

BIM Technology in Application of Structure Construction in Hubei Olympic Sports Center

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Abstract: With the rapid development of modern large-span and large-complex steel structure buildings, at present the Building Information Modeling (BIM) technology plays an important role from the design to the construction of a building. This study takes the Comprehensive Gymnasium of Hubei Olympic Sports Center as the carrier and introduce the BIM technology from two aspects; The technology; and the management. Further, the optimal application of BIM technology in the complex component nodes, the technical guidance of component processing, and the correction and verification of drawings were emphatically analyzed in this paper. An engineering practice shows that the application of BIM technology has greatly improved the production efficiency, shortened the construction period, reduced unnecessary cost, and lastly laid a solid foundation for the smooth completion of the project.

Keywords: BIM; Steel structures; Technology and management; Complex joints

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1. Introduction

As a new tool of architecture, engineering, and civil engineering, Building Information Model (BIM) realizes the integration of building information, which runs through the whole cycle of buildings in terms of design, construction, operation, and maintenance. It can integrate all types of information on the whole life cycle of buildings into a three-dimensional model database, thereby the personnel who are involved in the construction process can work together based on BIM, to improve the work efficiency, to reduce construction costs, and to realize sustainable development.

The State Council of China's Opinions on Promoting the Sustainable and Healthy Development of the Construction Industry (No. 19 of the State Administration), the Ministry of Housing and Urban-Rural Development and other departments 'Guidance on Promoting the Coordinated Development of Intelligent Construction and Building Industrialization' and 'Several Opinions on Accelerating the Development of New Building Industrialization' point out that the BIM technology should be vigorously promoted. The integration of the application process of BIM technology in the whole life cycle of new building industrialization, and the integration and innovative application process of new technologies such as BIM, Internet, Internet of things, big data, cloud computing, mobile communication, artificial intelligence, and block chain in the whole construction process should be accelerated.

With the development of society, people's aim in pursuing of healthy life is increasing day by day. As an important public place to meet people, and to enjoy and relax the body and mind, large stadiums have

attracted much attention. However, large stadiums usually require more functionality and aesthetics of buildings, and the structure of the buildings is more complex, further the construction process is more difficult. Additionally, the construction of the complex large stadiums required the multi-disciplinary coordination to ensure the building quality and production safety, subsequently to improve engineering construction efficiency. How to apply BIM technology in the construction of large stadiums, how to transmit the required information to different majors, and how to improve the construction efficiency is the focus of current BIM technology research.

