# Overview of Three-Dimensional GIS Data Models

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***Abstract*—Nowadays the requirements of users for application three- dimensional Geography Information Systems (3D GIS) are very large. The success key of these applications is 3D GIS data model. The paper focuses on brief presenting again the 3D GIS data models which have been proposed in the past. The paper uses the tables to compare models based on various criteria in the application of 3D GIS.**

***Index Terms*—3D, data model, GIS.**

## I. INTRODUCTION

Spatial database supports the applications that data types are characterized by spatial properties. Spatial attributes describe a space object with three factors: location, shape, size. These elements are suitable for graphic representation more than by the numeric value, string representation. The researches and developments in this area began in the 1990s. The development of 3D GIS based on 2D GIS. If 3D objects presentation by projection of 2D, it can produce losses related to the attributes, relationships between these 3D objects with other objects [1][2]. Moreover, it will create difficulties in understanding and spatial analysis on 3D objects. The complexity of 3D GIS data structures require careful analysis when adding three-dimensional in 2D GIS data model.

3D GIS are a system that be able represent, manage, and manipulate, analysis information links with 3D phenomena [3]. 3D GIS data model is the key to 3D GIS [4] and is a big topic in the five major topics of 3D GIS: WebGIS, data presentation, spatial analysis, data model and data collection. The selecting a data model to represent 3D objects 3D GIS for a specific application will determine methods to store, access ways, how to manage, how to handle the display and the data constraints. There are many models of the authors have suggested [5], [6], [7], [8], [9], [10]. The purpose of the paper provides an overview of 3D data model have been proposed, compares between the models on important criteria by tables. These tables will help us to recognize the development trend of the 3D GIS model data in the future. The attempts to classify the models will be the foundation for the researches related to 3D GIS and 4D GIS. Previously several authors have made this issue [11], [12], [13], however the works still missed some of models appearing recently and some criteria missed.

The paper proposes four tables to compare and four main types to classify the models: 3D objects are represented by its boundaries, by voxel elements, by a combination of the 3D basic block and by a combination of the above methods.

This paper structure includes six parts. Part 2, 3, 4, 5 describes the data models that represented 3D objects by theirs boundaries, by voxel, 3D basic blocks and by the combination method. Part 6 has five comparison tables of models on many different criteria

## II. REPRESENTATION 3D OBJECTS BY ITS BOUNDARIES

B-REP method represents a 3D object based on the elements already defined [4], [6], including: Point, Line, Surface, and Body. In particular, the line can be straight lines, the arcs, circles. Surface may be flat polygons, the surface created by the arcs, the cone surface, the cylindrical surface. . . Volume is an extension of the surface to represent 3D blocks; the blocks can be the box, cone, cylinder or combination of these blocks. B-REP method is suitable for representing 3D objects artificial shape and scalar.

### A. 3D-FDS (Format Data Structure)

3D-FDS model proposed by Molenaar 1990 [5], [11], [24], Rikker and colleagues developed in 1993. The basis objects of model are Body, Surface, Line, and Point. The geometric elements in model are Node, Arc, Edge, and Face. Arc is a straight line, Arc and Face does not intersect. Edge, Face is two-dimensional. Surface has boundary and may have some surfaces not nested inside. Arc and Node can exist inside the Face or Body.

### B. TEN (Tetrahedral Network)

The model proposed by Pilouk 1996 [5], [11] based on four basic objects Point, Line, Surface, Body. The geometric elements in the model include Arc, Node, Triangle and Tetrahedron. A Body was created by the Tetrahedrons. A Surface is created by Faces; Line is created by the Arcs. Node is a component of the Arc; the Arc is a component of the Triangle. Triangle is a component of Tetrahedron, the exceptions are not considered. TEN model is not suitable for building applications because it creates a large volume of unnecessary data. TEN is suitable for manipulation and calculation query in the geological application.

