

Network Topology in 3D GIS

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Abstract

Nowadays the attribute 3D is widely used and it is an essential requirement for every system to provide the possibility to work in 3D. That is true for the Geographical Information Systems also, that is why they have been expanded with several new effective 3D tools, which ensure the professionals to create 2D and 3D maps faster than earlier. The systems are usually capable to visualise 3D maps with buildings and objects, but what about performing different analysis.

Large buildings, shopping centres have appeared all over the world, that is why it has become essential to be able to determine for example the shortest path also inside these types of buildings. Thus the softwares are expected to include network topology building and analysing tools. Two popular GIS applications are reviewed: the AutoCAD Map 3D 2010 from Autodesk and the ArcGIS 9.2 version from ESRI. Both systems contain tools for managing 3D, but there is no information about the possibility of building 3D topology in section where topology operations are discussed. This was the reason why built-in topology and analysing tools have been studied, and the SDKs have been explored as well.

Keywords: GIS, 3D topology, shortest path, AutoCAD Map, ArcGIS

1. Introduction

The need for being able to analyse and manipulate true 3D data is rapidly increasing. The popular and significant geographical information systems have to deal with this challenge, but are they able to do it? Two GIS softwares have been reviewed in order to find the answer to the questions concerning to 3D topology.

Topology is a major area of mathematics concerned with spatial properties that are preserved under continuous deformations of objects, for example, deformations that involve stretching, but no tearing or gluing. In GIS topology describes the relationships between points, lines, surfaces and solids that are non-metric (qualitative) properties of geographic objects that remain constant when the geographic

space of objects is distorted. For example, when a map is stretched, properties such as distance and angle change, whereas topological properties such as adjacency and containment do not [5]. Three types of topology can be defined usually: node, network and polygon topology, but this paper brings into focus just the network topology.

Network topology is modelled by points and line segments. For example, street intersections, fuses, switches, water valves, and the confluence of stream reaches are usually referred to as nodes in topological models, while streets, transmission lines, pipes, and stream reaches are regarded as edges or lines. Network topological relationships define how lines connect with each other at nodes [6]. Additional data for describing the properties of nodes and edges are needed as well that are referred to attribute data. The most frequent used network analysis tool is determining the shortest path that can be interpreted in 3D as well.

2. AutoCAD Map 2010

AutoCAD product family is the most well-known product line of the Autodesk. It is classically thought of as a software for computer-aided design (CAD), but later it has been expanded by GIS functionality. The company became the third larger GIS software vendor by 2003 [7]. Autodesk provides several development platforms to build applications. In case of Autodesk Map Lisp, Visual Basic or even C# can be chosen.

2.1. Creating spatial polylines

The first step when defining a network topology is to create the spatial polylines. There are two methods to do this: an existing source drawing containing the elements can be attached to the map, or we can draw them ourselves. The GIS component of the AutoCAD Map was designed to make planar objects which can cause difficulties if 3D polylines are needed. Lines, polylines can be drawn in the plane x, y, and in other planes parallel with it, but the software doesn't allow to create a polyline with endpoints of different z coordinates. This problem can be solved if we switch into the Drawings view, where several spatial objects are available. The only thing we have to do for creating spatial polylines is to set acad3D for the template of the map instead of map3d. Former restrictions do not run in this template any more, so the necessary 3D polylines can be drawn with ease.

2.1.1. Building 3D topology

Spatial polylines and primitives were used in the map prepared for performing tests. While building the topology the software omitted the primitives, but used the polylines regardless their positions. During the visualization all the polylines appeared in their appropriate positions. In spite of this the topology was incorrect

in case of nodes with identical x, y coordinates, and the software warned us when loading the topology next time.

2.1.2. Analysis

To perform analysis Autodesk Map asks for just x, y coordinates of the nodes. If the topology does not contain 2 nodes with identical x, y coordinates then Map performs the analysis correctly (Figure 1.).

