

BUILDING MODELING AND VISUALIZATION FOR URBAN ENVIRONMENT

Efstratios Stambouglou Jie Shan*

Geomatics Engineering, School of Civil Engineering, Purdue University, West Lafayette, IN 47907-1284, USA
jshan@ecn.purdue.edu

Commission IV, Working Group IV/6

KEY WORDS: Visualization, Virtual Reality, Photorealistic, Building Modeling, 3-D City Model

ABSTRACT:

One of the primary objectives for geospatial data collection and processing is to generate realistic visualization products of sufficient resolution. Because of the ever growing global urbanization and the complexity of geographic features, realistic urban visualization becomes a major challenge for geospatial research, development and practice. This paper discusses various building modeling approaches and presents its realistic visualization results. Three modelling approaches, flat roof, triangulated irregular network and constructive solid geometry, are described. To create a photorealistic views, textures of for building roofs and walls are respectively acquired from aerial and ground photographs. Addressed in this paper are modelling generation, texture mapping and photorealistic visualization. Various examples are presented for the discussion and demonstration. Photorealistic views over the Purdue campus are shown. Our results and analyses justify the need for a GIS package to further integrate advanced 3-D modeling and animation functions to more effectively model and visualize complex urban environment.

1. INTRODUCTION

One of the primary objectives for geospatial data collection and processing is to generate realistic visualization products of sufficient resolution. Because of the ever growing global urbanization and the complexity of geographic features, realistic urban visualization becomes a major challenge for geospatial research, development and practice. To achieve this objective, urban geospatial features need to be effectively modeled at the required levels of resolution and detail (Brenner and Haala, 1999). In the past studies, most geospatial features, including terrain, roads, water bodies, vegetation and residence blocks, have been successfully modeled via various two-dimensional (2-D) data structures and tools. However, 3-D geospatial features, such as buildings, may not be well represented by and suitable for existing data models (Braun, et, al, 1995). This demands for new approaches to modeling and thereafter visualizing complex 3-D geographic features (Förstner, 1999). Moreover, because of the popularity of GIS and its capability of integrating and handling different types of geographic data, it is desired that an advanced GIS package be able to model and visualize complex urban environment (Zlatanova and Gruber, 1998).

This paper will discuss various building modeling approaches and presents its realistic visualization results. We conceptualise the building modeling as geometric modeling, texture modeling and their association. This concept is related to the requirement on the levels of resolution and detail of visualization. Different modeling approaches are then studied in terms of their efficiency, fidelity and their integration with geographic information system (GIS). As the simplest modeling approach, buildings are characterized by their footprint polygons with each associated with a height as the polygon attribute. The three dimensional shape of a building is obtained by extruding the footprint polygon with its height attribute. This modeling approach results in buildings with flat roofs or stepwise flat roofs and can be handled by standard GIS functions. The second modeling approach uses triangulated irregular network

(TIN). This approach can accommodate complex building shapes and incorporate common terrain data for visualization purpose. As for the third modeling approach, the constructive solid geometry (CSG) principle is utilized. With this approach, a complex building is assembled by or built with simple geometric primitives, such as plane, sphere, cube and cylinder. Boolean operations applied to these geometric primitives are used to create the complex shape of a building. Issues to integrate this complex model into a GIS are discussed. In order to achieve a photo-realistic building modeling and appearance, image textures collected from aerial and/or ground photographs need to be associated to the roofs and walls of buildings. Also discussed is the approach to mapping texture images to geometric models, which will affect the efficiency of view navigation and its fidelity.

The rest of the paper is organized as follows. Section 2 describes and compares three building modelling approaches with simple and complicated buildings. It also shows the integration of building data with other geospatial data, such as terrain and roads. Texture collection and mapping are discussed in Section 4, where aerial and ground photographs are used for building roofs and walls respectively. Section 5 addresses the issues related to the generation of a photorealistic view, including appearance definition, texture mapping, use of light and sky design. The paper is summarized in Section 6. Sample results of photorealistic visualization over the Purdue campus are presented.

2. BUILDING MODELS

2.1 Flat roof model

The flat roof model of a building is an extrusion in the vertical direction of a 2-D building footprint. In this modelling, the building footprint can take any complex 2-D shape, however, building roofs are flat or piecewise flat. All the side-walls are vertical. The extrusion can be based on the number of floors or the real height of the building. A 2-D building footprint usually

* to whom contacts may be addressed.

consists of a number of polygons. The topology of the building only involves the topology of the 2-D polygon. The common border of polygons and intersection of edges need to be treated as one single entity respectively so that the extrusion in the vertical direction will not cause topologic conflict or 3-D visual artefacts on the roof. Figure 1 shows a 3-D view of the extruded buildings along with other geographic features over a part of Purdue campus.



