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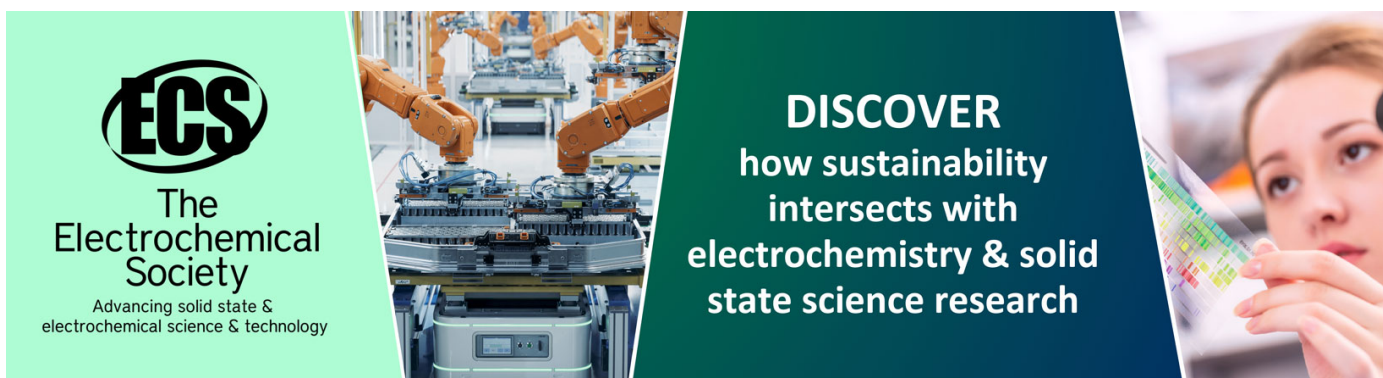
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Research on Design and Construction Optimization of Bionic Dendritic Steel Structure Based on BIM

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Abstract. As a branch of the vertical support structure, the tree-shaped steel column is more and more used in large-span buildings due to its beautiful shape. In the deepening design of the tree truss structure and the construction of special-shaped steel structure, design of branch angles of tree columns and construction precision control will directly affect the roof structure safety, architectural aesthetics and ornamental, which are the focus of construction control. By making use of the finite element software to analyze the relationship between the internal force and the angle at the node of the tree bar, the branching angle of the tree column is optimized; by exploiting BIM technology, the installation accuracy of steel components and the rework rate are ensured in their better conditions.

1. Introduction

1.1. Background

The Bionic Dendritic Steel Structure is a kind of space bionic structure, which is modeled after the shape of the tree and belongs to the category of architectural bionic structure. The structure of "tree structure" was first proposed by German architect Frei Otto in the 1960s[1]. It uses steel pipes to resemble the shape of tree shrews. The rods form a large supporting space, flexible in shape, and have the advantages of simple and reasonable force, novel and beautiful shape. In recent years, they have been widely used in large-span buildings, and scholars have carried out more on this new bionic structure.

At present, the research on tree structure mainly focuses on shape optimization, node structure design, force performance analysis and construction technology. In the aspect of shape optimization of tree structure, a lot of research was done from the University of Stuttgart, the Institute of Structural Mechanics (IB-Ekkehard Ramm) and the Institute of Light Structure Research (IL-Frei Otto) [2-4]. Japan's M. Kawaguchi et al. studied the morphological value and static performance of dendritic structures[5]. American scholar Peter Von Buelow's research was from the perspective of genetic algorithm. Jeffrey Hunt, Walter Haase, etc from the U. S. carried out their study based on the principle of self-balancing[6-7]. In China, scholars as Wu Yue, Wang Minggui, Luo Yongchi, Zhang Jinming, Wang Zhongquan, Chen Jun, Ma Hongbu et al. did some productive research on form finding methods, form finding procedure and result analysis of tree structure, stability design methods,



hoisting, welding process and unloading detection under various working conditions and other key points of tree structure[8-14].

Most of the above studies are carried out on a tree structure with symmetry, while few studies are on the optimal angles of the branches of the heterogeneous asymmetric tree column. In the construction technology, most of the traditional direct construction methods are adopted, but BIM technology is less used to guide the construction.

1.2. Introduction of research object

Zengcheng Children's Palace is located on the east side of the central axis of Hanglu Lake City in Zengcheng District of Guangzhou City. The building height is 31.9m, covering an area of 26291.30m². The total construction area of the project is 56099.60m² (including 6 floors above ground level of 32953.70m² and the underground second floor area totaling 23145.90 m²).

