are accessible via Internet without particular installation on the user computer unless they require some particular plug-ins. Such WebGIS can provide the same services on different Web browsers. However, spatial data loading can be time consuming when spatial data are visualized especially 3D data. And many security procedures have to be maintained to secure data access. The 3rd dimension is not yet widespread in WebGIS. It is limited to some 3D virtual models with restricted functionalities.

PROPOSAL

In this section, an alternative approach is proposed to visualize and analyse spatial data within an Internet-based 3D GIS. It takes in account many parameters, i.e. usability of services, simplicity of use, ergonomics, etc.

Multi-level Spatial Database

The Spatial Database (SDB) is organised through a set of integrated levels as shown in Figure 1.

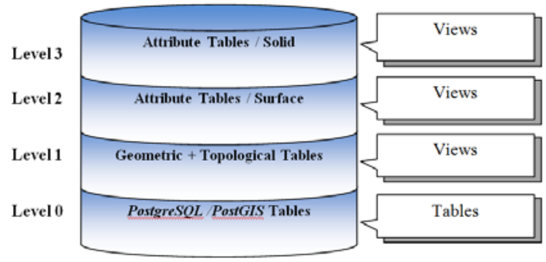

Figure 1. Multilevel PostgreSQL/PostGIS database.

The SDB consists in a set of tables, SQL views and stored procedures. A SQL view is a virtual table (it does not physically exist) materialized by SQL Select queries on one or many linked tables or views. Each view is a filter of the content of referenced tables and views. Such filter can restrict both columns and rows of the referenced tables. Views provide security by hiding sensitive or irrelevant parts of the database.
The different levels of the SDB are the following:

- Level 0: it consists in basic tables obtained by the integration of vector files (*shapefile*, *dxf*, etc.*)* in the database.
- Level 1: it consists in views interpreted from tables of level 0. It contains geometric and topological views (*geo_point*, *geo_line*, *geo_surface*, *geo_solid*, etc.).
- Level 2: It consists of views containing attribute properties corresponding to each surface, i.e. color, texture, layer, etc.
- Level 3: It consists in attributes properties corresponding to solids or groups of surfaces, i.e. *Building_Identifier*.

Since SQL queries using joins between two or many tables are the most time consuming and since 3D data visualization requires a continuous connection to data sources, several optimization procedures are taken in account to facilitate data interrogation. Firstly, all geometric and topological data required to 3D visualization are collected from different input tables and stored in *geo_suraface* and *geo_solid* views. Such views consist in the union of different SQL queries on input tables. They contain only data required for visualization and topological interrogation. Secondly, data visualization requires a continuous connection to data sources. It is not so optimized if such data are accessed directly in the database. The solution consists in data loading in onetime to a buffer memory. This solution allows a faster data access and releases the database which can be accessed simultaneously by many users.

The organization of the SDB through a set of levels allows users to distinguish geometric and topological data (consisting essentially in the spatial data visualization) and attribute data (consisting in data analysis). It allows an easy comprehension of the database structure and so an easy spatial data interrogation. Since spatial data, especially 3D data are generally very huge, the optimization of the database is necessary. Indeed, a set of optimization procedures are carried out to increase the spatial data querying performance, data integrity and availability, etc. Database indexation is an efficient technique to speed retrieval operations on a database tables. PostgreSQL/PostGIS proposes a spatial indexation called *GiST* (*Generalized Search Tree*) which is used in this SDB to accelerate data accessing and querying. The most time consuming SQL queries are those using joins. SQL joins are used to query data from two or more tables and views, based on a relationship between certain columns in these tables and views. It is a technique to avoid the problem of data redundancy in a database. But, it is costly in term of response time. To optimize data storage in the SDB, geometric and topological properties are stored in the same views, for example the surfaces composing a solid are stored in an array in the view *geo_solid*. That way, there is no joins between views *geo_solid* and *geo_surface*. The same method is applied for *geo_line* (defined by two vertices) and *geo_surface* (defined by a set vertices and edges).

