3D GIS: CURRENT STATUS AND PERSPECTIVES

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ABSTRACT:

Currently, variety of software is already capable of handling a wide range of spatial problems, beginning with approaches for describing spatial objects to quite complex analysis and 3D visualisation. However, increasing number of applications need more advanced tools for representing and analysing the 3D world. Among all types of systems dealing with spatial information, GIS has proven to be the most sophisticated system that operates with the largest scope of objects (spatial and semantic), relationships and provide means to analyse them. However, what is the status of the 3D GIS? It is the aim of this paper to find the answer by analysing both software available and efforts of researchers. An overview of several commercial systems and a 3D case study performed in Oracle and Microstation provides knowledge about the 3D functionality offered by commercial systems. The most significant achievements in the 3D research area concerning key issues of 3D GIS, i.e. 3D structuring and 3D topology portray the current research status. At the end, the paper addresses some of the issues and problems involved in developing such a system and recommends directions for further research. The scope of the paper is limited to 3D GIS systems and research in vector domain. Problems of subsurface applications are excluded as well.

1 INTRODUCTION

The need of 3D information is rapidly increasing. Currently, the most often quoted areas of human activities can be summarised as 3D urban planning, environmental monitoring, telecommunications, public rescue operations, landscape planning, geological and mining activities, transportation monitoring, real-estate market, hydrographical activities, utility management and military applications. Practically, the area of interest grows significantly when the 3D GIS functionality is available on the market. The role of geo-information in all kinds of business processes is getting quite transparent. Such term as “location-specific information” and “location-based services” become a part of the daily business language to denote the link between the virtual world of information (transactions, events, internet communication) and the real world of information - customers, inventory, shipping and the like. Most business transactions rely on information systems to be executed successfully as the geo-information (location-specific information) is critical for many of them (see Sonnen and Morris, 2000). Once the developments in the 3D GIS provide a compatible functionality and performance, the spatial information services will evolve into the third dimension.

Traditionally, the GIS system should be able to maintain information about spatial phenomena and provide means to analyse it and thus gain knowledge of the surrounding world. In general, consensus on the demanded functionality of GIS is achieved already years ago. The tasks or the functions of a GIS are specified as follows (see Raper and Maguire, 1992): 1) data capture, 2) data structuring, 3) data manipulation, 4) data analysis, and 5) data presentation. Indeed, 3D GIS aims at providing the same functionality as 2D GIS. Unfortunately, such 3D systems are still not available on the market. The development of 3D GIS is not an easy task. Nowadays, 2D GISs are common and widely used to handle most of the 2D GIS tasks in a very efficient manner. However, the same kind of systems fail to operate with 3D data if more advanced 3D tasks are demanded. A variety of different software (i.e. 2D GIS, DBMS and CAD) is employed to maintain the objects of interest and extract the required information. Due to deficiency of any of the system to handle 3D objects, the data are spread between several systems. For example, one system is used for data storage and another for 3D visualisation. This situation often faces inconsistency problems, which results in extra time, efforts and money to find the appropriate solution.

This paper summarises the current status of 3D GIS development. First, we concentrate on recent achievements reported by vendors. We briefly present our survey on the possibilities of some GIS’s available in the market and analyse a case study completed on commercial systems. Second, we review attempts of researchers toward providing an appropriate structures and operations for 3D spatial analysis and visualisation. Final discussion recommends directions and topics for further research and implementations.

2 3D GIS IN THE MARKET

There are few systems available in the market that can be categorised as systems that attempts to provide a solution for 3D representation and analysis. Four systems are chosen for detailed consideration, because they constitute a large share of the GIS market and provide some 3D data processing functions. The systems are the 3D Analyst of ArcView (see ESRI Inc.), Imagine VirtualGIS (ERDAS Inc., http://www.erdas.com), GeoMedia Terrain (Intergraph Inc., http://www.integraph.com) and PAMAP GIS Topographer (PCIGEOMATICS, http:// www .pcigeomatics.com). Parts of the following text are based on available literature and Web-based product reviews.