Figure 1. Extruded buildings over Purdue

The other distinction of this modelling approach is its simplicity and supportability by most GIS packages. In addition, the thematic attributes, such as building name, usage and number of floors or building height can be directly associated to the building object.

2.2 TIN Model

In the previous modelling approach, different geographic features are often organized separately as different layers. In the 3-D view, these layers are stacked together according to their natural sequence, such as ground (DEM, digital elevation model) at the bottom, roads and vegetation in the middle, and buildings on the top. Although this multiple layer structure is convenient for spatial and thematic query, it may bring non-realistic artefacts in the 3-D view. At large scale, high resolution view, it can be noticed that features are 'floating' slightly over the ground, so are the vegetation and roads. To overcome this problem, all layers need to be combined into one single file. The flexibility of TIN (triangulated irregular network) structure allows us to accomplish this task. In addition, this will let image textures be draped over the combined virtual model. Since functional surfaces don't support vertical walls, i.e., cannot have two different Z values at the same (X,Y) location, the TIN approach in current GIS packages, e.g., ArcGIS, creates the walls as near-vertical through the use of breaklines and buffering. The building footprint polygons are added to the terrain TIN as breaklines. They then get buffered inward by a specified small distance to create polygons that represent the rooftops. Figure 2 shows a part of Purdue campus draped with aerial images over a combined terrain and buildings TIN model.

2.3 CSG model

To model complex buildings, more advanced tools are needed. Constructive solid geometry (CSG) is introduced for this purpose and used widely in CAD (computer aided design) and computer graphics. This model is featured with fixed topology and geometry. In this approach, a complex building model is built from a composed set of parameterised primitives (Ware, 1994). A 3D object represented using a hierarchy of vertices,



Figure 2. Combined TIN of buildings and DEM

edges and faces. The object's surface is a collection of faces that intersect each other only at the common edge. Each face is made of edges and vertices that bound the surface patch it self. The edge of the face does not have to be a straight line, nor does the face have to be a planar surface. Instead of lines and places it is possible to use parametric curves and surfaces to describe the shapes of the elements. The positions and shapes of these geometric elements are usually referred to as the geometry of the boundary model. On the other hand the connections and relationships between the elements are referred to as the topology of the boundary model. (Lammi, 1996).

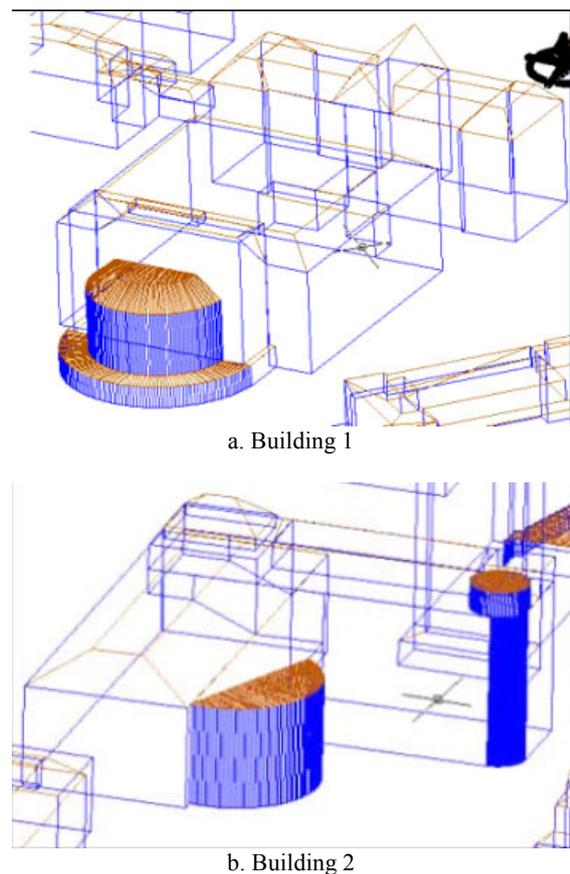


Figure 3. Complicated building models from CAD

Different data structures that can be used to represent boundary models include polygon based, vertex based, edge based, and face based models. An example of a polygon-based model would be a polyhedral model. This contains only a set of planar face elements but no topological information about them. It only describes the geometric shape of the surfaces. A polyhedral model can be categorized within the generic models. On the other hand, the vertex, edge, and face-based models, inherently

enable the representation of topological information. For a boundary model to be valid, the objects that comprise it must fulfill the following criteria:

- The set of faces is closed
- Faces intersect each other only at common edges and vertices.
- Edges of the faces do not intersect themselves.

