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Application of Digital Technology in Road and Bridge Design

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Abstract: With the development and progress of science and technology, road and bridge design has experienced rapid development, from the initial manual drawing design to the popularity of Computer-Aided Design (CAD), and then to today's digital software design era. Early designers relied on hand-drawn paper design forms which was time-consuming and error-prone. Digital support for road and bridge design not only saves the design time but the design quality has also achieved a qualitative leap. This paper engages in the application of digital technology in road and bridge design, to provide technical reference for China's road and bridge engineering design units, to promote the popularity of Civil3D and other advanced design software in the field of engineering design and development, ultimately contributing to the sustainable development of China's road and bridge engineering.

Keywords: Road and bridge design; Digital technology; Civil3D; Modelling; Three-dimensional view; Earth calculation

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1. Introduction

Under the background of further technological innovation, the current digital design has become the mainstream of the road and bridge design field, Autodesk's Civil3D, Bentley's MicroStation, CARD and HintCAD, and other software integration of multidisciplinary information, three-dimensional models can further enhance the level of integration of design and construction. Designs can be based on comprehensive design and analysis tools, effectively improving the automation level of road and bridge engineering design and collaboration efficiency. Comprehensive analysis and digital design software not only improve the quality of road and bridge design but also provide significant support for the subsequent project construction and management. It can be seen that digital technology drives the road and bridge engineering design industry to take off.

2. Road and bridge design requirements in the new era

2.1. Balancing functionality and economy

In the new era, road and bridge design must take into account both functionality and economy. In the context of social and economic development, when traffic demand increases, roads and bridges not only need to meet the basic function but also need to have a high level of service. This requires designers to fully consider traffic flow, service level, user experience, and other multi-dimensional factors in the program planning to ensure that the design meets the functional requirements. Simultaneously, in the market trend of rising construction costs, the design should meet the functional requirements based on optimizing resource allocation and cost control to ensure that the project has a high degree of economic feasibility.

2.2. Safety and environmental protection

Road and bridge design must take into account safety and environmental protection. For safety, designers need to fully consider the road and bridge structural stability, seismic performance, and durability to ensure that the project is always in a safe operating state in a variety of extreme conditions. As for environmental protection in modern road and bridge engineering, minimize the negative impact on the environment, and maximize the protection of ecological balance where the design stage needs to give priority to the use of environmentally friendly materials, and processes, and reduce pollution and energy consumption.

2.3. Long-term benefits and sustainable development

The road and bridge design in the new era needs to pay great attention to long-term benefits and sustainable development. Compared to the traditional design, modern road and bridge design, other than focusing on short-term construction and use costs, pays more attention to long-term maintenance and operational benefits. Additionally, designers also need to comprehensively consider the long-term impact of the project on society, the economy, and the environment, and adopt sustainable design ideas and methods to ensure that road and bridge projects obtain good comprehensive benefits in the whole life cycle [1].

3. The application value of digital technology in road and bridge design

3.1. Enhance the design efficiency

The traditional manual design, two-dimensional CAD design, often needs to spend a lot of time dealing with complex engineering data and drawings. With the support of digital technology, using advanced three-dimensional (3D) design software such as Civil3D and Bentley, designers can quickly generate and modify 3D models, and achieve dynamic adjustment of design through parametric design, which not only saves design time but also ensures accuracy, consistency, and standard of design.

3.2. Optimize resource management

Through digital tools, designers can comprehensively manage the whole life cycle information of roads and bridges, including design, construction, maintenance, and other stages. This makes the integration and sharing of data from various disciplines more efficient and eliminates a large number of wasteful resource problems caused by lagging and inaccurate information.

3.3. Enhance the ability of collaboration between various professions

Modern road and bridge design projects usually involve multidisciplinary and collaborative work, such as structural engineering, traffic engineering, environmental engineering, and so on.