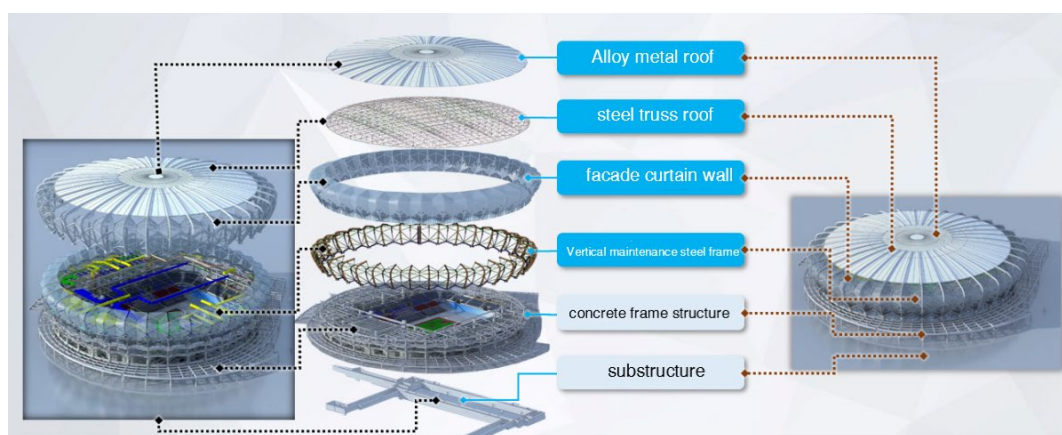


Figure 1. BIM model diagram of Hubei Olympic Center

In recent years, many scholars have studied the application of BIM technology in the construction process of large stadiums. Zhang Yuting et al.,^[1] applied BIM technology in the national snowmobile sled center project, and solved the problem of special-shaped track design and complex terrain site leveling, subsequently greatly improved the construction quality of the sports venues. In addition, Zhao et al.,^[2] integrate the BIM technology in the Beijing Yanqi Lake International Convention and Exhibition Center project, further established the engineering data management system, which improved the efficiency of construction data archiving and reduced the time which is needed to find important data or information. Next, Nie Qiao et al.,^[3] optimize the design of climbing formwork system of super high-rise office buildings by using BIM technology, without changing its stress situation, increasing the space for welding and installation of trusses, and reducing the construction difficulty. Further Ding et al.,^[4] established the construction hazard management system by using the advantages of BIM technology data transmission, and improved the speed of the construction process, accident prevention and management combined with the actual large steel structure project. Lin Wu et al.,^[5] combined BIM technology with a critical path method to establish a construction risk early warning system considering both time and construction resources, and visualize the risk of potential construction progress. In addition, Tong Zhong et al.,^[6] combined BIM technology with geographic information system, and developed a method to convert engineering and its surrounding environment into BIM model, for a better reflection of the engineering practice. Qin Yawei et al.,^[7] combined the BIM technology with 3D laser scanning technology to monitor the machining accuracy and construction error of the components, thereby greatly improve the closure accuracy of bridge engineering. Su et al.,^[8] applied BIM technology to simulate assembly in the construction of large weight, large clearance, and large span steel truss, which improved the construction efficiency, and alleviated the pressure of construction progress. By establishing the mainstream analysis software BIM interface, Li Huafeng et al.,^[9] conducted a dynamic elastic-plastic analysis on the whole and complex stress nodes of the Shaoxing Stadium project, and simulated the wind tunnel analysis on the whole structure, which reduced the secondary modeling and improved the design efficiency.

There is no systematic study on the application of BIM technology in the spherical steel truss roof engineering was conducted previously. Therefore, in this paper combined with the comprehensive gymnasium project of Hubei Olympic Sports Center, during the construction process of the spherical crown steel truss roof and facade steel structure project, and BIM applications in the whole construction process such as 3D layout management technology, platform collaborative management, visual bottoming, collision inspection are used. Additionally, the BIM-based node optimization design^[10], component fine processing, multi-software drawing deepening design, and information sharing technology are also studied. The research content of this paper will be beneficial in the use and development of BIM technology for similar projects in the future.

Hubei Province Olympic Sports Complex Project, as the 7th World Military Games men's gymnastics venue in 2019 with a building area of 36750 m² and a height of 26.1 m. It is composed of a comprehensive gymnasium with a power station on the ground. The main structure of this building is, one floor on the ground (local four floors) and one floor in the underground. The stadium is composed of a spherical steel truss roof and facade steel structure modeling system. The structure is complex and changeable, the steel structure is large with the total steel consumption is about 1700 t. The maximum span of the steel structure is about 70 m, and the diameter of steel roof is about 118 m. A large building area, spherical joints, and arc bars of roof lead to the complex positioning in the construction process. There are many embedded parts in the steel structure of the concrete structure, with the shape and spatial position change greatly, resulting in a significant increase in the measurement lofting calculation data and difficulty in the measurement process. The steel roof is connected to the curtain wall structure which is irregular curved surface as a whole. The collision probability is large and the inspection process is difficult to be conducted during the construction process. This project uses BIM technology to coordinate the multi-disciplinary conflicts, optimize the unreasonable and potential risk points in the construction process and design, and finally ensure the smooth implementation of production and the construction process. The BIM model diagram of the Hubei Olympic Center is shown in **Figure 1**.

2. Engineering optimization of Hubei Olympic Sports Complex based on BIM technology

2.1. Application of node optimization design

The roof of this project is a spherical crown shaped super-large span inverted triangle steel structure truss roof system, which is composed of 14 main and 5 secondary trusses. The longest steel truss is 116 m, and the longest span is 70 m. There are 4534 circular pipe members, 3347 nodes, and 25 types of circular pipe section specifications. All nodes are on the gradient surface, and it is difficult to strengthen the design of 3D modeling of spatial truss. Among them, 2492 main joints are subjected to relatively large force with their structures, mainly connected by one chord and five web members with various angles. In order to prevent local instability, this project refers to the treatment methods that are used in the Wuhan International Expo Center and other projects^[11-13], and the cross-insert plate with large bearing capacity is inserted into the chord to further strengthen the web member. The main node is placed at the intersection of the primary and secondary trusses, and its spatial angle positioning is complex and changeable. The slot positioning and machining accuracy of the upper insert plate of the member play a decisive role in the quality of truss assembly and structural safety. In addition, the chord and web members have many dimensions and complex types. From the perspective of structure, the round pipes with multi-bars and multi-angles intersect at one point, which makes it difficult to manufacture and to ensure the welding quality.

