Data Structuring and Visualization of 3D Urban Data

Some Aspects of the Doctoral Research " 3D GIS for Urban Development"

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Abstract

The major idea of the current research is to build a concept for a 3D GIS appropriate for maintenance and real-time manipulation of municipality data via Internet. A model containing geometric and thematic information about objects, spatial and thematic relationships should be developed. The research focuses the geometric aspect of the problem with emphasis on development of a scheme to exchange data between the database and rendering engines for visualization, navigation and manipulation.

The approach for visualization and interaction is based on the utilization of Virtual Reality Modeling Language (VRML) and 3D Formal Data Structure (3D FDS). The VRML is chosen to model the scene for visualization, i.e. to describe geometry, introduce dynamics, illuminate the model, work via Internet, while 3D FDS is considered as basic data structure for data storage and spatial analysis.

A variety of visualization queries were performed in order to test suitability of the couple 3D FDS and VRML for interaction with the model via Internet. The results of queries were visualized in HTML and VRML browsers. The experimental work has revealed several shortcomings of 3D FDS with respect to fast composing of the VRML file:

1. The storage of coboundary relationship per *face,* i.e. *left/right body,* imposes maintenance of information about "air" body and "underground" body, which speeds down the formation of surfaces and bodies.
2. The explicit storage of boundary relationship per *arc*, i.e. *begin /end node,* does not show many advantages but requires extra traversing of one more table for visualization.
3. The implicit description of "holes" complicates the algorithms for coordinates extraction.

It can be concluded that all the necessary information for visualization of point, line, surface and simple body objects can be extracted from the 3D FDS. However, organization of data is not efficient to supply data for the followed approach.

One direction of the future work is related to extension of the conceptual model toward refinement of the object identification, aggregation of multi-dimensional objects, definition of parameters describing behavior of object, developing a technique supporting LOD visualization. Another aim is refinement of the concept for partitioning of the objects, especially surface objects, in order to avoid rendering pitfalls. The aspects addressed here contribute to clarification of a strategy for real-time manipulation of data.

1. Introduction

The investigations of the current research are towards a strategy for a 3D GIS capable to deal with 3D urban information, allowing interactive spatial queries via Internet. Each of these key issues requires specific consideration and influences the selection of: 1)methods to collect data, 2)approaches to organize, retrieve and maintain information and 3) techniques to visualize, navigate and interactively query the model (Tempfli and Pilouk 1996).

3D urban data have always been difficult to organize basically due to the complex geometry. Variety of regular and irregular shapes, overhanging elements, concave shapes, multi-layered constructions, etc. are some of the trouble stones. The complexity requires appropriate subdivision of the space for simplification of the data set and facilitation of data storage. In contrary, attribute and thematic data very often are assigned to composition of objects. The quite large amounts of data (geometry, text, texture) bring up questions of storage on distributed systems and special structuring of data (e.g. LOD for geometry and texture) for fast rendering.

A new aspect of the pursued 3D GIS is the manner of query and display of the outcomes. In the years of fast hardware and software development it is impossible to overlook some existing techniques for visualization and navigation through models. At least low level virtual reality (VR) techniques like walk-through fly-over, examine, etc. has to be offered to improve legibility of data, facilitate manipulation and orientation inside the model. Many software vendors already provide either tools to navigate through the model or export files which can be visualized in VR browsers. Techniques for introducing and controlling dynamic objects are already standardized and platform independent. Therefore, working on a 3D data structure, relevant information for visualization and interaction should be considered. The scope of the information stored per object has to be extended to embrace data and parameters for scene creation and dynamics.

The users of urban data are usually from various companies (e.g. municipality, electrical, water&sewage companies, tourist agencies, etc.) distributed in different building and parts of the town. Remote access to the information is obligatory if we want to: 1)to reduce the time and man-power for service and 2) to eliminate visiting the GIS server to request information. One way is to build an Intranet network only among the users. Ànother way is to connect to Internet and fetch information via Internet. In both cases client-server connection should be established (see Figure 1)

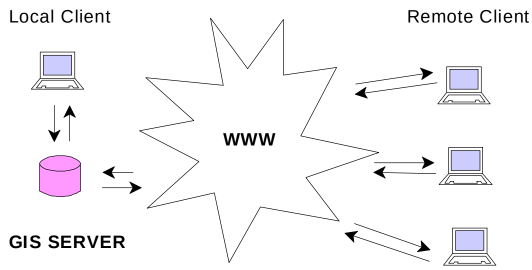


Figure 1: Client-server 3D GIS

Among the various problems related to 3D VR GIS the presented paper focuses on several issues related to appropriate data structure for storage and retrieval of information not only for spatial analysis but also for visualization. First, a short explanation of the method for visualization and query will be given, second, the structure of VRML and 3D FDS will be clarified and finally some conclusions and recommendations about 3D FDS as a data structure capable to store data and respond to queries via Internet will be presented.