The digital design platform can provide a unified and collaborative information sharing and collaboration environment for each profession. The professional team in the design stage of road and bridge engineering can view, edit, and update the design data on the same platform, based on the realization of data sharing to reduce the information transfer error, and time delay, and to break the barrier of information silos [2].

4. Research on the application of digital technology in road and bridge design

4.1. Technology overview

Civil3D, developed by Autodesk, belongs to a design and documentation software, which is mainly used in the field of civil engineering. This technology can be based on the construction, the use of three-dimensional models, and the use of parametric design combined with dynamic analysis to achieve efficient design, management, and optimization of civil engineering projects. In terms of technical principles, Civil3D mainly uses construction together with road and bridge engineering information modeling technology to create detailed 3D digital models, which cover all the infrastructures under the project, such as roads, bridges, and drainage systems. Concurrently, Civil3D also supports terrain modeling, surface analysis, and longitudinal and cross-section generation, which can ensure the deep integration of high-precision geographic data and engineering data during the design phase.

4.2. Data management and modeling

4.2.1. Terrain model creation

The terrain model is an important part of Civil3D-based road and bridge design, and the accuracy of the terrain model is directly related to the accuracy and feasibility of the subsequent structure design. During the creation of the terrain model, firstly, the system carries out data collection, using Light Detection and Ranging (LiDAR) scanning, aerial images, traditional ground surveying, and other channels to achieve the collection of geological data of the project site for data format conversion and preliminary processing of the data.

Secondly, using the Surface-Terrain Surface tool in Civil3D, the processed elevation point data is imported into the function module. The Surface module then generates a terrain surface model using the Triangulated Irregular Network (TIN) method. During this process, the designer must set the coordinate system to ensure the geographic information aligns correctly. Finally, the generated terrain model needs to be checked and corrected. At this stage, the designer can quickly identify the matching error by comparing the measured data, and then manually adjust the wrong area, adding and supplementing measurements to improve the accuracy of the terrain model. **Figure 1** shows the schematic diagram of the Civil3D-based terrain model design.

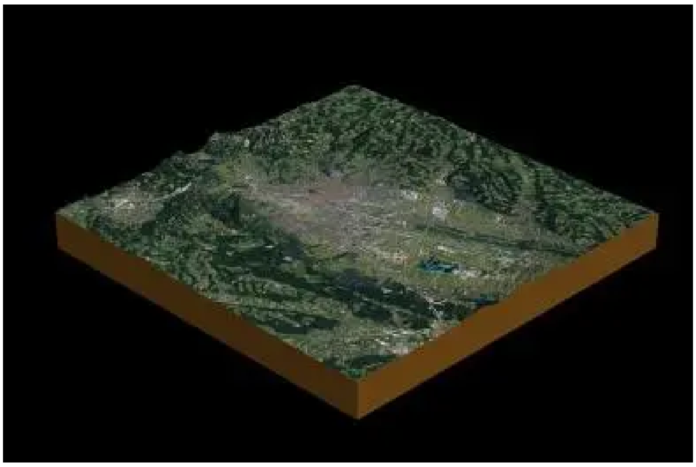

Figure 1. Illustration of Civil3D-based terrain model design

4.2.2. 3D view and simulation

3D view and simulation are a key part of Civil3D software for comprehensively displaying and evaluating design solutions. Based on the switching of different angles and viewpoints in Civil3D, road and bridge engineering designers can comprehensively review the terrain and the design structure. In the design stage, firstly, Civil3D is used for accurate geometric modeling and parametric design of roads, bridges, and ancillary facilities. Simultaneously, the engineering structure is organically combined with the terrain model to ensure that the design scheme is reasonable, feasible, and well-matched with the terrain conditions.

