CATIA-BASED BIM TECHNOLOGY IN HIGHWAY TUNNEL DESIGN

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ABSTRACT

Referring to CATIA's 'assemblies + parts' modeling method, CATIA-based BIM (Building Information Modeling) technology has been proposed for highway tunnel design in this paper. A tunnel BIM is created by CATIA, which is based on a real case in China, focusing on the following 3 aspects: (1) Creating tunnel bolts by UDF + Loop cyclic arrangement method; (2) Using Sketch Tracer module to create tunnel portal; (3) Parameter is used to create and call the Catalog database. Then, bolt collision inspection and U-shaped groove concrete statistics are conducted with the help of the tunnel BIM created. Finally, the finite element analysis of tunnel construction process is carried out through the CATIA-Midas interface. The results demonstrate that the CATIA-based BIM technology can well adapt to the characteristics of tunnel and have well potential applications in tunnel design.

KEYWORDS

Highway tunnel, Design, CATIA, BIM, Function application

INTRODUCTION

In the recent time, the accelerating adoption of Building Information Modeling (BIM) in the building field has presented a powerful momentum for rapid development worldwide [1-3]. However, unlike the above-ground buildings, on the one hand, the highway tunnel has the characteristics of strip-shaped distribution, unknown surrounding rock and frequent design changes [4-7]. On the other hand, the current building BIM technology cannot be directly applied to the tunnel field due to differences in software platforms and industry standards [8]. Therefore, although great achievements have been obtained in building field by BIM, there is limited research on tunnel BIM [9-11]. In China, compared with the building BIM technical standard issued in 2017, the research of tunnel BIM standard is still in the exploratory stage, which will greatly restrict the promotion of BIM technology in tunnel engineering [12, 13]. Accordingly, the application of BIM in tunnel has necessitated further research.

Presently, the research of BIM mainly focuses on theory, functional application, result analysis, etc., but lack of further research on the modeling process [14-16]. BIM modeling is a time-consuming process in a project, which directly determines the efficiency of the project design [17-19]. However, with the development of BIM technology, its modeling method has not been improved greatly. As an underground project, tunnels have higher complexity than above-ground buildings, and the traditional modeling method for buildings is not suitable to the tunnel BIM [20]. Thus, it is necessary to study the modeling methods applicable to tunnel BIM [21-23]. Due to the strip-shaped distribution and uneven geological properties of tunnels [24-26], the creation of tunnel BIM needs to be carried out in blocks. Although this is quite different from the features of BIM in the building filed, it is exactly the same as the 'assemblies + parts' modeling approach that CATIA software exhibits during the mechanical modeling process [27, 28].

Based on a real case in China, this paper has proposed the CATIA-based BIM technology in

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tunnel design, which organized as follows. Section 2 discusses the conception of CATIA-based BIM technology. Section 3 describes the background and detailed modeling operations. In Section 4, the function application is conducted via the Jinjishan tunnel BIM created. Finally, Section 5 concludes the paper and summarizes its main findings.

CATIA-BASED BIM TECHNOLOGY

BIM, which helps improve the efficiency in the construction industry, is not simply integrating digital information, but a digital information model that can be used to design, build, and operate [29-31]. The role of BIM throughout the life of construction project is shown in Figure 1.
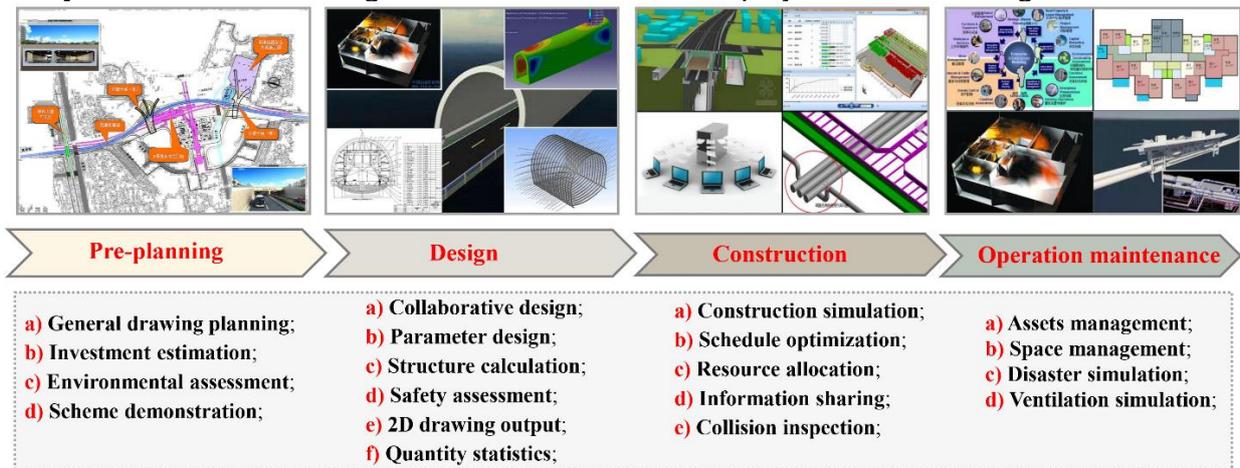