2.1 Traditional GIS vendors

ArcView 3D Analys, ESRI: The 3D Analyst (3DA) is one of the modules available in ArcView GIS. ArcView is designed to provide stand alone and corporate wide (using client-server network connectivity) integration of spatial data. With 3DA one can manipulate basically 2.5D data such as surface generation, volume computation, draping raster images, terrain inter-visibility from one point to another. The system works mainly with vector data. Raster files can be incorporated into 3DA, but only for improving the display of vector data. During the last three years, ESRI has further developed the 3D Analyst for the ArcGIS 8.1 environment. ArcGIS consists of the Desktop and Workstation components. The Desktop component is based on personal computer (PC) and Microsoft Windows operating system, while the Workstation component is available for both PC and UNIX platforms. ESRI also introduced a new ArcScene desktop application as part of the 3D Analyst extention to ArcGIS 8.1. ArcScene is a stand-alone application that provides all the capabilities similar to 3DA with enhanced 3D visualization, flyby, texture mapping on building facades, 3D symbols, animation and surface analysis for both raster and vector data. Commonly used CAD data formats (e.g. DGN, DXF, DWG) can directly be read and displayed in ArcScene. ArcScene can also access and display both raster and vector data stored on the multi-user geographic database using ESRI Spatial Data Engine (SDE) or data service on the Internet in the distributed environment using ESRI ArcIMS. Although major progress on improving 3D visualization, animation, and data access has been made, full 3D geometry for 3D representation, topological relationships and analysis are still the areas left to be addressed.

Imagine VirtualGIS, ERDAS: It is worth mentioning that the Imagine system was originally developed for remote sensing and image processing tasks. Recently, the system has provided a module for GIS. The GIS module is called VirtualGIS and provides some three-dimensional visual analysis tools. The system has run under various computer systems ranging from personal computers to workstations. It is a system that has an emphasis on dynamic visualisation and real-time display in the 3D display environment. Besides various and extensive 3D visualizations, the system also provides fly-through capabilities. As with 3DA this system also centres on 3D visualization with true 3D GIS functions hardly available.

GeoMedia Terrain, Integraph.Inc: GeoMedia Terrain is one of the subsystems that work under the GeoMedia GIS. The system runs under the Windows operating systems. The Terrain system performs three major terrain tasks, namely, terrain analysis, terrain model generations, and fly-through. In general, the Terrain serves as DTM module for the GeoMedia GIS without true 3D GIS capabilities.

PAMAP GIS Topograph, PCIGeomatics: It runs under Windows95/98 and NT operating systems. PAMAP GIS is a raster and vector system. Besides its 2D GIS functions, the system has a module for handling 2.5D data, called Topographer. Four main GIS module, i.e. Mapper, Modeller, Networker and Analyser form the core system. For 2D data handling, the system performs GIS tasks as in the systems mentioned earlier. Most of the so-called 3D functions in the Topographer work as by any DTM packages, for example terrain surface generation, terrain surfaces analysis (e.g. calculation of area, volume) and 3D visualisation (such as perspective viewing). This system also focuses on 3D display of terrain data.

In summary, all the systems revealed little provision of 3D GIS functionality in terms of 3D structuring, 3D manipulation and 3D analysis but most of them can handle efficiently 3D data in the 3D visualization aspect. A fully integrated 3D GIS solution has yet to be offered by general purposed GIS vendor.

2.2 The tandem DBMS &CAD

The GIS, i.e. integration of semantic, geometric data and spatial relationships, seems to be the most appropriate system ensuring a large scope of analysis and thus serving many applications and daily activities. Therefore vendors dealing with either spatial or semantic information attempt to provide some GIS functionality already for years. CAD vendors (such as Autodesk, Bentley) provide means to link semantic data to 2D, 3D geometry and organise topologically structured layers; DBMS (Oracle, Informix) introduce spatial descriptors to represent geometry data and maintain them together with the semantic data.

A logical consequence of all the attempts is the agreement on the manner for representing, accessing and disseminating spatial information, i.e. the OpenGIS specifications (see OpenGIS specifications). This agreement makes possible efforts of vendors and researches from different fields to be united and streamed to one direction, i.e. development of a functional GIS. As a result, increasing number of DBMS offer already functionality to store, retrieve and analyse spatial data. Moreover, growing number of CAD vendors develop tools to access, visualise and edit the spatial data maintained in DBMS. Among the several DBMS (Oracle, Informix, Ingres) and CAD/GIS applications (Microstation, AutoCAD, MapInfo) already embracing OpenGIS specifications, we have selected Oracle Spatial 8i and the new product of Bentley, Microstation Geographics iSpatial to investigate the 3D operations offered. GeoGraphics iSpatial establishes a connection directly to Oracle Spatial 8i.

