Developing an Indoor Evacuation Simulator using a Hybrid 3D Model

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Abstract:
Although 3D models are getting used increasingly in many areas including architecture, urban planning, environmental analysis and hazard management, they mostly have been used as visualization purposes without using topological structure or information. Thus, 3D models generally have limitations for being used in indoor spatial analyses since the information of each indoor object or relationships between them are not defined. On the other hand, 3D topology, although have been dealt with in many theoretical studies, is too complex to be implemented in real-world indoor applications. In this study, we suggest a hybrid 3D data model that combines 3D visualization and 2D topology features. Instead of using file-based GIS layers, we constructed spatial data using a spatial DBMS, which allows faster computations and analyses. The stored spatial data are queried and visualized in 2D or 3D. In this study, we developed an evacuation simulator using the PostGIS, a spatial DBMS and illustrated the processes for storage, computation and visualization using a campus building data.

1. Introduction

3D models are applied to wide range of areas including architecture, urban planning, environmental analysis and hazard management. 3D spatial information as well as 2D is being demanded with increasing underground structures and complex buildings. Use of 3D GIS is especially getting attention not only for visualization purposes but for such applications as indoor positioning, navigation and evacuation.

However, currently used 3D models, although frequently called 3D GIS, are used mainly for visualization and lack topological data structure which is the key functionality in 2D GIS that enables various analyses. Although 3D topology has been the topic in many theoretical studies, they are mostly limited to representing outer volumes. Indoor level topology requires far more number of objects and complex relationship between them to be implemented in real-world applications. In this study, we suggested a hybrid 3D models that can be constructed with less complexity. We combined the advantages of visualization from 3D models and topological features from 2D GIS. We used a spatial DBMS to store 2D spatial data, which supports the topology-based computations. As in most relational DBMSs that use relationship between tables, we can similarly implement relationship between spatial objects using spatial DBMS, which allows us to perform various queries, analyses and data management. The retrieved data from spatial DBMS can also be visualized both in 2D and 3D.

In this study, we first analyzed 3D modeling techniques that can be applied to building a spatial DBMS, and then proposed a data model and applied to a real-world spatial DBMS. Since we used PostgreSQL/PostGIS, an open source spatial DBMS and the data were constructed following OGC(Open Geospatial Consortium) standards, the proposed system can easily be ported to different platforms. Using the developed spatial data, we built an indoor evacuation simulator and tested using a campus building model. Here, we showed processes to store and visualize the computed evacuation routes in 3D indoor space.

2. 3D Hybrid Data Modeling

We first analyzed related studies before building 3D indoor data in a spatial DBMS. Among a number of 3D primitives possible to model 3D spatial objects, those suggested by Zlatanova (2000) and some others are notable. She defined a hierarchical boundary representation (Figure 1). Here, a polyhedron is defined by its faces; each of them is again defined by vertices (x, y, z). Note that edges that constitute a face are not defined explicitly in this model. Similar 3D primitives and implementations using DBMSs can be found in some other studies (Stoter et al. 2002, 2003, 2006, Arens et al. 2005). They used similar 3D hierarchical model shown in Figure 1 mostly for representing outer surfaces of buildings dealing with a building as a polyhedron or a volume. When there is no need for representing inner spaces of a building, such approaches can be effectively implemented in a DBMS. However, indoor spaces require far more objects to represent and relationships between them. Such complete topological arrangement for indoor spaces makes it difficult to implement in a DBMS, not just because of the complexity but because a single query would require many levels of hierarchical joins, which is undesirable for computational aspects using a DBMS.

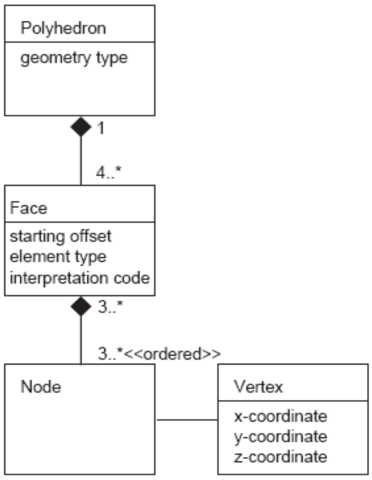

Figure 1. UML diagram describing storage of polyhedron primitive.