Let us consider the sum of the lengths of the two lines in topology A, located in the x, y plane in the figure. This sum is greater than the sum of the another two red lines length, which are not in the x, y plane. In the case of topology B the roles are exchanged. Our observations show that AutoCAD is able to determine the shortest path in both cases so in spite of the 2D input data the software takes into account the real length of the lines, and not the length of the line projected to the x, y plane. However if the topology contains two or more points with the same x, y coordinates, but with different z coordinates then discontinuity can occur in the shortest path. The Figure 2 helps us to understand the reason for the discontinuity.

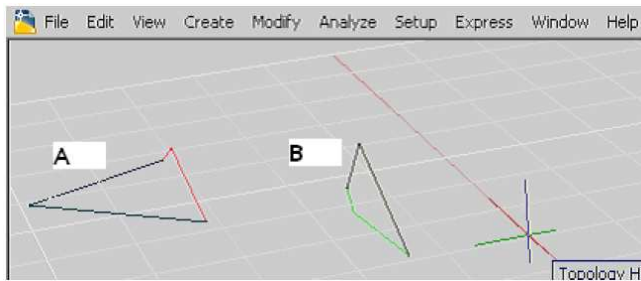


Figure 1: The proper visualized shortest paths in AutoCAD Map

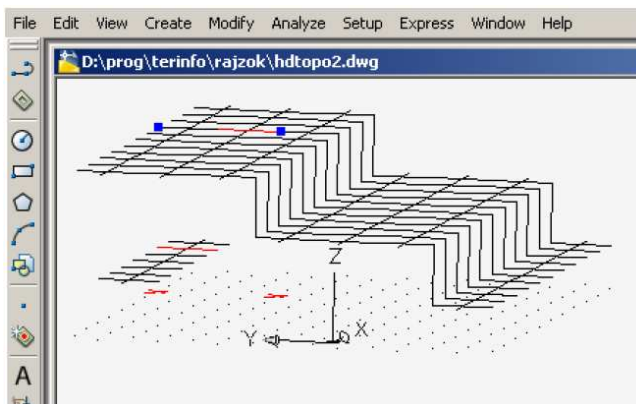


Figure 2: Discontinuity of the recommended shortest path

During defining a topology, points under grids indicate the nodes at the end-points of line segments. Although the line system is terraced-shaped to the direction of axis z , the z coordinates of all nodes equal to zero. Thus the nodes with the same x , y coordinates coincide. This can be probably the reason why some 3D topologies cannot be rebuilt even by the system again based on the stored information, and why we get a message telling us that the topology is incorrect. Unfortunately the analyzing tools produce invalid results as well in case of 3D topology. In the Figure 2 the suggested shortest path can be seen where the selected starting point and the ending point are denoted by blue squares while the red lines belong to the incorrect recommended path calculated by the software.

2.2. Application Programming Interface

The AutoCAD supports different developing platforms from which the C# was chosen to explore how the topology can be handled by program codes. During last years Autodesk improved the geographical data storage facilities widely. The new FDO (Feature Data Object) technology took effects to the programming interfaces as well. More significant difference can be measured between the languages used for programming. Lisp and Visual Basic macros can be used mainly for programming inner statements while Visual Basic and C# applications are more suitable for developing complex projects and for handling the new data storage mechanism with ease.

2.2.1. Support for creating spatial line system

The program asks type Point3d when providing the endpoints of lines that is why this operation can be performed without any further problem regardless of the type of the active document [4].

2.2.2. Building 3D topology

The building of a 3D topology is not supported yet basically. Some functions have not been implemented yet, but there exist some functions, which can be used to build the topology [4]. Alike the user interface the program can not take into consideration the primitive types and just the polylines are used to build the topology.

2.2.3. Realization and realizability of the analysis tools

Altering the input

Through the user interface of AutoCAD Map it is possible to build then to visualize correctly a 3D topology containing not just x , y -planed polylines, in spite of this it accepts only the x , y coordinates of the points when performing network analysis. The Figure 2 shows that during determining the shortest path the marked point is projected immediately to the x , y plane (denoted by red x). On the other hand the built-in function can go with 3 coordinates. Unfortunately the function

provided by the proper z coordinates is not able to determine correctly the shortest path, which can be seen in the figure.