The organisation of data within Geographics iSpatial is defined in a project hierarchical structure. *Project* refers to as the root and represents the data for the entire study area. The second level is the *category*, which groups features with a similar theme (e.g. buildings, rivers). One project can have many categories but a category may belong to only one project. *Feature* is at the third level and represents one or more objects in the real world (e.g. the bank building, the school building). A feature incorporates all the attribute and geometric data available for a particular real object. A category may have many features but a feature may belong to only one category. Feature is the basic structural unit in GeoGraphics iSpatial. To be able to distinguish between different spatial objects stored in Oracle Spatial 8i, each object has to be assigned to a feature. Furthermore, edited and newly created objects cannot be posted in the database without attributing predefined features to them. Geometry of the objects is organised in one or more *spatial layers.*

The geometry in Oracle Spatial 8i is defined by the *geometric type*. Oracle Spatial 8i supports 2D geometric types, i.e. point, line and polygon (see Oracle Spatial 8i). Lines and polygons are represented as an ordered set of points. The indication for a closed polygon is equivalence of the first and the last point. Self-intersecting lines are supported and they do not become polygons. Self-intersecting polygons are not supported. The geometric types are defined in the Oracle Spatial 8i object-relational model as objects (i.e. *mdsys.sdo_geometry)* and contain information about type, dimension, coordinate system, holes, and provide the list with the coordinates. The structure of the object is given bellow:

Name	Null?	Type
SDO_GTYPE		NUMBER
SDO_SRID		NUMBER
SDO_POINT		SDO_POINT_TYPE
SDO_ELEM_INFO		SDO_ELEM_INFO_ARRAY
SDO_ORDINATES		SDO_ORDINATE_ARRAY

Despite the 2D geometry types, 3D coordinates can be maintained. For example, the five parameters of the geometry object for a 3D polygon with four vertices *v*(X,Y,Z), i.e. *v1* (10, 10, 0), *v2* (11, 9, 1), *v3* (11, 12, 0) and *v4* (9, 11, 1) will have the following values:

SDO_GTYPE = 3003. The first 3 indicates three-dimensional object and the second 3 indicates a polygon.
SDO_SRID = NULL. The coordinate system is not specified, i.e. decoded in the coordinates.
SDO_POINT = NULL. The described type is polygon and therefore the value is NULL.
SDL_ELEM_INFO = (1, 1003, 1). The first 1 in the sequence 1,1003,1 gives details about the geometry type (i.e. a simple polygon connected by straight lines). 1003 indicates that the polygon is an exterior ring. The final 1 specifies the geometry type, i.e. polygon. Furthermore, these particular values certify that the polygon does not contain holes.
SDO_ORDINATES = (10, 10, 0, 11, 9, 1, 11, 12, 0, 9, 11, 1, 10, 10, 0).

2.2.1 Case study: the city of Vienna: In this case study, we assumed the following scenario: the user has 3D data organised only in a database (a quite common case for real world data), i.e. no file with graphical information (e.g. DGN) exists. We have experimented with a set of 1600 buildings from the city of Vienna. Planar rectangular faces constitute each building. The data are organised according to the Simplified Spatial Structure (see Zlatanova 2000) and further converted to the geometry representation of Oracle Spatial 8i. The conversion is completed with a topology-geometry procedure similar to the one described in Oosterom et al 2002.

Since the Oracle Spatial 8i geometry does not maintain a true 3D object, we represented every building as a set of faces (walls, flat roofs and foundations). The faces are stored as polygons with 3D coordinates. The data set with 1600 buildings is organised in a relational table (BODY_SDO) that originally consisted of only four columns namely (MSLINK, BODY_ID, FACE_ID and SHAPE). The column SHAPE contains the *mdsys.sdo_geo*metry object, i.e. the polygons. Thus the links between FACE_ID and SHAPE is 1:1 and the link between FACE_ID and BODY_ID is m:1. Table 1 illustrates the content of the relational table BODY_SDO before (in bold) and after connection to Geographics iSpatial. Furthermore, the spatial data is indexed with R-three index (i.e. BODY_IDX_RT$ table was created), and registered in the USER_SDO_GEOMETRY_ METADATA table by giving the name of the table (i.e. BODY_SDO), the name of the column with geometry (i.e. SHAPE) and the range of the data set. Examples with SQL statements accomplishing these operations can be found in Stoter and Oosterom 2002.