In this study, we suggest an alternative approach for building an indoor spatial data model, which is a hybrid structure between 3D model and 2D GIS-based model. As is known well, currently used 2D GIS layers contain well-defined topological structure among data primitives (points, lines and polygons). By creating each floor in a building as a GIS layer, we can take advantage of the topological features and their analytical characteristics without specifically defining a new data model. Because pedestrians move on the surface of the floor, defining 2D topology for each floor would suffice for the purpose for getting relationships of rooms and hallways. Here, the floor layers play the role as the 'navigable' surfaces. Each GIS floor layer can then be imbedded into 3D model for visualization purpose. This way, we can build a 'quasi' 3D model with less cost.

Figure 2 shows the process for building 2D floor layers and a 3D building model. First, CAD-based building floor plans are converted 2D GIS layers (ESRI Shapefile format). Then, they are stored into the PostgreSQL/PostGIS database. Maintaining spatial data in DBMSs gives faster queries than using file-based GIS layers and more flexibility in developing applications than using proprietary software. We used the OpenGL for 3D visualization. The retrieved floor layers are extruded as much as the height of walls and imbedded into the 3D model in the right places. Network structure is built using links representing hallways and nodes representing rooms and stored in the database along with 2D layers (Figure 3).

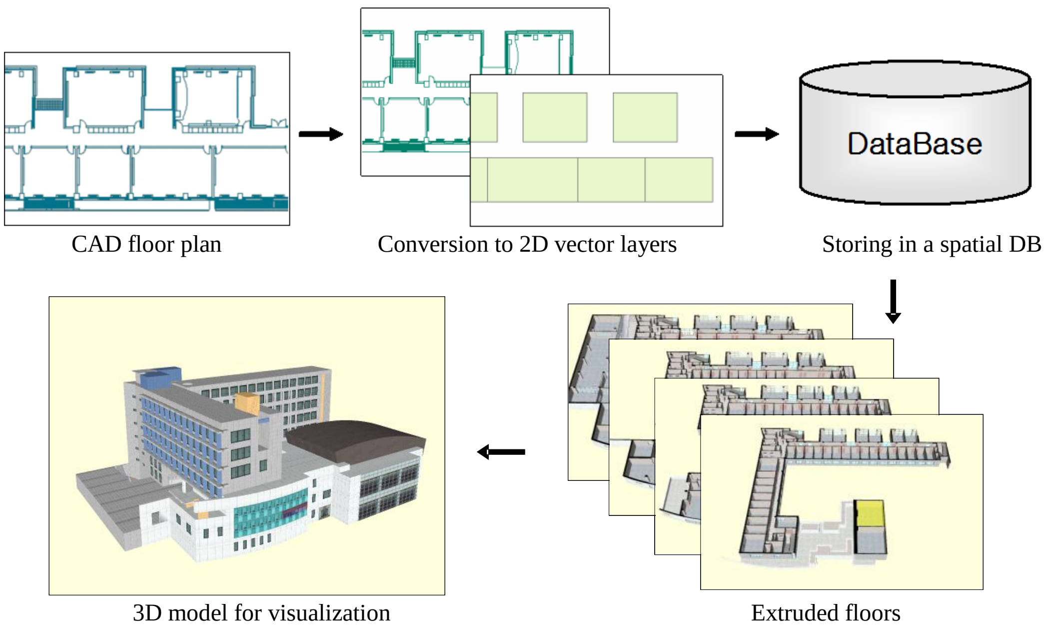

Figure 2. Building 2D-GIS floor layers and 3D model

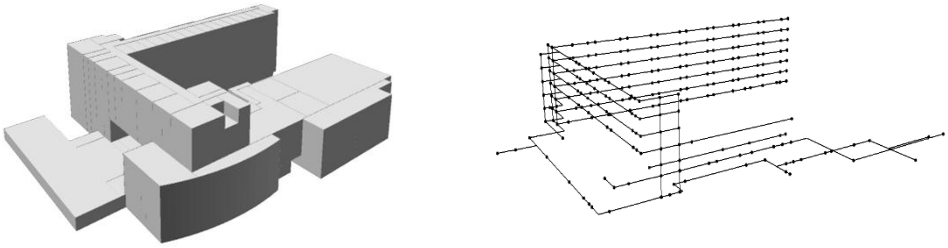

Figure 3. Building the network structure