2. The approach

The approach followed in the research is based on a combination of tools and techniques for access and exchange of data via Internet/Intranet (see Figure 1). Text information is visualized in the HTML and the VRML is utilized for graphic information. This implies that the user has to be provided with software to browse text and graphics at the client station. The client works on a subset of the information (graphic model or text in form of tables, lists, etc.) which physically can be either on the server or copied to the client computer. The process of query, visualization and modification has several stages:

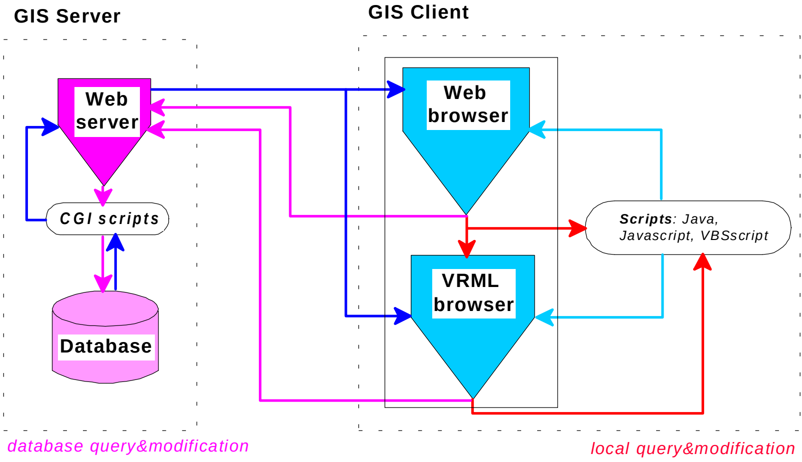
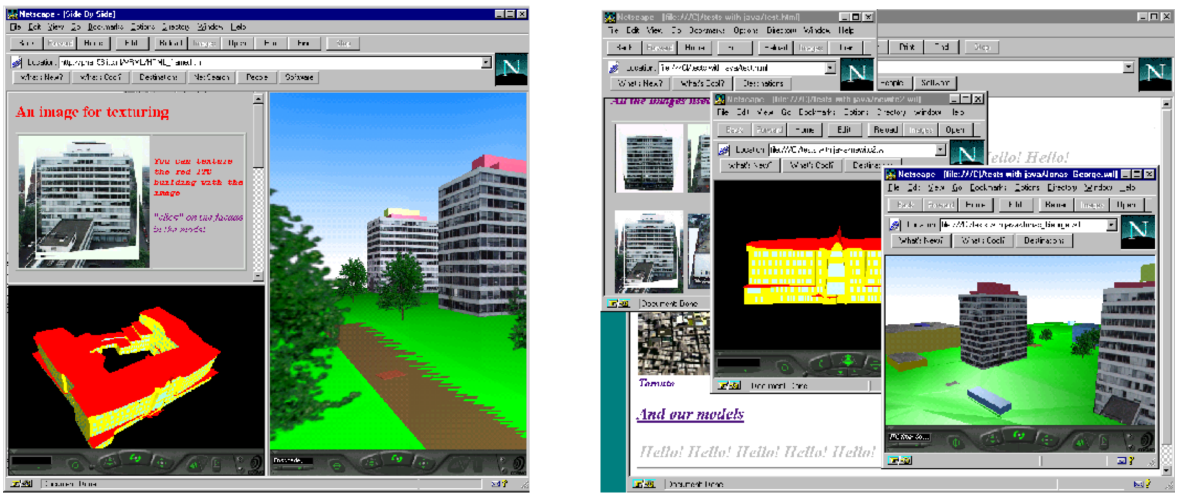


Figure 2: Data flow in client-server 3D GIS

1. User identification. At this stage a broad spectrum of important issues related to the protection of the database, multi-user access, priority for modifications, etc. has to take place. Since the problems are beyond the scope of the research, they will not be discussed further.