For road design, based on the Assembly tool module to create road and bridge section templates, define the road and bridge cross-section structure level. This step needs to cover the shoulder, road surface, drainage facilities, and other basic parts. Next, use the Corridor function to complete the setting of the cross-section template, along the center line and the longitudinal section of the stretch, forming a preliminary complete three-dimensional model of the road project. During the bridge design phase, the bridge module under Civil3D is used to model the OCT structure, covering the piers, abutments, main bridge structure, and ancillary facilities. The bridge model is integrated into the 3D model of the road to ensure that the bridge location and the road connection are reasonable and smooth and the process can be gradually adjusted and optimized through the "Bridge Integration Tool" of Civil3D. The process can be gradually adjusted and optimized by Civil3D's "Bridge Integration Tool" [3]. **Figure 2** shows the schematic diagram of the bridge 3D model based on Civil3D.

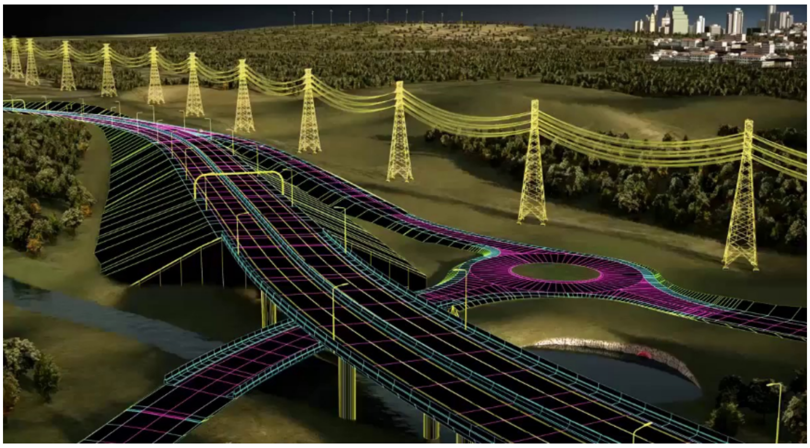

Figure 2. Schematic diagram of the bridge 3D model based on Civil3D

Secondly, the simulation analysis and optimization are carried out. This process requires a line-of-sight analysis, which uses Civil3D's line-of-sight analysis tool to check whether the roads and bridges have a good line-of-sight and to check all possible line-of-sight obstacles. It then carries out the traffic flow simulation and the bridge load capacity simulation based on the "Analysis Function" under the bridge module, to ensure that the design results meet the requirements for use. Afterwards, traffic flow simulation and bridge load capacity simulation are carried out based on the "Analysis Function" under the bridge module to ensure that the design results meet the usage requirements. Finally, the Civil3D's "View Control" function module is used to render the 3D model of the road and bridge from different angles and viewpoints, to display the design results in an all-round way [4].

4.3. Preliminary route optimization adjustment

After the construction and simulation of the 3D model of road and bridge engineering, Civil3D can optimize and adjust the preliminary route based on intelligent algorithms and automated tools.

4.3.1. Route plane optimization

During route plan optimization, parametric adjustment is one approach where Civil3D automatically optimizes the route layout based on preset design rules. In this process, the designer adjusts parameters such as curve radius, straight segment length, and intersection locations, while Civil3D automatically implements these adjustments to ensure the route achieves the optimal path while meeting engineering specifications. Additionally, by integrating terrain and existing facilities data, Civil3D uses obstacle avoidance algorithms (such as Voronoi) to automatically adjust the route, avoiding terrain obstacles, buildings, and other infrastructure.

4.3.2. Longitudinal section optimization

For longitudinal section optimization, the Civil3D software can optimize the longitudinal section slope and elevation information by automatically analyzing the terrain relief. Using linear programming and curve fitting algorithms, Civil3D will automatically adjust the design line to reduce the construction difficulty as well as the amount of earthwork [5]. Concurrently, the system under this process will automatically adjust the route elevation according to the theory of the center of gravity, making the fill and excavation reach a high degree of balance, reducing the amount of engineering earthwork deployment and further compressing the construction cost.