The 3D GIS architecture

The technical architecture of the 3D GIS proposed in this paper is described in Figure 2. It can be qualified as simple browser-server architecture. It is composed of three main parts: users, data and Internet application to process spatial data. According to his privileges, a user can be an administrator of a database or just a simple user who can visualize and manipulate data. Spatial data are stored in a spatial PostgreSQL/PostGIS database on the server and can be accessed remotely via Internet. These data can be also stored in a local database installed on the work station of a particular user. With these purposes, an Internet application is carried out to i) integrate vector data, i.e. shape format (ESRI shape file), DXF (Drawing eXchange Format), etc. in the spatial database, ii) visualize 3D spatial data and related attribute information on a Web client, iii) propose several functionalities of spatial data analysis.

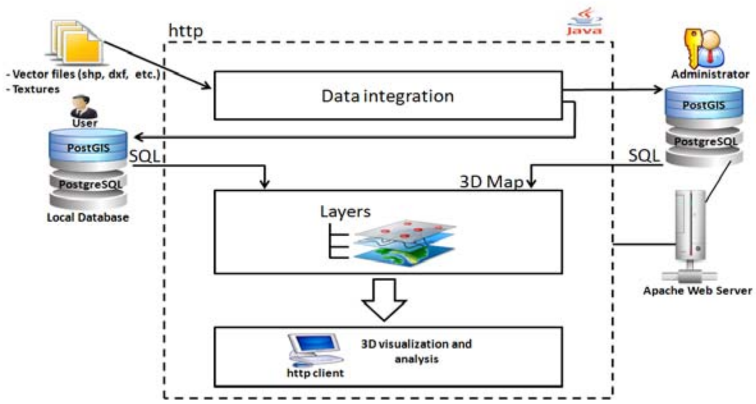

Figure 2. Architecture of the Internet-Based 3D GIS.

To carry out this architecture, an Apache Web server is installed using a WAMP (Windows Apache MySQL PHP) server. Since spatial data are stored in a PostgreSQL/PostGIS database, a connection procedure is necessary. Therefore, PHP (Hypertext Preprocessor) is used to connect a Web client to the database. The architecture could be qualified as an Apache-PostgreSQL/PostGIS server including all tools to query the spatial database. 3D data visualization on the Web client is carried out using a java applet. It uses the performance of the java language for scheduling algorithms, for using graphical API (Application Programming Interface), i.e. OpenGL, JGraph, or other, for the portability of java, etc. To secure local data accessing, the java applet is cryptographically signed and the user authorizes or not the applet to accede to data stored locally in his machine. And to secure data stored on the server, every user has a login and a password and can only read data.

Data Integration in the Spatial Database

The source files which contain spatial data are stored generally as shape, DXF structures. Such kind of files contains a special structure which is not directly adequate with our spatial database schema. Generally, these files do not contain neither information about solids nor semantic data. And since this work deals with 3D building, such kind of information is necessary. The integration of buildings needs complementary semantic data. Both of building and buildings components (roofs, facades, openings, etc.) have to be referenced by unique identifiers. A transformation on these files could be so useful. Thus, an algorithm is carried out to export these files to the spatial database. Firstly, some topological information is added to the first dataset. A unique identifier is associated to each point, each edge and each polygon. Then, the topological relationships polygon-points and polygon-edges are identified. Then, a unique identifier is associated to each solid corresponding to a building and solid-surfaces relationships are identified. Thus, a preprocessing is used to structure the dataset in order to manage each building as a singular object. Geometric and topological data are enriched by semantic dataset stored in attribute tables. The transformation of the first dataset generates a coherent spatial database containing geometric, topological and semantic data about 3D buildings. Figure 3 demonstrates the simplified structure of the spatial database represented as an UML (Unified Modeling Language) class diagram.