2. Query. The steps to request information are standard and widely implemented for various purposes (purchasing, searching). After user identification, the web server returns an initial form, where the user can specify what kind of information he/she needs. The form is filled out by the user and send by the web browser at the client station (see Figure 2) back to the web server. The server executes a script which extracts the necessary information from the data base, creates (on fly) a certain file (or files) and returns the result to the client. The simplest request to the web server is to return the URL of a file which already exist, e.g. a file with the 3D graphic model of the entire town. Most often, however, the queries to the GIS server will be initiated by a user action inside the 3D model, e.g. the click with the mouse on a building can be interpreted by the browser as request of information about the owner of the building.



a) one window **b) several separate windows**

Figure 3: VRML and HTML browsers at the client station

3. Data visualization. The information received at the client site is visualized either in a HTML browser (text, 2D graphics, etc.) or in a VRML browser (3D graphics and text). The user can interact with the 3D model inside the VR browser, fly-over, walk-trough, examine and at the same time browse text information in the HTML browser. This can be displayed at the client screen in several ways: one window with several frames (see Figure 3a), several new windows (see Figure 3b) or combinations of them. The individual windows provide the user with more freedom to resize and adjust observed models, however,

they complicate the control on displayed information and very soon create chaos on the client desktop. The way to visualize 3D graphic information on the Internet is similar to visualization of text information. A file with complete description of the scene for visualization, i.e. geometry, text, lights, texture, camera position, is created. The file is processed further by a VR browser which parses the information and creates a scene graph. In fact the VR browser plays the role of the rendering engine in our approach.

4. Data modification. The term “data modifications” states for each change with the data set (geometry and text). Graphic data modification can be deletion, adding, changing some values in the data set. When the changes cover very large areas, indeed, automatic methods should be developed. Our interest, however, is in small changes which the user prefers to make manually. For example, texture changing for simulating future changes of facades, operations on geometry for setting up a new building, positioning of trees to design vegetation. The way to make such small modifications of geometric information is to utilize techniques provided by the VRML, i.e. sensors, interpolators, or by scripts (Java, JavaScript or VBS scripts) written by the user and supported by the browser at the client station. The scripts run only at the client side and do not influence the information on the server, neither the other clients. If the user is authorized to change the information in the data base he has to follow a fill_out procedure similar to the query of database, i.e. a form with desired parameters for modification and their new values has to be filled in and sent to the server for processing by a CGI script on the server (see Table 1).

Table 1: Techniques for interactive manipulation of 3D GIS data

	local changes	global changes
server (database)	CGI scripts	database updating software
client	VRML, Java, etc.	VRML, Java, etc.

Flexibility of the system in terms of an easy adjustment for various tasks, hardware and software independence of the clients, are the major advantage of the approach. The software development does not need to start from scratch. Many software modules already exist, e.g. fill-out forms, SQL scripts to access databases, security techniques, etc. A significant advantage is the use of Web and VRML browsers for display, which in practice, releases the software developer of the tedious work on graphics user interface. The approach ensures easy, low cost, standardized access to 3D models.

3. Data structures

One of the big challenges in 3D urban modeling is the visualization process with respect to increase readability of data and realism of the model. Another advanced issue is interaction with the model and dynamic modifications, which require clarification of object’s behavior. With respect to data structuring this means 1)enhanced attribute information related to the visualization of geometry, e.g. material and color for rendering, texture for texture mapping, 2)parameters characterizing the behavior of dynamic objects. The strategy for visualization and manipulation, described above, implies that VRML is used for scene design. Another data structure, i.e. 3D FDS is used for data storage. Apparently, the major operation within the query&visualization process is a conversion between 3D FDS and the standard VRML. Therefore, first, we will make short overview of the mechanisms provided by the VRML to model 3D objects and after that we will clarify the concept of 3D FDS.

3.1 VRML

Among the rendering languages, VRML is a high-level language for scene modeling providing not only techniques and methods for rendering but also dynamics. The dynamics range from techniques to play animation to detecting user actions (e.g. “mouse click”) and consequent reaction of objects. In this aspect the methods provided by the language can be classified as methods for scene design (geometry, lights, textures, etc.) and methods to bring dynamics.

The geometry can be performed by using predefined shapes (cone, box, sphere, etc.) or by sets of faces, lines and points. Since most of the geometry in urban areas is derived from measurements, it is difficult to operate with predefined shapes. Therefore we will concentrate on the way VRML handles irregular shapes. The main unit in the VRML is an object named *node* that can be everything, e.g.. geometry, text, view. The *node* dealing with geometry is *Shape*, which has three basic elements: *appearance*, *geometry* and *behavior*. The appearance contains data for rendering, behavior can be simulated by a combination of sensors for detection of user's actions and interpolators for changing object's parameters.