In this paper, the corresponding node component model is created based on the BIM technology, as shown in **Figure 2**. Combined with the finite element method, the reliability of the force transmission path of the node is analyzed and calculated. The load transfer path of joint member is: Tube truss chord → Cross

plate → Tube truss straight web member → Tube truss inclined web member → Steel support → Concrete structure. The cross plate is the hinge of force transmission of truss structure members, therefore the angle accuracy and weld reliability of the cross plate in the joint have to be ensured. The inclined web member in the welding area of the multi-bar-multi-angle intersecting cross-plate joint is used as the rear part. At the same time, in order to further enhance the reliability of the cross-plate weld at the joint, there is a 3 mm gap between the chord slot and the cross-plate to make sure that the weld is fully fused, thereby the force transmission of the cross-plate is more direct and smoother, and also to improve the mechanical performance of the joint. Further, the node assembly simulation method is used to simulate the assembly in detail design software Tekla Structure to verify the correctness of the node assembly sequence and the operability of the welding process to ensure the safety and reliability of the construction.

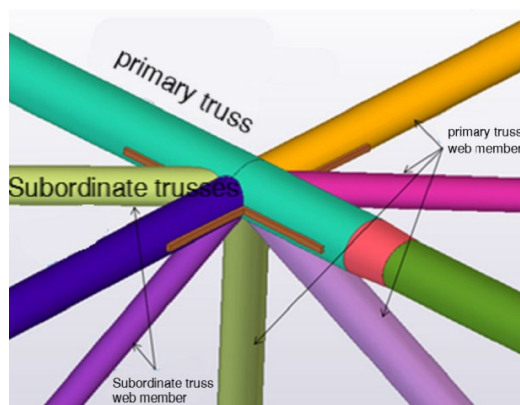


Figure 2. Cruciform panel joints model

2.2. Component fine machining application

There are many composite joints and bending bars involved in this project, and the truss manufacturing is a difficult process. The trusses used in this project including the cutting of intersecting lines, bending of chords, cutting, groove, docking and accessories processing, shot blasting, paint spraying, and other steps. In order to improve the machining precision of truss components and further to ensure that the structure does not affect the safety, and to prevent the use of production due to machining errors in the process of construction, therefore, this project uses the line model of BIM technology to strengthen the design of numerical control intersecting line cutting of circular pipe parts. In the numerical control programming, the corresponding groove, angle, and other parameters should be included to ensure high precision intersecting cutting, improve the accuracy of assembly, and the welding quality of intersecting mouth. Firstly, the welding shrinkage reserved for members of various specifications is determined by experiments, and then the reserved welding shrinkage is included in the calculation of the break length of the steel pipe. In this project, for steel pipes less than 16 mm, 1.5 mm welding shrinkage band is reserved for each pair of interfaces, and 2.5 mm is reserved for steel pipes which is greater than 16 mm. Additionally, in order to meet the requirements of the specification and to save materials, the circular docking process is performed during the steel pipe cutting process with the connection length not be less than 650 mm. In the process of cutting the intersecting steel pipe, firstly the intersecting line analysis is performed, and then the data are transferred to the NC machining software, and the repeated modeling using different software increases the workload. In this project, with the help of BIM technology, the building information transfer process between Tekla Structure → WIN3D → PIPE-COAST three software is established, which greatly reduces the modeling amount and further prevent the reduction in the engineering quality which caused by the interdisciplinary modeling error.

- (1) The Tekla Structure three-dimensional wireframe model is established, and different diameters are expressed in different colors, and the model is converted into a standard DXF format conversion file.
- (2) The DXF file is imported into the WIN3D design software, and the diameter is distinguished according to the color. The intersecting line of the intersecting rod is analyzed in WIN3D.
- (3) The intersection line analysis results were imported into PIPE-COAST software to determine the welding shrinkage, mechanical cutting shrinkage, cutting speed, and the groove angle. Then, reasonable nesting was conducted according to the material specifications, and the cutting process was carried out in batches.

