3D Cadastre System using the Node-Relation Structure in GIS

Jiyeong Lee, Ph.D. and
Hamid Yunus
Department of Geography, Minnesota State University
Mankato, MN 56001
Phone: 507-389-2824, E-Mail: leej@mnsu.edu and hamid.yunus@mnsu.edu

Abstract: The foundation for the development of GIS throughout a local government is cadastral GIS applications. The applications need to maintain the cadastral data known as the tax assessment role, to evaluate land values including buildings and physical structures. Because the current 2D Cadastre systems with 3D visualizations (ArcScene) is a framework to support comprehensive land-related information such as land use, buildings, flood hazards, income and population at the parcel level, there are limitations in representing the complex internal structure of the buildings on geometric and thematic dimensions in the 3D entity (room units) level. It may create difficulty to understand and analyze the human behavior in micro-scale environments. This study, therefore, intends to propose a new approach in creating a 3D cadastre using a 3D topological data model based on Node-Relation Structure in order to represent the 3D attribute data integrated with the 3D spatial data (geometric and topological data) of 3D objects in 3D GIS.

I. Introduction

Terrorist attacks at the World Trade Center (WTC) in New York City and the Pentagon in Washington, D.C., on September 11, 2001, resulted in serious structural damage and collapse of buildings. Like other similar disasters (e.g. the bombing of the Alfred P. Murrah Federal Building in Oklahoma City on April 19, 1995), these events not only affected multi-level structures in urban areas but also impacted upon their immediate environment at street level in ways that considerably reduced the speed of emergency response. The complex internal structure of these buildings and the restricted number of access points at street level also hindered speedy escape and made rescues particularly difficult in this emergency situation (Kwan and Lee, 2003). When disasters occur in these types of complex multi-level structures, a short period of time (e.g.

5 minutes) may mean a significant change in the disaster environment in which trapped people need to escape and rescue personnel have to operate.

One important similarity of these multi-level structures (such as buildings) is that they involve compartmentalized zones or areas connected by complex transport routes such as corridors. In addition, different levels of these structures are connected by a limited number of vertical conduits such as elevators and stairways. Many GIS-based (Geographic Information Systems) analytical techniques can be applied for direct rescue personnel and their quick evacuation or rescue in these *micro-spatial environments* if their internal structure can be represented using navigable 3D GIS data models (Lee, 2001a,b,c). Further, as the horizontal and vertical conduits within multi-level structures are ultimately connected to the ground transportation systems, much would be gained in emergency response time through establishing a real-time 3D GIS that links together the traffic systems within these structures with the ground transportation system. However, in order to implement the 3D GIS applications, not only representing geometric 3D descriptions and spatial (topological) relationships between 3D objects (units such as office rooms and residential units) of the internal structure of urban objects (such as buildings), but also the attribute data (description data) of 3D objects should be represented (such as ownership, room use, occupancy, etc).

3-D GIS research covers all aspects of accurate data acquisition, storage, and analysis. The common theme is the *need to realize the real world, treat it like a 3-Dimensional object, and to represent it accordingly, both thematically as well as data attributes.* Mostly, the real world is *graphically represented* in to three dimensions but the underlying data does not reflect all the necessary attributes of a three dimensional cadastre, hence ignoring the topological relationships. This dilemma is caused by the absence of proper commercial 3-D GIS systems. Some of the most common problems related to such techniques are:

- Overlapping of features in three dimension
- The exponential relationship of one feature to the neighbors, when represented in three dimensions
- The topological distortion of data
- Data and feature queries (spatial queries) in three dimensions
- The distance and direction representation as compared to the real world
- Data standard, consistency, and quality
- Feature representation for a smooth optical result and the techniques for achieving this task

- The estimation/approximation of some or all of the data, especially the ones in the third dimension

There are several more problems that are not mentioned, nevertheless, the above mentioned points are the main core of the larger problem.