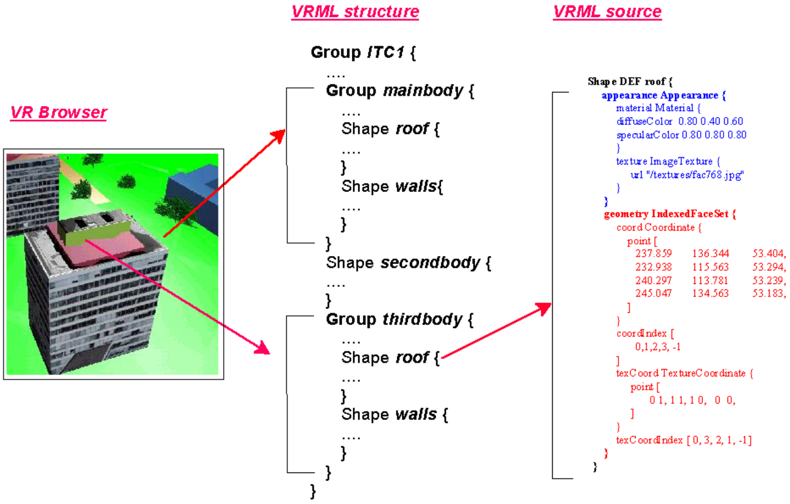


Figure 4: Modeling with VRML

The geometry is presented by two lists: 1) the set of the all point coordinates composing an object and 2) ordered lists of points constituting the bordering faces (see Figure 4). The model created in this way is a typical shape model. Each solid object can be expressed as a function of *faces* and each *face* as function of *vertices*. There is no principal difference in geometry of surfaces and solid objects. Line objects are lists of *vertices*. The objects are embedded in Euclidean space.

The language follows an object oriented approach ensuring aggregations, encapsulation, classification, and inheritance mechanisms. Topology is build only among the vertices constituting one object. Despite the ability to create aggregations of objects, relationships "inside" can be derived only by metric computations.

The VRML is quite suitable for urban modeling giving answer to some important questions, e.g. how to increase the realism, how to visualize data in a faster manner. The solution of the VRML for realism is several operators allowing mapping of real photo images onto geometry. The way of mapping requires surface objects textured with the same image file to be grouped (separated) in one object (see Figure 4, *shape roof*). A special *node* permits Levels of Detail (LOD) techniques to be applied during visualization. The technique is simple and quite effective for real-time interaction with the model (Gruber et al. 1997). One object has several geometric descriptions (usually three): very detailed, e.g. all geometric details of the buildings plus texture; less detailed, e.g. only geometry without texture and coarse, e.g. only outlines of the buildings. The browser uses these several geometric descriptions per object for near and distant views, i.e. when the object is far way from the observer a less detailed geometry is used.

In conclusion, the language is very flexible for composing objects, creating dynamic scenes, interactive work via Internet, however, it is appropriate neither for data storage nor for performing spatial operations nor for fast rendering. It could be considered an intermediate step between data storage and visualization. The browser creates its own scene graph (a kind of hierarchical data structure) for real time visualization and applies the needed algorithms for rendering.

3.2 3D FDS

3D FDS was chosen for a basic data structure due to: ability for thematic and geometric description per objects, vector approach to build geometry and 3D topology, expressed mainly as boundary relationships (Molenaar 1992). The data structure was tested already for various spatial analysis and promising results

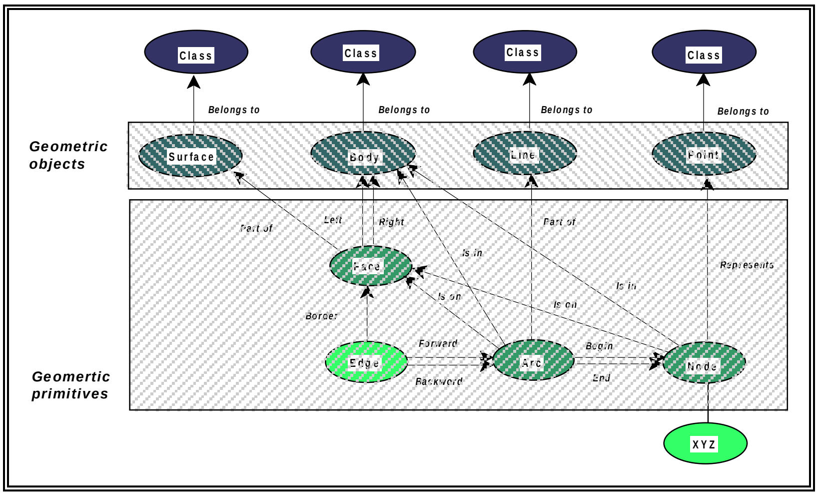


Figure 5: 3D FDS - conceptual model

were obtained (Rikkers et al. 1993, Pilouk 1996). Three levels can be distinguished in the model: two for geometry and one for thematic classes (see Figure 5). Twelve conventions clarify model constraints, rules for decomposition and intersection.

The first fundamental assumption is a full subdivision of the space, which implies that 1)the border between two n-D objects is always only one (n-1) D object (n = 1,2,3) and 2)outer space (air) also should be considered an object. The approach is opposite to the one followed in VRML, where composite of objects are build up, without information about the adjacent objects.