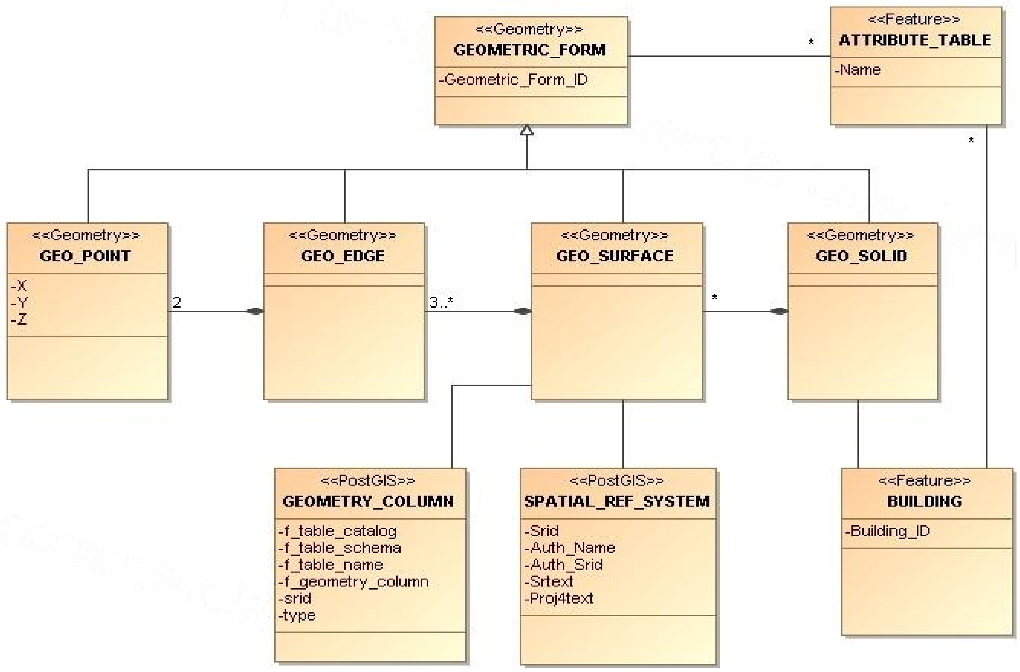

Figure 3. Spatial Database structure.

These classes are defined by three types of stereotypes: <<Geometry>>, <<Feature>> and <<PostGIS>>. <<Geometry>> consists in the different geometric forms and the topological relationships between them to form a 3D model. <<Feature>> consists in attribute tables related to the geometric model. <<PostGIS>> consists in tables predefined by PostGIS which are GEOMETRY_COLUMN and SPATIAL_REF_SYSTEM. The basic components of the database are the geometric and PostGIS tables which can be extensible when adding feature or attribute tables.

Data Representation Within the Internet-based 3D GIS

The major aim of this work is the establishment of a “dynamic” Internet-Based 3D GIS. User can define his own dataset and analysis functionalities. A dynamic GIS provides flexible services to process the whole or only a part of data stored in the database. Therefore, data processing can be easier and faster. Data are organized through a set of layers. In order to make his 3D map and according to his privileges, the user connects to a database and creates one or many layers through a set of SQL queries. Figure 4 shows the conceptual model of a layer.

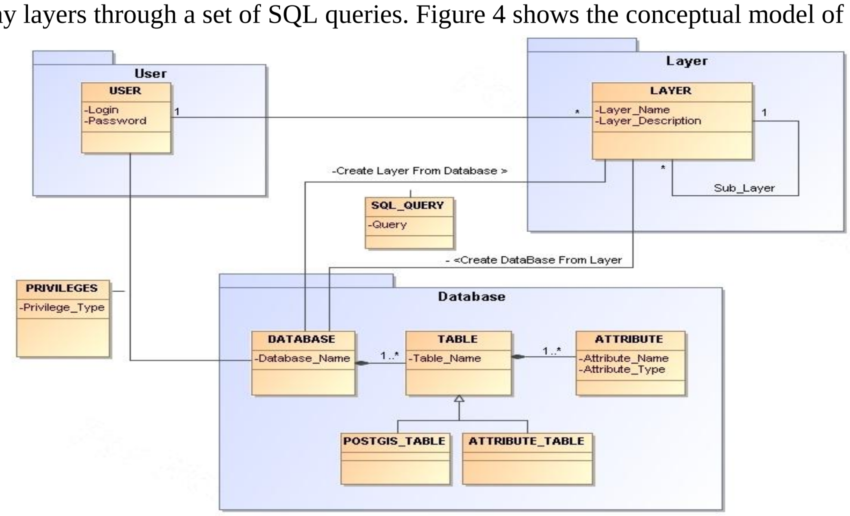

Figure 4. The conceptual model of a layer of spatial data.

