# Representations built from a true geographic database

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# REPRESENTATIONS BUILD FROM A TRUE GEOGRAPHIC DATABASE

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**Abstract:** The development of a system for geovisualization under the Centre for 3D GeoInformation (3DGI) at Aalborg University, Denmark, has exposed the need for a rethinking of the representation of virtual environments. The system GRIFINOR, developed at 3DGI, Aalborg University, DK, is capable of creating this object-orientation and furthermore does this on top of a true Geographic database. A true Geographic database can be characterized as a database that can cover the whole world in 3d and with a spatial reference given by geographic coordinates. Build on top of this is a customised viewer, based on the Xith (Java) scenegraph. The viewer reads the objects directly from the database and solves the question about Level-of-Detail on buildings, orientation in relation to terrain and rendering of the model. All this is done in something very close to real-time. This paper will discuss different possibilities for representation of the objects from a geovisualization aspect.



**Keywords:** 3D geovisualization, virtual environments, object-orientation, spatial indexing, global index.

## REPRESENTATIONS BUILD FROM A TRUE GEOGRAPHIC DATABASE

## 1 INTRODUCTION TO SOME IMPORTANT CONCEPTS

This paper addresses some vital challenges regarding the handling of different concepts for representations of virtual environments in real-time applications. It will also present important new results from research done in this specific subject. The system GRIFINOR for real-time geovisualization has been developed during the last couple of years at Centre for 3D GeoInformation, Aalborg University.

As stated in recent literature, the traditional cartography and other forms of visualization of the geographic world in one or another form are different kinds of geovisualization. 3D geovisualization is a special case of geovisualization, where focus is on the creation and modelling of 3D spaces to represent objects as well as attribute information about these objects in virtual environments (MacEachren et al., 2001, Dykes et al., 2005).

Urban planning and architecture are both application areas, where the use of virtual environments has proved to be a very strong medium. In many of these cases, 3D models have provided the spatial framework for planning proposals where it has been specifically important to evaluate the form and the spatial concepts for the architecture and the planning. This is the most direct way to map and visualize in 3D. These 3D mappings and visualizations have also proven very valuable after realization in relation to building and property management. This is especially a fact in the more complex and high-rise urban environments. Other 3D modelling initiatives within the urban context can be seen in the field of facility management and urban management such as in the 3D modelling of a cadastre (Zlatanova, 2000, Batty et al., 2001, Bodum, 2002, Bodum et al., 2002, Nielsen, 2002, Coors, 2003, Andersen et al. 2004).

Another very successful implementation of 3D into geovisualization is within the field of large-scale terrain databases. These terrain visualizations can have several different aims, such as fly simulation and pilot training, but in recent years they have also been used more and more as interface for a fly-through of virtual landscapes. The terrain databases have in many cases also been combined with different GIS solutions so that they provide a possible visualization platform for other geoinformation (Kolar, 2004b).

But current technologies for 3D geovisualization have some important limitations. The main problems are closely connected to the spatial data infrastructure of virtual environments for real-time applications. The basic structures of these models are very fragmented and do not live up to the general public demands of interoperability within the geoinformation domain. These fragmentations can be seen in:

- Geometry
- Topology
- Semantics
- Geography
- Time

The concept of GIS has traditionally been a computational representation of a map (in 2D) and a relational representation through tabular data. The representation is based on the model of 1 to n layers of geographical features or raster. To be able to work with these layers interactively, it is necessary that they refer to the same geographic datum and projection, and that the geographic coordinates refer to the same coordinate system. This puts a lot of constrains on the whole concept of GIS. Therefore it is not possible to represent real (global) 3D space within the original concept of GIS. There have been many suggestions to the solution of this conceptual problem, but they all build on projected and local systems(Pilouk, 1996, Stoter, 2004).