Fig. 1 - The role of BIM in different stages of the project

CATIA (Computer Aided Tri-Dimensional Interface Application) is a mainstream CAD/CAE/CAM integrated software in the world, which is widely used in many fields. CATIA's unique hybrid modeling technology and complex surface design module making CATIA a leader in design/analysis/manufacturing integration [32]. CATIA V5 [33] which is used in this paper has a rich design module library (about 140 design modules) for the enterprise to establish a life cycle for the project development and research work environment.
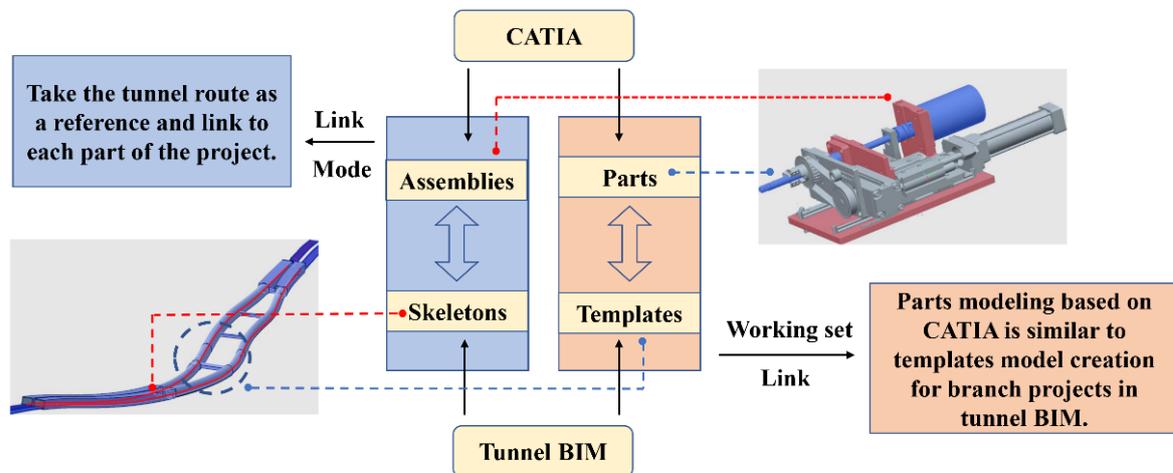

Fig. 2 - Comparison of CATIA and tunnel BIM

Different from the characteristics created by BIM integration in the building field, the tunnel BIM block creation method is similar to the assemblies + parts modeling method exhibited by the

CATIA in the mechanical modeling process. Therefore, CATIA-based 'skeletons + templates' modeling method can be well suited to the characteristics of tunnels [34-36]. A comparison of the features of CATIA and tunnel BIM is shown in Figure 2. In the skeletons + templates modeling method, the skeletons are similar to the assemblies in the mechanical modeling, which are used for reference between various components in tunnel modeling. The templates are similar to parts, which are the sub-projects in the tunnel model, including shafts, holes, crosswalks, etc [37, 38].

CASE STUDY

Background

Jinjishan tunnel is located in the northeastern section of the Second Ring Road in Fuzhou City, Fujian Province, China. With a total length of 1650 m (from Hudong East road to Helin Elevated Bridge), the tunnel is a double-hole two-lane urban highway tunnel divided by the upper and lower, as shown in Figure 3. Jinjishan belongs to the middle-low mountain, its surrounding areas of the mountain are mostly shallow trenches caused by artificial excavation. The part of the mountain that the tunnel crossing is composed mainly of gravel and clay, and the geological conditions are relatively stable. Meanwhile, due to the existence of Jinan River, the tunnel has a long subsurface excavation section, and both ends of the tunnel are U-shaped grooves.
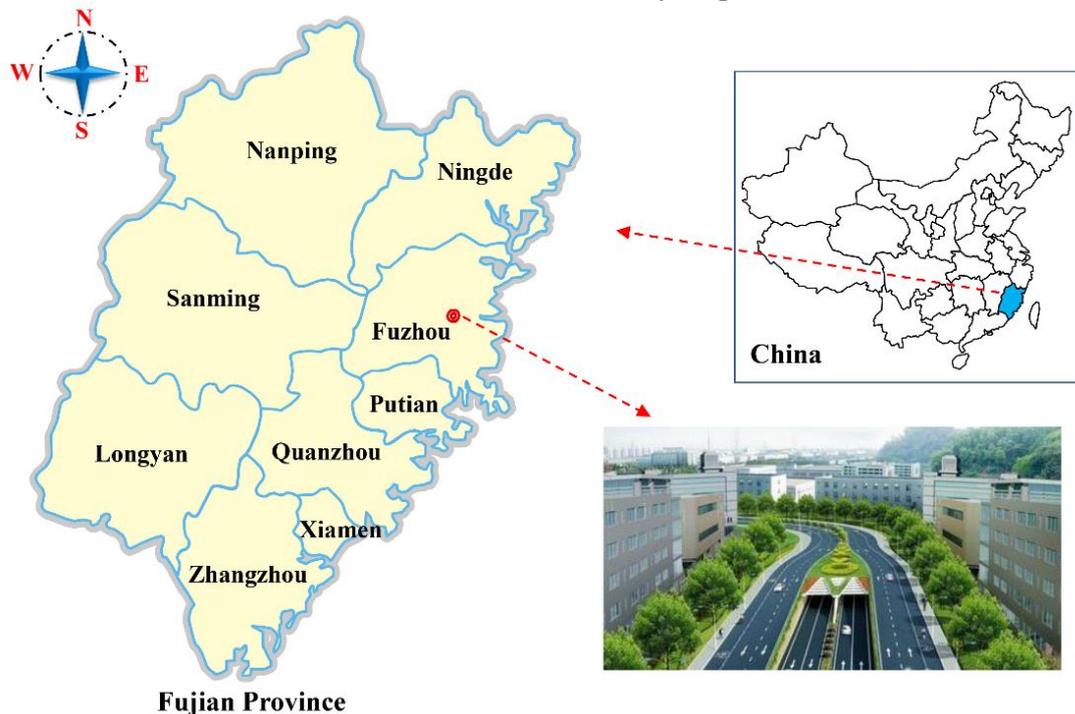