### C. OO Model (Object Oriented Model)

De la Losa and Cervelle proposed 1999 [4], [6]. The model can represent and manage the 2D hole and 3D tunnel. It can represent and support the complex spatial objects by using object-oriented approach. The model is built on four basic objects: 0-Simplex, 1-Simplex, 2-Simplex, 3-Simplex. Model uses 3 geometric elements: Nodes, Arc, and Face. Direction of Face should be store. Simplex is a basic geometric objects given in its dimension. Each dimension has a least element called Simplex. Simplex of n-dimension

Manuscript received September 4, 2012; revised November 18, 2012.

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is called n-Simplex.

### D. SSM (Simplified Spatial Model)

Zlatanova proposed in 2000 [5], [14]. The model focuses on the implementation of the query displayed on the 3D web application. The author uses only two geometric elements: Nodes and Face and four basic objects: Point, Line, Surface, Body. Model does not use 1D elements Arc. Face is convex and directed. The topology relationships are represented explicitly. Node can inside in the Face and Face can inside Body. Direction of Face is stored. The sequence of Nodes created Face should store in the relationship. Model built for 3D GIS applications with Web-based technologies.

### E. SOMAS (Solid Object Management System)

The model is proposed in 2001 by Plund [5], [10], including four basic entities: Pointentity, Lineentity, Polygonentity, Solidentity and 4 geometric elements: Vertex, Edge, Face, and Solid. Each vertex has a corresponding Pointentity. Vertex is defined by three coordinates (X, Y, Z). Two points start and end created each Edge. Each Lineentity created by one or more Edge. A Face was created from Edges; each Polygonentity was created from Faces. Solid is surrounded by Faces. Each Solidentity corresponds to a Solid. The objects will be transformed into relations in relation database.

### F. UDM (Urban Data Model)

The model was proposed by Coors in 2003 [5], [15], based on four basic objects Point, Line, Surface, Body. Model uses two geometric elements Node and Face. Arc is not recommended in this model. Three Nodes define each Face, so that the model reduces some relationships Node-Arc, Arc-Face. The advantages of mode are data storage efficiency, simple model and it was used in applications of urban management.

In 2010, Anh Nguyen.G.T proposed some innovations for 2D and 3D objects of UDM [16]. 3D objects were specified by cylinder, prism, cone and pyramid. These bodies were represented by new methods instead of represented by triangles. The innovations reduced query time and data size.

### G. OO 3D (Object Oriented 3D)

Shi and colleagues were suggested in 2003 [5], [10]. The model was developed based on object-oriented model and three basic geometric elements: Node, Segment, and Triangle. The basic objects in models are Point, Line, Surface, and Volume. The relationship between objects based on the links. This is a model used for software SpaceInfo, the model proved effective for display functional and display speeds faster than previous models due to the characteristics of object-oriented approach but data size are large.

### H. CITYGML Model

Gerhard Groger and his colleagues suggested in 2007 [8]. The idea of model build 3D city model in the open form and based XML. The purpose of the model is to develop common definitions related to the entities, attributes and relationships in 3D City models, so different applications can share a common data source. CityGML model is represented by objects of the geometry model GML 3. This model is based on ISO 19107; it represents 3D objects as B_REP method. Each dimension is a primitive geometry: the object 0D is Point, 1D object is a_CURVE, 2D object is a_SURFACE and 3D object is a_SOLID. Each geometric object has the reference coordinate system. A Solid is surrounded by the surfaces, a surface is surrounded by the a_CURVES, and an a_CURVE is limited by straight lines. A surface is represented by the polygons. Composite is a particularly complex object, it can only contain elements with the same dimensions. Their elements are disjoint but they must have topology relations between boundaries. A composite can be CompositeSOLID, CompositeSURFACE, and CompositeCURVE. Trianglesurface is particular Surface; it is used to represent terrain. Trianglesurface is an explicit combination of the Triangles. CityGML has not only spatial property but also semantic property

## III. Representation 3D Objects by Voxel Elements

The 'voxel' term had originated from two words 'volume' and 'pixel'. A voxel is a volume element [17], [18]. Voxels are introduced to represent geobodies [19]. The simplest representation of voxels has face that its shape is square. In the complex representation, face has a different size and shape [20].