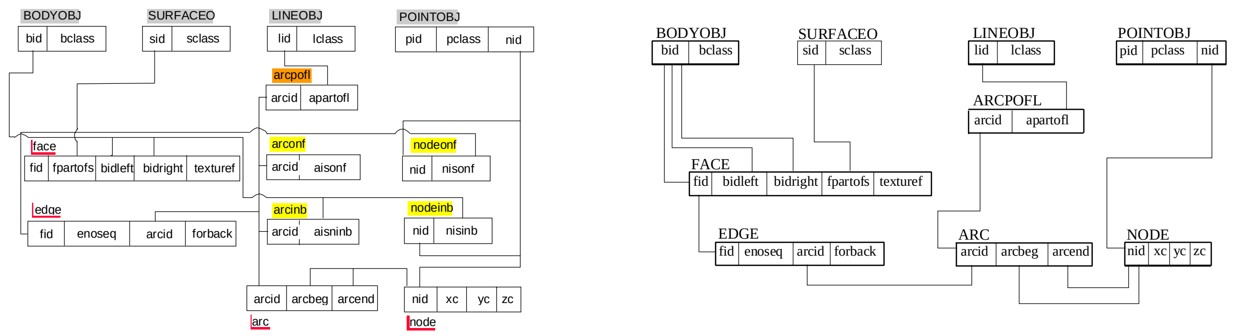
The other fundament of 3D FDS is “the single valued map”, i.e. a geometric primitive (*node*, *arc*, *face* and *edge*) can appear in the description of only one elementary object of the same dimension (Molenaar 1989). In contrast, the VRML allows one primitive to be part of several objects. The idea of single valued approach is to partition the space into non-overlapping (only relationship “meet”) objects (0,1,2,3 D) and thus ensuring 1:1 relationships between objects and primitives of same dimensions, e.g. *surface* and *face*. In fact, the data model is a partition of non-overlapping elementary objects of the same class. Some elementary objects from different classes can overlap, e.g. relationships “node on face”, “arc on face” are explicitly stored.

The structure has *node*, *arc*, *edge* and *face* as constructive primitives. The primitive *edge* is introduces only as a supporting element, defining *left* and *right,* however, it contains the orientation of the faces, which is important information for rendering engines, indicating which side of the face to be colored.

4. Implementation of the model (relational data structure)

The conceptual model was tested, first for sufficiency of data to create the scene for visualization in the VRML and second, for efficient traverse of the database to guarantee reasonable fast on-fly creation of documents on the server. We used the implementation of 3D FDS into relation data structure presented by (Rikkers et al. 1993) and extended by (Tempfli and Pilouk 1996) for texture storage. The data model is mapped into 13 normalized tables (see Figure 6a). All the tables were realized (Paintsil, 1997) except “node on face”, “node in body”, “arc on face”, “arc in body” (see Figure 6b). Tables are stored in flat files and software to build the scene with VRML was developed. The experimental data set consists of buildings (*body*), *surface*, *line* and *point* objects from the central part of Enschede. The model is constructed by a semi-automated procedure developed at ITC (Zlatanova et al. 1998).

Since the data structure was tested mainly in the geometry domain, thematic analysis will not be discussed here. The queries of interest for our approach are related to extraction of geometric information: coordinates, composing geometry of an object and the correct order of points bordering a face.



a) all the tables **b) implemented tables**

Figure 6: 3D FDS - relation model

These queries, which we will name *visualization queries*, have two specific characteristics:

- the traverse starts always from the highest level, i.e. object level
- the traverse always ends on the lowest level, i.e. coordinates.

For example, to extract the coordinates of a *body* object, all the tables, i.e. *BODYOBJ*, *FACE*, *EDGE*, *ARC* and *NODE*, have to be visited. The time needed to scan the data base is proportional to the number of objects to be included in a VRML file. For example, the user has a VRML file of the entire model and wants to see the shortest way to a shop. He initiates a query and fills-in a form with the desired information, e.g. the address of the shop and the address of his location. All the needed objects inside the requested area are selected and then the visualization query is executed, i.e. "collect coordinates and description of faces/lines per object". After that, highlighting the selected objects by changing their color or appropriate animation should be applied. Note, that the query and creation of the VRML file have to be executed on a remote server and the resulting file has to be transferred back to the client. It is apparent that the time for traversing the database is crucial for the system.

A close look at the process of creating a VRML file reveals some disadvantages of the relational organization of data. The first problem comes from lack of explicit relationship *face part of body* . The query "collect all the *faces* composing a *body*" requires entering and traversing the *FACE* table each time when a *body* or *surface* object has to be included in the VRML file. Sometimes the number of faces, composing one building can grow tremendously, e.g. up to 4000 triangles for the new ITC building. Automatically generated DTM leads also to large amounts of triangles.