For several years it has been possible to model very detailed models of urban areas as virtual environments for real-time visualization. This development has taken place meanwhile computer graphics hardware and software (CAD-systems) have been updated and have become more accessible in terms of better usability and a better price/performance relation. The number of polygons visualized in models is much higher today than it was just 5 years ago. But even though the technology can do much more today, the concepts and basics of urban modelling are still hanging on to the same design philosophy. Geometry and information are stored in separate databases. This means difficulties when it is necessary to update and refine each of the systems. The major part of the urban models are optimized for fast querying in relation to the demands put on the model from the perspective of the graphical user interface. Geoinformation can normally only be accessed through a database-link (such as Open Database Connections - ODBC) or through hyper linking of the map. Only recently there has been examples of research within the subject of virtual urban environments, where both geometrical, topological and semantically aspects are covered in the same interoperable model (Kolbe et al., 2005, Zlatanova et al., 2004).

### Fragmented geometry

Models of 3D virtual environments in urban areas are typically produced by photogrammetric methods or through the use of airborne laserscannings. In either of these methods, the outputs are in most cases described as a boundary representation (B-rep) where rooftops, walls, significant details in facades etc. are present. To be more exact, the specific representation is a facetted B-rep, where an imaginary solid of the model is bounded by planar surfaces. Only points, planes and planar polygons are necessary and are implicitly represented by their vertex points. The structure resembles a patchwork, and the general problem with these representations is the lack of knowledge about semantics in the model. Which planar surfaces are representations of roof? Which surfaces are facades and how do you secure that the normal of the faces are pointing in the right direction? Furthermore, there are a lot of potential problems related to defining holes, surfaces in surfaces (windows etc.). These models are not very well suited for the logical structures of a GIS, where objects should be represented by some kind of geometry and the attributes should refer to something spatial. That is why the B-rep models typically are organised in a CAD (Computer-Aided Design) inspired structure.

**Fragmented topology**

Topological structures are the key to the relation between objects in a geodatabase, and in many cases it is the topology of the data, that helps with the analytical part of the GIS work. Just think about what the road network would be without topological structures. In the case of urban 3D models, the need for a topological structure is obvious since there are so many relations to keep track of in a 3D geodatabase. But at the moment there is no commercial solution that supports 3D topology. The reason for this is the complexity of the problem. There are so many possible solutions when the relation between two "multipolygons" should be described. If they intersect, it will still be difficult to describe this intersection through a logical expression. Virtual environments in 3D therefore lack the topology.

**Fragmented semantics**

The modelling of virtual environments is not a standardised process. There are no common rules in either the conceptual data modelling or in the geometrical modelling. The models are constructed without common semantic rules. The purpose of semantics is to provide meaning to structures that do not have any generic conceptual or logical sense by itself. This could be a geometrical structure such as a surface with *n* vertex points. In a spatial database there might be an attribute to this object that said something about the identity of the object. The value for this attribute could be "roof". This information would be valuable and useful in both the modelling and in the query of the model when it was finished. But semantic rules could give much more intelligence to the model. The roof object could then test itself for alignment, material, pitch and other characteristics. This would also mean a better chance for understanding the geometrical and topological structures. A specific piece of the roof would be a section of a building, which could be an aggregation of many object classes.

**Fragmented geography**

Each city has its own frame of reference and the 3D models of urban areas are normally limited to specific areas of the city. This means that the models are represented as individual segments either computational represented through the different files for each specific geographic tile of the model or conceptually through different layers or different geographic reference systems. Each time a new part of the model is needed in the system, this will require either reading a new file or converting the data to common formats. What are needed are a common geographical reference and a system of distributed servers that can be accessed through the Internet. In a real geographic representation of the world, it should be possible to have access to 3D models of virtual environments from different parts of the country or even the world. Then it would be possible to navigate from one city to another. This kind of solution is in line with the concepts of Digital Earth, and can be seen in different commercial solutions such as ArcGlobe from ESRI.