Altering the location of a node

The developer's guide explores [2] that the network nodes have no z coordinates at all. It seems to be a contradiction that in the supported programming languages topology nodes are stored as type `Point3d` or some other equivalent type, which can ensure to analyze a 3D topology. The topology is stored as a list of edges (`FullEdgesCollection`) and nodes (`NodesCollection`) [5]. We already know that the z coordinates of nodes equal to zero. But objects reached through the edges have the proper coordinates, so the z coordinate of a node can be read with ease. There is a function called `moveNode(Point3d)` that can be used to move a node, but it does not solve our problem, because if we want a node to move to a new position where the z coordinate is not zero an `ArgumentException` occurs. No doubt, that Autodesk stores just 2D data in the background.

If we want to build and analyze an arbitrary 3D topology we need to define new tools and functions to do it.

3. ESRI ArcGIS 9.2

ESRI was established in 1969, and nowadays it is the largest GIS software vendor at the market. ArcGIS is an integrated family of products aimed at both end-users and technical developers and run on hand-held devices, desktop personal computers and servers [7]. ArcGIS Desktop includes a suit of applications, which can be used to perform any GIS task, from simple to advanced.

ArcReader is a free, easy-to-use desktop mapping application that allows users to view, explore, and print maps and globes. ArcCatalog provides a user interface, similar to Windows Explorer, to manage geographic information, such as maps, globes, data files, geodatabases, geoprocessing toolboxes, metadata and GIS services. The main application is ArcMap, which is used for all 2D mapping and editing tasks as well as for map-based query and analysis. 3DAnalyst is an ArcGIS extension that provides advanced tools for three-dimensional visualization, analysis, and surface generation. ArcScene, which is a component of this extension, lets the analyst make perspective view scenes in which users can navigate and interact with GIS data. Another part is ArcGlobe that can be used for Earth 3D visualization. Additional extensions are available for other special purposes as well.

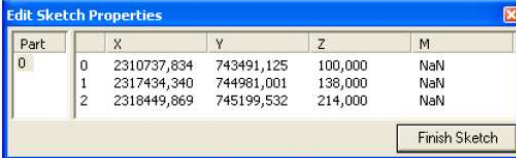
3.1. Support for creating spatial line system

The user interface of ArcGIS Desktop products serves mainly to manage and analyze maps, so if we need 3D surfaces or polylines we often import measured data or use different external tools. Creating 3D polylines can be achieved by importing data from AutoCAD, or by using a simple text file [1].

3.1.1. Building 3D topology

A topology can be based on data coming from a shapefile or a geodatabase [8]. Both file type have been created from the AutoCAD drawing that can be seen in the Figure 2. To get a shapefile in AutoCAD we have to export the data after opening the drawing. The visualization of the resulting shapefile and the original drawing are identical. It is interesting that the geodatabase, produced by using the command ArcToolBox→Conversion Tools→To Geodatabase→Import From CAD, varies from one we expect (see Figure 4).

Bold green lines denote lines that have been involved in the geodatabase while black lines refer to the original drawing. The points with the same x, y coordinates but with different z coordinates cause the problems like in AutoCAD. That is the reason for not stopping our investigations on how to build a 3D network from a shapefile. The new network can be created from the exported file in ArcCatalog. While building the network a message appears warning us, that 22 zero-lengthened lines were found. These lines can be seen as vertical line segments in the Figure 4.



Part	X	Y	Z	M
0	2310737,834	743491,125	100,000	NaN
1	2317434,340	744981,001	138,000	NaN
2	2318449,869	745199,532	214,000	NaN

Figure 3: The three coordinates of a polyline consisted of 3 points

If we are familiar with ArcObjects [1], we can define a feature class of polyline type, which point features have got correct z coordinates (Figure 3). The question is whether the behavior of the line system will change or not. Our experiences show that unfortunately nothing has been altered.