This principle has been addressed in variety of studies, e.g., (Gruen and Wang, 1998), (Braun et al, 1995), (Ioannidid et al, 2000). From the previous one can rule out self-intersecting objects, objects that are open. Also from the previous one can understand that each edge only belongs to exactly 2 faces. In general more than one technique is used for the representation of models, in what is called a hybrid approach. In our approach when we created the model in the CAD environment we used a 3D face as a primitive, and made sure the topology is valid by creating the model using some rules. Figure 3 shows two complicated building models over the Purdue campus.

3. TEXTURE MAPPING

A photorealistic view requires buildings have realistic textures other than simple shading (Nakos and Tzelepis, 1998). After having finished the model in AutoCAD we decided to work with 3D Studio Max (Peterson, 1998; Matossian, 2001) to create the photorealistic views of the campus. To apply texture to individual objects in 3D studio, like different parts of walls and roofs, when importing from AutoCAD into 3D Studio, it is important to distinguish between objects, since they are handled separately only when they are either of different color, have different attributes (in this case 3D face and mesh are handled as different objects) or are in different layers. That made it necessary to create layers in AutoCAD for the roof objects, and different layers for the fountain and walls. Putting texture on the faces is the next step. In our study, building roof textures are obtained from aerial images while terrestrial images are used to acquire building wall textures.

3.1 Roof Texture

To create the roof texture, we used the aerial photograph, which was draped on top of the roofs and base. All the roofs were handled as one object together with the face placed at zero elevation that had the same extents as the image. The result is very realistic. If the walls were the same object as the roof, then the texture of the roof looks like it's continuing on the walls making the result very unrealistic. To keep good resolution, we did not use *.jpg image format as it sometimes requires more rendering time due to decompressing for display.

3.2 Wall Textures

To create the wall textures, we took photographs of some building walls on the ground. The photographs were taken using a Kodak digital camera, and a Canon 35mm roll film camera. The pictures from the roll film were developed and scanned using a Microtek scanner. Precision for these images was not as important as with the roof texture so the resolution was kept relatively low. Taking the pictures was not easy due to occlusions, trees (Figure 4a), long facades (Figure 4c) or not enough room between buildings. Capturing the whole façade in one frame was most of the times impossible. All pictures were taken from ground level, with very few being perpendicular to the facades due to lack of space. The roll camera had a very

wide-angle 24mm lens making things easier, but this created distortion on the images (Figure 4b). Once the texture images are collected, they need to be associated to each building wall. This is done by using a 2-D perspective transformation.

It should be noted that having all walls photographed is practically impossible and unnecessary. For the building walls that we didn't use picture derived photorealistic textures, we used bitmaps of tiled and concrete bricks. Some buildings used textures from ground photograph of a similar building. We tried to use different ones for each building to create individuality. It is found the bitmap library is useful for this purpose. Figure 5 presents two buildings mapped with image and bitmap textures.



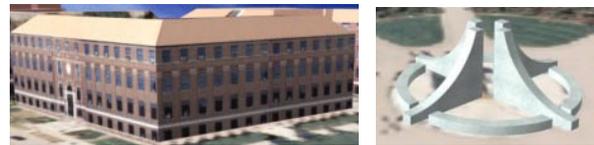
a. Tree occlusion

b. Wide-angle distortion



c. Long façade

Figure 4. Textures for walls



a. Building

b. Fountain

Figure 5. Building with mapped textures

4. PHOTOREALISTIC VISUALIZATION

The objective in this step is to create a realistic view of the built models. For this purpose, we used one of the most commonly used software in the market, 3DS Max (Peterson, 1998; Matossian, 2001). As addressed earlier, in order to assign textures to 3D objects within 3DS Max, they have to be 3D faces or meshes. Also for different faces to be imported as different objects, they have to be in different layers. Our final AutoCAD model was changed to reflect these needs. Whatever object was going to be used with the aerial image as a texture, was put in a layer called "roof" so that it could be handled as one object. Every object that was not vertical was considered to be part of the roof object. For some buildings we made different textures for each wall which also meant that each wall was in it's own layer, but for most we used one texture that was mapped to all walls which means that all walls were put in one layer. For really small walls we decided to use a brick maps. To create the texture, first one has to create a material using the material editor (Figure 6). For a simple texture map, the bitmap is used as diffuse color map. We also tried to use the same bitmaps with bump maps. The result for the aerial image was not realistic because of the relatively low resolution of the bitmap, and because there are many trees and other structures that create "noise". For the wall maps, due to the big distance

from the walls when viewing, the difference is not significant. A bump map creates the illusion of surface by perturbing normals using the intensity values of a map.

