Study on 3D Terrain Generation and Lightweighting Method of Highway

Yinghao Chen¹,²*, Leisheng Zhou³ and Jianping Xia³

¹ Research Institute of Highway, Ministry Transport, Beijing 10088, China.
² China-Road Transportation Verification & Inspection Hi-Tech Co., Ltd, Ministry Transport, Beijing 10088, China.
³ Qilu Transportation Development Group Co., Ltd, Jinan, Shandong, 250001, China.

*Corresponding author’s e-mail: 450346899@qq.com

Abstract. BIM technology is widely used in highway engineering projects. During the transformation of 2D design and application to 3D, especially for special strip projects such as highways, 3D terrain has problems such as large loading efficiency and low efficiency. Based on the Beijing-Shanghai Highway reconstruction and expansion project, this paper studies the three-dimensional terrain generation and lightweight conversion methods of highway. The terrain construction method is optimized during the formation phase of the terrain, and the polygon is triangulated using the triangular surface growth algorithm. By generating the PHM (Polyhedral Mesh) terrain surface, a three-dimensional terrain model with no deviation, small volume and high generation efficiency is realized. The lightweight 3D terrain model generated by the modeling software can further simplify the 3D terrain and realize the pyramid terrain model with different loading accuracy with different sight distance through grid conversion and tin buffer generation. At the same time, the terrain is projected on satellite images, and the surrounding scenes are deeply fused. The results show that the lightening of terrain in the modeling stage is conducive to improving the modeling efficiency, eliminating the problems of large volume and stuttering of conventional terrain models, and improving the efficiency of terrain export. In the application phase, format conversion and pyramid loading are performed on the terrain, and the lightweight loading of the terrain model is truly realized. The terrain model is seamlessly integrated with the BIM road and other models, and at the same time, it covers elements such as satellite films, enabling real-time browsing based on the B/S (Browser/Server).

1. Introduction
At present, BIM technology is widely used in the infrastructure industry. For large highway projects, BIM technology has played a significant management role in engineering survey, design, supervision, construction, operation and maintenance, etc., and has improved the industry’s sophisticated design level, construction manufacturing and management capabilities [1]. However, in the process of gradually shifting from two-dimensional to three-dimensional, there are still many problems that need to be solved urgently. Among them, the problem of low-efficiency generation and large data volume of three-dimensional terrain is an important factor to limit the overall three-dimensional application of large projects. The advantages of three-dimensional terrain over two-dimensional terrain are obvious, especially for areas with mountainous highways with obvious terrain fluctuations and large filling and
excavation areas. Using three-dimensional terrain directly to design can allow designers to design the line more intuitively and efficiently. It also improves the innovative thinking of the scheme [2]. The combination of visual 3D terrain and road, bridge, culvert, tunnel and other BIM models effectively improves the decision-making ability of project participants. Therefore, how to realize the efficient construction and application of 3D terrain is the key to realize the application ability of BIM technology. As early as 1999, Qi Min [3] began to study the technology of 3D terrain generation and real-time display, and summarized the methods to raise the problem of data volume limitation. In 2011, Xu Tianxin [4] studied the construction of three-dimensional terrain in domestic scenic spots, and realized fine reconstruction of small-scale terrain. By 2017, Yuan Songhe [5] and others summarized and researched the three-dimensional terrain data structure and summarized the methods for storing and scheduling massive terrain data. In the past two years, Yu Fengshu [6] and others based on the idea of a triangular prism model and comprehensively used BIM technology to propose an algorithm for constructing a BIM model of a geological body. Sun Shaonan [7] studied the method of quickly establishing a 3D terrain model by using UAV tilt photography technology to achieve batch and automated 3D modeling goals in a small area. Niu Zuopeng [8] proposed the use of Kriging to optimize the problem of discrete terrain data or null area of terrain data that caused the terrain surface to be created to be not smooth enough, and deep concave or convex.

Existing researches have focused on small-scale and regional-scale projects, do not involve the study of three-dimensional terrain of large highway and other special strip projects, and do not involve in-depth optimization and lightweight of terrain. In this paper, the method of terrain optimization is proposed by using BIM Technology and GIS technology, which is applied to the reconstruction and expansion project of Beijing Shanghai highway, and a set of reusable large volume 3D terrain generation and lightweight solution is proposed.

2. Project profile

The Xintai Hub to Linyi section was completed and opened to traffic in 1999. The design speed is 120km/h, which is a two-way four-lane highway with a width of 28.0 meters. With the rapid development of China's economy and society, the highway transportation capacity of the pre-construction is tight and the service level is seriously degraded. Therefore, it is necessary to renovate and expand the Xintai-Linyi section of the Beijing-Shanghai Highway.