### Fragmented time

Most 3D models are produced for making off-line animations, off-line simulation or stills. Not many models are prepared for browsing in real-time. If they are prepared for real-time, it is almost for certain in a reduced edition. That would be with low level-of-detail (LoD) or without textures. This means that many of the models are separated from time, and it becomes difficult to use them for browsing in real-time. Another problem with temporal information is the lack of decent metadata for the models. That means it is very difficult to get an up to date version of the model, or to visualize the model to different historic moments in time. In 3D models for virtual environments it becomes even more important for the quality of the model to have a correct timestamp on every object in the model. If the model is going to be used for spatio-temporal modelling in GIS, this could put even higher demands on the registration of time for the objects.

### Science of virtual environments

The science of virtual environments is about modelling and simulation of a specific domain within a specific scientific field. The science of virtual environments is therefore also about many other things that relates to the modelling and simulation. This could be the generalization, visualization, manipulation, perception and interpretation of these virtual environments. An important decision to take in the design of a virtual environment is the representation of the objects. There are generally speaking two different kinds of representation that are important to understand when working with virtual environments. That is the logical representation and the visual representation. The logical representation is defined in relation to the spatial data model for the objects in the model. The visual representation is the term used for building or constructing the virtual environment, which includes important decisions about what to include/exclude, Level-of-Detail (LoD) and the level of realism in the model.

## 2 GRIFINOR

To facilitate these fundamental system needs and raise the general level of comprehension for spatial information of various kinds, a new technological platform called GRIFINOR is suggested. GRIFINOR allows access to geographically referenced information through three-dimensional graphics. In order to actually implement such a technology, it is crucial to define a general platform for a solution. The purpose of GRIFINOR is to minimize the number of conceptual and technological problems such as the fragmentation problems, while keeping the technology general for adding new features to the system. The vision of a virtual representation of our planet that would enable a person to explore and interact with any natural and cultural information gathered about the Earth addresses an abundance of problems, which would be too overwhelming to cope with. Efforts have been carried out for years attempting to find a suitable solution for such a technology, referred to as Digital Earth (Gore, 1998, Leclerc et al., 2002).

In contrast to this approach, which attempts to define the way different information can be visually presented, we define a fundamental technology that provides a base for an arbitrary number of smaller applications focused on visualization of specific information. This solution provides a modularized approach towards Digital Earth.

## The name GRIFINOR

The griffins are legendary creatures – half eagle and half lion. Griffins are powerful - and so is GRIFINOR. They can fly across vast areas, but can also walk on the ground, if necessary. Griffins belonged to the Gods. Their appearance inspired respect, and even though they looked malevolent, they were actually here to do well. Their main task was to guard or protect, and they had sufficient skills to carry out this mission autonomously.

Griffins are still here with us. Leaning out from buildings and from the top of roofs, they watch us. Even as protectors of the churches we can see them as part of the ornaments, providing a message from above. As such, Griffins were used to express visual messages to people – as spatial models – as sculptures. GRIFINOR has inherited this feature of expressing itself visually, and when used in geovisualization, the link between the past and the future is established. GRIFINOR is therefore a digital griffin. It is here to foster and navigate our digital world and further to provide a visual perspective of our environment. GRIFINOR can fly even higher than its legendary predecessors and has the whole globe within its field of vision (Bodum et al., 2005).

## GRIFINOR platform

GRIFINOR will be a platform for different sorts of applications. A system for 3D geovisualization is, in contrast to an ordinary GIS system, which at most handles surfaces and 2D objects with height information, a system that can store, retrieve, analyze, simplify, generate, and visualize spatial data that are generic 3 dimensional. Furthermore it allows user interaction with these data. GRIFINOR will be able to handle "soft" real-time demands as well as being application and device adaptable - that is the system will be module based and object oriented so it can be adapted to PDA's, PC's, mobile units and so on, without requiring alterations to the code of the applications. GRIFINOR is collaborative so that more than one user per session can experience and interact in the same virtual world. It is build around one or more database technologies, used in a scalable and distributable system, in which large amounts of data will be present (magnitudes of about one TB), powerful server hardware and fast 3D graphic hardware. GRIFINOR is part of a research project and for that reason the users are not specified ahead of time. The user group is potentially vast from system- and application programmers and administrators to users of applications in GRIFINOR.