Fig. 3 - The location of Jinjishan tunnel

Mountain modelling
Data extraction

Google Earth [39] is a database that contains a large amount of terrain elevation information. In this paper, the rectangular tool is used to select the area, where the elevation data needs to be extracted, in the map near Jinjishan, which is opened by Google Earth. Since the elevation data extracted from Google Earth is not compatible with CATIA, elevation data extracted needs to be saved in .asc format [40-43], as shown in Figure 4.
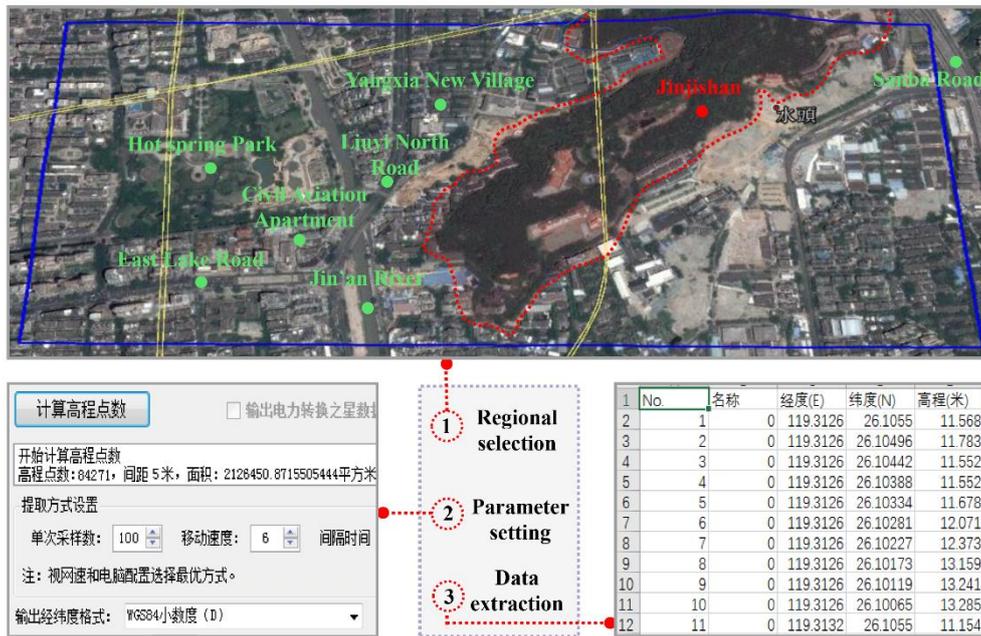

Fig. 4 - Terrain data extraction of Jinjishan tunnel based on Google Earth

Data import

Based on the .asc file mentioned in section 3.2.1, the corresponding envelope surface (Jinjishan model) can be generated in the Digitized Shape Editor module of CATIA. As shown in Figure 5, importing the extracted .asc file into the Digitized Shape Editor module initially, and then generating the envelope surface (the control parameter is the dot pitch). The surface is a non-editable basic element, which is different from the general surface element. In the next step, to ensure that it can be edited, the surface needs to be regenerated. Meanwhile, the surface is smoothed to make it closer to the natural mountain.
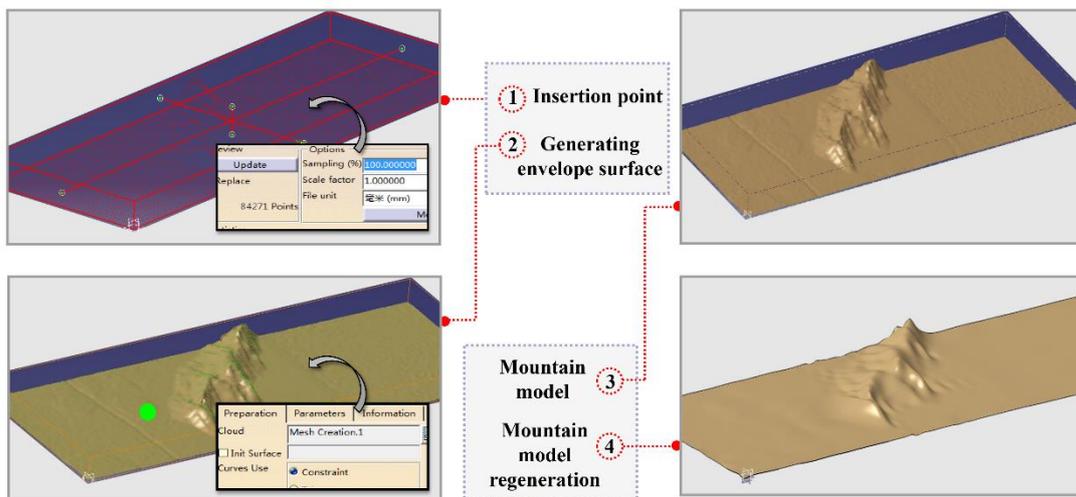

Fig. 5 - Mountain modeling based on the Digitized Shape Editor

Tunnel skeleton design

The skeleton contains the tunnel route and the tunnel lining structure, in the BIM modeling process. After the tunnel skeleton design is completed, every template structure (such as crosswalk, U-groove, electromechanical structural, ventilation structural) is linked with the tunnel

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skeleton by assembling to form the BIM of the entire tunnel project [44, 45].