The user defines a significant name and a semantic description for each layer. The same layer can be divided into a set of sub layers. After the visualization and analysis performed on a layer, the user can store the dataset corresponding to such layer in the database. Layers can be private or public. Figure 6 shows three layers (DTM, Facades and Roofs) created via an SQL query on two different databases. To accelerate data visualization and querying, the result of the SQL query is stored locally in a buffer memory on the user workstation. Data stored locally can be then exported in the form of shape files or a PostgreSQL database. Also, metadata (date of creation, user, annotations, etc) about layers are exported in the database and can be shared between users. The user who creates a layer can use it privately or share it with other users.

3D objects can have a multi-representation within the same layer. It depends on different types of attributes, on particular localization, on user queries, on visualization scale, on LoD (Level of Detail), etc. For example, buildings can be represented by a unique layer of solids or by a layer of facades and a layer of roofs. According to layer description above, to each layer, is associated a set of properties which can be stored in the distant database (for all users) or locally (for current user).

Once data are imported and organized through a set of layers, the GIS platform proposes a set of tools to manipulate these data. 3D GIS users are supplied with some main functionalities of existing tools working on spatial data, i.e. ArcGIS, MapInfo, etc. such functionalities could be very interesting in term of data visualization and interpretation.

The basic functionalities are moving (forward, backward, right, left, up and down), rotation (roll, pitch and yaw), bird's eye view (viewing simultaneously a part of buildings facades and roofs), models zooming (zoom in and zoom out), orientation (north, south, east and west), etc. (Figure 5).

Figure 5. Some visualization functionalities of the 3D GIS.

Rotate 3D models allows showing different parts of such model with different point of view. There are two kinds of rotation: i) Rotation around the centre of the 3D scene (the centre of mass for example). This kind of rotation is useful when the zoom level is very low. ii) Rotation around a target point chosen by the user when the zoom level is very high. In the field of 3D buildings model, there are two significant rotation axis: i) Rotation around Z axis allows rotation around a particular object or the whole scene, ii) Rotation around horizontal axis of view allows tilting the model in order to see a different perspective of the explored area. 3D zooming could be also divided into two types: i) Zooming the whole scene. ii) Zooming a particular object in the scene. The scene can be also centred on a target which will become the central point for rotation or zooming. To make a 3D model more interactive, user can handle the visibility parameters: the coordinates of the point of view and of the target can be defined by the user, the characteristics of the perspective (position, target, focal length, etc.), the rendering mode (wireframe, surfaces, hidden lines, etc.). User can also calculate a visibility scene from one or many points. When moving the mouse into the scene, the coordinates of the point of view and the orientation of the 3D model (north, south, east and west) are showed to user. Thus, the model could simulate the reality and facilitates the user comprehension.