Table 1: Description of BODY_SDO table. The columns in regular font are added by GeoGraphics iSpatial (see the text)

Name	Null?	Type
MSLINK	**NOT NULL**	**NUMBER(10)**
BODY_ID		**NUMBER(10)**
FACE_ID		**NUMBER(10)**
SHAPE		**MDSYS.SDO_GEOMETRY**
BODY_SDO_DFLAG		NUMBER(10)
BODY_SDO_UDL		RAW(200)
BODY_SDO_LOCK		NUMBER(10)
BODY_SDO_FID		FCODE_LIST
BODY_SDO_CREATED		DATE
BODY_SDO_REVD		DATE
BODY_SDO_RETIRED		DATE
BODY_SDO_XML		VARCHAR2(1024)
BODY_SDO_TXT		VARCHAR2(1024)
BODY_SDO_STYLE		UG_STYLE

This user-defined representation of geometry is further accessed within GeoGraphics iSpatial. Since the steps that one has to follow are not that trivial, they will be explained in the following section.

1. *Creating project, category and features*. Bearing in mind, the basic conceptual structure of GeoGraphics iSpatial we created a project (Vienna), a category (buildings) and several features (build1, build2, build3 and build4) in GeoGraphis iSpatial. This operation resulted in 12 relational tables in Oracle Spatial 8i. The names of the tables created by GeoGraphics iSpatial and us (in bold) are listed bellow:

BODY_IDX_RT$, BODY_SDO, CATEGORY, FEATURE, MAPS, MSCATALOG, UGCATEGORY, UGCOMMAND, UGFEATURE, UGJOIN_CAT, UGLAYER, UGMAP, UGMAPINDEX, UGTABLE_CAT

Among all the tables, MSCATALOG and FEATURE are of practical interest. The first table maintains reference to all the tables used in the project. The second one contains information (names, codes, unique identifiers, etc.) related to all the features created by the user.

The spatial data (BODY_SDO table) becomes visible in the Query tool (see Figure 1, Spatial Query), i.e. it is possible to query and display the entire layer. However, the settings are not sufficient to post data in the database. The table has to be linked to a spatial layer and the objects to features.

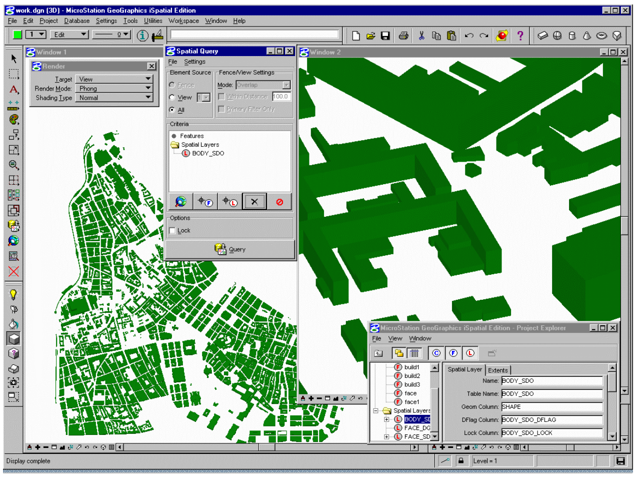

Figure 1: GeoGraphics iSpatial, query of the layer BODY_SDO

2. *Creating spatial layer*. The table with the geometry (i.e. BODY_SDO) with geometry column SHAPE has to be referred as a spatial layer in GeoGraphics iSpatial. Further, all the features that are to be associated with objects in this layer need to be assigned to the layer (again in GeoGraphics iSpatial). This operation extended our table BODY_SDO with 10 new columns (see Table 1).

3. *Linking spatial objects with features*. First, one should make sure that the table with the spatial data (i.e. BODY_SDO) is declared in the table MSCATALOG. The project tables CATALOG and FEATURE are automatically registered there by GeoGraphics iSpatial under entity numbers 1 and 2. Second, the column BODY_SDO_FID (in the BODY_SDO table) has to be populated. The column references a feature (from FEATURE) to a particular object (from BODY_SDO). The operation can be performed either in GeoGraphics iSpatial or Oracle. Last, all the values in the column BODY_SDO_LOCK (giving information about the owner of the data) have to be set 0 (i.e. belong to the owner of the table). A PL/SQL script (a high-

level language supported by Oracle) completes these two operations:

```
… FOR i in n..m LOOP
      update body_sdo set body_sdo_fid = fcode_list (fcode_item
(2,4,1,0), fcode_item (5,i,0,0)) where body_id=i;
     update body_sdo set body_sdo_lock = 0 where body_id=i;
 END LOOP; …
```

Fcode_item (p_1, p_2, p_3, p_4) provides the link between feature and spatial object. The first of *fcode_item's* is related to the feature as it is described in the FEATURE table and the second to the spatial object from the BODY_SDO table. Parameter p_1 is the number of the two tables in the MSCATALOG (as it appears under the column ENTITY). Parameter p_2 is the number of the feature in FEATURE table (given in MSLINK column) and the identifier of the object (i.e. BODY_ID). Note that in this case, one feature (i.e. number 4) is assigned to several objects. The third parameters give indication whether the description is for feature (i.e. 1) or spatial object (i.e. 0). Cases with multiple references between object and feature are resolved by introducing a new *fcode_item* in the *fcode_list* description.