GRIFINOR has four main components that can be described individually. This is the GeoDB (2D geographic relational database) that supports the construction of 3D objects, the GRIFINOR object database (ODB), the GRIFINOR viewer and finally the applications of GRIFINOR. Only the ODB and the viewer will be mentioned in this paper. This is because the focus of this paper is on the logical and the visual representation.

**Object database (ODB)**

The ODB handles the persistent low-level storage of dynamic objects in the GRIFINOR system. An actual system is composed of a network of 1 to *n* ODB servers distributed on the Internet. The system features unique distributed spatial indexing algorithms and persistent data structures optimized for efficient 3D level-of-detail queries. The ODB is unique for GRIFINOR due to the fact that there are no commercial solutions that can perform the needed tasks.

Some of the commercial database solutions were tested in the initial phase of the development, which resulted in the conclusion that there were very serious shortcomings regarding the indexing of objects in 3D and regarding the necessity to query the database in something very close to real-time. The commercial databases were simply not fast enough for the purpose of GRIFINOR. A new object-oriented database was developed and beside the storage of the objects there is now a database for the different classes. The structure also means that a new class can be introduced very easily and that existing objects can be reclassified. Another important thing about a customized object-oriented database is also the ability to test and reengineer the database up against the viewer developed for GRIFINOR. This involves also the communication between server and client.

**Index for Distributed spatial Object (DSO-index)**

The DSO-index is a distributable data structure suitable for indexing 3D objects on world scale, suitable for progressive LoD queries for visualization. DSO-index is based on an octree-like data structure. The physical extends of the top node are somewhat bigger than the Earth or the planet it is applied to. In each octree node it is possible to assign a set of objects through distributed object pointers. Child octree nodes are optional and also marked by explicit distributed pointers. The use of distributed object pointers for both the index tree and the objects grants the possibility of distributing data on as many servers as desired. Since all nodes and objects are directly or indirectly referenced from the top node, this node acts as a reference to the world, and multiple versions of the world can be created in the same system by making multiple top nodes.

As an integral part of the concept, it is necessary to define a method for calculating a LoD-measure for 3D objects – e.g. the average triangle size or the precision of the object. A method for relating the LoD-measure of the 3D objects (or specific detail of 3D objects) to the level in the tree must also be defined in such a way that it follows the subdivisions of octree (a length measure is halved for each subdivision, an area measure is square-rooted, and a cubic measure is cubic-rooted). In effect this provides a mapping between the LoD objects and the relevant node in the global octree structure.

Identification of the exact node, into which a 3D object should be inserted, can therefore be calculated without the presence of the data that constitutes the index data structure. The actual storing and insertion is performed according to the distributed object storage system, which can either traverse the tree explicitly to locate the insertion node or it can adhere to a preset (possibly also hierarchical) distribution policy.

When used for visualization, the index allows for querying the visually most important objects at a given viewpoint and dynamically altering the fidelity of the visualization according to the capabilities of the hardware and the network as well as user preferences. This is an important feature in a real-time system running on limited bandwidth connections since it is possible after a relatively short time to show a coarse representation which is progressively being refined over a possibly much longer time into the view of the final fidelity. At anytime the user is free to move to other places where new information is determined to be more important and thus gets higher priority for download.

Technically, since the tree structure is given implicitly, it is possible to identify which nodes are relevant to the visualization and which are not, without actually loading them. However, the depth of the tree at various places is not known in advance since it is data driven, so if only the client is capable of executing queries, only one level in the tree can be expanded for each query. If more levels are desired, a server capable of executing partial queries is needed as well as an octree node distribution policy, which increases the likelihood of a node and its child nodes being stored on the same server. To optimize communication efficiency with servers, queries to the same server can be grouped into multi-object queries and multi-sub-query queries. Additionally, objects can be cached locally and clients can form a peer-to-peer network to relieve object servers. For optimization of the visualization, the octree structure can be utilized for view culling.