Route skeleton design

The tunnel route is a reference for every component model to link with. The modeling of the skeleton is based on a 2D CAD design drawing of the tunnel route. As shown in Figure 6 (a), the sectional drawing and planar drawing of tunnel CAD route are first imported into the mountain model generated in Chapter 3.2, respectively. Then the spatial skeleton of the tunnel route is generated through the function of the mixed curve.

Tunnel lining design

The mountain model should be translucent, for the convenience of modeling. To facilitate future modeling, the added modeling reference plane is inserted according to the crosswalks, carriageway and the different lining modules (U-shaped groove modules, open-cut and subsurface excavation modules at tunnel entrance and exit). The CAD drawings of the tunnel are introduced onto the tunnel route, and the pavement and the lining are stretched to obtain a solid model of the tunnel lining skeleton. Meanwhile, to highlight a section, the color property can be changed, showing in Figure 6 (b).
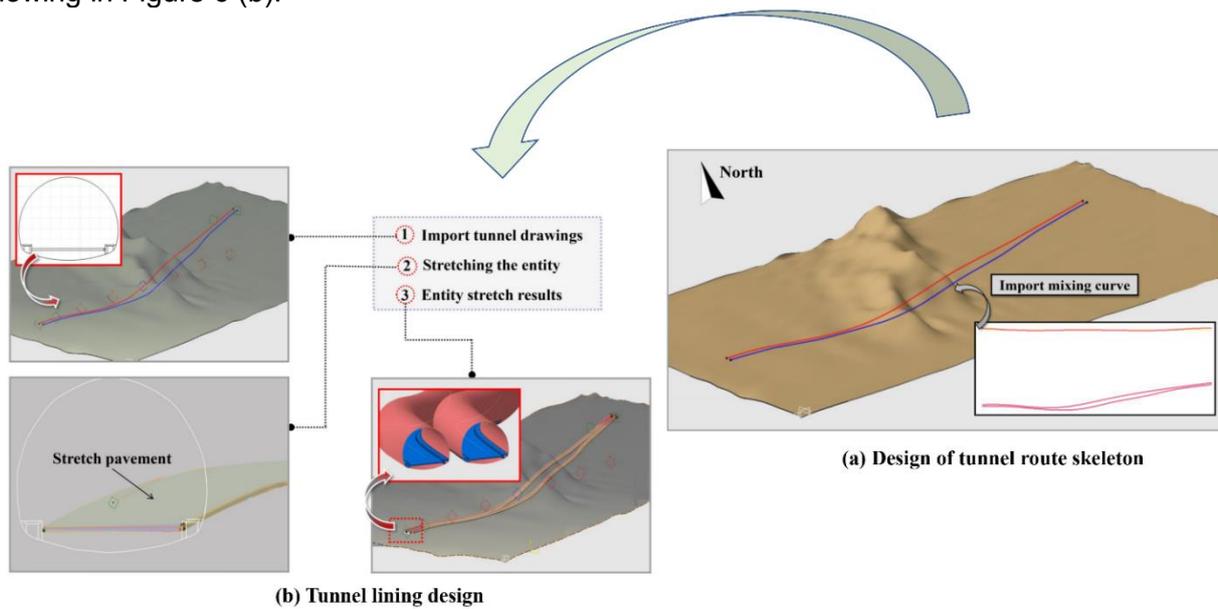

(b) Tunnel lining design

(a) Design of tunnel route skeleton

Fig. 6 - Tunnel skeleton design
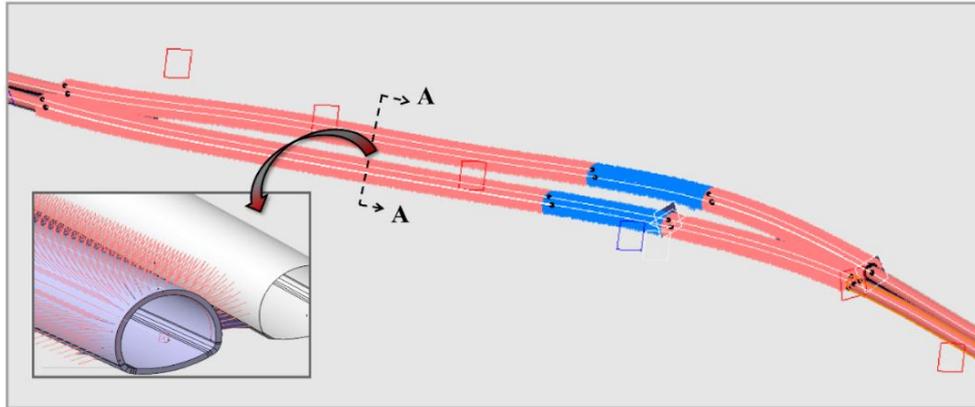
Tunnel bolts design

Fig. 7 - Tunnel bolts circulation result based on UDF + Loop method

The UDF + Loop [33] cycle arrangement method in CATIA can be used to design tunnel bolts since the bolts are arranged along the tunnel route regularly [46, 47]. All bolts on a certain section of the tunnel are set as a user-defined feature (UDF), and the Loop function is used to control the UDF to replicate cyclically along the tunnel route (the parameter t in the UDF controls the spacing between the replicated bolts). The cyclic replication results of the bolt components of the Jinjishan tunnel are shown in Figure 7.