The compulsory storage of left and right body per a face introduces a lot of useless repetitive information. For example, the information stored in the *FACE* table for a DTM is:

Table 2: Example of DTM data stored in the *FACE* table

fid	bodyleft	bodyright	fpartofs
…	…	…	…
1245	-1	0	5
1246	-1	0	5
1247	-1	0	5
…	…	…	…

where 0 stands for air, -1 for underground and 5 is the identifier of the surface.

An improvement could be obtained if the *FACE* table is released a bit of all the data. The table contains links, which provide all the faces composing both *body* and *surface*. The way of storage has the an apparent advantage for the link *body-surface.* However, it is difficult to predict for a particular area how many surfaces will be formed and certainly not every face is a part of surface. Therefore, the table *face* can be further normalized and the link *face part of surface* can be separated. This step limits search for all the faces composing a *surface* only among the *surface* objects and avoid the traverse of the *FACE* table.

The previous step influences, however, the storage of the texture reference. In this research, real-photo images are used for texture. In this context, the field *texturef* points to a separate table containing the name of the image file (JPEG, GIF, PGN) and a list of 2D texture coordinates for mapping onto geometry. The texture information is a type of attribute data related to the geometry of the objects. One object (*body* or *surface*) can be textured with several images and one image file can be used for several *surfaces*. The approach followed in this research is a separate image file for texturing per face. More details related to this topic can be found in (Sithole 1997). An advantage of this approach is the ease of data storage, while a limitation is the impossibility to wrap a *surface* with one image file. In many cases draping with one image file is much more efficient, e.g. a DTM. To avoid this limitation the reference to the texture can be replaced in the table *FACEPOFS* and enumeration of the faces part of surface has to be provided (see Figure 8a).

As was stated before, an indication which side of the face is textured can be necessary, e.g. two adjacent buildings with a common wall (see Figure 4). This is quite important issue for dynamic modeling: suppose the user shifts *body2,* both the wall of *body1,* which consists of *face1* and *face2,* and the wall of *body2* have to have appropriate texture. For the purpose, a new column *orient* should be added in the table *FACEPOFS* (see Figure 8a). A record in the *FACEPOFS* table is created only if the surface is created or texture exists. In other words in each case of existence of texture a surface object should be created. The procedure for constructing textured body will be: 1)collect all the *faces* from *face* table, 2) compare orientation of the collected *faces* and the orientation in *facepos* and assign the corresponding texture.

Modeling of line objects with VRML showed that visualization of simple lines does not provide realistic view of the object. Better performance can be achieved if tiny cylinders instead of lines and small spheres instead of points are used. Line modeling with predefined primitives (cylinders, spheres, etc.), however, require begin and end of *line* object to be established. The information in 3D FDS (only *arc* identifiers) is sufficient to construct the *line* object, however the direction of the entire object is not known. The storage of the direction will speed up the process of extracting data for visualization, as well. The order of *nodes* is needed, which makes the problem similar to order of *nodes* in *edges,* where *forward/backward* information is kept. Only a list of *arcs* will give the sequence of *nodes* but not beginning and end of the lines. Therefore a column with *enoseq* is added to the *ARCPOFL* table (see Figure 8b).

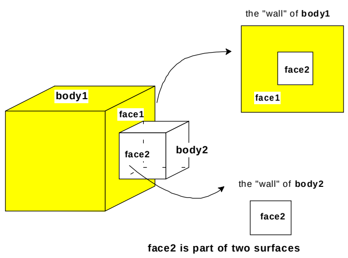
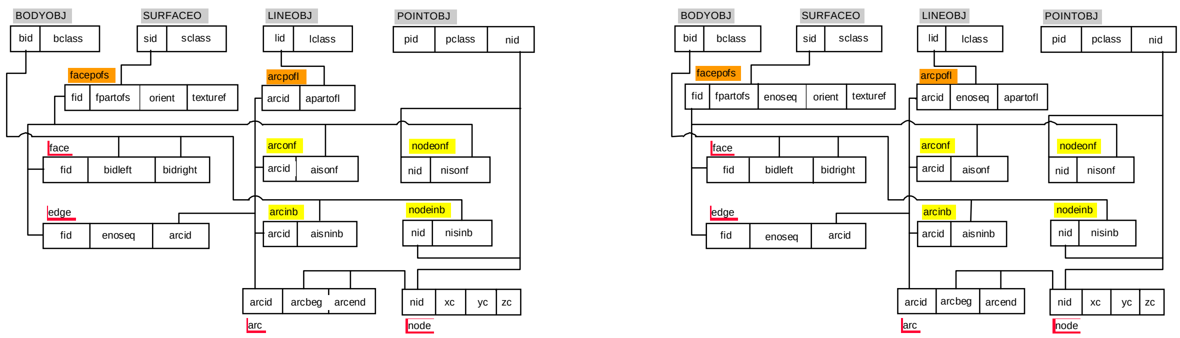