**Topographic surface representation indexed using global grid**

Among the many new facilities in the database is also the geographical index that enables the client to query at a global scale. This is one of the things that make GRIFINOR a true geographic database system. In fact it is possible to store the world in the same database and therefore navigate around the globe and only query the same database. The core concept is to have an algorithm, which transforms more complex 3D indexing into a simpler and established linear (one dimensional) index. At the same time it exploits 2.5D indexing concepts, which are used in currently planar geographic solutions, and relate them to a spherical surface in order to facilitate global geographic applications. This provides a general approach that can be used with any existing DBMS technology with indexing capabilities.

The indexing transformation uses a method that divides 3D space through a tessellation marked off on the unit sphere using a geometric approach known as global grid. An original global grid, based on concepts of Voronoi tessellation, has been devised and implemented. This facilitates proximity spatial queries around planet's surface. A set of algorithms for processing basic spatial queries has been also elaborated.

The result is an unambiguous tessellation, which means that no data describing the geometry of the tessellation scheme are necessary. This feature is similar to the regular property of raster data. Such property enables to identify a linear order among the units of the spatial tessellation. This can be used directly with existing DBMS indices. Moreover the unambiguous tessellation exists for an arbitrary number of levels with different resolution of the tessellation. It is convenient for applications with multiple level of detail (LoD), which is critical for an interactive visualization.

A terrain data representation that exploits the LoD capabilities of the global indexing algorithm is coupled with the solution. The representation of the terrain surface does not store topology of the surface explicitly but uses a surface reconstruction algorithm at run-time. This provides flexibility in storing terrain data. Flexibility means; possibility to distribute storage on many places which constitute the same terrain model; elimination of dealing with topology neither across borders of individual tessellation cells (tiles) nor between LoD; and providing a generic data representation that is suitable for an analytical application in contrast to a data representation devoted to visualization purposes only (Kolar, 2004a).