Tunnel portal design

In this paper, the Sketch Tracer module [33] of CATIA is used to design the U-shaped groove portal of Jinjishan tunnel, as shown in Figure 8. Firstly, the plan and longitudinal section of the U-groove CAD design drawings are imported, and the curve blending function is used to generate the spatial contour curve of the U-shaped groove. Then, the curve bridge function is used to generate the spatial surface of the U-shaped groove, and finally the space surface is closed as a U-shaped groove entity.
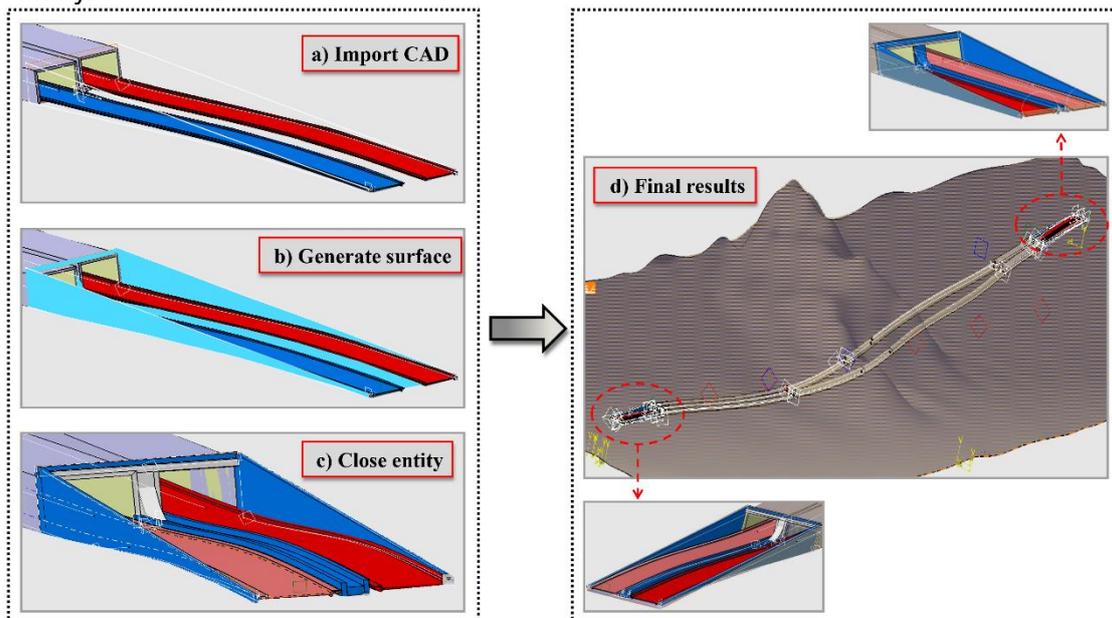

Fig. 8 - Modeling process of U-shaped groove

Parameter-driven Catalog

CATIA's Catalog function saves components as standard parts that can be controlled by available parameters. The Catalog function avoids the need for repetitive modeling, saving a great deal of time.

Catalog creation (taking a crosswalk as an example).

Creating a crosswalk Catalog and driving it with parameters will greatly reduce the workload because a large number of crosswalks have the similar structure [48, 49]. When designing a tunnel crosswalk, the size of the crosswalk can be changed by adjusting the parameters in the design table. Crosswalk model Catalog consists of 3 steps: (1) creating model and function relations; (2) associating design tables; (3) linking and importing Catalog files by combining the above model and design tables, as shown in Figure 9 (a).

Catalog calling.