The main building is a reinforced concrete frame structure, and the steel structure is mainly used as a skeleton of the roof and the outer wall aluminum plate. The central cylinder part is a combination of steel pipe column and H-shaped steel beam, and the cylindrical roof is in the shape of irregular steel tree truss; the roofing protection system consists of upper roof layer (aluminum-magnesium alloy plate + fire rock wool) and lower roof layer (fluorine) Carbon sprayed aluminum plate). The outer frame of the building is an aluminum curtain wall with a reasonable design life of 50 years. The total steel used in the project is 1,500 tons.

The central cylinder section is connected to the roof and the reinforced concrete cylinder by a profiled steel structure and transmits the roof load to the cylinder. The roof tree raft structure system consists of a circular steel pipe and a roof H-shaped steel beam to form a space structure system; the steel pipe column and the beam connection node are bolted. The shape replaces the conventional steel column to support the roof structure, and the joint design is diverse and the force is complicated (Figure 1 and Figure 2).



Figure 1. The rendering of Zengcheng Children's Palace.

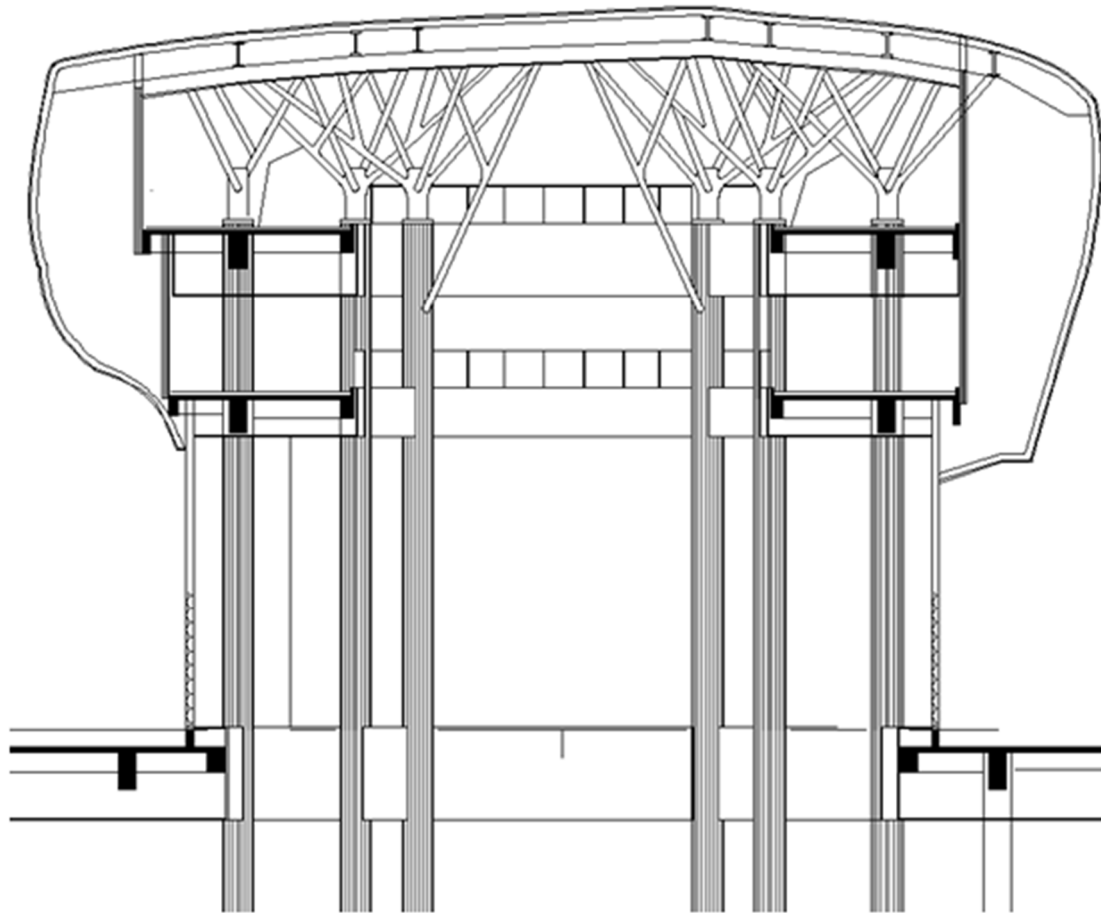


Figure 2. Sectional view of the center tube tree column.

