THE MODELLING OF URBAN LANDSCAPES

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Commission III, Working Group IWG III/4

KEY WORDS : Geometry, Urban, Acquisition, Modeling, Reliability, Three-dimensional, DEM/DTM

ABSTRACT

Geographic information systems with a real three-dimensional structure do not really exist at this time. The requirements in three-dimensional administration do not often justify the complexity of such systems. However the facilities offered by the administration of the real third dimension exceed widely the notion of height information. So more and more users are interested in this supplementary dimension. It's all the more true in urban environments as the height of the features is often equal or greater than the size of the features on the ground.

A first approach of the problem consists to decompose complex three-dimensional features in two dimensional features that we are able to administrate.

A constructive approach for such models is based on objects that are built with blocks themselves constituted by geometrical primitives. These geometrical primitives are classical geometric elements or CAD-elements that contain construction and data acquisition constraints defined by the user. New types of geometrical elements called bands, traces, faces and points with a supplementary dimension complete the initial library of features types.

All constitutive elements of a 3-D object are grouped and surrounded by and envelope. This envelope allows to select the finished object or to include it in the 3-D space even if it is not finished.

To come back to the detailing grade and the geometrical precision searched for, the different 3-D objects are hierarchically decomposed into basic elements. Each basic element contains its own local coordinate system, which can be used to integrate and fit into it other data by using coordinate transformation.

The thematic and descriptive data are hierarchically structured like the hierarchical construction of the different 3-D objects.

RESUME

A l'heure actuelle, les systèmes d'information géographique ne comportent pas encore véritablement une réelle et complète structure 3-D. En effet, la nécessité de l'utilisation de cette 3^{eme} dimension ne justifie souvent pas la complexité de tels systèmes. Cependant les solutions apportées par la gestion d'une réelle 3^{eme} dimension dépassent de loin la notion d'information altimétrique. C'est pourquoi de plus en plus d'utilisateurs sont intéressés par cette dimension supplémentaire.

Ceci est d'autant plus vrai dans les paysages urbains, où la hauteur des objets est souvent égale ou supérieure aux dimensions de l'objet au sol.

Une première approche consiste à décomposer les objets complexes à 3 dimensions en des objets à 2 dimensions qui se gèrent facilement.

Une autre solution se fonde sur des objets constitués de blocs eux-mêmes construits à partir de primitives géométriques. Ces primitives géométriques sont des corps géométriques classiques ou des corps issus du dessin assisté par ordinateur et élaborés d'après des contraintes de construction et des méthodes d'acquisition définies par l'utilisateur. De nouveaux types d'éléments géométriques tels que des bandes, des traces, des faces et des points flanqués d'une dimension supplémentaires viennent compléter la palette d'éléments initiaux.

Tous les éléments constitutifs d'un objet 3-D sont regroupés et entourés par une enveloppe. Celle-ci permet à la fois de sélectionner l'objet, s'il est achevé, ou de l'inclure dans l'espace 3-D, tout en restant inachevé.

Pour revenir au niveau de détail et de précision géométrique recherché, les différents objets 3-D sont redécomposés hiérarchiquement en des éléments de base. Chaque élément de base comporte son propre système de coordonnées, ce qui permet l'intégration et l'adaptation des données supplémentaires par le biais d'une transformation de coordonnées.

Les données thématiques et descriptives sont structurées hiérarchiquement d'après la hiérarchie de construction des différents objets 3-D.

INTRODUCTION

A Geographic Information System (GIS) is a system that is used to manage and represent data for the description of a part of the earth.
In the most existing GIS packages the third dimension is not considered as a real dimension, but is only considered as a supplementary dimension or rather as a supplementary information.
At present, the well used GISs contain data that apply only to two dimensions in the specific ground system and that are completed with height information. These GISs are called 2.5-D or 2-D + 1-D (Bill, Fritsch, 1991) (Kraus, 1991).
A Digital Terrain Model (DTM), in which only the third dimension is significant, can be a part of these GISs and is another important, well defined and often integrated concept.
The aim of most existing 3-D systems is the viewing of 3-D perspectives to perform urban planning, insertion of urbanistic projects into urban areas. A real 3-D model involves the use of a structure where for each point the x, y and z coordinate have the same significance (Rongxing, 1994).