Every Catalog file [33] includes 3 associated parts (models, design tables, and parameters). During the modeling process, the model in the Catalog file can be called by copying and pasting the Catalog file and moving it to the corresponding location. In this case, the crosswalk model in the Catalog can be copied and pasted into the Jinjishan tunnel model directly, as shown in Figure 9. During the copying process, if there are no required configuration parameters in the design table, the corresponding parameter values can be modified in the design table to meet the needs of the model creation.
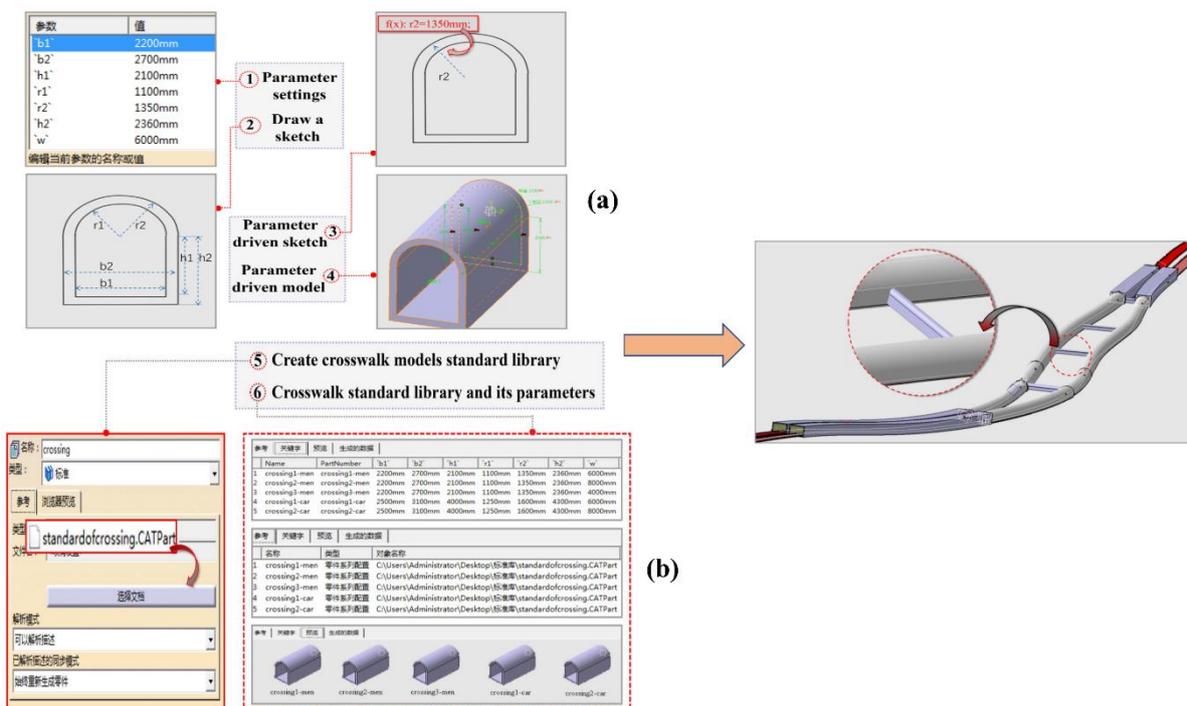

Fig. 9 - Creating and calling a crosswalk Catalog

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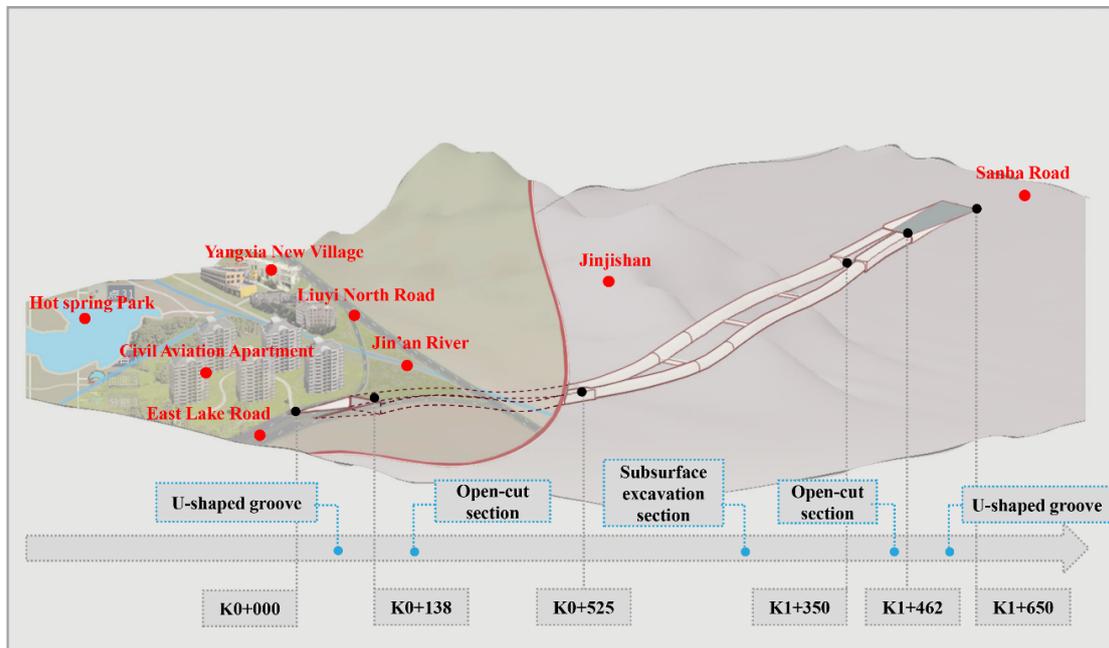
FUNCTIONAL APPLICATION

Fig. 10 - CATIA-based BIM model of Jinjishan tunnel

Collision inspection

Due to the particularity of the tunnel, many problems cannot be expressed in the 2D CAD drawings. However, during the construction stage, many problems in the tunnel design are discovered [50-52]. Collision inspection can avoid problems such as tunnel bolts collision and pipeline crossing during construction, which greatly improves the construction efficiency [53-55] Therefore, collision inspection before tunnel construction is a critical task in tunnel design.