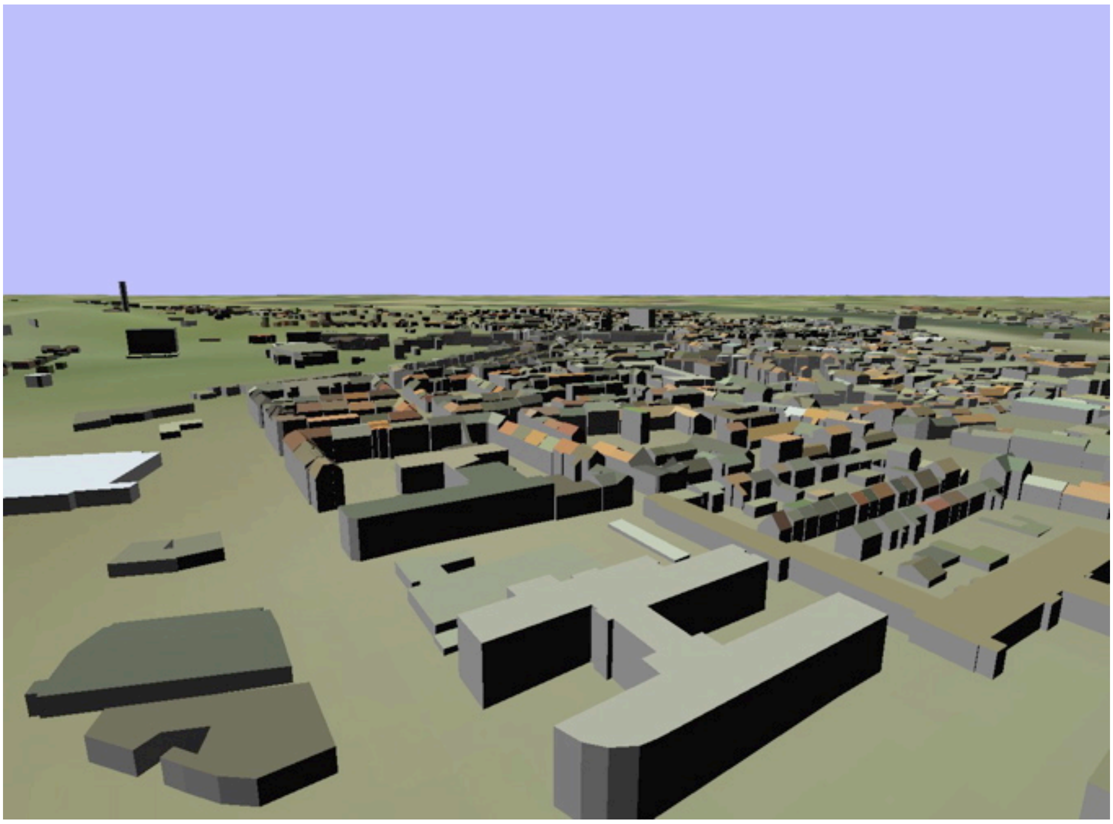

**Figure 1 Objects loaded in GRIFINOR viewer**

### GRIFINOR viewer

The GRIFINOR viewer should be both independent of certain hardware and very flexible in use. To fulfil these demands it was decided to use Java for the development and to build it around an open source scene-graph called Xith3D. As the Viewer is based on Java technology, it provides the flexibility of running on various different platforms such as: MacOS X, Linux, and Windows, directly from a web browser. Future PDAs and cell phones with sufficient hardware should be able to run the Viewer as well with minor modifications. The viewer also offers a suite of navigational tools for interaction with the 3D virtual environment.

In the subject of global visual navigation not many solutions convenient for an implementation are present. By providing a simple mathematical solution, we aim at facilitating adoption of similar navigations in other global systems for interactive geographic visualization. In traditional navigation, up is related to models based on flat approximation of the surface. The globally applicable navigation algorithm induces a practical value by estimating of the gravitational up vector at any given position of the user in relation to the globe and aligning the view accordingly. This means that on a local scale, navigation can appear to work like a traditional flat navigation algorithm, which the user might already be familiar with, but this navigation just works on the whole globe instead of a restricted flat space. On a global scale it is more apparent that the navigation works differently, simply because it is more obvious that the world is spherically represented. We try to address this improvement by explaining a possible use of the proposed navigation.

Similar to navigation of planar maps, the user can, for example, look over a 3D area, which is actually part of a spherical model; looking down one can zoom-in and zoom-out and pan to any side. The navigation within the GRIFINOR viewer also allows the user to raise the view up, look to the sides and survey in a three dimensional context with streets and buildings surpassing the terrain. Heading to a particular direction one can move forth and back following certain elevation level. The user can also move further from the surface and if more global issues are at interest. At this global point of view it becomes apparent that moving forth or back, the navigation actually has to follow spherical shape of the Earth in order to preserve the user's elevation level. This provides a natural experience for humans and offers a visual navigation and perception at many scales (Ilsøe et al., 2005).

## 3 CONCLUSIONS

By promoting GRIFINOR to applications within the domain of urban modelling and use it as platform for 3D geovisualization of virtual environments, it will be possible to reduce the complications regarding fragmentation of geometry, topology, semantics, geography and time within traditional 3D urban modelling. The object-orientation and use of a true geographic database will create space for new innovative solutions. Another aspect with similar importance is the qualitative assessments of these new media for geovisualization. Although many things will be possible with a platform like GRIFINOR, research in usability must be put forward on the agenda. We still do not know enough about how 3D geovisualization can add quality to the handling of geoinformation. It is therefore necessary to do comprehensive research within this domain.