4.3.3. Cross-section optimization

During the cross-section optimization, Civil3D will automatically select and match the best cross-section templates based on multi-template matching the cross-section design standard [6]. At this stage, designers can preset multiple template schemes within Civil3D and the system automatically switches templates based on project topography and design requirements to achieve refined design. For road and bridge slopes, the slope rate and shape of the roadside can be optimized based on the dynamic adjustment function of Civil3D, which improves the stability and safety of the slopes and reduces the amount of slope protection work in the later construction stage.

4.3.4. Conflict detection and adjustment

Civil3D has an automatic conflict detection function. After the 3D model is generated and initially optimized, Civil3D can automatically check whether there are potential conflict points between the route and other facilities (bridges, pipelines, buildings) around the selected site. Under this process, the system provides intelligent adjustment suggestions for road and bridge engineering designers based on the conflict detection results, and automatically makes adjustments, such as modifying the route alignment, adjusting the route elevation, and optimizing the structural design of roads and bridges [7].

4.4. Earthwork calculation and measurement

4.4.1. Accurate earthwork calculation

For the calculation of earthwork volume, after realizing route optimization, the system automatically divides the boundary of the design area and generates the tuning plane at the same time. It then applies volume calculation methods such as “the prism method” and “grid method” followed by calculating the earthwork volume by comparing the ground model (the original terrain) and the design model (the improved terrain). By comparing the difference between the ground model and the design model, the volume of excavation and filling can be determined [8]. Civil3D software has a built-in earthwork calculation tool, which can quickly output a detailed earthwork volume report to the designer.

4.4.2. Construction material estimation

The estimation of construction materials mainly involves the accurate prediction of the quantity and specification of various types of construction materials required in road and bridge projects, the specific steps are as follows.

(1) Set up the material types and requirements. According to the design standards and specifications, the designer inputs the types of construction materials (steel reinforcement, concrete, etc.) and the unit dosage standards in Civil3D software.

(2) Civil3D automatically extracts the length, width, bridge span, bridge height, and other geometric features of the structural elements from the completed 3D model. Based on the original geometric features of the design combined with the standard of material usage per unit volume of the road and bridge project, it automatically calculates the total demand for various materials.

(3) The system automatically generates a detailed list of construction materials, which shows the specifications, quantities, and total amount of different materials in detail, providing a reference basis for subsequent construction preparation. This is shown in **Figure 3**.

Volume Report

Project: C:\Civil3D 2020\AutoCAD 2020\C3D\Help\Civil Tutorials\Drawings\Earthworks-1.dwg
Alignment: Centerline (1)
Sample Line Group: SLG-1
Start Sta: 0+00.000
End Sta: 17+29.049