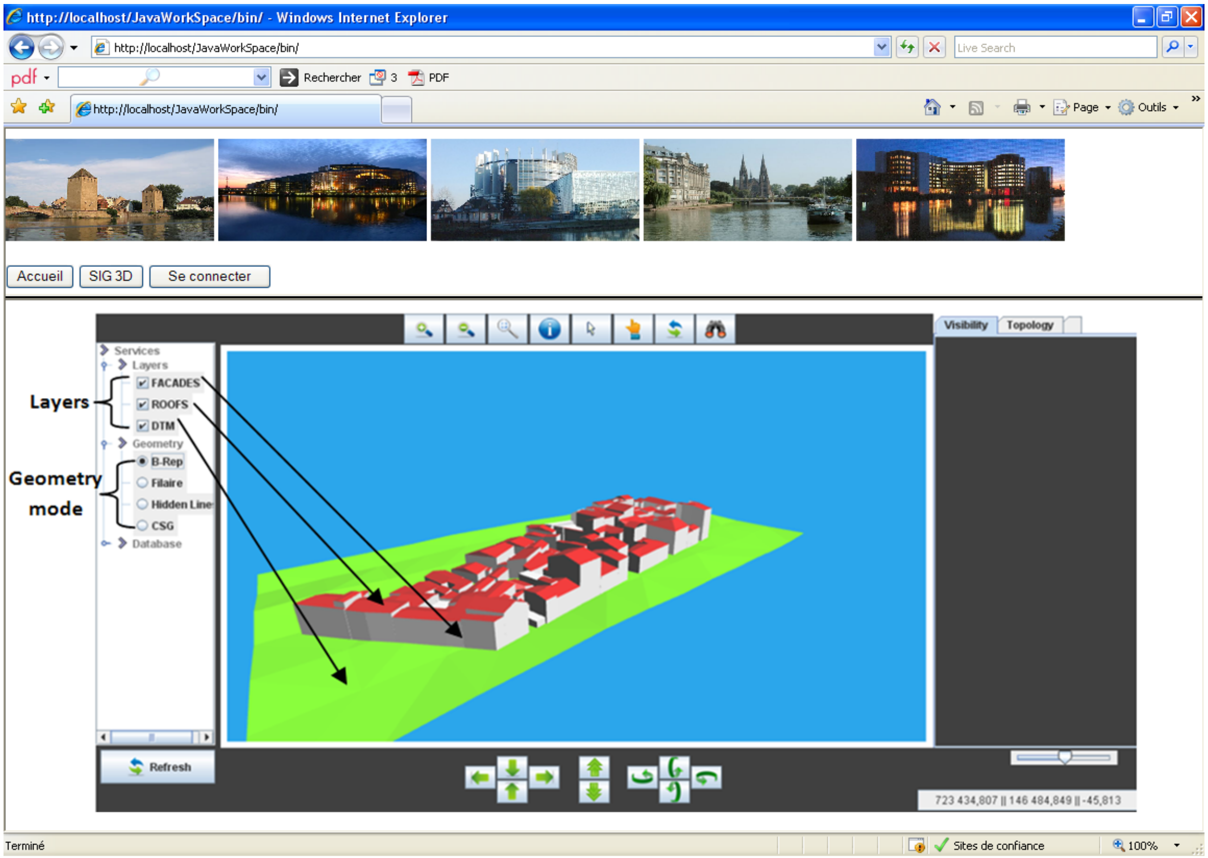

Figure 6. Data representation through a set of layers.

Data Analysis

It is not possible to list exhaustively the analysis functionalities which could be provided by a 3D GIS. A GIS is generally created to meet some needs and sometimes it is intended to be used by particular users. This paper proposes a 3D urban GIS whose functionalities could be useful locally or over Internet.

In wide disseminated Internet-Based GIS, the classical three basic functionalities are routing, finding addresses and identification of an object selected by the user in the 3D scene. In this work, the identification and selection functionalities will be particularly developed. User can view attribute data about a part of a 3D object (ID, name, usage, functions, geometry, etc.).

The annotation of layers is necessary to facilitate their comprehension and search. The annotation consists in metadata which describe very well each layer. The user expresses his feedbacks, comments and interpretations in structured way in order to be exploited by other users. These feedbacks allow the enrichment of knowledge of persons working on the same dataset. With this purposes, user feedbacks are classified as follow: information about place, information about period, information about the context, and comments. Annotations are stored in an XML file whose schema is described in Figure 7.

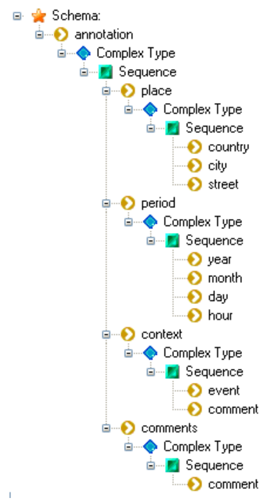

Figure 7. XML Schema of annotation documents.

The interrogation of one or many layers can be textual or graphical. The aim is to assist user when querying data. Figure 8 shows a graphical query associating two layers. It consists in the calculation of the intersection of two layers. Shapes are linked with current layers of a given user or layers stored in the database.

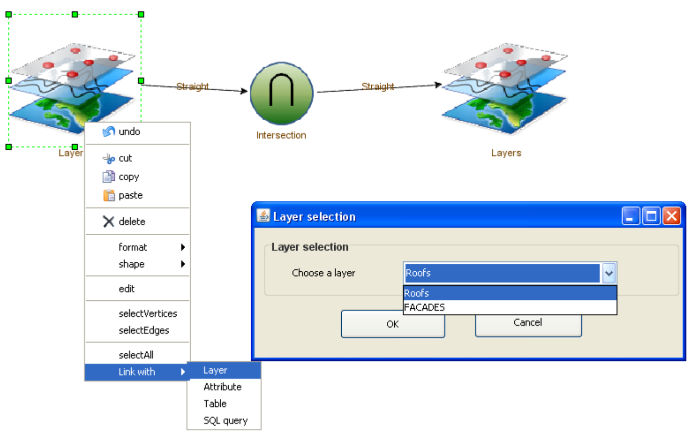

Figure 8. A graphical query on a set of layers.