1. OBJECTS IN URBAN LANDSCAPES

GISs are used to manage objects that describe a specific part of the earth reality.
In an urban landscape there are artificial objects which have a very complex architecture. This is the reason why these objects contain very complex shapes.
Objects contain often very significant characteristics in the third dimension because they are often higher than wide. A house or an apartment building can not be efficiently modelled with an area boundary. They have got heights, several floors, cellars of which the fittings out could be significant to be represented and managed.
There are also other types of objects that are very complex, like bridges, tunnels or underground buildings, and that in addition have got overlapping parts. This kind of objects needs more than one level for their description. Our system has to allow also the managing of such complex objects. This is only possible if the third dimension is considered as a real dimension and as a real part of the objects.

2. GEOMETRIC RELIABILITY

The important factors in the definition of a system are the geographic position in the 3-D space and the geometric particularities of the data. These particularities will make it possible to oppose the systems based on a reliable geometry with the systems expected for the only representation and visualisation.
The 3-D data are acquired by using surveying and photogrammetric techniques with the principal objective of achieving and preserving a reliable object. This can be performed by storing as data all the measures obtained during the acquisition.
The storage of all ground measures allows to get primary acquired data in reply to specific geometric queries.
The object representation could be slightly different than the measures done because it results from the fitting out of the measures to geometric and topologic constraints.

3. BASIC STRUCTURE

In wide area systems that do not contain very complex and subtle elements, a Digital Terrain Model (DTM) can be used as a basic structure of the 3-D model. In this case, the DTM is the structure that holds up the objects.
In a real and complete 3-D model, the DTM is the inferior part of the superficial objects but is also the superior part of the underground objects or, more generally, will determine the intersection between the ground and the objects placed over, under or in it.
This DTM is very important and is to be considered as the basic concept of this modelling. It is used to define and to build the ground terrain surface, but can also be used to form and to build complex surfaced shapes (Kager, Halmer, Heitzinger, 1996).

4. THE MODELLING OF 3-D OBJECTS

In order to achieve geometric reliability, solids from the concept of constructive solid geometry can not be the only primitives used for efficient 3-D modelling. Nevertheless, this concept can give us a library of initial geometric shapes.
To supplement this concept, new types of complex objects can be hierarchically defined. These new complex object types are in fact the result of the combination of blocks by using geometric constructive operators. Blocks are themselves a combination of basic primitives which are, at last, split up to increase the precision grade.

4.1. Envelope of the blocks

Each block placed in the 3-D space is surrounded by an envelope (smallest surrounding prism). The envelopes make it possible to integrate objects which are not definitively formed into the 3-D space. These envelopes are also used for the selection of the objects by their graphic representation.
There are two types of envelopes : the validated one that contain definitively formed objects and the not validated one that contain not definitively formed objects.
These different envelopes ask the problem of continuity management between adjoining envelopes. Two adjoining objects contained in two validated envelopes will define several common intersections on the objects themselves.
Two adjoining and not definitively formed objects that are contained in two not validated envelopes will define their intersections on the envelopes and not on the objects themselves.
In the not validated envelopes all the construction parameters of each object must be stored with the objects so that their constructions can be fulfilled in a next step.
These different concepts can be extended to the primitives of objects that can that way be validated or not.

