Application of BIM Technology in Hyperbolic Thin-Shell Concrete Roof Construction: Post-print

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Abstract

During the construction of the Longping Rice Museum project, BIM technology provided scientific guidance for the formwork erection, quantity takeoff, and construction surveying of the hyperbolic thin-shell concrete roof; the i Ban mobile application technology rendered project management more extensive, transparent, efficient, and expeditious. Through the construction application of BIM technology, the project duration was substantially shortened, costs were saved, and considerable social and economic benefits were achieved.

Full Text

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Abstract: During the construction of the Longping Rice Museum project, BIM technology provided scientific guidance for formwork support, quantity surveying, and construction measurement of the hyperbolic thin-shell concrete roof. Concurrently, the iBan mobile application technology enabled more extensive, transparent, efficient, and rapid project management. Through the construction application of BIM technology, the project significantly shortened its construction period, reduced costs, and achieved notable social and economic benefits.

Keywords: BIM; Hyperbolic Roof; Engineering Application; Informatization; Project Management

1. Introduction

BIM (Building Information Modeling) is a building information integration system that uses three-dimensional digital modeling as its carrier and the entire building lifecycle as its main thread, linking together all information required by various segments of the construction industry chain. BIM enables management and coordination across project phases including preliminary design, construction, and post-completion property operation, featuring characteristics of visualization, coordination, simulation, optimization, and drawing generation. In recent years, with the rapid development of China' s construction industry, BIM technology has gained increasingly widespread recognition and application in engineering construction [?]. The Ministry of Housing and Urban-Rural Development and several provincial governments have issued advisory guidance documents promoting BIM technology application [?]. As a new generation of innovative computer-aided design tools and production methods, BIM technology represents the direct application of construction informatization in the building industry, driving a technological revolution that transforms traditional extensive construction practices into refined, efficient, and unified processes. This revolution is considered another major technological breakthrough following the 20th-century shift from manual drafting to CAD technology.

The Longping Rice Museum is located in Longping New District of Changsha City, on the east bank of the Liuyang River, and represents China's first rice museum as well as a key construction project in Hunan Province. The architectural form resembles seven grains of rice [Figure 1: see original paper], with a total floor area of 19,300 m^2, comprising one main museum building, one supporting building, and one independent underground garage. The main museum building has two above-ground floors and one underground floor, the supporting building has two above-ground floors and one underground floor, and the independent underground garage has one underground floor. The structural system is a frame structure with a hyperbolic thin-shell concrete roof featuring variable-section curved beams and numerous right-angled trapezoidal columns. The maximum clear height of the exhibition hall is 19.6 m, presenting significant construction challenges. Traditional construction techniques would be time-consuming and material-intensive, making it difficult to meet design quality requirements, particularly for the hyperbolic roof concrete beams and slabs.

Moreover, conventional quantity surveying tools cannot accurately calculate the formwork surface area, reinforcement, and concrete volume for hyperbolic roofs. In response to these challenges, the company adopted BIM technology during the project bidding phase. Figures 2-5 illustrate the BIM models for various disciplines of the museum. Due to space limitations, this paper focuses exclusively on BIM technology application in the hyperbolic thin-shell concrete roof construction. The primary technical characteristics and difficulties of this hyperbolic thin-shell concrete roof are as follows:

1. The hyperbolic thin-shell concrete roof features a complex measurement and positioning system. Any two sections of the roof beams and slabs have different curvatures, with varying structural curves throughout, making construction layout extremely difficult.
2. Roof elevation control at various points is challenging, with inconsistent formwork support pole heights. Custom-cutting of support steel pipes, reinforcement bars, and formwork for different roof sections is extremely difficult, and positioning is problematic. Horizontal steel pipes for beam and slab formwork must be bent according to roof curvature, with some sections requiring cutting after bending.
3. Calculating formwork surface area, reinforcement quantity, and concrete volume for the hyperbolic roof support system is extremely difficult. Traditional measurement tools lack precision and hinder project cost control.

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2. BIM Technology Application

2.1 Pre-Construction Preparation

Prior to construction, the project team established a BIM workstation, conducted technical personnel training, equipped necessary software and hardware, and developed a BIM work plan . The workstation configured BIM software based on project requirements, primarily using Revit and Glodon with other software as supplements . Hardware configuration balanced daily operational needs with rational resource allocation, providing high-performance workstation equipment with main parameters detailed in [Figure 6: see original paper].

2.2 Specific BIM Implementation

2.2.1 Modeling Environment Setup Due to the complex geometry of the hyperbolic thin-shell roof, the project selected the relatively flexible conceptual massing environment for modeling:

1. Set reference planes according to axis positions in elevations and reference points at design elevations.
2. Established a reference plane for the roof eave bottom in elevations and selected it as the working plane before switching to floor plan view.
3. Set planar reference points at corresponding axis positions in the floor plan according to design drawings.
4. In elevation view, sequentially set reference planes at axis positions as working planes and switched to 3D mode to draw arcs connecting reference points on the same plane using model lines.