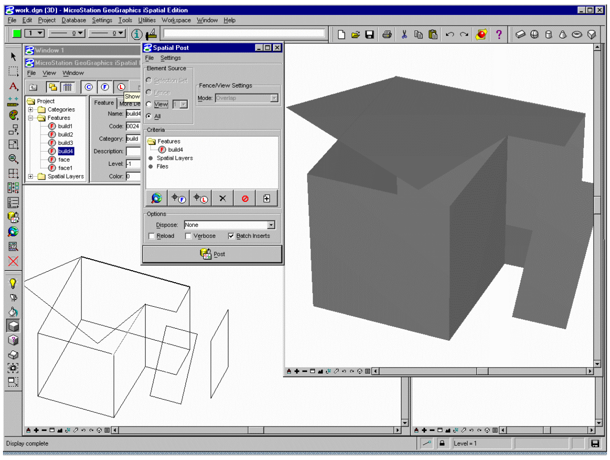

Figure 2: GeoGraphics iSpatial, editing and posting a feature

Having all the initialisations done, it became possible to query the data as they are defined in Oracle Spatial 8i. The query can be specified either per layer (see Figure 1) or per feature (see Figure 2). We have tested editing, creating new objects and posting them to the database. More examples, related to combining 2D and 3D data can be found in Stoter and Oorsterom, 2002.

2.2.2 Analysis: This case study exhibited valuable information related to 3D functionality currently offered. It has clearly showed that the operations needed to access and manipulate spatial data are still not transparent, standardised and user-friendly. The user is expected to have excellent skills in both systems, i.e. understanding the conceptual representation in GeoGraphics iSpatial and being aware of the implementation in relational tables in Oracle Spatial 8i.

Data Structuring. The concepts implemented in both systems follow closely the OpenGIS specifications, i.e. the notation of a *geographic feature*, which spatial characteristics are represented by geometric and topological primitives. Nevertheless, the implementations are still not completely application independent. The test has revealed that one significant part of the information about the geographic feature is maintained at a database level. However, the notations (table names, columns, object definitions) have very specific application-oriented (in this case Microstation) meaning. For example, if the user decides to keep the database and change the CAD package, he/she will need to create the feature-geometry link from scratch.

Moreover, the *feature* introduced in GeoGraphics iSpatial, allows the user to define arbitrary number of *feature types* and link them to geometric data. However, the further classification of features is restricted to only one level (categories), i.e. classification of categories in not supported. Two classifications levels may appear insufficient in describing 3D world objects. For example, looking at a building, at least three levels of hierarchy might be necessary, i.e. a particular room, an apartment, and a floor. Conceptually, the *layer* can be used as a container of geometry types with specific characteristics, but one-to-one correspondence between a spatial layer in GeoGraphics iSpatial and a relational table in Oracle Spatial 8i, may lead to an unnecessary partitioning of the data and complicate the consistency check.

As it was mentioned before, despite the lack of a real 3D object, description of 3D data is possible in the geometry types of Orcale spatial. The Z value is maintained together with the X,Y values, i.e. it is not an attribute. Another positive discovering is the definition of *mdsys,sdo_geometry* object in Oracle Spatial 8i 8i, which allows a straight forward extension toward describing a 3D object. Stoter and Oosterom, 2002 propose appropriate values for SDO_GTYPE, SDO_SRID, SDO_POINT, SDO_ELEM_INFO and SDO_ORDINATES D to describe 3D objects (e.g. tetrahedron, polyhedron, polyhedron with holes, etc.). The SDO_ORDINATES array is suggested to have two sections, i.e. a list of coordinates and references to the list. This approach will reduce considerably the size of the array, which is a critical consideration in maintaining 3D data.

The support of parameters to describe physical properties of 3D objects is still missing. Currently, the feature description (in FEATURE and UGFEATURE tables) permits properties of lines (e.g. colour, width, gaps width, type line) to be specified, but no properties of polygons are considered. For example, the colour of the polygon (in a rendering mode) is selected with respect to the colour of the line. 3D realistic visualisation is practically not possible due to lack of a mechanism to specify texture parameters per face.