User can select objects in the 3D model to accomplish various tasks. Selection can be carried out on whole objects or on object parts. The selection allows choosing a set of particular objects or object parts in order to process or to query the selected zone. Thus, user can do a new selection, add or remove some elements from the active selection, inverse selection, etc. These functionalities make it possible selecting different sets of objects, and in a second step to perform the combination of selections. In the combination of selections, one selection set is used as parameter for the extraction of the candidates from the second selection set. In this case, geometric operations are often used. Objects selection can be carried out graphically (mouse click, drag and drop, etc.) or through its attribute values (the user types some objects attributes, geographic or 3D localization, combination of attributes and localization, etc.). Basically, source data in this work do not contain information about solids. But, to enrich the model, it is possible to join the geometric table with attribute tables, i.e. join polygons table with buildings table. Then the user can define selection criteria on the 3D model based on a particular attribute. Figure 9 shows how a selection criteria based on the attribute *id_batimen* (Building_Id) is added to layer.

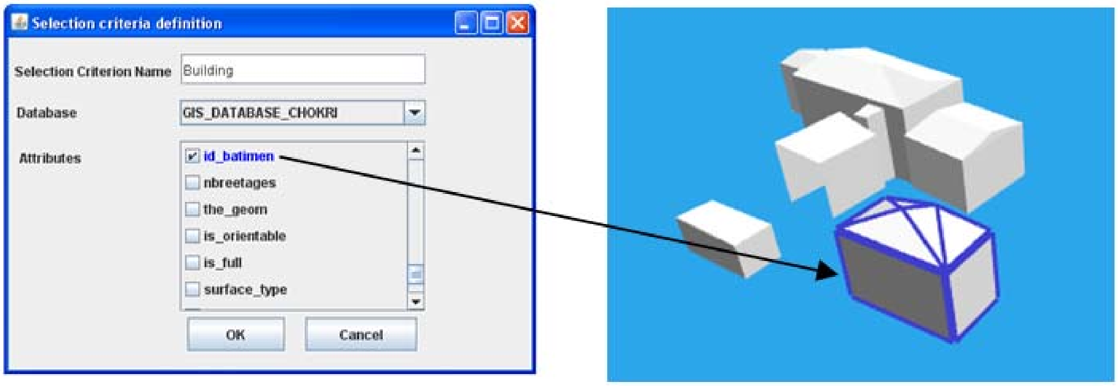

Figure 9. Solid selection example based on an attribute feature *id_batimen* (Building_Id).

It is not possible, in this paper, to include all the functionalities proposed by the Internet-based 3D GIS. The user is able to manage both of the visualization and the interrogation of spatial data. Therefore, he can view 3D models as B-Rep (Boundary Representation) surfaces, linear representation, CSG (Constructive Solid Geometry) (Koussa *et al*, 2009), etc. The GIS provides information about data structure, database tables and metadata. Therefore, user could understand the context and the concepts of the GIS. So, he could query data efficiently.

Discussion

This work aims the establishment of an Internet-based 3D GIS. Users are able to handle the organization of their own dataset. Therefore, 3D models are not predefined and their creation is dynamic. The system is tested in an Intranet and it works well. However, much amelioration is required, i.e. optimization of a concurrent access from several users, an optimization strategy to keep data transfer low, and mechanisms that deal with a stateless protocol (http), etc. such amelioration is the aim of the next step of this work.

CONCLUSION

This paper presents our research work in the field of 3D GIS and their deployment over Internet. The main idea is to allow users to create dynamically their dataset through a set of layers. The organization of spatial data through a set of significant layers could be useful in term of data comprehension, simplification, analysis, etc. The existing Internet-Based GIS supply users with predefined maps or 3D models. The contribution of this work is the dynamic creation of 3D GIS over Internet. However, this work needs more concentration in term of data transfer optimization, data security, users management, concurrent access from several users, etc.

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