In order to represent the complex internal structure of the buildings on geometric and thematic dimensions, there are some limitations in the current 2D Cadastre systems (Molen, 2003), which is a framework to support comprehensive land-related information such as land use, buildings, flood hazards, income and population at the parcel level. Although Geo-information has already proven its importance for many applications, a number of human activities (e.g. cadastre and land management, emergency services, traffic navigation, and urban planning) have utilized spatial data in 2D (two-dimension) space (Raper, 2000). However, the real world is three-dimensional, in micro-spatial environments the two dimensions are not sufficient. The 3D objects presented as 2D projections in Geographic Information Systems (GIS) may loose some of their properties and spatial relationships to other objects (Billen and Zlatanova, 2003). It may create difficulty to understand, analyze and evaluate the human behavior in micro-scale environments such as within a building (Coors, 2003: Kwan and Lee, 2003).

This purpose of this study intends to propose a new approach in creating a 3D cadastre using a 3D topological data model based on Node-Relation Structure (Lee 2001a) in order to represent the 3D attribute data (thematic properties) integrated with the 3D spatial data (geometric and topological data) of spatial objects in 3D GIS systems. The conceptual topological 3D data model represents the topological relationships such as adjacency and connectivity between 3D geographic entities in graph theory. It is because the proposed data model consisting of a set of nodes and a set of edges is based on a network-based approach.

II. Methodology

The primal classes of the model are Node, Edge, and Network. A node consists of an identifier and a position data in 3D (x,y,z-coordinates), and an edge consists of an identifier, start node, and end node. The class Network consists of an identifier and lists of all nodes and of all edges in a network. Each node in the database has attribute data such as an identifier, room use, occupancy data, and sensed data collected by numerous sensors including temperature, smoke, gas, and fire detectors. Because the unit of Intelligent Building System (IBS) is a single room, the sensed data provide room-based information that is also a description of node characteristics in the 3D network. The description data can be obtained from the County Auditor's office, which collects the data to assess a property's taxes within a jurisdiction. An edge has attribute data including an identifier, population in each room, occupant movement, elevators/stairway capacity, corridor capacity and traffic flow impedance. Most of these data can be obtained by various types of sensors and transmitted via the communications infrastructure of an IBS.

II-1. Possible Solution Techniques

In the past decade, several different techniques and approaches are proposed addressing a different set of the posed problems. The common theme is: the rewards of an accurate 3-Dimensional model and the ability to query efficiently, based on a third dimension and the uses of it.

The main task is to realize the topological relationship between different features, either geographic or geometric. There is a natural existing attitude towards several of the objects being treated as *fake* or *non-real* objects, due to the human inability to imagine such objects as three dimensional. The first step is the representation of the simple shape feature – point, lines, and polygons – into three dimensional features – sphere, polyhedron. Every feature is considered to have a degree of dimension – i.e. a point has a zero dimension, line has one dimension, and other surfaces and bodies are represented in two and three dimensions.

Another part of the possible solution is the relationship of one element (feature) to another feature in a topological relationship, and that can be of three main types: total relation (completely contain), partial relation (intersection), or no relation.

Third issue deals with better data consistency for the topological relationships. In the absence of a universal standard for data design, the topological relationships suffer in terms of data quality, e.g. a piece of land may belong to more than one cadastral unit.

The last issue is the visual or optical representation. Transmission of huge amount of topological data in a networked environment requires a high level of optimal visualization, as well as efficient data querying and access.

This paper proposes a solution that integrates several of the above-mentioned issues. The proposed solution is a two-part solution as follows:

⇒ The "places" or "spaces" – i.e. rooms, buildings, or volumes – are represented by **Node** points, the intersecting boundaries that define a "neighborhood" relationship between two nodes are represented by **Edges** and this also signify connectivity between different "spaces".

This way, a network of nodes and edges is generated. The vertically multi layers are represented by **Master_Nodes** – i.e. *another sub-network for connectivity between different levels.* **KEY:** All of the geometric features are given a name or key to uniquely identify each feature.