Station	Cut Area (Sq.ft.)	Cut Volume (Cu.yd.)	Reusable Volume (Cu.yd.)	Fill Area (Sq.ft.)	Fill Volume (Cu.yd.)	Cum. Cut Vol. (Cu.yd.)	Cum. Reusable Vol. (Cu.yd.)	Cum. Fill Vol. (Cu.yd.)	Cum. Net Vol. (Cu.yd.)
0+00.000	2376.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0+25.000	2746.32	2371.82	2371.82	0.00	0.00	2371.82	2371.82	0.00	2371.82
0+50.000	3109.56	2711.05	2711.05	0.00	0.00	5082.87	5082.87	0.00	5082.87
0+75.000	3466.40	3044.42	3044.42	0.00	0.00	8127.29	8127.29	0.00	8127.29
1+00.000	3694.66	3315.30	3315.30	0.42	0.19	11442.59	11442.59	0.19	11442.40
1+25.000	4015.53	3569.53	3569.53	0.13	0.25	15012.13	15012.13	0.44	15011.68
1+50.000	4321.17	3859.59	3859.59	0.00	0.06	18871.71	18871.71	0.50	18871.21
1+75.000	4606.35	4133.11	4133.11	0.00	0.00	23004.82	23004.82	0.50	23004.32
1+90.600	4770.94	2708.99	2708.99	0.00	0.00	25713.82	25713.82	0.50	25713.32
2+00.000	4852.97	1675.27	1675.27	0.00	0.00	27389.09	27389.09	0.50	27388.59
2+25.000	4958.52	4542.35	4542.35	0.00	0.00	31931.45	31931.45	0.50	31930.94
2+50.000	4959.53	4591.69	4591.69	0.00	0.00	36523.14	36523.14	0.50	36522.63
2+75.000	4872.57	4551.90	4551.90	0.00	0.00	41075.03	41075.03	0.50	41074.53
3+00.000	4765.96	4462.28	4462.28	0.00	0.00	45537.31	45537.31	0.50	45536.81
3+16.000	4699.52	2804.59	2804.59	0.16	0.05	48341.90	48341.90	0.55	48341.35
3+25.000	4622.10	1553.60	1553.60	0.40	0.09	49895.50	49895.50	0.65	49894.86
3+50.000	4431.74	4191.59	4191.59	0.00	0.19	54087.10	54087.10	0.83	54086.27
3+75.000	4338.18	4060.14	4060.14	0.00	0.00	58147.24	58147.24	0.83	58146.41
3+99.500	4075.33	3817.24	3817.24	0.00	0.00	61964.48	61964.48	0.83	61963.65
4+00.000	4070.09	75.42	75.42	0.00	0.00	62039.90	62039.90	0.83	62039.07
4+20.566	3855.00	3018.22	3018.22	0.00	0.00	65058.12	65058.12	0.83	65057.29
4+25.000	3809.45	629.40	629.40	0.00	0.00	65687.52	65687.52	0.83	65686.69
4+50.000	3561.58	3412.51	3412.51	0.00	0.00	69100.03	69100.03	0.83	69099.20
4+70.566	3369.05	2639.48	2639.48	0.00	0.00	71739.51	71739.51	0.83	71738.68
4+75.000	3328.87	550.03	550.03	0.00	0.00	72289.54	72289.54	0.83	72288.71

Figure 3. Civil3D-based bill of materials

4.5. Interactive design and review

4.5.1. Team collaboration and sharing

During the design of road and bridge projects, Civil3D provides powerful collaborative design and data-sharing functions. During design, design team members can collaborate in real-time on a unified platform. Through cloud-based data management and version control, designers from different disciplines can access and edit design files at the same time, and be able to use the latest version of design data. Simultaneously, Civil3D supports the direct sharing of Drawing (DWG) files, allowing team members to conveniently perform design and modifications in a CAD environment. This facilitates the interactive design through team collaboration and sharing, enhancing the scientific validity and feasibility of the design results.

4.5.2. Multi-party evaluation and feedback processing

After completing the design of a road and bridge project and entering the project evaluation stage, Civil3D's multi-party collaboration function can effectively integrate the opinions of different stakeholders and designers of different disciplines. During the review and feedback period, the chief designer can convene the client, the construction unit, the supervisor, and other related units to jointly carry out the design review based on the cloud platform and desktop application. During the multi-party review process, all parties can directly mark and comment on the model, and the feedback information will be recorded and updated by Civil3D in real-time. Through the interactive review, not only can the road and bridge engineering design problems be discovered and solved promptly, but also the design solutions can be continuously optimized to ensure that the design results meet the needs of all parties [9].

5. Conclusion

As analyzed above, this paper provides a detailed study of road and bridge engineering design supported by digital technology. After briefly reviewing the requirements of road and bridge design in the new era and the application value of digital technology, this paper uses Civil3D technology as an example to discuss how to achieve data management and modeling, route optimization and adjustment, earthwork calculation and measurement, and collaborative review in the design phase. Civil3D-based collaborative review helps road and bridge engineering design units to improve the efficiency and quality of their designs, laying a solid foundation for subsequent construction and contributing to the sustainable development of China's road and bridge engineering.

Disclosure statement

The author declares no conflict of interest.

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