

## Research and Application of BIM-based Virtual Construction Simulation System for Large-scale Steel Structures (Postprint)

**Authors:** Hu Dejun, Zhang Baiyan, Wang Shuai, Kou Jinlong

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### Abstract

This study investigates a BIM-based virtual construction simulation system for large-scale steel structures and its application in practical engineering. Construction of large-scale steel structures is characterized by complex environmental factors, high operational requirements, and numerous safety hazards that are difficult to comprehensively address. To overcome these challenges, a virtual construction simulation system integrating Unity3d and BIM can fully leverage and visualize engineering design information, realistically presenting construction sites under various scenarios. This system can be employed for construction site management and technical disclosure, enabling comprehensive identification of quality and safety hazards. Its successful application in the long-span steel truss construction project at Hangzhou Shangcheng District Sports Center significantly enhanced construction efficiency while ensuring comprehensive quality and safety throughout the construction process.

### Full Text

## Research and Application of a BIM-Based Virtual Construction Simulation System for Large Steel Structures

**Hu Dejun<sup>1</sup>, Zhang Baiyan<sup>2</sup>, Wang Shuai<sup>1</sup>, Kou Jinlong<sup>2</sup>**

<sup>1</sup>. Yaosha Holding Group Co., Ltd., Hangzhou 310000, China

<sup>2</sup>. College of Civil Engineering and Architecture, Zhejiang University, Hangzhou 310058, China

### Abstract

This paper presents the development and practical application of a BIM-based virtual construction simulation system for large steel structures. Large steel

structure construction is characterized by complex environmental factors, demanding operational requirements, and numerous safety hazards that are difficult to fully anticipate. To address these challenges, a virtual construction simulation system integrating Unity3D and BIM technology can effectively utilize and visualize engineering design information, realistically displaying construction sites under various scenarios for site management, technical disclosure, and comprehensive identification of quality and safety risks. The successful application of this system in the large-span steel truss construction of Hangzhou Shangcheng District Sports Center significantly improved construction efficiency while ensuring quality and safety throughout the construction process.

**Keywords:** Virtual Reality; Unity3D; BIM; Steel Structure; Construction Design

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## 1. Introduction

With continuous advances in information technology, construction management has become increasingly sophisticated, achieving substantial progress in controlling construction cost, quality, schedule, and safety. Following the Ministry of Housing and Urban-Rural Development's explicit call in the "Opinions on Promoting the Development and Reform of the Construction Industry" to "promote the application of building information modeling (BIM) and other information technologies throughout the entire process of engineering design, construction, and operation and maintenance to improve comprehensive benefits," BIM technology has gradually matured in construction projects. Its applications in engineering information management [?], dynamic construction site layout [?], and construction cost control [?] have greatly enhanced construction management efficiency.

To further meet the demand for construction site visualization and assist project managers in decision-making and site management while providing efficient pre-job training and safety education for workers, the integration of virtual reality (VR) and BIM has become a current research focus. Unity3D is a comprehensive VR development platform that enables efficient interfacing with BIM, allowing developers to implement various VR interactive experiences through C# scripting. Virtual simulation based on the Unity3D platform has been developed and applied in decoration [?], surveying [?], mining [?], and shipbuilding [?], achieving promising results.

In the construction field, however, VR applications remain in their infancy, with most still relying on animation rendering or commercial template-based VR software with fixed functionality, resulting in insufficient interactive experience and diminished application effectiveness. The large-span steel truss lifting project at Hangzhou Shangcheng District Sports Center features complex processes, high operational requirements, and numerous safety hazards, necessitating a VR system with robust interactivity. This paper investigates a BIM+Unity3D-based

virtual construction simulation system for large steel structures and successfully implements it in this project, effectively improving construction efficiency and ensuring quality and safety.

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## 2. Project Overview

Hangzhou Shangcheng District Sports Center is a multi-level sports complex with a main structure of frame-shear wall construction and partial steel structure. The water polo hall and basketball hall are located on the fifth and ninth floors, respectively, with steel truss floor systems and concrete spectator stands below. The steel truss floor consists of six large-span steel trusses and connecting steel beams, spanning 39.2 meters in length, 33.2 meters in width, and 4.1 meters in height. The large-span steel truss weighs over 390 tons, and finite element analysis indicates a maximum mid-span deformation of approximately 8 mm. Following expert evaluation, the construction method involves assembling the floor system on the concrete slab before lifting the entire steel truss into position using a hydraulic lifting system, as shown in [Figure 1: see original paper].

The large-span steel truss features 12 lifting points, with a lifting platform and hydraulic equipment installed on the floor above the installation location. During hydraulic lifting, strict synchronization must be maintained among different lifting points, with elevation differences controlled within  $\pm 20$  mm. When the inclination of steel strands exceeds  $1^\circ$ , lifting must be paused, and the structure's four corners temporarily connected to adjacent main structures with steel wires to restrict horizontal sway. Additionally, hydraulic cylinders and synchronous control equipment require rational site layout to manage the entire construction process. Due to complex environmental factors, demanding operational requirements, and numerous safety hazards, high-quality construction disclosure and thorough hazard identification are essential to ensure successful hydraulic lifting of the large-span steel truss.

