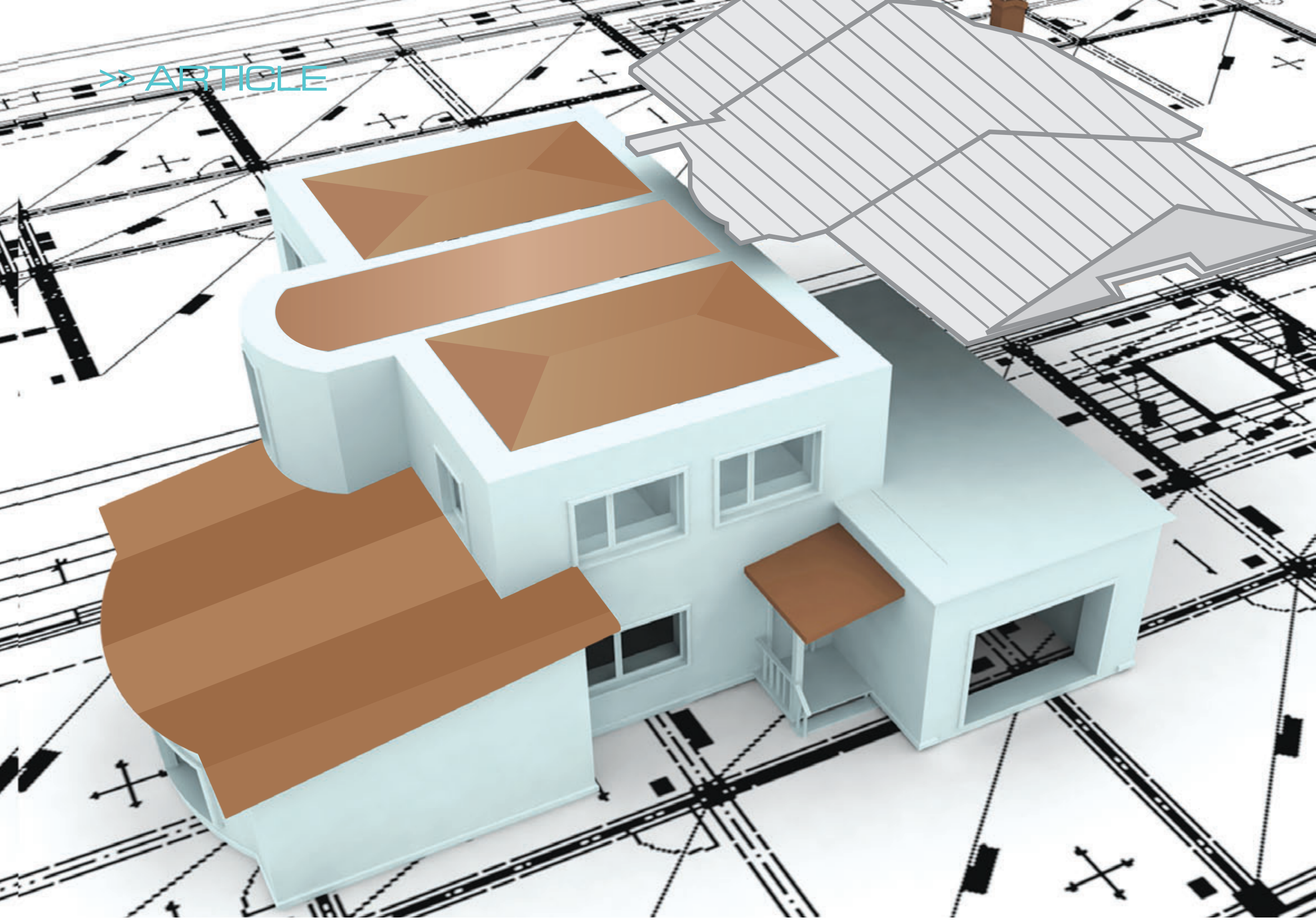

Quest for an integrated 3D model

Developing an integrated 3D model that is scalable and takes into consideration various aspects of 3D re-construction, is vital for the bright future of 3D GIS, avers Sisi Zlatonova

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The scientific community and the Geographic Information Systems (GIS) industry have investigated and developed tools for many aspects of 3D GIS for a diversity of applications such as urban planning, cadastre, utility management and environmental issues. GIS intends to cover the entire process of data collection, processing, management, analysis and visualisation of data, but most commonly, the individual researchers and developers focus on one specific aspect. This tendency is even stronger when looking into the third dimension. Much progress has been observed in sensor technology, mobile data collection approaches and processing algorithms. The approaches for automatic 3D re-construction are improving and some good results have been reported at scientific forums. Recently, the technical limitations to the use of 3D information (such as computer power and tools for 3D visualisation) have decreased and in most of the cases (especially in the urban context), the evolution to 3D objects is going well. Large contributions to this process have new web-based visualisation environments such as Google Earth and Microsoft Virtual Earth, which have made the access to and visualisation of 3D data natural and understandable for a large audience (see Figure 1).