The maximum bending capacity of JXW-500 pipe bender used in this project is $\phi 426 \times 16$ mm, and the pipe size of this project is within the standard range. The main control point of pipe bending arc is; The rise of bending arc; Pipes with different radius arc; Ovality of steel pipe; and Steel pipe arc straight weld staggered. When the bending radius is too small, the mechanical bending arc is used at first, then the flame bending arc is used to correct it to ensure the node accuracy. After bending, the diameter change of the steel pipe is less than 2mm (when the diameter is less than 300mm, it is the smaller value of 1mm and 0. % of the design diameter), the wall thickness change is less than 1mm and the smaller value of 10% of the design wall thickness, and the sagittal height deviation is less than 5mm. The surface of the steel pipe cannot appear as crease and uneven. After the arc bending, the end is cut, and the groove is made by pipe groove at the welding end, and the longitudinal line is drawn in the tooling, which is separated by 90° four and the circumferential line of the node, and the punch is punched to facilitate the docking of the steel pipe. After the arc bending process is completed, the ground sample is taken to measure the arc size. The main control contents are: arch height, radius, chord length, and others. The size deviation exceeding the specification requirements must be corrected, and the next process manufacturing process can only be performed after all the control contents meet the specification requirements.

The positioning relationship of the space truss multi-bar intersection plate joint in this project directly affects the stress transfer between the web member and the chord member, and it is an important connection node of the roof structure system. If the spatial positioning relationship of this node has a large deviation, it will directly affect the overall spatial morphology and structural safety of the structure, therefore it is necessary to ensure the accuracy of its processing and manufacturing process. Because the automatic machining of CNC machine tools cannot be realized by slotting the plate of curved arc components, it is necessary to draw the control dimension of slotting into the deepening design drawings, and then slotting it by semi-automatic cutting method.

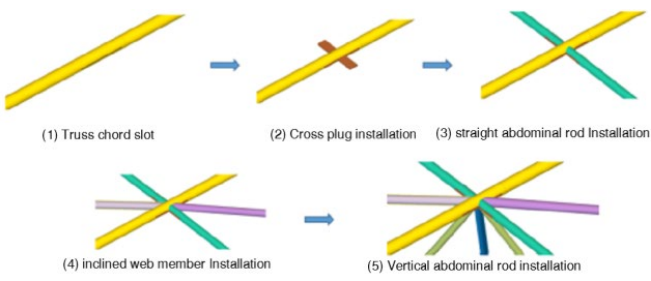


Figure 3. Cruciform panel joints assembly simulation



Figure 4. Joints assembling picture

The three-dimensional solid model built by Tekla Structure software can reflect the spatial positioning size of each member and the node angle of multi-bar intersecting plate. The Tekla model is shown in **Figure 3**. The drawings are automatically generated by the software followed by the conversion of the spatial size of the member into the plane projection size, and then through different section response vector height and

out-of-plane size. Based on the theoretical data and combined with the thickness and shape size of the plate, the slot size and angle of the multi-bar intersection plate can be calculated, to ultimately determine the spatial positioning size of the multi-bar intersection plate node of the spatial truss. In the process of slotting, firstly in the processing platform, the plane projection size of the bar is set out, and then, the angle steel is used to make the height frame in a Z direction out of the plane, and the slot size of the bar is determined based on the simulation of the insertion angle and external size of the multi-bar intersecting plate. When slotting, the semi-automatic flame cutting machine is used for manual slotting operation. Considering the pre-deformation of the truss assembly and the accuracy of the interface, computer-aided simulation preassembly is used, the picture of joints assembling is shown in **Figure 4**.

3. Conclusion

In recent years, BIM technology has been developed rapidly, and has been used widely in civil engineering, mechanical and electrical engineering, steel structure, decoration, and other majors in the construction industry. It has gradually become an important means in improving the construction efficiency and engineering quality of national high-quality projects. Based on the comprehensive gymnasium project of the Hubei Olympic Sports Center, this paper summarizes the following experience and conclusions:

- (1) Using BIM technology to optimize all kinds of complex nodes, which can realize visual analysis of component node strength from design to processing.
- (2) Using BIM technology to strengthen the design drawings, and timely feedback problems through collision detection, which can improve the accuracy of the drawings.
- (3) BIM technology provides technical guidance for component processing in the factory, effectively controls the cost, further improves the accuracy of component processing.
- (4) Through information sharing and collaborative management, the production efficiency and personnel on-site management level of the project can be greatly improved.

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Disclosure statement

The authors declare no conflict of interest.

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