3. System Implementation

The system was developed using C# with the OpenGL as the 3D visualization component and the PostgreSQL/PostGIS as the spatial DBMS. The system is largely divided into two parts; one for retrieving and visualizing the DBMS data in 2D and the other for 3D visualization of buildings and paths computed from 2D layers (Figure 4).

2D layer part basically plays a role as a GIS layer manager which provides data access and retrieval and some controllers for visualization such as selection, queries, zooming and panning. Also, using the building network data, it lets the user to choose an origin and a destination, followed by the computation for a shortest path and visualization of it. For the shortest path computation, we used the pgRouting, a PostgreSQL/PostGIS module that provides routing functionality. The 3D display module accesses the DBMS for visualization of the building. As mentioned above, the retrieved floor layers are extruded as much as the wall height and imbedded into the 3D volume for displaying the indoor spaces. The information for the computed shortest path from 2D manager is sent to 3D module and displayed using colored symbols. This OpenGL-based 3D module also provides such functionality as move and rotation.

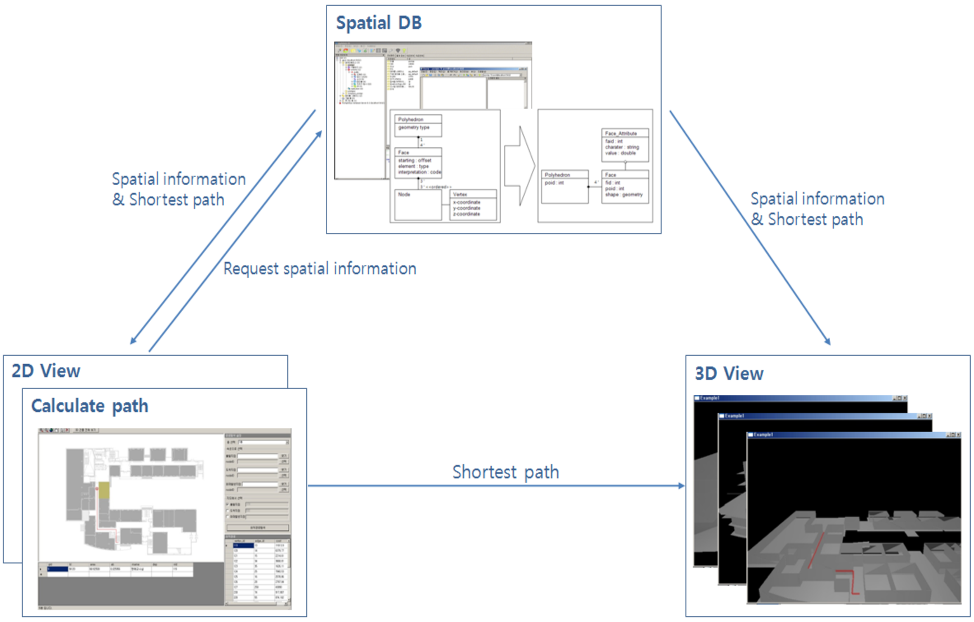

Figure 4. The system architecture

Figure 5 shows an evacuation simulation result. The left figure shows the 2D manager and the right is the 3D display module. The 2D interface also provides different query functions about room attributes as well as the path information. The 3D display window in the right side of the figure opens in response to the user's command to display the 3D indoor along with the resulting path.