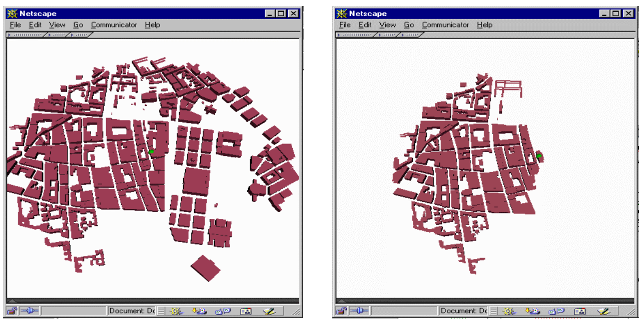

Figure 3: Oracle Spatial 8i query: left) spatial operator SDO_WITHIN_DISTANCE and right) function FOV

Data Analysis. Real possibilities to analyse 3D data in GeoGraphis iSpatial and Oracle Spatial 8i are still missing. As mentioned before, the topological primitives are not implemented yet. Tools in GeoGraphics iSpatial to create 2D topological layers or tools in Oracle Spatial 8i to perform spatial operations are provided but they operate with only X,Y coordinates. Some of the operations accept X,Y,Z values but the computations are purely 2D. Figure 3 illustrates a query performed on the same data set (table BODY_SDO) utilising the Oracle spatial 8i operator SDO_WITHIN_DISTANCE and a further extension to find a Field-of-View (FOV) for given direction and angle of view. The SQL query utilising the spatial operator is given bellow:

```
SELECT body_id, face_id, shape FROM body_sdo
WHERE sdo_within_distance (shape, mdsys.sdo_geometry
(3001,NULL, mdsys.sdo_point_type (x_Input, y_Input, z_Input),
NULL, NULL),'distance=700') = 'TRUE';
```

Data Manipulation and Visualisation. Apparently the greatest benefits of the DBMS-CAD integration are in the area of visualisation and editing of data. It is well known and frequently commented that the amount of data to be visualised in 3D increases tremendously and requires supplementary techniques (LOD, on-fly simplification, etc.) for fast rendering. Having 3D data stored in a database, the user has the possibility to extract only a limited set of data (e.g. one neighbourhood instead of one town) and thus critically reduce the time for loading. For example, the whole Vienna data set (about 19000 polygons) is loaded for about 3-4 minutes in comparison to one building that comes up for fractions of a second. Locating, editing and examining a particular object become also quick, simple and convenient. Indeed, the elements that can be edited correspond to the geometry representation in Oracle Spatial 8i. In our case, one building is aggregation of several faces but practically the accessible elements are "loose" polygons. The editing operations are restricted to the defined objects (in our case polygons and their vertices). For example, a shift of one vertex will change the vertex of the selected polygon (see Figure 2). Moreover, many of the shapes provided by MicroStation cannot be posted to the database. This is to say, spheres, cylinders, cubes and all types of extruded shapes, have to be simplified to points, lines and polygons.

3 3D GIS IN THE RESEARCH

The research in 3D GIS is intensive and covers all aspects of the collecting, storing and analysing real world phenomena. Among all, 3D analysis and the issues related (topological models, frameworks for representing spatial relationships, 3D visualisation) are mostly in the focus of investigations.

Topological model: The topological model is closely related to the representation of spatial relationships, which are the fundament of a large group of operations to be performed in GIS, e.g. inclusion, adjacency, equality, direction, intersection, connectivity, and their appropriate description and maintenance is inevitable. Several 3D models have already been reported in the literature. Each of the models has strong and weak points for representing spatial objects.