### A. 3D arrays Model

This model has a simplest data structure using to represent 3D objects [4], [6]. The elements in a 3D array have two values in 0, 1. Value 0 describes the background value and 1 describes each element in the 3D array was captured by 3D objects. If a 3D object is scanned in a 3D array where the elements of the original array is initialized with value 0 then after scanning to 3D objects, the elements have value 1 using to represent for that 3D object.

### B. Octree Model

Octree is an extension of quadtree. Octree is a 3D model based on volume; it is more efficient than the method of 3D array [4], [21], [22]. Octree representation is better than a pure voxel representation by large cubes [23]. Quadtree is a representation method by tree structure. Generally, a quadtree is defined based on a smallest cube containing 3D objects need representation. Initial cube is divided into eight child cubes. A quadtree based on a partition of the recursive algorithm. In the tree, each node either a leaf or it has 8 child nodes. Each node will have three values F, E, P. F describes an element is completely occupied by the object, E is not occupied and P is occupied a part. Only the nodes P are divided into 8. Characteristics of quadtree model are simple data structure, convenient operation. However, the data size is large and requires more costs for process.

## IV. Representation 3D Objects by a Combination of the 3D Basic Block

CSG (Constructive solid geometry) model represents a 3D object by a combination of 3D elements were defined [4], [6]. The 3D elements are generally common shapes such as cube, cylinder, cone, prism, and sphere. The relationship between these objects includes transformation and logic operators. The logic operators are union, intersection, minus.

The transformations are rotation, change the scale, and translate. CSG model commonly used in CAD. CSG is very convenient to calculate the volume of objects; CSG is not suitable to represent objects with unusual geometry. CSG model suits where the model focuses on the global structure more than local structure [24].

## V. THE COMBINED MODELS

### A. V3D model

Xinhua Wang and colleagues suggested in 2000 based on the idea of integrating raster images and vector data on 3D GIS model [9]. Model uses 4 basis objects Point, Line, Surface, and Body. Point is 0D object, but no size. Line is the 1D object; it is built on the connection of straight lines. Surface objects are 2D or 2.5D, it has area, circumference and is built on the face known as Facet. The model uses 3 geometric elements corresponding to the objects Node, Edge, Facet. Node can represent for a begin or an end vertices of an Edge. Edge is a line segment, it has the beginning node and ending node, it can be a part of Line or a portion of Facet. Facet is the intermediate geometry element, which is represented through Edges. A Facet is related to an Image. DTM is a special kind of data to describe the sequence of Facet, a standard data types can be represented by regular cells or irregular.

### B. Combined Model Between CSG and B_REP

Chokri, Koussa, Mathieu, Koehl proposed in 2009 based on new idea. 3D objects are represented by combination of two methods B_REP and CSG. B_REP model used in four basic objects Point, Line, Surface, and Solid [7]. Two vertices define a Line. A Surface is defined from closed-strings; it can be no direction or direction. A Surface may be full or empty. Empty_Surface used to describe the hole. A Solid is represented by a set of surrounding Surface. It may be full, or empty. Full_Solid is created by the set of Surfaces, inside of theirs not be modeled. A CSG_Composit is created by union, intersect, minus between the Solids. Advantages of this approach are based on the advantages of B_REP and CSG method.

## VI. COMPARE MODELS

### A. Comparing the Models on the Following Criteria: Surface Representation Method, Objects Inside Representation

Most models are not applying the method of surfaces triangular. Some models have focused on inside representation the 3D objects, such as the model is object-oriented approach, CSG and voxel. Almost the models focus on representation the outside of 3D objects (Table I).