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## 3. BIM-Based Virtual Construction System for Large Steel Structures

The implementation of this virtual construction simulation system primarily involves five processes: 3D model import, scene element rendering, interactive command addition, UI design, and system deployment, as shown in [Figure 2: see original paper].

**3.1 3D Model Import** The existing BIM model of the sports center was retrieved, and considering the construction progress during steel truss lifting, only portions of the overall model up to and including the fifth floor were retained, as shown in Figure 3: see original paper. The model was exported from Revit

as an FBX file and imported into Unity3D, as shown in Figure 3: see original paper.

After import, physical properties must be added to enhance prototype fidelity. Collision volume is the most critical property; without it, objects would pass through each other during movement. Collision volumes are added by selecting Physics-Collider, with Mesh Collider used for complex geometries. Additionally, to enable realistic physical effects under various forces (e.g., gravity causing objects to fall), rigidbody properties must be added by selecting Physics-Rigidbody.

**3.2 Scene Element Rendering** To realistically simulate actual construction site conditions, various scene elements were added, including sound effects, sky, lighting, and weather.

Four primary sound sources exist at the Hangzhou Shangcheng District Sports Center site: overlapping construction operations, rain and wind during inclement weather, footsteps, and hydraulic cylinder activation during truss lifting. The first three sounds maintain relatively constant volume regardless of location, so they were added as Audio-Audio Source properties to the character model with corresponding audio files. Hydraulic cylinder sounds vary with distance, so this property was added directly to the cylinder objects.

The sky is controlled by Unity3D' s built-in Skybox, set as clear and cloudless, with the sun' s position controllable along with the light source.

All object rendering is achieved through lighting. The default light source is Directional Light, representing sunlight with directionality. By controlling the Rotation property values (x, y, z), the illumination direction can be adjusted. When parallel to the ground, it simulates dawn or dusk; when perpendicular with the source above the main structure, it simulates noon; when below the structure, it simulates night. The Skybox and sun respond accordingly, as shown in Figure 4: see original paper and Figure 4: see original paper. Considering nighttime installation work, point light sources were arranged at appropriate locations for illumination, as shown in Figure 4: see original paper.

Weather systems are represented using Particle Systems. Since lifting operations occur in summer, rain impact must be considered. Unity3D' s particle effects offer nearly a hundred control parameters, but for rain simulation, the primary adjustments involve Duration, Start Speed, Max Particles, Shape, and Renderer to control raindrop lifecycle, falling speed, quantity, direction, and form. [Figure 5: see original paper] illustrates the simulated rainy construction scenario.

**3.3 Interactive Command Implementation** Interaction is achieved primarily through C# scripts attached to corresponding objects. In Unity3D, all character interactions are controlled jointly by the Animator module and C# scripts. The Animator module provides character animation logic, as shown in [Figure 6: see original paper]. Each character model includes an Avatar module

that divides the body into joints (hands, feet, arms, legs, shoulders, neck, etc.), enabling motion parameters to be defined for different parts.

C# scripts serve two main functions: (1) changing the character model's spatial position and orientation, and (2) setting keystrokes to modify motion parameter values. For example, the following C# statements control crouching with the "C" key:

```
Bool crouch = Input.GetKey (KeyCode.C);  
m_{Character}.Move (crouch);
```

[Figure 7: see original paper] shows the character models used in this project, capable of standing, walking, running, jumping, and crouching for comprehensive site exploration. Additionally, ThirdPerson Camera and FirstPerson Camera were implemented with C# scripts for perspective switching:

```
Void SwitchCamera (int index) {  
    int i = 0;  
    for (i = 0; i < cameras.Length; i++) {  
        if (i != index) {  
            cameras[i].GetComponent<Camera>().enabled = false;  
        } else {  
            cameras[i].GetComponent<Camera>().enabled = true;  
        }  
    }  
}
```

Beyond character control, key processes in steel truss lifting can also be simulated. Compared to the BIM model, the VR model of the steel truss was positioned on the concrete slab. Lifting points were created at both ends of each truss, controlled by the "8" and "5" keys on the numeric keypad. Sample control statements:

```
float up = Input.GetAxis ("SteelTruss");  
float risingHeight = 9.0f;  
if (up > 0) {  
    if (transform.position[1] < risingHeight) {  
        transform.Translate (2 * Vector3.up * up * Time.deltaTime, Space.World);  
    }  
}  
if (up < 0) {  
    if (transform.position[1] > 0) {  
        transform.Translate (2 * Vector3.up * up * Time.deltaTime, Space.World);  
    }  
}
```

Steel strands must move synchronously with the truss to create realistic lifting visuals. Unlike the truss, strands also undergo length changes, requiring adjustment of both spatial position and Transform-Scale properties. Figure 8: see

original paper shows the truss during lifting.