Carlson 1987 proposed a model called the simplicial complex. The simplex is the simplest representation of a cell. 0-simples is a point, 1-simples is the straight line between two points, 2-simplex is the triangle composed by three 1-simplexes and 3-simples is the tetrahedron composed by three 2-simplexes. The author uses the simplexes to denote spatial objects of node, line, surface, and volume. The model can be extended to *n*-dimensions. Molenaar 1992 presents a 3D topological model called 3D Formal Vector Data Structure (3DFDS). The model maintains nodes, arcs, edges and faces that are used to describe four types of features named points, lines, surfaces and bodies. Compare to the simplex approach, 3DFDS has less restrictions to the objects, e.g. the 2-cell (face) can have arbitrary number of 1-cells. Furthermore, some spatial relationships are explicitly stored, i.e. face-body. The model belongs to the group of Boundary representations (B-reps). Cambray 1993 proposes CAD models for 3D objects combined with DTM as a way to create 3D GIS that is a combination of Constructive Solid Geometry (CSG) and B-rep. Pigot 1995, developed a 3D topological model based on 0,1,2, 3 cell, which maintains an explicit description of relationships between cells. Work by Pilouk 1996 focussed on the use of TIN data structure and relational database for 2D and 2.5D spatial data. He proposes an integrated data model for 3D GIS (i.e. TIN and 3D FDS), which produced a practical approach to the problem. Moreover, the author develops the Tetrahedron Network (TEN) data structure that is based on simplexes. The structure assures strict consistency check, built on the generalised Euler's Equality. De la Losa 1998 and Pfund 2001 propose object-oriented models similar to Molenaar's one but they have include several more explicitly stored spatial relationships. For example, De la Losa maintains the relationship arc-faces as strict ordering of faces is introduced. Zlatanova 2000 discusses some aspects of the data structuring and 3D visualisation with respect to data query over the Web. The proposed data structure lacks the 1-cell in order to improve the performance of the system. Abdul-Rahman 2000 focuses on the object-oriented TIN (2D and 3D) based GIS. The conceptual and the logical model are developed based on the Molenaar's data model.

The consensus on a 3D topological model is not achieved yet.

Formalism for detecting spatial relationships: OpenGIS consortium has adopted two frameworks to detect spatial relationships known as Egenhofer operators and Clementini operators based on the 9-intersection model (see Egenhofer and Herring, 1992, Clementini and Di Felice 1994). Although the topology is considered the most appropriate mechanism to describe spatial relationships, the study on other mathematical frameworks continues. Billen et all 2002 propose another framework (i.e. the Dimensional model) for representing spatial relationships, built up in affine space and convexity properties of the constructing elements (named dimensional elements). The Dimensional model allows larger variations in grouping spatial relationships compare to the 9-intersection model.

Data Presentation: Advances in the area of computer graphics have made visual media a major ingredient of the current interface in the communication and interaction with computers. Therefore the research related to the visualisation of real world 3D data is mostly "shifted" to the computer graphics society. Many viewers and browsers as stand-alone applications and plug-ins have been developed to quickly visualise and navigate through 3D models for a variety of applications. New algorithms and implementations are reported daily. The design criteria, however, are fast rendering techniques based on internal structures rather than utilisation of database representations. TerraExplorer (SkyLine, 2002), the current leader for visualising large 3D textured data from real world and the first software with acceptable performance, also requires re-structuring of data.

Another significant area of 3D GIS research is devoted to Web applications. The Web has already shown a great potential in improving accessibility to 2D spatial information (raster or vector maps) hosted in different computer systems over the Internet. 3D data were even not transferable over the Web until five years ago. The first attempt to disseminate and explore 3D data, i.e. VRML, appeared to be rather "heavy" for encoding real geo-data due to the lack of a successful compression concept. Despite the drawbacks, the language became a tool for research visualisation. Researchers could concentrate on data structuring and analysis and leave the rendering issues to browsers offered freely on Internet. The research on spatial query and 3D visualisation utilising VRML has resulted in a few prototype systems (see Coors and Jung 1998, Lindenbeck and Ulmer 1998, Zlatanova2000). GeoVRML (VRML extended with geo-nodes) and Geographic Modelling language (GML) are another promising opportunities for representing 3D data on the Web. Based on XML concepts, GML provides larger freedom, flexibility and operability than VRML.

4 DISCUSSION

In this paper we reported our study on current 3D GIS status considering developments reported by vendors and researchers. The major 3D progress is observed in the area of data presentation. All traditional GIS vendors provide extended tools for 3D navigation, animation and exploration. However, still many of these systems are lacking full 3D geometry for 3D representation. OpenGIS specifications seem to be adopted rapidly by DBMS&CAD&GIS developers. In this order, the understanding for GIS is changing. Instead of a monolith, desktop, individual system, GIS is becoming an integration of strong database management (ensuring data consistency and user control) and powerful editing and visualisation environment (inheriting advanced computer graphics achievements). At present, only the first step is made, i.e. the implementations focus mostly on the geometry. 2D topological representations and operations are intensively in process of implementation. The third dimension with respect to topological issues is still in the hands of the researchers.

The case study clearly showed the benefits of a standardised spatial data structuring as well as revealed the very early stage of the integration. The large number of specialised settings, the application dependent feature-geometry linkage, the limited semantic hierarchy, the spatial operators utilising only X, Y values, are some of the issues that need further improvements.