In this respect, it is hard to define clearly what a 3D Geographic Information System is. Strictly speaking 3D GIS should be able to offer the same functionality as the traditional desktop GIS system. The most critical difference of GIS compared to other software has always been the possibility to perform spatial analysis and visualise them. This means practically that the models (topology, geometry, network, spatial occupancy enumerations, free form surfaces etc.) have to be first agreed upon. As soon as the models are available, they can be mapped to database structures or file representations (e.g. gml, kml, shape, dxf) and used for management or for exchange over Internet and between applications. It should be noted that most of the presently available Web applications aim at portraying (publishing) 3D data and hardly consider editing and analysis of 3D data. Although some Web services (especially vendor-specific) allow some more elaborated operations, the third dimension is still in its infancy.

The progress in 3D modelling is apparent especially in the vector domain for representing crisp objects: geometry models are widely available and used (DBMS, GIS software), topological models are investigated and some good prototypes are successfully tested (1Spatial, CC-modeller etc.) and network models are emerging for indoor representations. The importance of semantics is increasingly recognised and a 3D semantic model has become a standard in 2008.

Geometric models are the most straightforward 3D models, which maintain the coordinates together with the objects. Although resulting in large volumes of data (a set of coordinates might be repeated several times in the description of one features) these models are simple and fast. Geometric models require the existing DBMS to be compatible to manage spatial data. However, the third dimension has become a serious challenge for the developers of DBMS that manage spatial data.

A large number of experiments have been performed by researchers to investigate possibilities to store, query and visualise features with their 3D coordinates. Mainstream DBMS can maintain 3D data in a relatively standardised way. The data can be accessed and visualised by a large number of front-end applications. Oracle spatial 11g has implemented the first 3D data type (polyhedron) and it is expected that soon other DBMS will follow. Large number of well-known spatial operations and functions only support 2D data. Moreover, managing various spatial data types and operations have proved to be very difficult as they vary with each DBMS. The statement: select c from b where a <200, where c,a are numerical data type, can be executed in every DBMS. However if c is a spatial data type, the SQL statement differs from one DBMS to another. In some cases (e.g. Oracle Spatial), even the names of the spatial data types are not that apparent.

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Figure 1: Visualisation of TUDelft campus in Google Earth

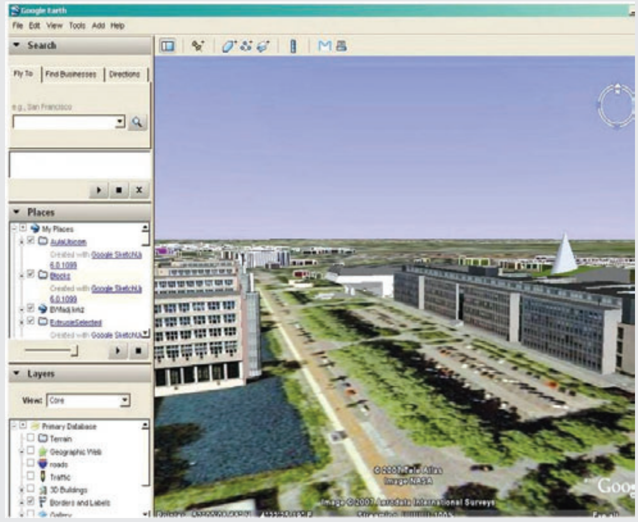


Figure 2: 3D block model represented and TEN (courtesy Dr Friso Peninga)

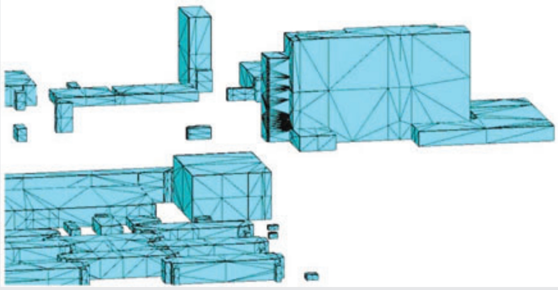
Another interesting aspect of 3D modelling is that it extends beyond the traditional simple features – point, lines, polygons and solids. The OGC Abstract specifications suggest a range of parametric and freeform shapes to be employed in the GIS domain, but currently no GIS package or DBMS can handle them.

Oracle Spatial has one complex data type sdo_geometry composed of several parameters indicating type geometry, dimension, and an array with the x,y,z coordinates. At present GIS and AEC systems provide connectors to mostly Oracle Spatial, but there is a strong tendency for changes, e.g. PostGIS, MySQL, GRASS are also increasingly used.

