Research on 3D Terrain Visualization based on GIS in the Mountainous Area—Taking Xiping Town as an Example

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Abstract

In this paper, visualization technology for building 3D terrain scenes had been discussed. We first analyzed the state of the arts of available 3D terrain visualization technologies by comparing the strengths and weakness of each technology. Second, we used Esri’s ArcGIS as the platform to demonstrate the 3D TIN generating algorithm and 3D analysis functions. Then, we chose Xiping Town (a typical town in the mountainous area in Anxi County, Fujian Province, China) as an example to explain the workflow and process of 3D terrain visualization in GIS system. Last, we summarized the linkage between 3D visualization results with land use strategy. The main contribution of this research was to improve the communication level in urban planning, with the support of GIS technology and updated 3D modelling techniques.

Keywords: Digital City, 3D GIS, Terrain Visualization, ArcGIS

1. Introduction

With the acceleration of China’s new round of urbanization, urban areas are exploding in a quicker pace. As a result, new technologies, for example, digital city technologies, are becoming more and more appealing [1-3]. In urban planning practice, considering the special needs, i.e., public participation, mass data to be dealt with, quantitative analysis, and easy understanding for common people, researchers are looking for updated technologies for promoting the implementation quality of urban planning [4-6]. Traditionally, urban planners analyzed and expressed urban problems in plan map of two dimensions. It is obviously that the analysis and expression by two-dimensional form increasingly shows its shortcomings in full communication and understanding. For example, the original three-dimensional information about the topographic construct and analysis may be compressed, concealed, and even lost in the traditional 2D mapping process. As a result, the space scenes cannot be reproduced, which will leads to empirical judgments and unscientific analysis and solutions.

Against this backdrop, there is a development tendency for planning domain to promote the innovation of planning and design method by using advanced technologies, i.e., 3D GIS [7-10]. The adoption of new technologies will improve the rationality and universality of urban planning tasks, as well as reduce the negative impact of the uncertainty of “art” in traditional urban planning implementation.

In this paper, we will discuss 3D terrain visualization problem based on GIS technologies [11-13]. Specifically, we will use available commercial GIS software for our analysis [14-16]. We will use Xiping Town as an example to demonstrate the detailed implementation issues and the meanings of 3D terrain visualization for urban land use planning.

The remainder of this paper is organized as follows. Section 2 discusses the state of the arts of 3D terrain visualization. Section 3 introduces the GIS-based 3D terrain visualization method, workflow and key issues in Esri’s ArcGIS platform. Section 4 is the case study and discussions. Finally, concluding remarks are presented in Section 5. The main contribution of this research was to improve the communication level in urban planning, with the support of GIS technology and updated 3D modelling techniques.
2. State of the arts of 3D terrain visualization

2.1. Direct 3D data acquisition

Direct 3D data acquisition mainly refers to the application of the advanced laser technique to acquire the precise data of the three-dimensional terrain measured in points [17]. The technique can scan the city in the air by laser at high inclination angles to quickly acquire the three-dimensional point-cloud data. It also can rapidly build a city ground model and construct a 3D building according to its feature point by use of specified software. If we can obtain the image meanwhile, the texture data acquisition can be achieved, which can greatly increase the speed and precision of constructing a 3D building. However, there are still some weaknesses at present such as insufficient precision at variable scale, difficulties in full acquisition of geometry and texture at side, high cost and so on. Thus, this type of direct 3D data acquisition technologies cannot get common used in the field of urban and rural planning at present.

2.2. 3D data conversion

This mainly refers to converting the three-dimensional geographic data into text form in computer language by applying computer and coding techniques such as Cult3D, Java3D, VRML, OpenGL, and then explaining it into three-dimensional scene according to certain specifications. These technical means are difficult to master without skilled background of computer language. The operation is also very complex. For example, when building a model we need write code from low level and the work to construct complex terrain can be very time-consuming. What’s more, these softwares are not specially developed to apply in the building and analysis of 3D terrains so that they can only meet the needs of 3D Terrain Visualization, and cannot make further analysis of the terrains. Thus, in the domain of urban and rural planning, these types of method have been getting limited used.