Although, quite significant number of works devoted to 3D data structuring, the research is concentrated around few basic ideas, as the level of explicitly described spatial relationships varies. Each suggested structure exhibits efficiency and deficiency with respect to a particular applications and operations to be performed. Still 3D GIS functionality to be addresses: 3D buffering, 3D shortest route, 3D inter-visibilities are some of the most appealing for research. Integration of object-oriented approaches with the 3D GIS raises research topics at a database level toward standard object descriptors and operations.

3D visualisation within 3D GIS requires appropriate means to visualise 3D spatial analysis, tools to effortlessly explore and navigate through large models in real time. Observations on the demand for 3D City models show user preferences for photo-true texturing. Trading photo-true texture brings up necessities to store parameters for mapping onto the geometry.

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REFERENCES

Abdul-Rahman, A., 2000. The design and implementation of two and three-dimensional triangular irregular network (TIN) based GIS. *PhD thesis*, University of Glasgow, Scotland, United Kingdom, 250 p.

Billen, R., S.Zlatanova, P. Mathonet and F. Boniver, 2002, The Dimensional model: a framework to distinguish spatial relationships, In: *Proceedings of Spatial Data Handling*, 8-12 July, Ottawa, Canada (to be published)

Cambray, de B., 1993. Three-dimensional (3D) modelling in a geographical database, In: *Proceedings of AutoCarto 11*, Bethesda, Maryland, pp. 338-347

Carlson, E., 1987, Three-dimensional conceptual modelling of subsurface structures, In: *Technical Papers of ASPRS/ACSM Annual Convention*, Baltimore, Vol. 4 , pp. 188-200

Clementini, E. and Di Felice P., 1994, A comparison of methods for representing topological relationships, In: *Information Sciences (80)*, pp. 1-34

Coors, V. and V. Jung, 1998, Using VRML as an Interface to the 3D Data Warehouse, In: *Proceedings of VRML'98*, New York

De La Losa, 1998, Toward a 3D GIS: Conception of a 3D GIS with a complete topological management, In: *Proceedings of GIS PlaNET'98 Conference,* Lisbon, Portugal

Egenhofer, M. J. and J. R Herring, 1992, Categorising topological relations between regions, lines and points in Geographic databases, *Technical report 94-1, NCGIA*, University of California.

ESRI, 1997, Using ArcView 3D Analyst. *ESRI Publication*, Redlands, California, USA, 118. p.

Lindenbeck, C. and H. Ulmer, 1998, Geology meets virtual reality: VRML visualisation server applications, In: *Proceedings of WSCG'98*, Vol. III, 3-19 February, Plzen, Czech Republic, pp. 402-408

Microstation GeoGraphics iSpatial, 2002, Bentley Systems Inc., available at: http://www2.bentley.com/products/default.cfm

Molenaar, M., 1992, A topology for 3D Vector Maps, In: *ITC Journal*, 1992-1, pp. 25-33

Oosterom, P. v, J. Stoter, W. Quak and S. Zlatanova, 2002, The balance between geometry and topology, In: *Proceedings of Spatial Data Handling*, 8-12 July, Ottawa, Canada (to be published)

OpenGIS specifications, 2002, OpenGIS Consortium, Inc., available at http://www.opengis.org/

Oracle Spatial 8i, 2002, User's guide and reference, available at: http://technet.oracle.com/doc/inter.815/a67295/toc.htm

Pfund, M., 2001, Topologic data structure for a 3D GIS, In: *Proceedings of ISPRS*, Vol.34, Part 2W2, 23-25 May, Bangkok, Thailand pp. 233-237

Pigot, S., 1995, A topological model for a 3-dimensional Spatial Information System, *PhD thesis*, University of Tasmania, Australia

Pilouk, M., 1996. Integrated modelling for 3D GIS. *PhD thesis*, ITC, The Netherlands, 200 p.

Raper, J, and D. J. Maguire, 1992, Design models and functionality in GIS. *Computer & Geosciences*, Pergamon Press, Vol. 18, No. 4, pp. 387-394

SkyLine, Software Systems, Inc., available at: http://www.skylinesoft.com/corporate/corporate_home.asp

Sonnen, D. and H. Morris, 2000, Location in CRM: Linking virtual information to the real world, IDC White Paper, 12p., available at: http://www.idc.com

Stoter, J. and P. van Oosterom, 2002, Incorporating 3D geo-objects into a 2D geo-DBMS, *Proceedings of ASPRS/ACSM*, 19-26 April, 2002, Washington, USA, (to be published)

Zlatanova, S., 2000, 3D GIS for urban development, *PhD thesis*, ITC, The Netherlands, 222 p.