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## REFERENCES

a) Books and Book chapters

Andersen, P. and Qvortrup, L. (Eds.) (2004) **Virtual Applications: Applications with Virtual Inhabited 3D Worlds**. London, Springer-Verlag.

Batty, M., Chapman, D., Evans, S., Haklay, M., Kueppers, S., Shiode, N., Smith, A. and Torrens, P. M. (2001) Visualizing the City: Communicating Urban Design to Planners and Decision Makers. In Brail, R. K. and Klosterman, R. E. (Eds.) **Planning Support Systems**. Redlands, ESRI Press.

Bodum, L. and Kjems, E. (2002) Mapping Virtual Worlds. In Qvortrup, L. (Ed.) **Virtual Space: Spatiality in Virtual Inhabited 3D Worlds**. London, Springer-Verlag.

Bodum, L., Kjems, E., Kolar, J., Ilsøe, P. M. and Overby, J. (2005) GRIFINOR: Integrated Object-Oriented Solution for Navigating Real-time 3D Virtual Environments. In Oosterom, P. V., Zlatanova, S. and Fendel, E. M. (Eds.) **Geo-information for Disaster Management**. Berlin, Springer Verlag.

Dykes, J., Maceachren, A. and Kraak, M.-J. (Eds.) (2005) **Exploring Geovisualization**, Elsevier Science Ltd.

Ilsøe, P. M. and Kolar, J. (2005) Geo Embedded Navigation. In Van Oosterom, P., Zlatanova, S. and Fendel, E. M. (Eds.) **Geo-information for Disaster Management**. Berlin, Springer Verlag.

Kolbe, T. H., Gröger, G. and Plümer, L. (2005) CityGML - Interoperable Access to 3D City Models. In Van Oosterom, P., Zlatanova, S. and Fendel, E. M. (Eds.) **Geo-information for Disaster Management**. Berlin, Springer Verlag.

Nielsen, R. (2002) Collaborative Spaces: Inhabited Virtual 3D Worlds. In Qvortrup, L. (Ed.) **Virtual Space - Spatiality in Virtual Inhabited 3D Worlds**. London, Springer-Verlag.

Pilouk, M. (1996) **Integrated Modelling for 3D GIS**. Wageningen Agricultural University and ITC, The Netherlands.

Stoter, J. (2004) **3D Cadastre**. Technical University, Delft.

Zlatanova, S. (2000) **3D GIS for Urban Development**. The International Institute for Aerospace Survey and Earth Sciences (ITC) and Institute for Computer Graphics and Vision. Enschede and Graz, ITC and Graz University of Technology.

b) Journal papers

Coors, V. (2003) 3D-GIS in networking environments. **Computers, Environment and Urban Systems, Vol. 27, No. 4**, 345-357.

MacEachren, A. M. and Kraak, M.-J. (2001) Research Challenges in Geovisualization. **Cartography and Geographic Information Science, Vol. 28, No. 1**, 3-12.

c) Papers presented to conferences

Bodum, L. (2002) 3D Mapping for Urban and Regional Planning. In Salling, M. J. (Ed.) **URISA Annual Conference 02**. CD-ROM ed. Chicago, URISA.

Kolar, J. (2004a) Global indexing of 3d vector geographic features. **XXth ISPRS Congress**. Istanbul, ISPRS.

Kolar, J. (2004b) Representation of geographic terrain surface using global indexing. In Brandt, S. A. (Ed.) **Geoinformatics 2004**. Gävle, Sweden, Gävle University Press.

Zlatanova, S., Holweg, D. and Coors, V. (2004) Geometrical and Topological Models for Real-time GIS. In Fendel, E. M. (Ed.) **UDMS 2004**. Chioggia, Italy.

d) Other documents

Gore, A. (1998) **The Digital Earth: Understanding our planet in the 21st Century**. California Science Center, Los Angeles.

Leclerc, Y. G., Reddy, M., Eriksen, M., Brecht, J. and Colleen, D. (2002) **SRI's Digital Earth Project**. Menlo Park, SRI International.