2.3. 2D data processing and 3D reproducing

This means giving a Z value to the 2D data and defining its 3D space attribute by using the modeling and analyzing software such as SketchUp and 3Dmax. Among them, some are mainly applied in field of architecture and industrial design and they amply focus on detail representation. However, those softwares depend too much upon personal experiences. Besides, for some large areas, the modeling process will produce redundant and huge data, and the task will be also repetitive. Thus, it will occupy too much time and manpower. From the perspective of efficiency, those softwares cannot meet the requirement of quick 3D Terrain Visualization of large areas.

2.4. GIS-based method for 3D visualization

The GIS suites developed by ESRI, i.e. ArcGIS, have capability of rapid data processing, powerful and convenient interfaces with easy operation. The 3D modules of the suite, i.e., ArcScene, possess powerful ability of building and analyzing 3D terrain, and the generated images are attractive. Besides, it can work well along with many other display and design softwares, i.e., Google Earth, CAD. The GIS suites can be an excellent tool to complete building, analyzing and displaying of the 3D terrain.

As shown in Figure 1, the same data had been visualized in different technologic platform. In CAD, the terrain is represented with line feature with different colors. In SketchUp (SU), the terrain is represented with extruded contour boundary. In ArcGIS, the terrain is represented with TIN. In 3DMAX, the terrain is represented with continuous surface. Among them, using ArcGIS for 3D terrain visualization have the strength in its quickness and convenience.
3. GIS-based 3D terrain visualization in ArcGIS

3.1. Introduction of ArcGIS’s 3D function

ArcScene collects most of the 3D function of ArcGIS. ArcScene is mainly used in building 3D terrain visualization because it supports 3D geometric element with Z value such as point, line, polygon, and multi patch. It can give a Z value to the 2D data and display its attribute in 3D space to accomplish the 3D terrain visualization. Different with those modeling softwares such as SketchUp, ArcScene saves the 3D information of data by its property sheet. It will not only help us quickly build 3D terrain visualization but also display data in different stypes such as elevation distribution, slope, aspect and the condition of shadow through various rendering methods. Meanwhile, it has a strong ability of data sharing with softwares such as Sketch Up, 3D Max, AutoCAD, etc.

3.2. Technical route

Figure 2 shows the technical route of 3D Terrain Building and Analysis. ArcGIS supports different 3D data format including raster surfaces, TIN surfaces, and 3D feature with Z value. The data of TIN surfaces are most frequently used in the analysis of terrain in urban planning. It is used to build continuous terrain based on the theory of “three points making a plane”. With the help of interconnecting triangles, we can calculate the elevation of any point on the plane by interpolation.
method. This kind of data has variable resolution and good zooming effect. Furthermore, its precision can be enough in building complex terrain in large scale.

3.3. The building of 3D terrain

The vectorized data files in DWG format can directly build TIN files by using ArcScene’s 3D analysis plug-in, while the grid files require the plug-in of Arcmap “DEM TO TIN” to accomplish the task. The realization of this process relies on fields coding the elevation information in its property sheet. Therefore, the key to build 3D terrain by ArcGIS is to gain the elevation information in the form of property sheet. More information could be added to the terrain:

1) Information from raster elements: It mainly refers to adding images of the earth’s surface such as aerial photographs or the RS images to the surface of 3D terrain to strengthen its photorealistic feeling. It can also make a more realistic and vivid display of water systems, roads and architectural layout than the traditional terrain display by using symbols.

2) Information from vector elements: It mainly means adding more rich elements such as rivers, lakes, roads and planning red line so that we can better reproduce the present condition of the terrain and to rich the understanding of the urban environment.