![Cross-sectional view of the double-sided widened roadbed of the main line of Beijing-Shanghai highway reconstruction and expansion.](image)

Figure 1. Cross-sectional view of the double-sided widened roadbed of the main line of Beijing-Shanghai highway reconstruction and expansion.

The Beijing-Shanghai Reconstruction and Expansion Project adopts the fully enclosed and fully interchanged highway standards. The two-way eight-lane standard is adopted, and the roadbed is 42m wide. The expansion method is double-sided spelling, as shown in Figure 1. The terrain of this project is complex, including iteration of existing road terrain and new road terrain, and the project is 232.393km long. The band-like features are very obvious, and the construction of three-dimensional terrain is very difficult. In order to realize the full project 3D terrain visualization and scene application, it is necessary to study a lightweight, high-precision 3D terrain implementation method that can be loaded step by step.
3. **3D BIM terrain generation and lightweight**

3.1. **Date source**

To generate 3D terrain, it must first have a data source. The data source comes down to a collection of points on the surface of the terrain, which specifically includes the 3D coordinates \((x, y, z)\) and color information \((RGB)\) of the points. 3D coordinates containing only points can also be used directly as a data source [9].

There are many formats of 3D terrain data sources, among which the more commonly used are pts, LAS, .xyz, PCD, asc, and txt formats. For highway reconstruction and expansion projects, for roads and terrains of existing projects that have been completed, XYZ point cloud data sources are generated by extracting elevation points and contour lines in archived CAD terrain design files. Considering the actual operation for many years, the current road design line shape has changed. In order to ensure that the existing road matches the designed terrain, a full-line Lidar scan of the existing road is performed to obtain Las data of the existing road and surrounding terrain. For interconnected and high-filled slope sections, in order to improve the measurement density and accuracy, a drone is used in conjunction with laser scanning to obtain a data source containing RGB.

3.2. **Terrain generation and lightweight**

The above data sources are respectively imported into the BIM modeling software CATIA. Through the merging of point cloud data sources, it can get the merged point cloud as shown in Fig 2 by eliminating the wrong point cloud data. The point cloud set is used to generate a surface, and the broken surface is repaired by supplementing and point cloud processing to complete the terrain surface model. The model obtained at this time cannot be used for Boolean operations with roads, bridges and other structures, and the terrain needs to be meshed. In the process of creating the terrain mesh surface, the excessive number of patches directly restricted the volume and loading efficiency of the terrain model [10]. In order to achieve the purpose of lightweighting the 3D terrain model, the terrain surface is meshed, and the triangle is used to triangulate the polygon by using the minimum internal angle principle through the triangle mesh area growth algorithm. The surfaces are broken up and divided into multiple segmented bodies. Patched triangular meshes are divided and optimized for each subdivided terrain surface to match the critical segmented body triangles. Through the software's internal algorithm, smooth the subdivided initial mesh, so as to achieve the purpose of repairing polygonal holes and lightweight terrain, and finally generate an overall triangular mesh terrain surface that can be subjected to Boolean operations.

The optimized terrain mesh surface occupies less memory, which effectively solves the problem of computer calculation difficulties and even crashes due to the large terrain volume of extra large highway projects. This method reduces the volume of the model while ensuring accuracy.
4. Lightweight terrain based on GIS

4.1. Model format conversion
After the terrain is imported into the GIS platform as a model format, if it is imported as a single model without conversion, the following problems exist:

1. The terrain exists as a model format. This terrain format is not a terrain format recognized by the GIS platform. It cannot add terrain information and cannot be integrated with surrounding terrain.

2. Although the modeling software is light-weighted, because the line is too long, to view the local model, the entire terrain needs to be loaded, the loading efficiency is low. This method still has dropped frames.

3. This format cannot cover satellite films, cannot carry information such as elevation, and cannot perform analysis tasks such as confluence and contour lines.