Wind effects were also added, considering slight asynchronization between hydraulic lifting points to comprehensively simulate various lifting conditions. To demonstrate construction scenarios under different weather and lighting conditions, interactive commands for weather and lighting control were implemented. Weather toggling between sunny and rainy conditions controls the particle system:

```
if (Input.GetKeyDown (KeyCode.Tab)) {
    if (rain == 0) {
        objects.SetActive (false);
        rain = 1;
    } else {
        objects.SetActive (true);
        rain = 0;
    }
}
```

The particle system off (on) corresponds to sunny (rainy) conditions, toggled by the “Tab” key. Lighting is controlled by adjusting the Directional Light’s Rotation property values (x, y, z, where  $-180 \leq x, y, z \leq 180$ ), specifically by changing the x-value:

```
float up = Input.GetAxis ("SunLight");
transform.Rotate (Vector3.right * Time.deltaTime, Space.World);
```

Pressing numeric keypad “+” sets “SunLight” to a positive value, moving the sun east to west; pressing “-” sets it negative, moving the sun west to east.

**3.4 User Interface Design** The user interface (UI) helps users quickly master the virtual construction simulation system while simplifying operations. [Figure 9: see original paper] shows the start interface UI, consisting of title, background textures, and instruction buttons. A new Scene was created in Unity3D using the built-in MainMenuGUI C# script as a foundation, with additional elements customized as needed.

Transitioning from the start interface to the scene requires C# scripting for buttons. For example, the “Start VR Journey” button uses:

```
if (GUI.Button(new Rect(playButton), "Start VR Journey")) {
    StartCoroutine("ButtonAction", "Hengjia");
}
```

This indicates that clicking the button loads the “Hengjia” scene (the virtual construction environment). Other buttons follow similar patterns.

The icons in the upper left and right corners of [Figure 10: see original paper] are in-scene UI buttons for restart and return-to-start functions.

**3.5 System Deployment** To enable project managers and workers to use the virtual construction simulation system anytime, anywhere, without being limited by development software, system deployment is necessary.

Selecting File-Build Settings opens the deployment interface to choose target Scenes and platforms. Unity3D supports multi-platform deployment (Windows, Mac, Linux, iOS, Android, etc.). Before deployment, all Scene files must be organized—typically two or more, with one for the start interface UI and others for various construction scenarios, as shown in [Figure 11: see original paper]. After organization, selecting Build completes deployment, generating .exe files.

### 3.6 System Features

1. **Efficiency:** Effectively utilizes existing BIM models, closely integrating with engineering projects to create virtual construction scenes based on actual models.
2. **Realism:** Authentically reproduces construction sites with physical properties for collision and gravity simulation; combinations of sound effects, sky, weather, and lighting can display various possible construction scenarios.
3. **High Interactivity:** Through C# scripting, diverse interaction forms can be designed, including character control, construction process control, and weather/time control, without functional limitations.

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## 4. Engineering Application Verification

The BIM-based virtual construction simulation system for large steel structures developed in this paper has been successfully applied to site management and worker training for the large-span steel truss lifting project at Hangzhou Shangcheng District Sports Center. The system comprehensively simulates real site conditions, considering environmental factors such as wind, rain, cloudy conditions, and nighttime operations, as well as random factors like lifting asynchronization. The application achieved outstanding results:

1. Through virtual simulation roaming, the site layout scheme for hydraulic cylinders and synchronous control equipment was comprehensively evaluated, as shown in [Figure 12: see original paper]. The final placement on the north side of the truss assembly level was selected, providing both ample space and sufficient visibility to control the entire lifting process.
2. By considering wind effects and slight asynchronization between lifting points, contact jamming between the steel truss and steel column nodes was identified as a potential issue that could halt lifting. The virtual construction simulation preemptively identified vulnerable steel column nodes, enabling workers to monitor them on-site and resolve issues immediately upon occurrence, as shown in [Figure 13: see original paper],

significantly improving construction efficiency.

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## 5. Conclusion

This paper investigated a BIM-based virtual construction simulation system for large steel structures, using the large-span steel truss hydraulic lifting project at Hangzhou Shangcheng District Sports Center as a case study. The system effectively leverages existing BIM models, enabling construction managers to rapidly build virtual construction simulation scenes.

Featuring efficiency, realism, and high interactivity, the system's application in the Shangcheng District Sports Center project helped construction managers: (1) design more rational site layouts for hydraulic cylinders and synchronous control equipment, and (2) prepare in advance for potential contact jamming between trusses and steel column nodes, substantially improving construction efficiency. Additionally, the system provides intuitive pre-construction disclosure and training for workers, effectively ensuring construction quality and safety.

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**First Author Information:**

Hu Dejun, male (1974-), Enterprise Technical Director, Senior Engineer. Research interests: Application of new construction technologies in project management.

Phone: 13173603690

Address: Meidu Plaza Tower A, 789 Moganshan Road, Hangzhou.

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