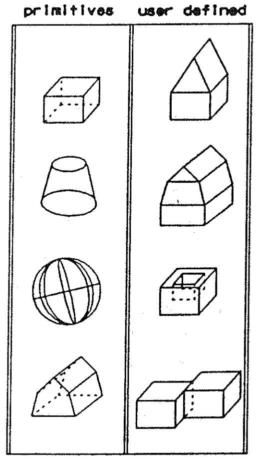

Figure 1. Basic and user defined primitives

4.2. Basic primitives

The basic primitives that are used are the classical boxes, spheres, cones and prisms. These different primitives contain more specific primitives with a more restrictive topology : a box contains a cube, a cone contains a cylinder, a prism contains a pyramid.
The topological definition of the basic primitives is taken from a library of predefined shapes.
An extension of these primitives involves new basic element types :

Bands, Traces, Faces, H(eight)-Summits, H(eight)-Contour Points , H(eight)-Points

considered as a regular surface limited by its surrounding shape.
It exists two different ways to define such a Band :
- the first way consists to acquire the superior shape of the Band and to project it onto a reference surface,
- the second way consists to acquire the shape directly on the ground surface (intersection between the Band and the ground surface) and to elevate it to a specific user defined level or elevation.

- A Trace is a linear based surface that is the equivalent to the surface based volume called Band described before. In this case, the acquired element is a line. The acquisition exists also in the two same ways as for Bands.
- H(eight)-Summits / -Contour Points / -Points are different types of points that are possible to be used in the model. Like with Bands and Traces, these different types of points make it possible to increase the dimension by one for an object that is acquired as a point (its projection on the ground surface is a point). Its linear dimension is defined between the measured summit and his projection onto the ground surface.

Like the Bands and Traces, the H-Elements can be acquired directly on the ground surface and then laid out to a user defined level or elevation.

- A Face is a surface that is contained in and that belongs hierarchically to another ground surface.

4.3. Other complex primitives and modelling

If a primitive does not exist in the library of basic primitives, then it can be created through its topology by using the different tools of a CAD-system (Figure 1.).
The different elements that compose the new objects are

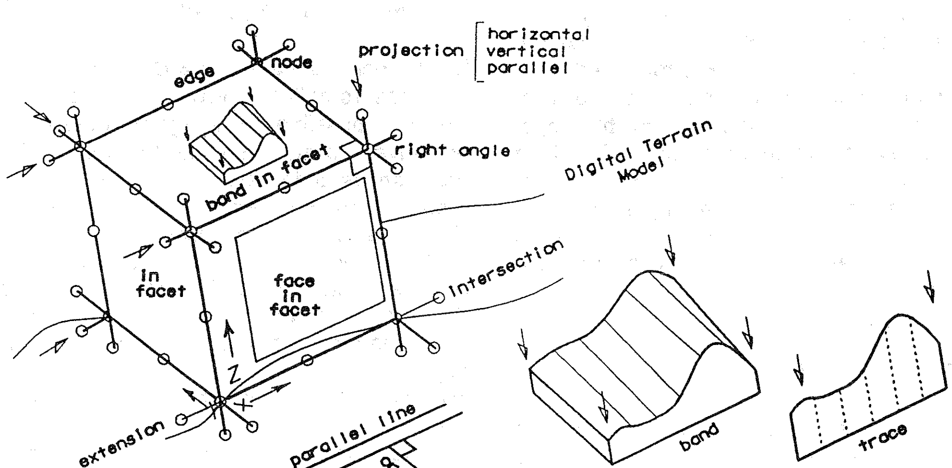

Figure 2. Tools and new element types

- A Band is an object that is acquired in form of a surface shape and that will be used as a volume. The volume is obtained by means of the projection of the acquired and measured surface on another surface which is the ground surface. The surface is

assembled in this way according to the topology of construction (right angles, elements in line, projection, extension, object membership...).
At time of the building of the CAD-primitives, the specific points used for the acquisition and the topology of these

user defined primitives are organised by the operator. (Figure 1.)
The object with its true geometry is the result of the adaptation of the measures carried out on this object to its topology.
A solution for the modelling of an undefined or not common surface, for example a curved road on a bridge, is given with a 3-D triangular irregular network as a surface model, which can be created with the DTM algorithms (Pfeiffer, Pottmann, 1996).