Collision inspection is performed based on the created tunnel BIM model (Figure 10). The components of collision inspection should be selected first, but due to the limitation of computer performance, it is not recommended to carry out one-time collision inspection on all components for large-scale projects. In this project, the steel arch structure components with frequent collision problems are selected for collision inspection. It is found that the design of the tunnel has a tunnel bolt collision problem, as shown in Figure 11.
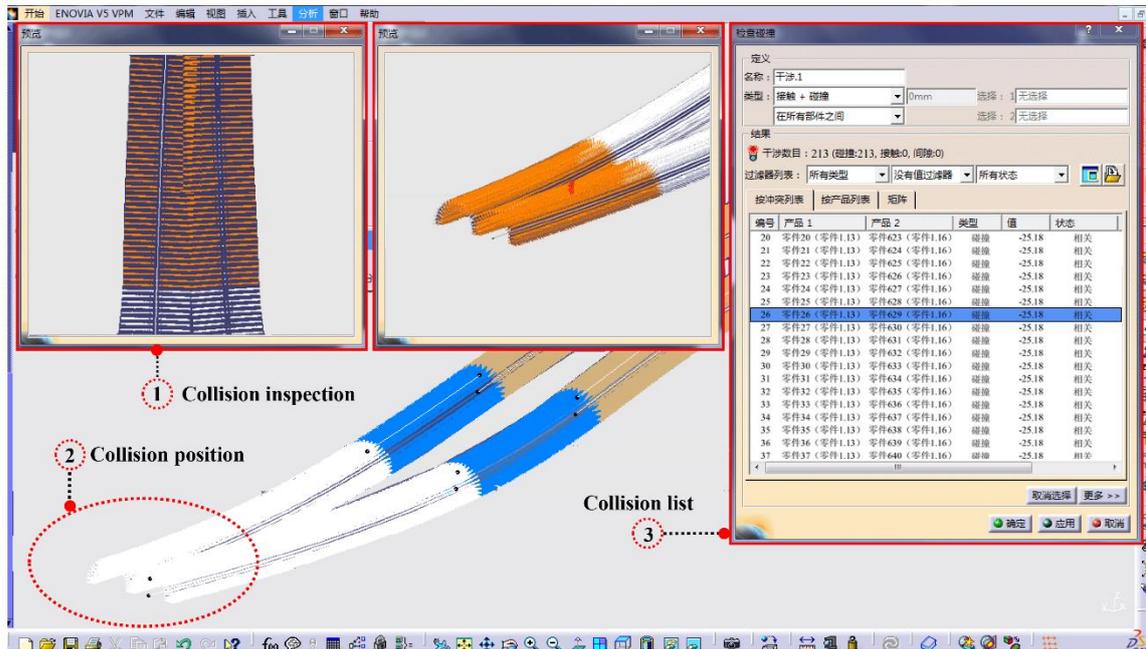
Fig. 11 - CATIA-based tunnel bolts collision inspection

The inspection reports are outputted after the collision inspection completed. Thus, the bolts design of the tunnel can be optimized to avoid the collision problem during construction.

Quantity statistics

The tunnel BIM model created (Figure 10) needs to be given attribute information to implement other functions in tunnel design and operation. The Drawing function module [33] of CATIA can automatically count the engineering quantity of the target model on the basis of its material attribute assignment. Taking the statistical U-shaped groove model C25 concrete engineering quantity as an example, as follows:

(1)   Setting material properties.

The material of the U-shaped groove model is C25 concrete, and since there is no pre-set C25 concrete material in the CATIA material database, the properties of the C25 material need to be defined.

(2)   Generating engineering quantity statistics table.

The U-shaped groove model of the tunnel portal is opened in the Drawing module to generate material statistics table. The statistical process and results are shown in Figure 12.
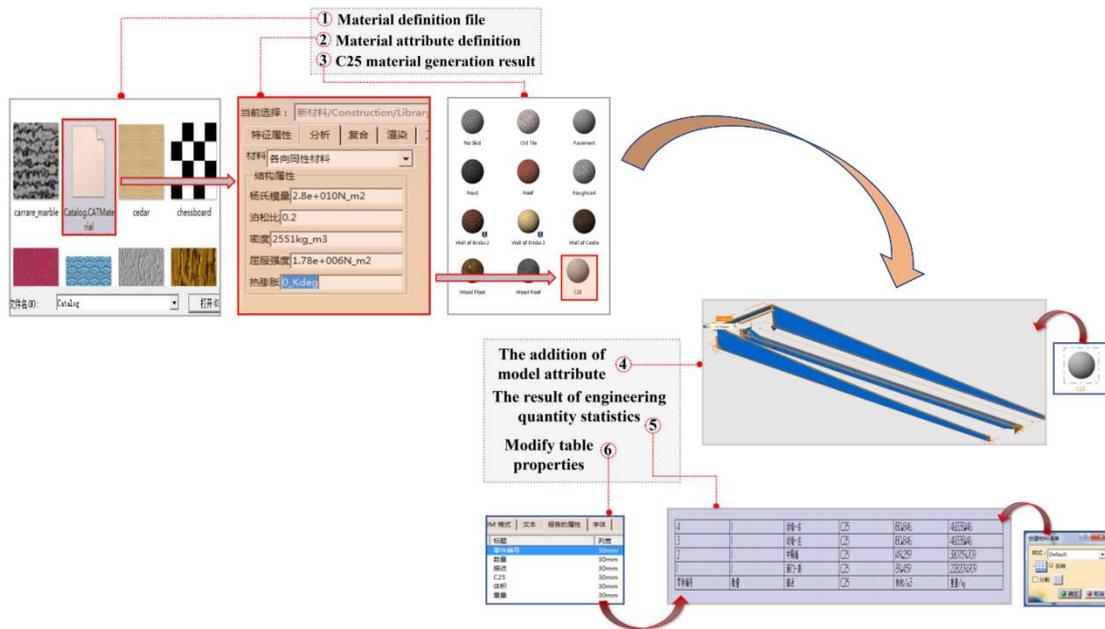