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### B. Comparing the Models on the Following Criteria: Primitive Elements, Geometry Elements and Application of the Model.

The models had very similar opinions about the main element; they are the object in reality, including Point, Line, Surface, and Body. The additional elements are the geometric objects; they are not true in reality and intermediate to link the basis elements. The sub-elements of different models are often different (Table II). Two models SSM and UDM have small data size. Voxel approach suits geological application and vector approach suits urban management.

TANLE I: COMPARING MODELS IN SURFACE REPRESENTATION METHOD AND OBJECTS INSIDE REPRESENTATION

| Style of model | Authors | Model | Surface representation | Objects inside representation |
|---|---|---|---|---|
| BREP | Molenaar, 1990 | 3DFDS | Non triangular | No |
| | Pilouk, 1996 | TEN | Triangular | Yes |
| | Zlatanova, 2000 | SSM | Non triangular | No |
| | Delalosa, 1999 | OO | Triangular | Yes |
| | Pfund, 2001 | SOMAS | Non triangular | No |
| | Coors, 2003 | UDM | Triangular | No |
| | Shi et al, 2003 | 00 3D | Triangular | Yes |
| | Groger et al, 2007 | City GML | Triangular | No |
| Voxel | NULL | 3D Array | Non triangular | Yes |
| | Meagher, 1984 | Octree | Non triangular | Yes |
| CSG | Samet, 1990 | CSG | Non triangular | Yes |
| Combi nation | Xinhua et al, 2000 | V-3D | Non triangular | Yes |
| | Chokri et al, 2009 | B_REP + CSG | Non triangular | No |

### C. Comparing the Models based On the Following Criteria: Spatial Structure, Direction, Measurement, and Topology

Most models have a vector space structure, except for Octree and 3D Array model. Topology relationships only have in two models 3DFDS and SSM. However, the topology relationships between objects in these two models also limited if it is compared with 2.5. Direction of spatial objects such as left- right, above-below, front-back and only be stored in four models 3DFDS, OO, SOMAS and UDM. Measurement of area, volume of 2D, 3D objects can be calculated in models of TEN, UDM, 3D Array, Octree, CSG, CSG+B_REP (Table III).

### D. Comparing Models based on Query Criteria: Attributes, Location, and Topology

Spatial query includes attribute, position and topology queries [25]. Only two models are stored topology relationship supporting for query: 3DFDS and SSM. Most models only represent spatial attributes of 3D objects, only two models represent semantic attributes of 3D objects: City GML, B_REP + CSG. The vector approaches can query the location of 3D objects (Table IV).

TABLE II: COMPARING THE MODELS IN PRIMITIVE ELEMENTS, GEOMETRY ELEMENTS, FOUNDATION, DATA SIZE, APPLICATION

| Style of model | Model name, primitive elements | Geometry elements | Main ideal | Data size | App |
|---|---|---|---|---|---|
| BREP | 3DFDS. Point, Line, surface, body | Node, arc, face | 2D GIS model | Large | 3D UM |
| | TEN. Point, Line, surface, body | Node, Arc triangle, tetra | Tetra hedron | Large | GA |
| | OO. 0-simplex, 1-simplex, 2-simplex, 3-simplex, | Node, arc, face | Oriented-Object, n-simplex | Large | 3D UM |
| | SSM. Point, line, surface, body | Node, face | Oriented - Object, topology | Small | 3D WEB Urban |
| | SOMAS. Point, line, polygon, solid | Vertex, edge face, solid | Oriented-Object | Large | 3D UM |
| | UDM. Point, line, surface, body | Node, face | Triangular | Small | 3D UM |
| | OO3D. Point, line, surface, volume | Triangle, segment, node | Oriented - Object, triangular | Large | 3D UM |
| | CityGML. Point, curve, surface, solid | Polygon, linestring | Define the standards of object | Large | 3D UM |
| Voxel | 3D Array. 3D array | None | Partition object by array | Very large | GA |
| | Octree. Cube | None | Partition object by voxel | Very large | GA |
| CSG | CSG. Basic 3D block | NULL | Combine basic 3D block | Small | CAD /CAM |
| Combination | V3D. Point, line, surface, body, raster | Node, edge, face | Combine BREP and raster | large | 3D UM |
| | B-REP + CSG. Point, Line, Surface, Body, Basic 3D block. | Linestring, Face | Combine BREP and CSG | large | 3D UM |

Notation: 3D UM: 3D Urban management, GA: Geological application, App: Application.