Many researchers addressed 3D topological models however, no commercial implementation of 3D topology is currently available. Topological models require unique identifiers for all the primitives, which are used to define the features and the relationships between them. The coordinates are stored exclusively with the nodes. The topological models have always been considered beneficial because they allow for compact storage (avoid redundancy), they maintain consistency of the data after editing, some spatial analyses are easy to perform etc. However, when the coordinates must be provided, an extra step has to be performed, i.e. the realisation of geometry for each feature (e.g. a building, a street) and a primitive it is constructed from (solid, line, polygon, point). This step might be time-consuming when many relations and primitives are maintained in the model. This remains true for a 3D topological model. Additionally, the complexity is much higher. Much research has already been done on number of primitives and relations and various 3D models were proposed such as 3D Formal Data Structure (3DFDS), Urban Data Model (UDM), Simplified Spatial Structure (SSS) and TEtraderal Network (TEN) based on their research. However, a topological model that integrates all these 3D models needs to be designed. Recent research concentrated again on TEN model. A TEN is very a simple well-defined model, ensuring flat faces and convex shapes allowing for robust consistent management. TEN can be used for modelling of almost all phenomena both natural and man-made,if we accept that real-world 3D objects are always volumetric; points, lines and surfaces are only abstractions to facilitate the modelling process. Some recent experiments with the corresponding data structure have clearly shown promising results.

Another interesting aspect of 3D modelling is that it extends beyond the traditional simple features – point, lines, polygons and solids. The OGC Abstract specifications suggest a range of parametric and freeform shapes to be employed in the GIS domain, but currently no GIS package or DBMS can handle them. Freeform curves and surfaces such as Bezier, B-spline and NURBS are becoming progressively important in AEC for design of buildings, towers, tunnels etc. Very often these models need to be integrated with 3D GIS for investigations and adjustment of the construction (e.g. for wind resistance). Presently, the only option for integration is to import the 3D GIS model in the AEC package. However such solutions can be maintained only within the industry proprietary files. Another much more elegant option would be to make possible management of these shapes in GIS and DBMS environment. We have initiated a research aiming at developing data types for DBMS. We have concentrated on NURBS since they have attractive characteristics:

- NURBS offers a common mathematical form for both, standard analytical shapes (e.g. cone, sphere) and freeform shapes;
- The shapes described by NURBS can be evaluated reasonably fast by numerically stable and accurate algorithms; and
- Important characteristic for modelling real-world objects is that they are invariant under affine as well as perspective transformations.



The only drawback of NURBS is the extra storage needed to define traditional shapes (e.g. circles). Using NURBS data types, a circle can be represented in different ways but the complexity is much higher compared to its mathematical definition (i.e. radius and centre point). The SQL below shows a NURBS data type developed at TUDelft and tested with various buildings.

SQL> desc GM_NURBSCurve	
Name	Type
Degree	Number
Controlpoints	GM_Pointarray
Knots	GM_Knotvector
Weights	GM_Weightarray
Trim	GM_Trim

Besides topology/geometry, thematic semantics of 3D objects should be established as well. For 3D city models only few thematic semantic models exist. A common understanding is that buildings and terrain objects are the most important features to describe in a 3D city model. Following this understanding, the current version of CityGML (the only 3D standard considering thematic semantics and 3D geometry/topology) has also incorporated only surface and above surface features. Many semantic models have been created and accepted as standards such as the North American Data Model and Geology Science Markup Language, (GeoSciML) for representing geological observations or TransXML for exchange of data in transportation world. The INSPIRE initiative in Europe harmonises information from different applications (themes). Many of these semantic representations are examples of subdivision of urban space into features, but they do not contain mapping to 3D geometric representations. In this respect, CityGML has initiated the research and developments toward integrated 3D semantic/ geometry/topology modelling. Further extensions of CityGML or similar models would be needed to allow seamless integration of objects above, below and on the surface.

One of the most valuable contributions of CityGML is the concept of Levels of Detail. Originally developed in Computer Graphics to speed up rendering, this concept is employed with a slightly different meaning in GIS. The LOD indicates the level of generalisation applied to a real-world object. One may find similarity between LOD and the concept for scale in 2D maps. Similar to 2D maps, the available technology, data sources or the intended application can have influence on the produced LOD. Currently, the LOD is best suited for modelling buildings, especially outside modelling. The LOD for indoor/inside is only one as it is not entirely clear how far GIS models should go. Interiors of buildings are considered an area of building construction domain, i.e. Building Information Models (BIM). However, BIM semantic is different. BIM focusses on the construction elements (walls, floors, doors, stairs, windows etc.) and not on the use of the spaces (rooms, corridors etc.) as in GIS. OGC Web Services Phase 4 has demonstrated a successful integration of BIM (based on Industrial Foundation Classes, IFC) and CityGML. Although IFC-CityGML (e.g. IFCexplorer) are already available, further research is required for robust semantic and geometric/ topologic conversion between BIM and 3DGIS models.

The success of 3D GIS depends on developing effective 3D models. As a large number of specialists, vendors and researchers are increasingly looking at the third dimension, developing an interoperable 3D model is essential for the success of 3D GIS. The management and exchange of information would be also relatively easy and straightforward. Indeed, it will not be possible to have one 3D model that would be able to serve all application domains. However, it should be not that difficult to agree on one core 3D integrated model (3DIM), which can be used as a reference for many applications. Practically, the topographic maps have played the role of such a core model for many decades in 2D. It is time to seriously think of a model that addresses the needs of markets and researchers and prevent thousands of different models from emerging in the coming years. GST