Fig. 12 - Statistics of C25 concrete quantity of tunnel portal

Finite element analysis based on CATIA-Midas interface

As one of the important platforms to realize BIM technology, CATIA provides many external interfaces to facilitate the creation and functional application of BIM. Although the tunnel construction process cannot be simulated by CATIA, CATIA-based BIM finite element analysis function is not prevented. Interfaces such as CATIA-Midas and CATIA-Ansys can assist in the finite element analysis of every process of the project. Taking the step excavation process of Jinjishan tunnel (K0+924 section) as an example, the CATIA-Midas interface [56] is used to analyze the arch settlement during construction. The result is shown in Figure 13.
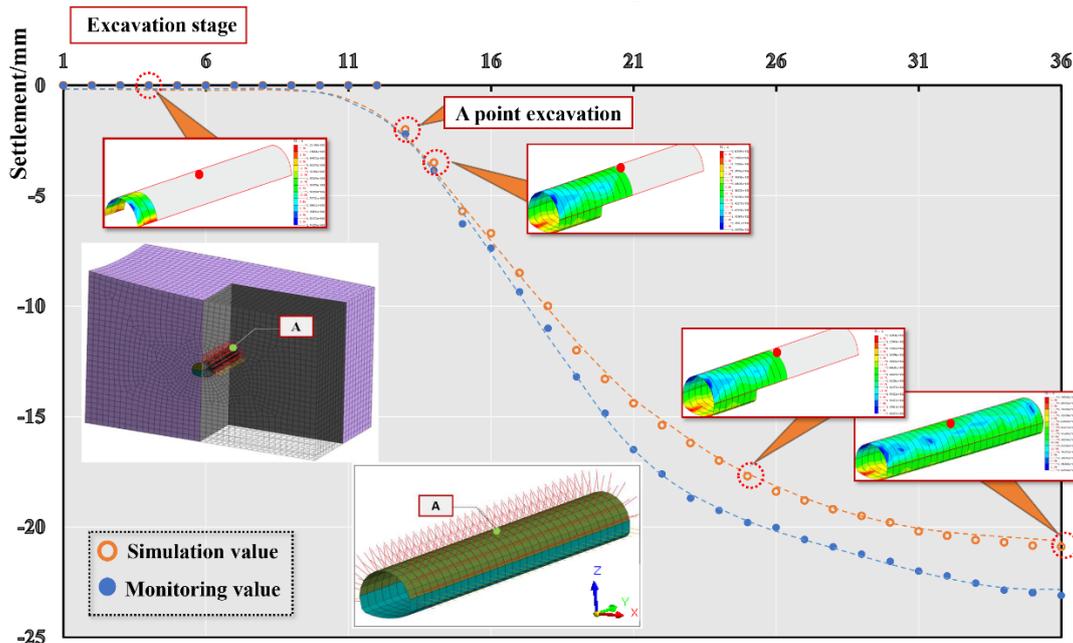

Fig. 13 - Comparison of simulation value and monitoring value

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The simulation value has the same trend as the field monitoring value, as shown in Figure 13. At the beginning (stage 13-24), with the excavation at point A (stage 13), the settlement of the arch at point A in Z direction changes more rapidly, which is caused by the disturbance of lining structures when excavation. Then, with the continuous excavation (25-36 stages), the disturbance of point A in the subsequent excavation process decreases gradually, and the settlement of point A in Z direction tends to be stable. The difference between the simulation value and monitored value curve is due to various factors such as systematic error, the difference between theory and actual engineering, and the heterogeneity of the geological properties of the mountain [57-59].

CONCLUSIONS

By involving into a real tunnel case, CATIA-based BIM technology was proved feasible and valuable. The main conclusions are as follows:

(1)   Referring to CATIA's assemblies + parts modeling method, the skeletons + templates modeling method adopted by CATIA-based BIM technology can better meet the tunnel strip distribution characteristics.

(2)   In CATIA modeling process, a variety of module collaborative modeling methods are studied: a) Digitized Shape Editor can accurately create mountain models; b) UDF + Loop layout method can be used for rapid cycle modeling under the control of programming language; c) Sketch Tracer can complete the creation of complex curved surface model and form a tunnel component solid model; d) Parameter-driven standard components saved by Catalog can be quickly adjusted and called for similar components which need for repetitive modeling, greatly improving efficiency.

(3)   Multi-module function of CATIA-based BIM technology enables more analysis functions: Through the collision inspection before construction, the problems of bolts collision and pipeline crossing during construction can be avoided, which greatly improves the construction efficiency. Drawing function module can automatically count the engineering quantity of the target model based on the material property, which greatly facilitates the tunnel design and construction work.

(4)   CATIA provides many external interfaces to facilitate the creation and functional application of BIM. Taking the CATIA-Midas interface as an example, this paper proves that the CATIA-based BIM technology can realize the multi-software synergy, which can better serve the tunnel engineering.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

ACKNOWLEDGMENTS

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