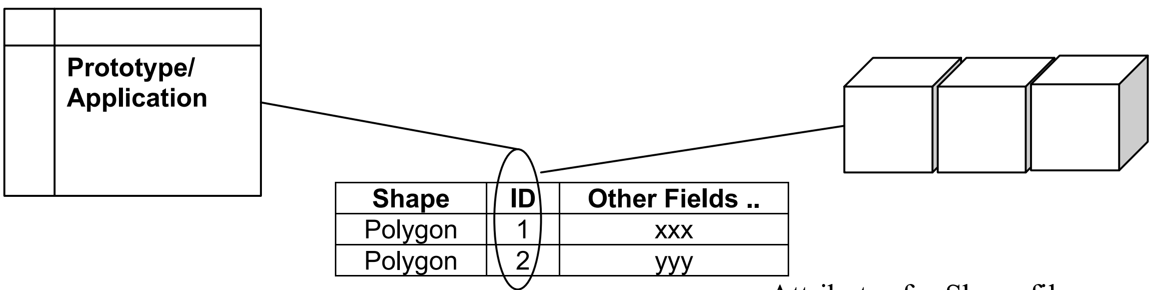
⇒ Each of the nodes are stored in a data storage unit – DBMS, files, spreadsheets – as attributes data, with a unique **ID** or **Reference Number**. The connectivity relationships (edges) are represented by a node's neighbor – i.e. to_node, from_node, etc – and the edges can be color coded to differentiate between the adjacency and connectivity relationship. For Master_Nodes, an extra attribute "up_node," is stored as well. **KEY:** All of the nodes are given a name or key **"ID"** to uniquely identify each node and this ID simply corresponds to matching geometric feature.

This two-part solution enables the user to run spatial queries faster; access, analyze, filter, and sort the data more efficiently; and administering, managing, and controlling the data is accomplished in a more structured and centralized way.

For a detailed explanation of the above-mentioned concepts and theories, refer to the cited references. For proposed implementation details and samples, please turn over to the section labeled "Implementation Proposal".

II-2. Conceptual Data Model

This part of research requires a high level of understanding of GIS concepts, especially spatial and attributes data, as well as a high understanding of computer systems. An integration process between a stand-alone "Network Generation Application" and shape files requires better concepts and understanding of high level computer programming. The foundation of ArcGIS is based on an existing programming language model, Visual Basic. Furthermore, a highly developed network requires careful analysis and efficient algorithm for faster processing and attributes data retrieval. The main goal is to establish a topological relationship between a shape file and a network through attributes data, i.e.:



Attributes for Shape files

This process provides a lot of flexibility in terms of spatial data and format. Eventually this model will be functional enough to accept many different data formats and generate a topological network with corresponding relationships. The following demonstration is provided in a 2-Dimensional format but it has the capability to be scaled up to a 3-Dimensional representation as well.

III. Pilot Project Implementation

There are several stages towards understanding and implementation of this topic:

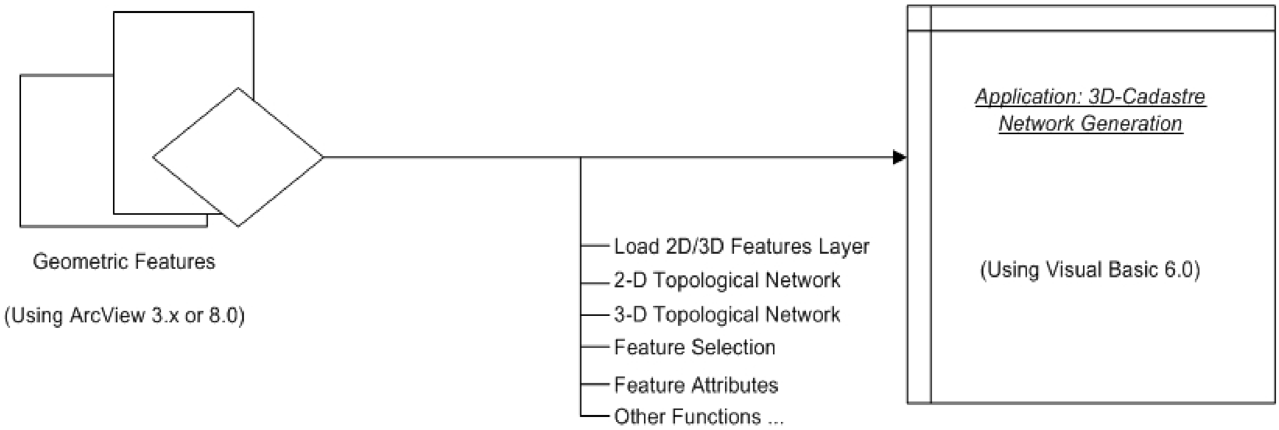
- Phase 1: Planning/Proposal
- Phase 2: Data Requirements
- Phase 3: Prototype Development
- Phase 4: Two-Dimensional topological relationship
- Phase 5: Three-Dimensional topological relationship
- Phase 6: Integration of Network Generation code
- Phase 7: Testing and Maintenance
- Phase 8: Enhancement/Modifications