Therefore, it is necessary to transform the terrain BIM model into the standard terrain format of the GIS platform. The terrain model needs to be converted into DSM raster data. The analysis of raster data is an important content of GIS spatial analysis. Raster data structure, also called grid structure, is a data organization method that expresses the distribution of spatial features or phenomena in the form of a two-dimensional matrix. In this paper, a GIS platform is used to create a "grid" DSM terrain through the "3D model (3D analysis)" terrain. Taking into account the terrain accuracy and controlling the amount of terrain data, the resolution is set to 0.05m / pixel. Transformed into DSM terrain raster data, it will have real terrain analysis capabilities. Using raster algebra operations, including arithmetic operations (addition, subtraction, multiplication, division, rounding, etc.), logical operations, conditional operations, function operations, and compound operations. It can perform distance analysis (straight distance, surface distance), hydrological analysis (flow direction analysis, catchment, division of river basins, river classification, etc.), statistical analysis (elevation analysis, zoning statistics), and flattening of grid terrain Mosaic work.

4.2. LOD layered loading and tiling
For long-line and high-speed projects, the corresponding DSM grid terrain is still a relatively large, high-density file. To achieve instant loading and browsing based on the B / S side, the lightweight terrain must still be segmented and instantiated. Finally, a three-dimensional tile cache (TIN format) with a LOD (level of detail) structure can be generated, and the model cache can be loaded, which can greatly improve the browsing performance and display effect of the BIM model.

![Distance control LOD hierarchical loading diagram.](image)

The key to generating terrain that can be used for instant loading is to implement LOD layer loading and tile processing.

The so-called LOD layering is to set different browsing requirements to load terrain models with different accuracy. That is to say, when the project is overviewed, there is no need to load a high-precision model for a long distance, and a low-precision model is loaded to release the performance of the machine. When focusing on a structure, there are fewer models in the view range, and the high-precision model is loaded accordingly. The model outside the view range still loads the low-precision model, and is added to the machine cache for call at any time. The number of LOD levels set in the
model cache. If it is set to 3, three levels of 0, 1, and 2 are generated, where layer 0 is a fine layer, layer 1 is a sub-fine layer, and layer 2 is a rough layer. The distance indicates the camera. Distance refers to the distance between the camera viewpoint and the model, which determines the fineness of the current scene display model. As shown in Figure 3, different distances display different model precision.

The so-called tile, that is, a single model is cut into a large number of finely divided files, accessed through the link index file. The terrain pyramid scale level of the current data can be used to segment each layer of terrain data according to the segmentation rules. The data of the area range corresponding to each segment will be stored as a slice file (cache file). It thus gets the terrain cache data. The partition type used in this paper to cache tree slices to create a tree pyramid is a quadtree. The quadtree is suitable for a spatial range with a large plane range and a small height difference.

The 3D tile cache can improve the display efficiency of 3D model data in the scene, and realize the real-time loading and viewing of B/S-based terrain and other BIM models.

4.3. Scene fusion
The generated TIN terrain can be fused with multi-source data to further improve the display effect. For TIN terrain overlays such as satellite films, route station numbers, landmarks, real-life models and other scenes, the 3D terrain multi-source data fusion based on BIM + GIS is truly realized. A microscopic BIM model is used for fine-grained management. Surrounding terrain models are superimposed with satellite and real terrain fusion scenes. Large scenes are loaded with open source satellites and DEM elevation data. At the same time, the full-scene fusion of routes and other signs is added for efficient and effective construction management. Accurate decision-making provides powerful data support, and provides a large-scale scene digital solution for digital highways and smart highways.

5. Platform application examples

![Figure 4. Beijing-Shanghai Reconstruction Highway Web Scene.](image)

Based on the above theories and methods, the terrain within the 232.393km range of the Beijing-Shanghai Reconstruction and Expansion Project was established in CATIA, and the corresponding lightweight terrain model was transformed into the model format, layered loading, and tiled. Integrating other elements such as satellite films, route stations, landmarks, and other elements, the platform's large scenes are instantly loaded on the web page as shown in Figure 4, which enables instant loading of large scenes based on the web without plugins.

In addition, the real-world terrain is generated through the collection of real-world data from the drone, and the BIM model for the reconstruction and expansion is superimposed. After the LOD layering and tile loading, the completion can be viewed immediately on the web. Site scene and can be
used as the basic data support for traffic organization simulation and construction organization simulation.

6. Conclusion
   (1) This paper uses BIM software to implement a lightweight construction method for large-volume 3D terrain;
   (2) In this paper, a terrain conversion method based on GIS platform is proposed, which can realize lightweight, layered loading and data fusion of 3D terrain scene;
   (3) Based on the above work, this paper realizes the scene loading of multi-source data of long line complex expressway based on B / S;
   (4) The method in this paper can currently realize the real-time browsing of web pages based on B / S. The optimization method for real-time viewing of large-volume models on mobile phones will be the focus of the next stage of research.

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