5. Selected model line arcs from each section and fitted them to generate the hyperbolic thin-shell roof model.
6. Loaded the model into the project environment to generate solid elements and created sections to obtain profile data.

2.2.2 Precise Model Construction Using Revit' s internal massing environment, the team established a precise model by drawing roof contour profiles at each axis position through three-point arc definition. After importing into the project environment, the face roof tool generated the curved hyperbolic thin-shell roof. Following creation of the accurate Revit model, precise model data was exported to produce physical formwork samples in advance, preemptively addressing key construction operation issues.

2.2.3 Information Extraction and Material Preparation The team extracted accurate information from the precise model for material customization and prefabrication:

1. Extracted accurate elevation information based on formwork support pole positions, deducted slab thickness and formwork system thickness to determine each pole' s height, and performed pre-assembly and cutting of steel pipes as needed.
2. Extracted length and curvature information for each reinforcement bar from the model for cutting and bending according to fabrication principles.
3. Conducted formwork pre-assembly based on the 3D model, then segmented according to formwork specifications for advance custom-cutting.

Since curvature radii and elevations varied across different hyperbolic roof concrete beams and slabs, the team exported detailed schedules of characteristic surface elevations and planar coordinates, relevant data, and drawings in advance, assigning dedicated personnel to track and guide construction workers in formwork operations, conducting continuous process inspection and timely correction. [Figure 7: see original paper] illustrates the BIM model of hyperbolic concrete roof beams and slabs and schematic diagrams of curved beam sections.

Hyperbolic thin-shell concrete roof formwork has limited domestic and international application. Before formal construction, the team erected samples based on BIM models and longitudinal sections of each beam to ensure construction quality, effectively guiding site operations while shortening the construction period and reducing wasteful cutting of on-site steel pipes, thereby saving costs [Figure 8: see original paper].

2.3 Quantity Surveying

Given the project' s architectural characteristics, structural forms from foundation to below-roof levels were relatively conventional and could be addressed using traditional software modeling. However, the hyperbolic thin-shell concrete roof structure rendered traditional quantity surveying software incapable of processing such geometric configurations. This project employed Revit for modeling and used Swell Revit 3D quantity surveying software to directly utilize Revit models for accurate quantity calculations.

Through BIM-related software, the team accurately performed quantity statistics for cost estimation during design, quantity budgeting before construction, and final quantity settlement after completion. The software also enabled precise quantity calculation of irregular components, facilitating material allocation, cost accounting, and settlement [Figure 9: see original paper].

2.4 Construction Surveying

The spatial positioning of the hyperbolic thin-shell concrete roof formwork system was extremely complex, making traditional surveying methods inadequate for quality requirements. During construction, BIM technology was employed to ensure main axis control precision and site visibility requirements. Main axes were deliberately selected to avoid various structures while satisfying fundamental surveying principles: long back sight and short fore sight. [Figure 10: see original paper] illustrates main axis selection for the roof model.

Using the "Point Layout" plugin, the team picked characteristic points on the guide model to obtain 3D coordinates. During roof concrete beam and slab formwork construction, surveyors accurately positioned the hyperbolic roof based on 3D coordinates exported from the BIM model, scientifically guiding site operations.

2.5 BIM5D Application

During construction, the project integrated civil, mechanical, electrical, and curtain wall models using the BIM platform as the core. The integrated model served as a carrier linking construction progress, contracts, costs, quality, safety, drawings, and material information. Leveraging BIM model characteristics of visual representation and calculability, the system provided data support for project schedule and cost control, material management, and other aspects, assisting management personnel in effective decision-making and refined management to reduce construction changes, shorten 工期, control costs, and improve quality [Figure 12: see original paper].

2.6 iBan Mobile Application

During construction, technical personnel used the iBan mobile application to photograph construction nodes on-site with mobile phones, uploading questionable node photos to the system backend terminal for correlation with BIM model locations. This facilitated convenient problem resolution in safety and quality meetings, significantly improving work efficiency. Project document controllers could promptly scan and upload design changes and engineering correspondence to the terminal for quick access by construction technicians. Additionally, all project managers could view information immediately via mobile phones, making project management more extensive, transparent, efficient, and rapid.

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3. Conclusion

The Longping Rice Museum construction project employed BIM technology to provide scientific guidance for hyperbolic thin-shell concrete roof formwork, quantity surveying, and construction measurement. The iBan mobile application technology enabled more extensive, transparent, efficient, and rapid project management. Through BIM technology application, the project significantly shortened its construction period, reduced costs, and achieved notable social and economic benefits.

Note: This project' s BIM technology application won second prize in the comprehensive category at Hunan Construction Engineering Group' s first "Transcendence Cup" BIM Competition (2015) and second prize in the individual category at the first China Construction Engineering BIM Competition (2015).

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Note: Figure translations are in progress. See original paper for figures.