When we imported the drawing file in 3DS Max we noticed that in some cases some of the 3D faces didn't show. After some research we found out that 3DS Max assigns a normal to the faces depending on the order the nodes were created. Back faces are not displayed nor rendered. So for some of the walls the normal is facing the inside of the building. To solve this when we created the materials, we made them 2-sided to make sure that texture will be mapped to both sides of the faces.

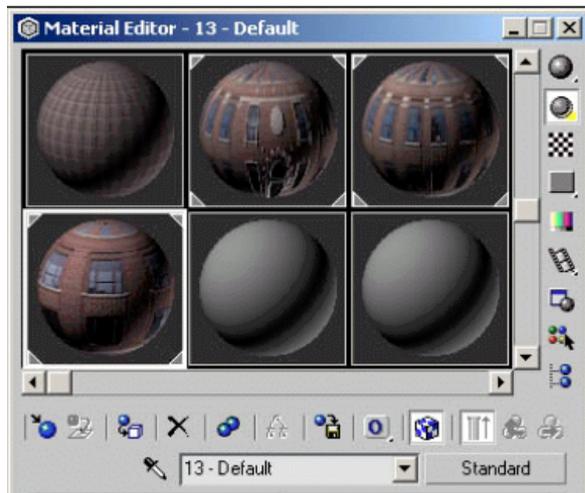


Figure 6. Material editor for the appearance of an object

After assigning the material to the object one has to align the map to the object. This is because each object has its own coordinate system which is different than that of the bitmap. To accomplish this, one has to apply mapping coordinates to the objects using a UVW modifier. UVW is the coordinate system of each object where U corresponds to width, V corresponds to the height, and W is the axis perpendicular to the UV plane. We used a box mapping fitted to the object. For the faces we had to manually rotate the coordinate system of the map to coincide with that of the object (Figure 7). As we mentioned before, this is essentially a two-dimensional projective transformation. To map the textures rigorously on the walls, one should have had coordinates of points in object space and their corresponding coordinates in image space. We actually do have these coordinates, since we have both the images, and the 3D faces,

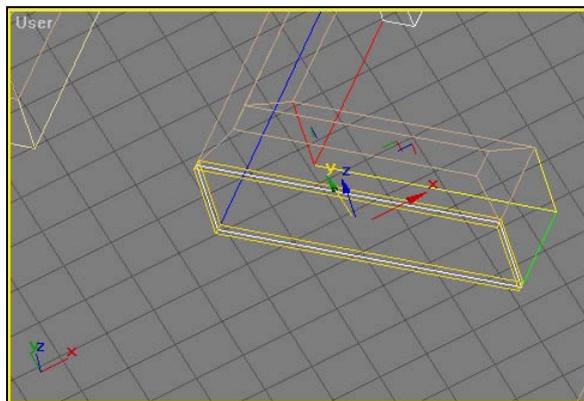


Figure 7. Aligning the map gizmo to the object.

but 3D studio cannot use this extra information. The mapping is thus done the way described previously.

The final touches included creating lights and an environment. We created four omni lights, which radiate light in all directions from a single source point. They can be moved around 3D space without restrictions. We used four in order to light the scene as good as possible. But to make the light not too intensive we set the intensity (which is controlled by the multiplier) at 0.5 to 0.6. We also created a directional light. A directional light uses a cylinder of illumination, which means that the rays are parallel. This is used as sunlight. In this case we also have reduced the intensity to 0.9.

To recreate an environment, we created a sphere that included the whole model. We wanted to recreate the effect of a real sky, which shouldn't move when changing viewing point (at least for small time frames). By using 3D Studio's environment utility, a bitmap can be used as a sky. Figure 8 shows the relationship of the sphere to the rest of the model. By creating the sphere and assigning the bitmap as a map to it, we created a sky that didn't move. The only problem is that no matter what mapping technique you use (planar, spherical, shrink wrap etc) the bitmap is rectangular, which means that there cannot be a good fit. Distortion will occur and the projection center might appear unless it is below the horizon.