Figure 7: An example of a *face* needed two textures

The tables *ARCINB* and *NODEINB* rise the question about *line* and *point* objects inside the *body* “air”. In practice, every *line* object such as lamp, traffic light, or *point* object, which is outside the buildings has to be registered in these tables. Although this issue is not related directly to the visualization process, it influences data storage, data editing and updating. Deletion of an object, which is inside the “air” *body* demands changes of the corresponding records in these tables. A better solution is the storage of only those *line* and *points* objects, which are inside other than ”air ” *bodies*.

The data structure keeps explicitly the relationships “node on face” and “arc on face”. These relationships are problematic for visualization in case of faces which are not triangles. In general, there is no conflict between the VRML and the3D FDS in the representation of faces with more than three *nodes*. The limitation comes from the rendering engines, which deal only with triangles. All the other faces are subdivided by the rendering engine (in our case a VR browser) into arbitrary triangles. However, variety of artifacts (e.g. an *arc* flying over the *face*) is observed on the screen, if an *arc* of “arc on face” relationships is not included into triangulation. The pitfall is observed even if the *face* is strictly planar and the *arc* lies exactly on it. That is to say the *arcs* and *nodes* have to be incorporated in the triangulation. The solution is not so simple. One way is algorithms for triangulation on fly, prior the creation of a VRML file format to be performed. Created triangles, however, are not part of the database and eventual changes in the geometry are difficult to be handled. The other way to avoid the problem is the storage of triangulated faces, which delivers new problems which will be discussed later. The obvious advantage is elimination of “arc on face” and “node on face” tables.



a) a separate table for face part of surface **b) ordered *faces* in *FACEPOFS* and *arcs* in *ARCPOFL***

Figure 8: Modifications of 3D FDS

A similar problem arises in case of visualization of holes. Most computer graphics models are based on the properties of 2D manifolds, which implies so called “opening” of the holes, i.e. connecting to the bordering face, to be performed. Not all the VR browsers can handle rendering of holes, but the capable ones require opening, which can be achieved by a special ordering of the *nodes*. Only in this case the face is triangulated correctly by the browser and the holes are visible. For example, the nodes on Figure 9b should be in the sequence 1,2,5,6,7,8,2,3,4,11,12,9,10,11,1. 3D FDS has no special indication of a hole. Holes are stored together with the parent *face* as the *arcs* bordering a hole are in opposite direction to the *arcs* bordering the face (see Figure 9a). Clearly, the holes can be recognized as the necessary order can be obtained by checking *arcend/arcbegin* relationship per *arc* in *ARC* table. This operation has to be performed for each *arc*, bordering a *face*. The more simple solution is subdivision of the face into triangles or convex figures.

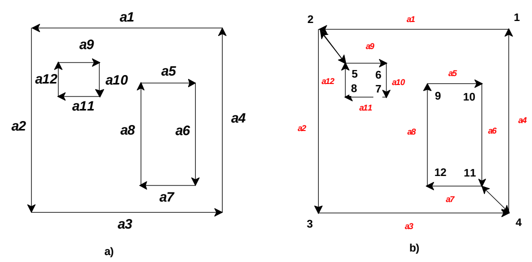


Figure 9: An example of a *face* with holes

Concave faces are another tricky issue of visualization. The algorithms for triangulation of multi-edges faces which are used by the browsers, need to be very fast in order to safe CPU time and as consequence of this very simple. They fail in most of the cases to triangulate concave *faces* (see Figure 10). Therefore, a parameter to indicate concave *faces* is included in the VRML. The parameter alarms the browser for a concave *face* and more sophisticated algorithm for triangulation is executed. The disadvantage is that the algorithm speeds down the visualization and should be used only when it is necessary. This implies that a flag for concavity of faces has to be available in the database. Again another solution is the prior triangulation of the faces.

Clearly, several problems, i.e. holes, concave shapes, “arc on face”, “node on face”, planarity of faces find their solution in further partition of faces into triangles. A well known disadvantage of a full triangulation of the model is the significant increase of data: a subdivision of a face bordered by n-*arc* (n>3) leads to (n-3) additional *faces* and (n-3) new *arc*. The growth of information is even faster for faces with holes, as the rate depends on the number of holes. The image pieces used for texturing also have to be subdivided and we face again enormous rise of data: triangular pieces of texture require larger storage space.

a) **correctly rendered concave face** b) **incorrectly rendered concave face**

Figure 10: Rendering pitfalls

Therefore, we consider the partition into convex faces the most suitable way to avoid a variety of modeling problems mentioned above. In general, the subdivided faces can be organized in 3D FDS but for the price of more data for storage.