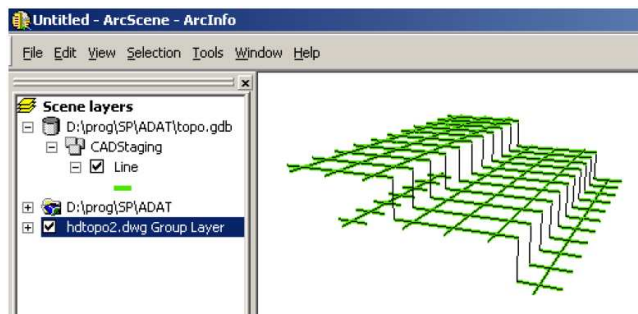


Figure 4: The difference between the original drawing and the geodatabase

3.1.2. Analysis tools

Network analysis tools are available from ArcMap, which basically does not support 3D visualization. The analysis is performed by using the x, y coordinates because

they can determine uniquely a point of the network according to the previous section.

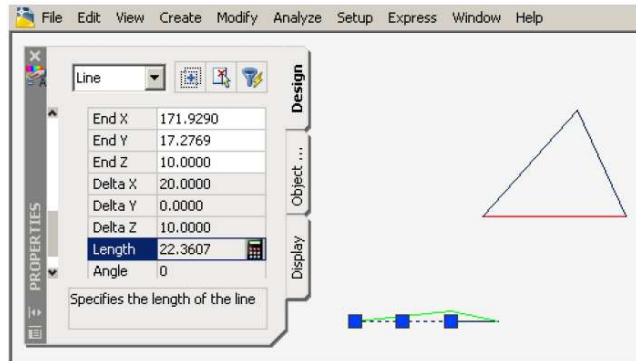


Figure 5: Measuring distance in AutoCAD

Unlike AutoCAD the greatest z coordinate will be significant, I mean the image of the network created from the lines mentioned above will be a continuous grid, and the software regards it this way while determining path. AutoCAD uses the proper length of the lines in spite of that during the analysis it takes into account just two coordinates, but this produces an appropriate path except for path containing vertical lines. An analysis on the same data in ArcMap produces different path. While AutoCAD is able to show the topology from an arbitrary view then we have to make do with just one view in ArcMap. The Figure 5 and 6 show the two 3D triangles from the Figure 1 projected to the x, y plane.

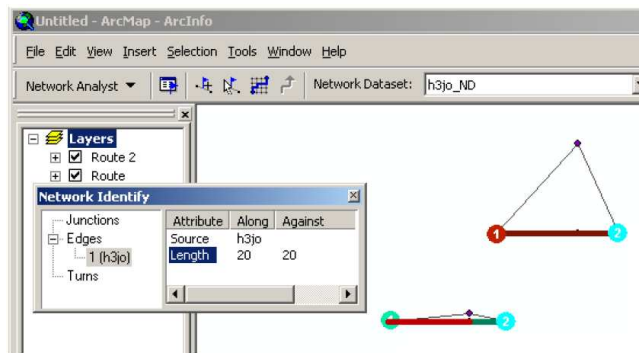


Figure 6: Measuring distance in ArcMap

AutoCAD has determined the distance based on three coordinates, but ArcMap has used just the x, y coordinates again when calculating the length of the lines. The sum of the highlighted line lengths belonging to the polyline in the bottom of the picture exceeds the sum of another two line lengths. The sum of their length in the image projected to the x, y plane is smaller than the sum of another two lines

length that is why the software recommends the lines denoted by red and green as the shortest path between the point 1 and 2.

4. Conclusion

It can be claimed that the newest products of the Autodesk and ESRI represents data such a way that does not really support to build and use an arbitrary 3D topology. However AutoCAD Map is able to determine the proper shortest path in case of most topologies, or indicates that the topology is incorrect. ESRI has implemented the operations for handling topologies exclusively in 2D. If we want to work with the length of the line segments an additional attribute has to be defined in order to store the proper length value.

Unfortunately either of the two softwares are not prepared to handle not-surface-based type of topology, which would be important in case of determining the shortest path inside a building. However this type of topology could be applied in several useful programs. It could promote the navigation inside the buildings or mountains for example. It could make possible the usage of the well-known path search systems if we want to find our path in the airports, in large shopping centers or even inside a town-sized skyscraper. A system that is capable to deal with a volumetric 3D topology could be useful not just in the everyday life but could be essential for emergency response, search-and-rescue, and tactical military operations help also.

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