4.4. Hierarchical splitting up of the primitives

To increase the geometric reliability the different primitives are split up into basic elements. This splitting up make it possible to perform the selection of all constitutive basic elements of a complex object.
The special case of the intersections between the primitives must also be taken into account. These special intersection are other constitutive and basic elements that will be manipulated, transformed and requested.
After acquisition of supplementary data, the model can be worked out again, and these new data are incorporated into the basic and decomposed structure through a coordinate transformation. A photogrammetric plotted frontage, full of subtle details can in this way be incorporated in a primitive face of an object. This face results of the splitting up of a volumic object -like a box- in sample surfaces surrounded by borderlines. The different characteristics of the elements like the corners, the nodes, the right vertical or horizontal edges are used for the adaptation and transformation of coordinate. The finally the homogeneity of the representation in the information system.

4.5. Local coordinate systems

Each 3-D element contains its own local coordinate system. This coordinate system is at first a rough one for the basic primitives. The local coordinate system is allocated to each element -in its dimensions- automatically or by the operator during the acquisition :

- For a point or an H-element, the local coordinate system is defined with an origin and three orthonormal axis.
- For a linear element, the local coordinate system is defined with an origin on the element and a principal direction along the element.
- For a surface element, the local coordinate system is also defined with an origin on the surface and three orthometric axis. The third axis allows to describe the depth in the surface element and can be used for the integration of a face into a surface.
- Complex 3D-objects can also have got local coordinate systems that are defined with characteristic points. These characteristic points allow to place or move the complex 3D-objects in the 3D-space.

The coordinate system can be oriented according to the nature, the way of acquisition and the utilization of the different elements.
The coordinate system becomes more accurate as the geometrical precision of the element becomes higher.