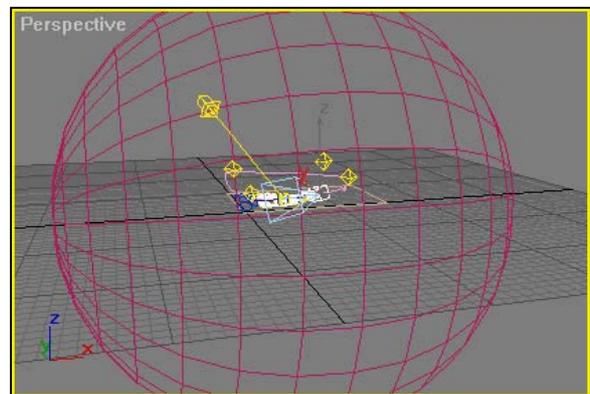


Figure 8 The sphere that is used as a sky to map the bitmap.

All of the above was implemented in creating a virtual model for the Purdue campus area. The final result is very realistic either on a building level especially when appropriate texture was used for the walls, or on a campus-wide level because the aerial image fits very nicely on top of the roofs, making up for lack of detail from the model. Rendering of the scene in a 640x480 frame took approximately 22 sec. We chose not to use the program's ray-tracing ability, which calculates shadows that are created from objects on other objects, for two reasons. One was that the aerial photograph already had shadows, and secondly because this option takes almost three times as long to render. We also decided not to have any shadows created on the buildings at all, since we believe that they would make some of the faces too dark to see. This is one more reason why we set up so many lights, to help in not having shadows anywhere. Different views are presented in Figure 9. A VRML model was also generated as shown in Figure 10.

5. CONCLUDING REMARKS

Urban environment can be modelled in different ways. With GIS, buildings can be created, connected to a table that contains thematic information about them, and then when needed viewed in three dimensions by extruding the polygons. TIN modelling is able to combine building models with other geographic data like DEM and features. However, these current GIS-supported

approaches have difficulty to handle complicated building models and map textures to each geometric primitives. As a contrast, CAD tools can model highly complicated buildings and provide sufficient details, however, at a cost of timely modelling process and its inability to handle different forms of geographic features. Photorealistic visualization requires building textures acquired separately from ground and aerial photographs. Mapping textures to the geometric primitives can

- a. View 1
- b. View 2

Figure 9. Photorealistic view

be a very tedious process. The study shows at current level of technology, photorealistic visualization requires an integration of different tools, including GIS to handle different types of geographic data, CAD to model complex buildings, and



visualization package to generate realistic views and render the



models. In particular, GIS packages need to be enhanced to accommodate CAD models and render complex views in a photorealistic manner. Our results and analyses justify the need for a GIS package to further integrate advanced 3-D modeling and animation functions to more effectively model and visualize complex urban environment.



Figure 10. VRML model

REFERENCES

- Braun C., Kolbe T.H., Lang F., Shickler W., Steinhage V., Cremers A.B., Förstner W., Plümer L. (1995). "Models for Photogrammetric Building Reconstruction.". *Computer & Graphics*, Vol. 19, No. 1, pp. 109-118.
- Brenner C. and Haala N. (1999), "On the production of 3D city models", *Geoinformatics*, (July/August issue).
- Förstner W., (1999). "3D City Models: Automatic and Semiautomatic Acquisition Methods.". D. Fritsch and R. Spiller (eds), *Photogrammetric week 99*, Wichmann Verlag, pp. 291-303.
- Gruen A. and Wang X. (1998). "CC-MODELER: A topology generator for 3D city models". *Proceedings of IAPRS*, Volume: XXXII, Part 4. Stuttgart, pp. 188-196.
- Ioannidis C., Potsiou C., Soile S., Badekas J. (2000). "Detailed 3D Representation of archaeological sites.". *IAPRS*, Vol. XXXIII, Amsterdam.
- Lammi J. (1996). "3D modeling of buildings from digital aerial imagery.". *International Archives of Photogrammetry & Remote Sensing*. Vol. XXXI, Part B2, Vienna.
- Matossian M. (2001). "3DS MAX for Windows.". *Visual quick start guide*. Peachpit Press.
- Nakos V. and Tzelepis N. (1998). "Three dimensional representation of urban areas using photorealism.". *5th National Cartography Convention*, Thessaloniki Greece.
- Peterson M. (1998). "3D Studio MAX2 Guide". Giourdas Press.
- Sinning-Meister M., Gruen A., Dan H. (1996). "3D City models for CAAD-supported analysis and design of urban areas.". *ISPRS Journal of Photogrammetry & Remote Sensing* 51, pp. 196-208.
- Ware C. (1994). "Advanced 3D Visualization Techniques.". *The 6th Canadian GIS Conference*, Ottawa, pp. 1694-1698.
- Zlatanova S. and Gruber M. (1998). "3D Urban GIS on the WEB: Data Structuring and Visualization.". *IAPRS*, Vol. 32, Part 4 "GIS between Visions and Applications", Stuttgart.