A major part of each phase is to define a textual statement about the scope and the goal of that particular phase.

III-1. Implementation Proposal

As mentioned earlier, this model can be implemented into a stand-alone portable application solution. There are two main distinct entities: 1) Geographical geometric data; 2) Geographical attributes data

The topological representation is based on the geometric data while the spatial querying and features selection is based on the attributes data. The geographical features and shape files can be created in either ArcView 3.x or 8.x while the stand-alone application is implemented in Visual Basic 6.0. Following is a general data-flow diagram of the intended system, titled *3-D Cadastre Network Generation*:



The Application loads the geographic shapes/layers as an object and has access to several thematic functions and feature attributes. The Implementation Proposal constitutes of Phase 3 - Phase 8 of the development process. The Application has several current functions and possible future functions to enhance the utility and use. Some of the important functions for features and data display, query, and representation are:

- Load thematic shape file into the Application as object/s ad represented in a 2-Dimensional plane
- Generation of a 2-Dimensional topological network as simple shape objects (**Edges** as lines, **Nodes** as circles, etc) in Visual Basic
- Store the topological network shape objects in an array, matching the theme's **Nodes IDs** to corresponding shapes **IDs** or **Reference Keys**
- Representing the thematic shape files in a 3-Dimensional plane
- Representing the existing topological network into a 3-Dimensional plane
- Data display, query, and search based on thematic features as well as topological network objects

III-2. Examples Demo

Following is a sample of a 2-Dimensional network generation programming pseudo code:

'This method searches for a feature with the same ID as the "mouse-clicked" node:

Procedure SearchForNode(grpahicNodeID as int, nodeID as int, mapControl as object){