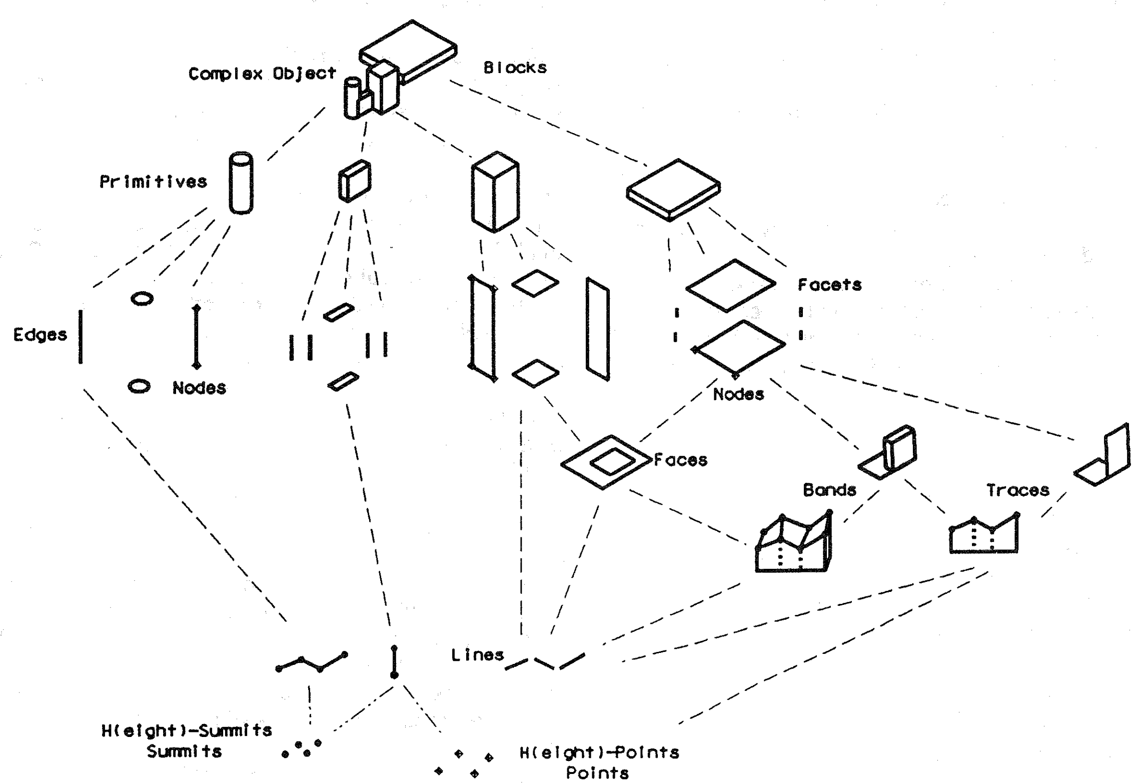

Figure 3. The hierarchical structure

storage of the two modes of initial coordinate systems allows to save the primary data -with geometrical value-, the adaptation from a coordinate system into another and

Transformations of coordinate allow the integration of elements into higher level primitives. The different coordinate systems are closely related to the measures carried out on the ground objects.

There are tools to combine the most accurate data with the other ones, or to leave the two data types separately in the same system. This coordinate system allows also the integration of hybrid data types like raster data, images, façade plottings (Grussenmeyer, 1994, Figure 4)

4.6. The hierarchical structure

Finally, the hierarchical structure of complex objects is the following : (Figure 3.)
3-D complex objects
.. Blocks
.... Primitives (Geometric or CAD)
...... Facets (basic elements : Edges / Contours / Nodes / Contour points)
.... Faces (basic elements : Lines / Summits / Contour points)
.... Bands (basic elements : Lines / H-Summits / H-Contour points)
.... Lines (basic elements : Lines / Summits)
.... Traces (basic elements : Lines / H-Summits / H-Contour points)
.... H-Points

5. DATA ACQUISITION AND CONSTRUCTION TOOLS

The data acquisition is performed by means of numeric information (coordinate). The adaptation and integration of the topology into the 3-D space takes place as soon as the metric data are measured.
The modelling of the objects is based on the way of acquisition and updating.
To build objects, it is necessary to have a range of specific tools : (Figure 2.)

- different projection modes (horizontal, vertical, parallel to predefined directions)
- different intersection modes (with the DTM, between objects, between surfaces)
- extensions, parallel lines, closing of polygons, angular predefined polygon ways.
- adjustment and integration of profuse data.

As soon as the terrain measures are sufficient in number for the definition of the object, this one is formed and placed in the restituted space. All the measured points

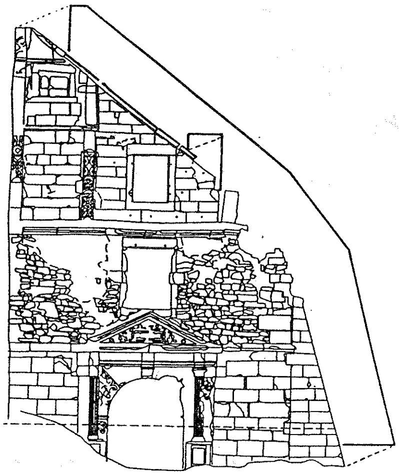

Figure 4. Architectural photogrammetry (Castle of Lichtenberg - France)

are stored as ground information. The final object is a hierarchical agregation of blocks which are a combination of basic primitives.

6. INTEGRATION OF TOPOLOGY AND ATTRIBUTE DATA

Besides geometric representations, topology and attribute data are two other important components in GISs. A harmonic integration of these components is a vital issue in 3-D developments (Rongxing, 1994).
The database is structured according to the modelling. The concepts of hierarchy and agregation are the basic concepts that define the relation between the complex objects and the primitive elements. The attribute data are structured from the same principles.

CONCLUSION

3-D urban objects can be classified into two categories : the regular and the irregular shaped objects. The irregular shaped objects can be modelled with DTM algorithms. The regular shaped objects are a combination of geometric primitives like the primitives of constructive solid geometry. But for preserving the geometric reliability it is necessary to supplement the structure of these primitives with a hierarchic composition of basic elements. Local coordinate systems and transformation tools are other very useful components of such systems.

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