2. Application of BIM technology in design optimization

There are eight tree-shaped columns with different shapes and joints at the center of the project. As the main force-bearing member, the tree-stem column bears the structural load of the roof and replaces the conventional steel column to support the roof. No other supporting structures are allowed around it. Because of the oblique support structure, the force analysis is very complicated, and the angle of each branch of the tree column is also not clear in the design scheme, which brings great difficulties to the construction. So, in the deepening design stage, the finite element software Ansys is used to simulate and analyze the space force of the tree column firstly, and the angles of the branches of the tree column are calculated and optimized. Then, the three-dimensional model of the engineering steel structure is created by Tekla software to generate the tree column. Node detail maps and various reports form a powerful control over subsequent construction progress and accuracy.

2.1. Finite Element Software Ansys Simulation Analysis Optimization

Taking a tree column and using the finite element software Ansys to establish a simulation model (Fig. 3), on the mechanical theory calculation principle, the angle of the tree node is optimized, and the relationship between the internal force and the angle at the node of the tree member is analyzed. Under the premise that the components meet the strength, stiffness and stability of normal operation, the angle of the node with the same load (ie the same bearing capacity) to minimize the quality of the tree structure (ie the least amount of steel) is optimal. Through the optimization design of the combination of ANSYS and 3D3S binary structure design, the structural displacement meets the requirements of the specification, and the structural forces are more reasonable.

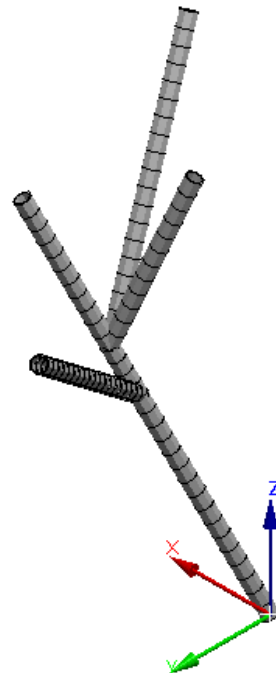


Figure 3. Tree column finite element model.

In order to facilitate the establishment of a parametric model, the angle corresponding to the curve in the finite element analysis "optimization result - optimization curve" is not the relative vertical angle between the branches in the global coordinate system. After multiple conversion calculations, the optimization results of the relative vertical angles between the branches in the global coordinate system are: 31° , 51° , 51.5° , 53.9° .

Through Ansys simulation analysis, the maximum comprehensive stress before optimization is 313.7MPa, and the optimized is 221.94MPa, and the optimization effect is 29.3%.

2.2 Steel structure deepening design based on BIM

Based on the simulation results of the finite element software Ansys simulation, the Tekla software is used to create the 3D model of the steel structure, which can generate the details of the tree column and the materials and component reports, etc., to guide the on-site construction and dynamic arrangement of material processing procurement. Form a clear and controllable construction schedule, saving labor and management costs.

3. Application of BIM technology in construction optimization

The project is based on BIM technology before construction. The digital simulation technology and on-site total station measurement and positioning are used to ensure the installation accuracy of the special-shaped tree truss structure, ensure the quality of the assembled welding of complex nodes, and realize the effective management and control of complex steel structure.

Using Navisworks software to carry out the virtual construction of each key node before construction (Figure 4), we can intuitively understand the steps of the whole construction (Figure 5), find out problems in the construction in advance, adjust and formulate a more reasonable construction plan. At the end of the project, the construction personnel have a clear and intuitive understanding of the construction process and requirements of the key nodes, to improve the construction accuracy. To ensure that the construction and installation accuracy of the roof steel beam and the tree truss steel structure is consistent with the BIM model, through digital processing technology and on-site total station, the method of measuring the positioning ensures the installation accuracy. By comparing with the traditional construction method, the BIM technology is used to guide the tree column to carry out

the assembly welding construction, which can reduce the rework rate to zero, meet the construction quality and accuracy requirements, save the construction period, machinery costs, management costs, and significant economic benefits.