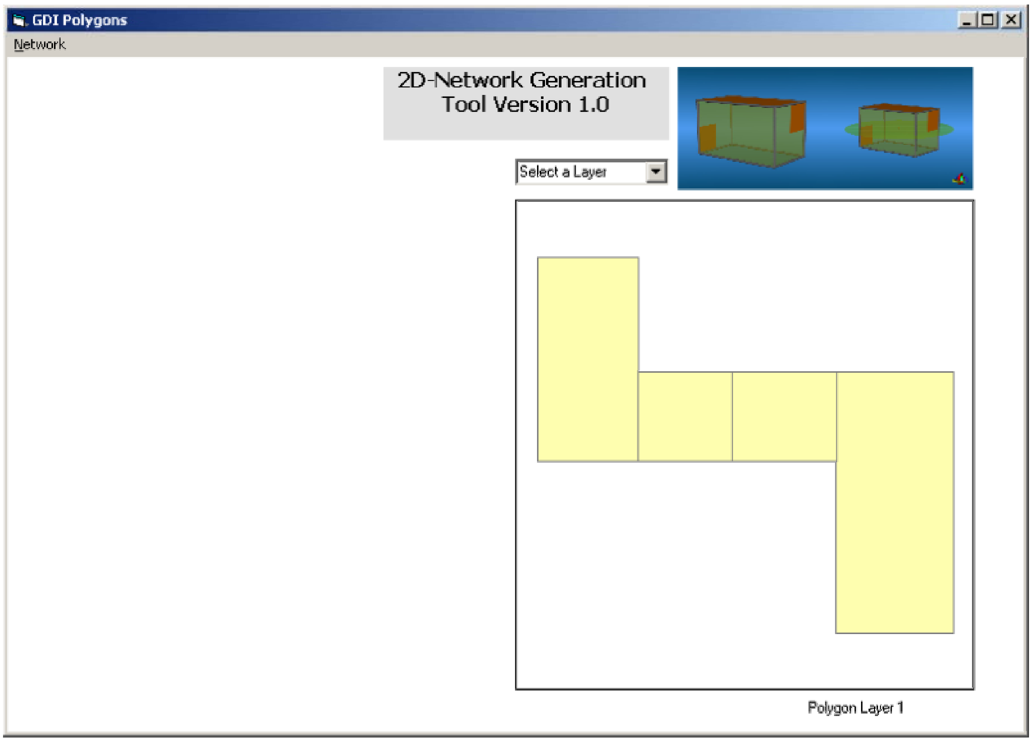
' Set an object for geographic theme/layer

```
        newLayer as object
        ‘ Set a variable to store geographic theme/layer attributes data;
        selectionSet as SelectionSet;
        counter as integer;

        ‘ Set the object to the input map layer
        Set newLayer = mapControl.Layer( );

        ‘ Retrieve the attributes from the layer
        Set selectionSet = newLayer.SelectionSet( );

        ‘ Match the ID of the “mouse-clicked” node with the ID in the attribute data
        For counter = 1 to selectionSet.Nothing{
                If selectionSet.Feature = graphicNodeID{
                        nodeID = graphicNodeID
                }
        }
        ‘ Return ID of the matched feature attribute
        return nodeID;
}
```

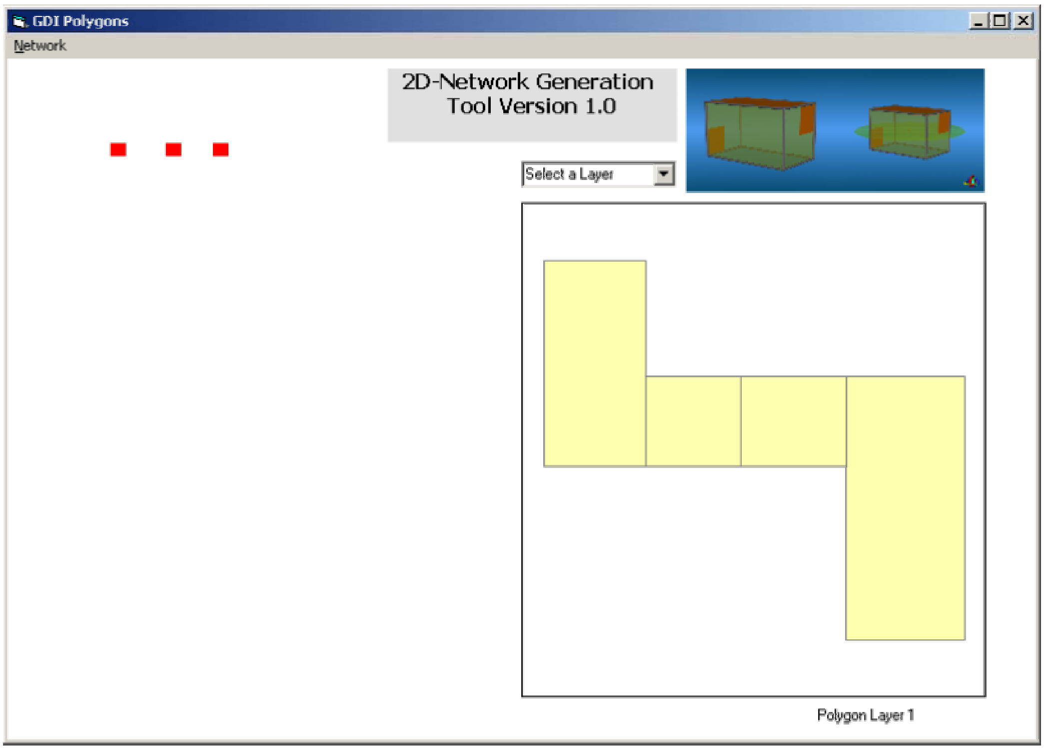
‘This method shows the program flow: click the node → Get the node’s ID → search for cooresponding feature in the attributes data:

```
Procedure findPolygon(){
        Capture mouse click event
        Get mouse clicked Node → graphicNodeID
        Run SearchForNode(graphicNodeID,….)
        Make corresponding NodeID active in maControl
        …….
}
```