3) Information from other 3D elements: It mainly includes importing the buildings and other 3D elements like large signal towers, substation facilities, plants, cars, etc. It has some significance for the reproducing scenes of 3D terrain visualization. The process can be realized by invoking the symbol library of ArcScene, or importing the symbols of the third-party software as symbols by the Symbol Property Editor of ArcScene to make more realistic reproduction. As to the import of the buildings, except for the method of symbol library, we can also import the building’s planar contour as polygon into ArcScene and then turn its elevation into Z value to stretch the entire 2D polygon into 3D format.

3.4. The analysis of 3D terrain

ArcScene can not only achieve good visual presentation effect, but also provide further 3D analysis functions. The analysis process is to extract the information from the TIN surfaces, and to render the TIN surfaces into grid files by linear interpolation and natural neighbor interpolation.
The 3D terrain analysis methods generally used in urban and rural planning are elevation, slope, and aspect. The elevation and the slope of the terrain determine the difficulty and workload of the terrain utilization, while the aspect determines its sunshine utilization effect. They are determining factors to judge the suitability and function layout of the terrain. The process can be achieved by invoking the three functions “Elevation”, “Slope” and “Aspect” in ArcScene and rendering the analysis data according to the basic elements including polygon, knot and fringe, which are also generated by data calculation of ArcGIS’s property sheet.

The important thing to note is that the expression of slope in ArcScene is different with what we generally use in urban and rural planning. We usually express the slope by the angle between horizon and the terrain, while what is usually used in ArcScene is the value of trigonometric function. Generally speaking, the conversion relationship between some major slope value in general planning and the expression value in ArcScene is as follows: 8% slope is 4.57 in ArcScene, while 15% is 8.53, and the general ultimate slope 20% is 14.

3.5. The follow-up work of 3D terrain

After completing the above steps, we have basically accomplished the expression and analysis of 3D terrain visualization. The follow-up work is mainly about outputing the results. The result files can be output in form of map. We can also display the 3D results in form of flash based on the analog roaming of the presetting path. Besides, we can transfer it into the VRML files based on JAVA language and then make further research by means of programming languages. We can also invoke it into ArcGlobe to present the terrain in large scale. The 3D terrain visualization in ArcGlobe can make observation and analysis from a more macroscopic angle. Also, the 3D results could be exported into KMZ format and then imported into Google Earth for digital communication and data sharing.

4. Case study and discussion

4.1. Study area

Xiping Town located within the south-central part of Anxi County, Fujian Province, is at the south of Mount Daiyun. The town is at longitude 117°50′~117°59′ east and latitude 24°56′~25°01′ north. Xiping Town has an area of 145.5 square kilometers. Lan Stream crosses the center of the township. New conceptual plan and land use plan will be taken for the county. Because of its complex landform and strained land, it is urgent to analyze its land resource with the 3D visualization technologies and quantitative methods.

4.2. Analysis of terrain

The data this paper used include digital CAD map, satellite photographs of this district that get from screenshots of Google Earth and some important vector file in DWG format. The CAD map is made from 1:1 mapping to Xiping, along with its major elements of 1 meter-division contours and the outlines of the river. The vector file covers the present condition of buildings, the storey of building, planned red line, road and the distribution of prime farmland. The DEM data set is provided by International Scientific & Technical Data Mirror Site, Computer Network Information Center, and Chinese Academy of Sciences (http://datamirror.csdb.cn).

In ArcScene, contour data is directly imported and TIN data could be generated. The TIN could be further beautified after elevation rendering, slope rendering, aspect rendering, as shown in Figure 3. Analysis linking with terrain and elevation shows that this region has a typical mountains landform—not very high but has distinct rising and falling, with its height sharply rises from 180m to almost 1000m, as shown in Figure 4. The entire land covers three high mountains and some small hills. The lower valley located at the center of the study area. It is certain that the available land in this region should be distributed around the lower valley and along the river. The available land of Xiping Town is mainly concentrated at the bottom of the valley. Moreover, Lanxi Stream passes through the town and northern part is restricted in developing. Within the town, the river crossing the town may
bring some disasters and risks. The further terrain processing could include hydrologic analysis, as shown in Figure 5.