One of the differences between 3D FDS and the VRML is related to the primitives used for description of objects. The 3D FDS maintains *arcs*, which is not a case in the VRML. In the 3D FDS, *arcs* are used only to express relationships among *nodes*, i.e. adjacency of *nodes* and establish their order, i.e. one of the *nodes* is first. These arcs are building elements for *line* objects and *edge* primitive, which are again sequences of *arcs*. Clearly, no other information than the order of *nodes* can be fetched from the *ARC* table. On the basis of this consideration we suggest to eliminate the *ARC* table from the data structure. A *line* object and *edge* primitive will be sequences of *nodes* (see Figure 11). The substitution of *sequence of arcs* with *sequence of nodes* in the *LINE* and *EDGE* tables will not increase the number of records drastically: it remains the same in the *EDGE* table and increases with one per *line* in the *LINE* table. Consequently, the global effect of this modification of the model will be significant reduction of data. The ARC table is one of the largest tables. The results of experiments with triangulated surfaces show that the ratio *faces:arcs:nodes* is 2:3:1. With elimination of the *ARC* table relationships "arc in body" and "arc on face" are also superfluous, because "node in body" and "node on face" will present the same spatial relationships. Further investigations, however, are necessary for the influence of this modification in spatial analysis domain. Deficit of *arcs* in a data model will complicate some spatial analysis with *line* objects. For example, the query "find with *bodies* are intersected by a given *line*", requires more operations than one presented in (Rikkers et al, 1993)

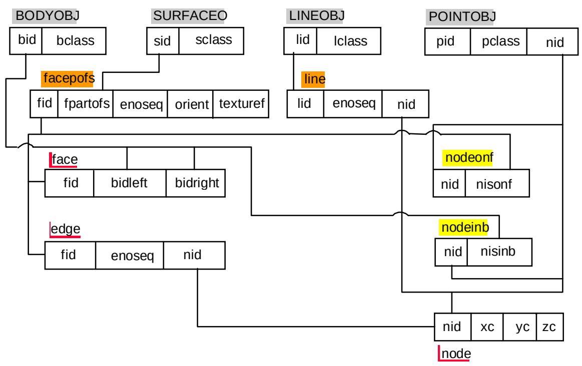


Figure 11: A data structure without *arcs*

The last problem concerning 3D FDS is related to organization of supported by the VRML LOD. The LOD can be predefined and stored in the database or they can be created on fly. The lack of a technique to assign more than one geometry description to an object, in practice, makes impossible the extension of the data structure to maintain LOD.

5. Conclusions and further research

The work on modeling urban areas utilizing the 3D FDS and the VRML revealed several obstacles, which make the combination not so successful. The first question of our investigations referred the adaptability of the 3D FDS to contain information sufficient for the scene design. The answer is positive: the 3D FDS supplies all the geometry information (coordinates, faces) needed for 3D visualization. Further elaboration of data structure could permit information about geometry attributes and behavior to be maintained. More sophisticated organization of texturing data has to be performed to enable advanced texturing techniques.

The troubles come with the dynamic query and adequate responses by the model in relatively fast manner. We have found the 3D FDS quite slow and not appropriate for real-time editing and manipulation via Internet. Based on our implementation work we figured out some week sides of the data structure, which can be summarized as follows:

- lack of spatial indexing: all the constructing primitives are stored in only four tables which have to be scanned for each object
- lack of explicit boundary information per *body* object, which requires collection of *faces* from the *FACE* table.
- storage of *arcbegin/arcend* relationship, which complicates algorithms for coordinate extraction.
- storage of coboundary relationship per *face,* i.e. *left/right body,* which leads to repetitive information
- the implicit description of “holes”, which requires more sophisticated and thus slower algorithms for data extraction.
- explicit storage of relationships “arc on face” and “node on face”, which involves algorithms for triangulation of the parent *face*
- single-valued concept, which makes organization of LOD and thus visualization of large photo textured models, impossible

One direction of future work is extension of the model toward aggregation of multi-dimensional objects and ability for parametric description. For the purpose, a data structure simplified to contain only *faces* and *nodes* will be used as basic topological model, on which an R-three structure will be build up. We expect to be able to organize easily several LOD and provide rules for aggregation of multi dimensional objects. Another aim is refinement of the concept for partitioning of the objects, especially surface objects, in order to avoid rendering pitfalls. The aspects addressed here contribute to clarification of a strategy for real-time manipulation of data and corresponding data structure for organization of data.

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