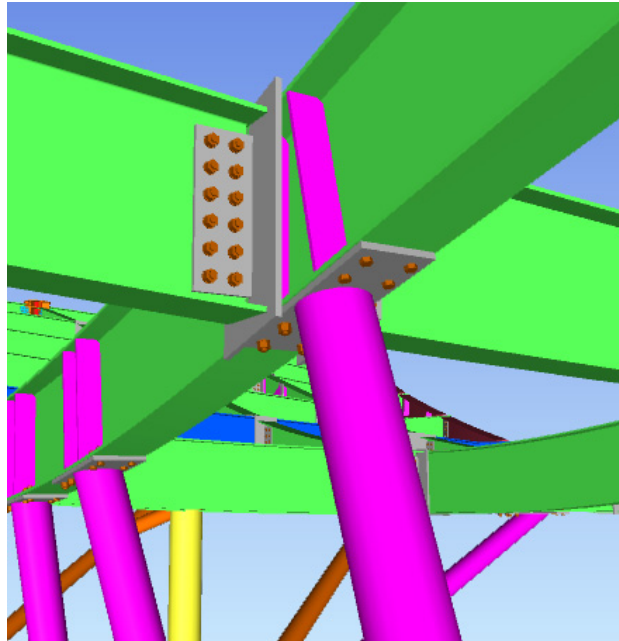


Figure 4. BIM virtual construction of complex beam-column joints.

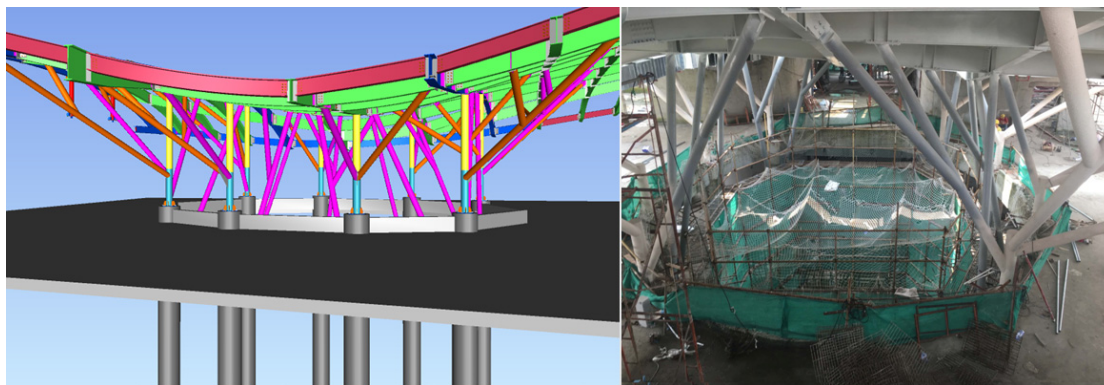


Figure 5. Comparison of BIM virtual construction and site construction.

4. Benefit analysis of BIM technology application

This project optimizes the design nodes and construction procedures of steel tree rafts by applying BIM technology in the design and construction stage. It is found that establishing BIM model for complex steel structure beam-column joints can effectively reduce the rework rate, ensure construction accuracy, and accelerate the construction of special-shaped steel structures. The progress, effective saving the construction period, and significant project benefits, can also produce significant savings in terms of machinery costs and management fees. The cost savings are shown in Table 1.

Table 1. Economic Benefit Analysis.

	Category	Unit	Quantity	Unit price (¥)	Total price (¥)
	Labor cost savings				

	Comprehensive working day	Working day	$2 \times 4 \times 30 = 240$	150	36000.00
Subtotal					36000.00
	Mechanical use savings				
	Temporary support and lifting costs			50000	50000.00
Subtotal					50000.00
	Duration savings	day	30	5500	165000.00
Subtotal					165000.00
	Management fee savings				
	management fee	day	30	10000	300000.00
Subtotal					300000.00
Totality					551000.00

It can be seen from Table 1 that through the rational use of BIM technology, the direct economic benefit is about 551,000 yuan.

5. Conclusion

Based on the BIM technology, this paper analyzes the design and construction optimization measures for the load-bearing steel structure of the shaped tree roof. Through the design stage ANSYS, 3D3S and Tekla to optimize the angle of the tree column and establish a three-dimensional model, a good foundation for the subsequent precision construction is laid; through the digital processing technology in the construction stage, Navisworks virtual construction and other measures, the visualization is realized, the welding efficiency and construction speed of the key complex nodes of the beam are greatly improved, column is reduced, and the rework rate is reduced to zero. Through the comprehensive application of BIM technology to optimize the design and construction of the tree-shaped steel structure, in line with the current national policy and the direction of green building development, the benefits in terms of construction period, cost, energy conservation and environmental protection are significant, and the social feedback is good, which promotes the technological progress of the industry and improves the enterprise technology. The level has a profound meaning and has a good promotion prospect.

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