**Figure 3.** Elvation, Slope, Aspect rendering for 3D terrain

**Figure 4.** Birdview of 3D terrain

**Figure 5.** Hydrologic analysis of terrain
4.3. Development strategy and landscape structure

1) Present condition analysis and development strategy: Analysis linking with slope rendering finds that there is little available land within planned red lines, and major flat land gathers at the valley which is located at the south of Lanxi Stream. Therefore, the planning structure of “one center and three axes” is finally confirmed, whose main developing direction is towards south, putting Y-shaped estuary district as its center. Analysis linking with buildings shows that the contradiction between land and population in Xiping is critical, with very tight land and limited new available land. However, the average building storey of the town is less than three. Therefore, intensive development model of high density and saving construction land are put forward in the planning strategy. Meanwhile, it establishes the development strategy of placing interior reform first and exterior expansion second, focusing on the reform of the town’s center and increasing the volume fraction and building density of built-up areas.

2) Development control and structure of landscape: Analysis linking with aspect rendering finds that within planned land, those who have a better landscape and orientation concentrate at the piedmont region located at the north of Lanxi Stream. This region has a better greening and certain slope. It’s not appropriate to undertake large-scale exploitation and construction, as a result of the possibility of flood for Lanxi Stream. Consequently, the northern piedmont region and easy-flooded northern region of Lanxi Stream are designated the area where building is restricted. Those regions are mainly used to public lawn, forming green belts along the river by accompanying with moderate-slope hills. Analysis of the superposed slope of 3D terrain and vegetation illustrates that the vegetation on the river banks is better and it is determined as the main landscape axis of the urban in the planning. Also, a central park is being set up, two sides of which are covered by green belts along the river, presented as the green road of the urban. Meanwhile, as a result of the beautiful natural mountain landscape around the urban, through the combination of ArcScene 3D terrain and sights analysis, several natural mountain-protection parks are being established around the urban, as the urban greening node.

5. Conclusion

From above analysis and case study, we can see the great advantage of the 3D terrain visualization over the traditional 2D terrain map. It can give the planners a more visual understanding of the region and land distribution, which contributes to analyzing the advantages and disadvantages of the condition. It will help planners face the challenges and opportunities to assist the formulation of the planning and strategy. We could summarize the strengthness of the GIS-based 3D terrain visualization into following points:

1) Assist making strategy for urban development: By applying ArcScene and adding vector factors such as rivers, road network, planning red line and so on, we could build reasonable 3D terrain scenario and extend our understanding of the relationship between urban pattern and surroundings. As a result, they will assist in making planning strategy more scientific, including development patterns, space structure, direction and axis of development and so on.

2) Assist making land use plan map: As the core task of urban and rural planning, land is the most important factor. 3D terrain analysis could provide a series of decision factors, such as slope, aspect, elevation, etc., which will be useful for support making land use suitability map and landscape sensitive map.

3) Assist preventing from disasters: Poor landform plays a crucial role in the occurrence of urban disasters. Surface analysis can provide a decision basis to urban planning for disaster preventing. For example, we can define the flooded area by applying hydrological analysis when there are rivers passing through the city. We can also find the multiple disaster regions of debris flow in the towns of mountainous area by analyzing the superimposed landform and hydrological slope.

4) Assist making infrastructure layout: In the aspect of infrastructure layouting, such as public service networks, road line, and pipelines, the 3D terrain has a great advantage over 2D picture, especially in the mountainous area. Because the distance on 2D picture may be not the actual distance between two sites with landform changes, which plays a determining role in defining service radius and selecting road lines and pipelines. We can locate the service facility on the 3D terrain and make buffer analysis so that we can identify the present problem and improve the facility layouting.
5) Assist making landscape layout: Usually, landscape layout is closely interrelated with natural mountain, water and forest. Meanwhile, it also has natural ties with the formation of terrain and landscape structure. After 3D terrain visualization and folding the slope and the aspect, more comprehensive understanding will be achieved in the aspect of landscape by referring to existing green belt and present conditions of landscape.

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6. References