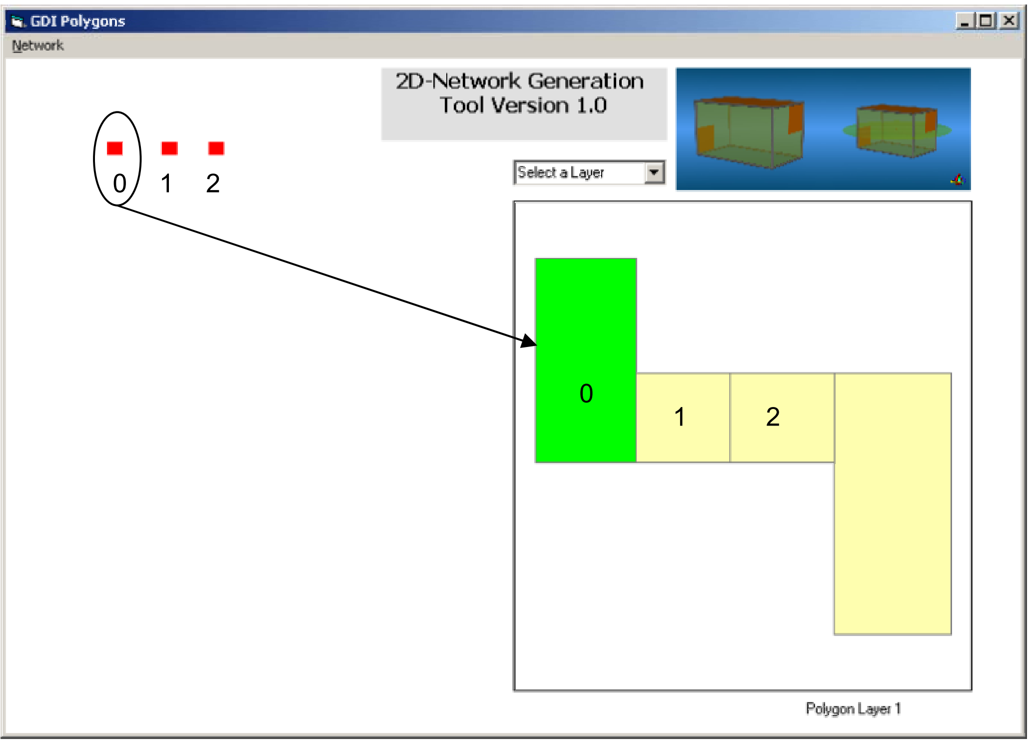
- Example of the Application interface:



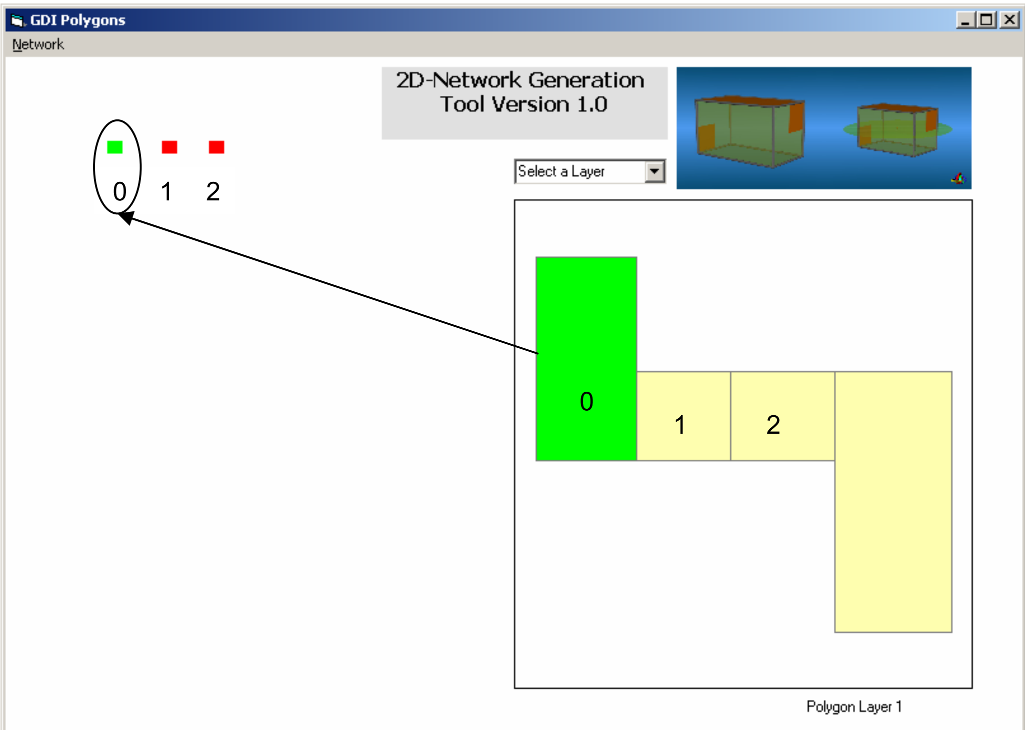
- Example of a sample small networks (only Nodes)



- Example of Map Features selection from Nodes:



- Another Example of Nodes selection from Map Features:



IV. Conclusion

Some of the solutions provided have been partially implemented in the existing software and tools while others need more research for a concrete foundation. The main goal of this document is to increase an awareness of the growing need for 3-Dimensional representation and the quest to search for efficient and possible solutions for achieving these objectives. It is also suggested that a prototypical solution is attached as a starting point for better explanation of the key concepts, however, avid readers can take the clues from these articles and use their imaginations for a living sample based on information they learned.

V. Reference

Billen, R., & Zlatanova, S. (2003). 3D spatial relationships model: A useful concept for 3D cadastre? *Computers, Environment and Urban Systems*, 27, 411-425.

Coors, V. (2003). 3D-GIS in networking environments. *Computers, Environment and Urban Systems*, 27, 345-357.

Kwan, M-P. and Lee, Jiyeong. (2004). Emergency response after 9/11: the potential of real-time 3D GIS for quick emergency response in micro-spatial environments, *Computers, Environment and Urban Systems* (in press).

Lee, Jiyeong. (2001a). *A 3D data model for representing topological relationships between spatial entities in built environments.* Ph.D. Dissertation, Department of Geography, The Ohio State University, Columbus, Ohio, U.S.A.

Lee, Jiyeong. (2001b). A spatial access oriented implementation of a topological data model for 3D urban entities. Paper presented at University Consortium for Geographic Information Science (UCGIS) Summer Assembly, Buffalo, New York, June 21-24.

Lee, Jiyeong. (2001c). 3D Data Model for Representing Topological Relations of Urban Features, In *Proceeding of 21st Annual ESRI International User Conference*, San Diego, CA.

Lee, Jiyeong (2004). A Spatial Access Oriented Implementation of a Topological Data Model for 3D Urban Entities, submitted for publications to *GeoInformatica* (in press).

Molen, P. V. D. (2003). Institutional aspects of 3D cadastre, *Computers, Environment and Urban Systems*, 27, 383-394.

Raper, J. (2000). *Multidimensional geographic information science*. London: Taylor and Francis.