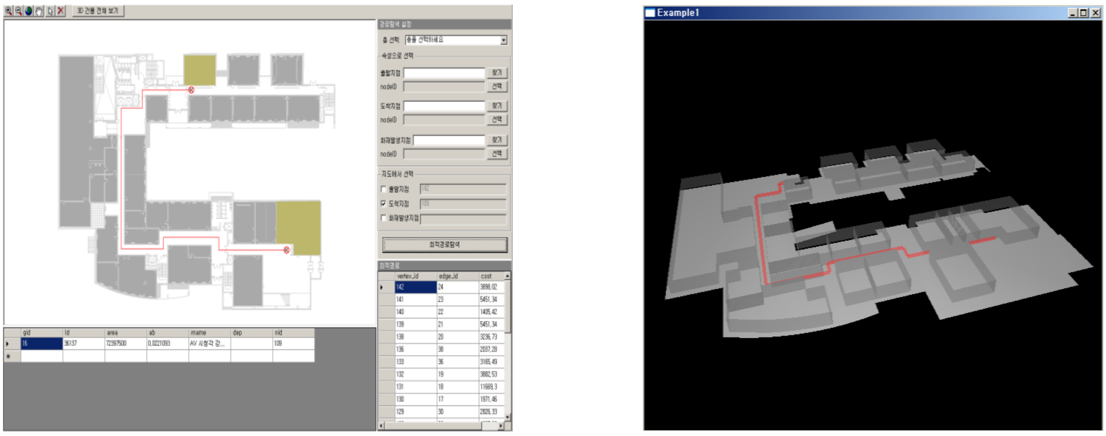

Figure 5. An evacuation simulation

4. Concluding Remarks

We proposed an alternative data model for 3D indoor spaces and applied it to an evacuation simulation. Instead of fully defining 3D primitives and relationships for building compartments in indoor spaces, we used existing 2D GIS layers to represent each floor in a building. Since the application domains such as evacuation uses floor surfaces as the 'navigable' spaces, defining 2D level topology suffices for the implementation purposes at a lower price. For 3D display, we built an OpenGL-based module that communicates with 2D counterpart in the system. We used an open source spatial DBMS in the system to increase computation speed, compatibility and maintainability. Evacuation simulations were performed using network data constructed along hallways in a building. The network structure played a role as not only paths but also the linkages in the stair cases between floors which are isolated each other in our data model. We are currently pursuing on-going research to implement more refined 3D topology for indoor spaces. As it is progressed, our model could also be applied to wider applications such as indoor sensors and indoor navigations.

References

Arens, C., Stoter, J.E., and van Oosterom, P.J.M., 2005, "Modelling 3D spatial objects in a geo-DBMS using a 3D primitive", Computers & Geosciences, Vol. 31, No. 2, pp.165-177.

Meijers, BM, Zlatanova, S & Pfeifer, N, 2005. 3D geo-information indoors: structuring for evacuation. In G Groeger & TH Kolbe (Eds.), Proceedings of the First International Workshop on Next Generation 3D City Models (pp. 11-16). Bonn: ISPRS/EuroSDR/DGPF/Universitaet Bonn.

Stoter, J.E., and van Oosterom, P.J.M., 2002, "Incorporating 3D geo-objects into a 2D geo-DBMS", ACSM-ASPRS 2002 Annual Conference Proceedings.

Stoter, J.E., Zlatanova, S., 2003. "Visualizing and editing of 3D objects organized in a DBMS". Proceedings EUROSDR Workshop : Rendering and Visualization, pp.14-29.

Stoter, J.E., and van Oosterom, P.J.M., 2006, 3D Cadaster in an International Context, Taylor & Francis.

Zlatanova, S., 2000, "3D GIS for urban development", PhD thesis, TUGraz , Austria, p.222.