TBALE III: COMPARING THE MODELS IN SPATIAL STRUCTURE, DIRECTION, MEASUREMENT, TOPOLOGY

| Model | Spatial structure | Direction | Measurement | Topology |
|---|---|---|---|---|
| 3DFDS | V | Yes | No | Yes |
| TEN | V | No | Yes | No |
| SSM | V | No | No | Yes |
| OO | V | Yes | No | No |
| SOMAS | V | Yes | No | No |
| UDM | V | Yes | Yes | No |
| OO 3D | V | No | No | No |
| CityGML | V | No | No | No |
| 3DArray | R | No | Yes | No |
| Octree | R | No | Yes | No |
| CSG | V | No | Yes | No |
| B_REP+CSG | V | No | Yes | No |
| V-3D | VR | No | No | No |

TANLE IV: COMPARING THE MODELS IN ATTRIBUTE, POSITION, TOPOLOGY RELATIONSHIP QUERY

| Model | Attribute query | Position query | Topology relationship query |
|---|---|---|---|
| 3DFDS | No | Yes | Yes |
| TEN | No | Yes | No |
| SSM | No | Yes | Yes |
| OO | No | Yes | No |
| SOMAS | No | Yes | No |
| UDM | No | Yes | No |
| OO 3D | No | Yes | No |
| CityGML | Yes | Yes | No |
| 3D Array | No | No | No |
| Octree | No | No | No |
| CSG | No | Yes | No |
| B_REP +CSG | Yes | Yes | No |
| V-3D | No | Yes | No |

### *E. Comparing Models based on Representation: Lod, Curve Surface, Semantic, History*

Levels of detail (LOD) are levels division to represent 3D objects. Only CityGML has 5 levels. Other models have only one. Models have no time dimension, so models haven’t evolution history of objects. Only CityGML has semantic attributes. Almost models can represent curve surfaces so voxels approach or trigulation. CGS can represent special curve surfaces (Table V).

TBALE V: COMPARING THE MODELS ABOUT LOD, CURVE SURFACE, SEMANTIC, HISTORY REPRESENTATION

| Model | LOD | Curve surface | Semantic | History |
|---|---|---|---|---|
| 3DFDS | 1 | No | No | No |
| TEN | 1 | Yes | No | No |
| SSM | 1 | No | No | No |
| OO | 1 | Yes | No | No |
| SOMAS | 1 | No | No | No |
| UDM | 1 | Yes | No | No |
| OO 3D | 1 | Yes | No | No |
| CityGML | 5 | Yes | Yes | No |
| 3D Array | 1 | Yes | No | No |
| Octree | 1 | Yes | No | No |
| CSG | 1 | Yes | No | No |
| B_REP +CSG | 1 | Yes | No | No |
| V-3D | 1 | No | No | No |

## VII. CONCLUSION

The main purpose of the paper is to present the development history, the main features of the 3D data model. Each model has different advantages and limitations. The advantages of this model may be difficult for the other models. Choosing model depends on to develop a specific 3D GIS application. This paper classifies models based on the nature of data structure on each model. The paper has created five comparison tables to 13 models on universal criteria in the areas of GIS, based on their characteristics. The tables again help the researchers have an overview of 3D GIS data model in past and recent years. It is the basis theory to envision in the next work of research and the important foundation for researchers to build models of 4D GIS later.

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