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Retraction

Retracted: Construction and Evaluation of Construction Safety Management System Based on BIM and Internet of Things

Security and Communication Networks

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Security and Communication Networks has retracted the article titled "Construction and Evaluation of Construction Safety Management System Based on BIM and Internet of Things" [1] due to concerns that the peer review process has been compromised.

Following an investigation conducted by the Hindawi Research Integrity team [2], significant concerns were identified with the peer reviewers assigned to this article; the investigation has concluded that the peer review process was compromised. We therefore can no longer trust the peer review process, and the article is being retracted with the agreement of the Chief Editor.

The authors do not agree to the retraction.

References

[1] H. Yu, F. Liu, and Y. Wang, "Construction and Evaluation of Construction Safety Management System Based on BIM and Internet of Things," *Security and Communication Networks*, vol. 2022, Article ID 1541241, 14 pages, 2022.

[2] L. Ferguson, "Advancing Research Integrity Collaboratively and with Vigour," 2022, https://www.hindawi.com/post/advancing-research-integrity-collaboratively-and-vigour/.

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Research Article

Construction and Evaluation of Construction Safety Management System Based on BIM and Internet of Things

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With the continuous development and maturity of technology, the Internet of Things has gradually been applied to various fields of work and life, for example, the use of the Internet of Things and road traffic, the use of the Internet of Things smart city for vehicle identification and GPS positioning, the use of the Internet of Things smart medical smart heart pulse monitoring device, and so on. And, the construction industry bears important responsibilities for the development of national infrastructure and people's livelihood. This article aims to study the application of BIM and Internet of Things technology in the safety management of construction sites, to drive technological development with industry needs, help expand the application fields of the Internet of Things, and promote the improvement of the national construction safety management system. This article uses BIM and Internet of Things technology to build a construction safety management system, focusing on the protection of people, through technical means, such as personnel activity control, hazard warning, major hazard monitoring, and multiple institutional measures, such as education, training, supervision, and protection, that collaborate to complete the protection and risk avoidance of operators in the process of building construction. The evaluation index of the safety management system is proposed through the analytic hierarchy process, and the dimension of the safety management system to prevent accidents is evaluated by the analytic hierarchy process. Taking the actual project as an example, the application effect of the remote monitoring system is qualitatively analyzed. On the basis of the analysis, from the three levels of policy, enterprise, and practitioners, several suggested measures that will help new technology to be applied to construction safety management are put forward. In the experiment part, the construction of the safety management system is first explained, then the appropriate system evaluation index is selected, and then the comprehensive ranking is conducted according to the relative importance weight of the highest-level elements in the same level, and the MATLAB software is used to test the consistency. The experimental results show that the construction safety management system constructed in this paper has been well perfected. The calculated weights of people and dangerous areas are as high as 0.578, so that people and dangerous areas can be controlled effectively. Fall accidents from high places can be prevented, full-time monitoring of foundation pit projects can also avoid fall and collapse accidents from high places, improve the comprehensiveness and advancement of construction safety management, and improve the level of construction safety management.

1. Introduction

The construction industry has always had a high incidence of accidents. In recent years, the number of accidents and deaths in the national construction industry has been increasing year by year. According to the statistics, the following five types of construction accidents accounted for more than 85% of all accidents: fall from height accidents accounted for about 35%, electrocution accidents accounted for about 20%, object strikes accounted for about 15%, mechanical injuries accounted for about 10%, and collapse accidents accounted for about 5%. It is very important to build a complete construction safety management system. At present, the safety level of the national construction industry still has a certain degree of mismatch with the development level of the entire industry. The application of BIM Internet of Things will help to make up for the shortcomings of the current construction safety management, improve the overall safety management level of the industry, and shorten the distance between the safety level of the construction industry and its development level. Moreover, the national construction site safety management system is basically complete, although the weakness lies in the implementation of the system and daily supervision. The limitations of "rule of man" lead to management loopholes, because "rule of man" has a strong personal subjective consciousness, and the management system is not comprehensive enough. But the application of BIM and the advantages of the Internet of Things technology can effectively improve the construction safety management system [1].

With the continuous development of society, companies that purely pursue profits can no longer develop sustainably. A large number of safety liability accidents have shown that the losses caused by accidents to an enterprise are far more than the previous safety investment. Therefore, construction companies should also change their development concepts, put people first, promote production with safety, and consider safety as the greatest profit. By improving the level of safety management and avoiding accidents, the economic losses caused by accidents to enterprises can be reduced. At the same time, a corporate image responsible for safety is conducive for the sustainable development of the company. The implementation of the system and the application of technology all revolve around "people." "Human" acts as the makers of the system and the executor of the rules at the same time, and its consciousness influences the implementation of the system. Therefore, the construction unit must pay attention to the cultivation of a safe atmosphere. Through safety education, training, and even punishment, we strengthen people's safety awareness, improve their recognition of various systems and technologies, cultivate a safe atmosphere, cultivate an environment by people, and restrain people by environment.

In recent years, many studies have focused on the application of advanced technology as a way to improve construction safety management. Building information modeling (BIM) is becoming more and more popular in the architecture, engineering, and construction (AEC) industry. Many researchers and practitioners have verified the advantages of BIM compared with traditional information technologies (such as Autodesk CAD). Pishdad-Bozorgi P's successful implementation of FM-based BIM can be achieved by clearly defining the composition of FM-based BIM, a seamless and practical process of collecting FM-based BIM data throughout the project development phase, and implementing interoperability plans, to exchange data between BIM tools and facility management systems, such as computerized maintenance management systems (CMMS). This study first defines and examines one of the first few pilot implementations of FM-enabled BIM, and discusses the challenges encountered and the lessons learned. The implementation process described in the pilot project and the lessons learned are for the successful implementation of FM-based BIM provides valuable insights [2]. In view of the ability of Building Information Modeling (BIM) as a multidisciplinary data repository, Egwunatum aims to explore and utilize the sustainable value of building information models in delivering and operating buildings that require less energy and emit fewer emissions. Carbon dioxide also provides a comfortable living environment for the occupants. The literature he cited shows that linking energy analysis tools with BIM models helps the project design team predict and create optimized energy consumption. To verify this discovery, he used the Arboleda project in the Dominican Republic to conduct an in-depth analysis of the completed BIM integrated construction project. The results show that energy analysis based on BIM helped the design team realize the world's first 103% positive energy building [3]. As one of the key drivers of BIM adoption, BIM users have a significant impact on the success level of BIM implementation. As a factor that leads to the success of the information system and indicates the intention to continue using it after the initial adoption, BIM user satisfaction is studied in this work. Based on data collected from 118 BIM engineers, Wang *G* studied the impact of five potential variables (such as attitude, perceived ease of use, perceived usefulness, senior management support, and goal management) on BIM user satisfaction in the AEC industry. The results of PLS (Partial Least Squares) show that perceived usefulness, top management support, and goal management are significantly related to BIM user satisfaction, while the impact of goal management [4], the complex requirements of the project, and the increase in the number of project participants have led to a large number of iterative BIM data exchange processes for professionals in different fields. Lee Y C studied that when BIM data are imported and exported from BIM authoring tools, seamless sharing and consistent maintenance of BIM data throughout the construction project requires a homogeneous BIM data exchange standard and a powerful verification framework. Several versions of the Industry Foundation Class (IFC) architecture provide a schematic basis for the BIM data exchange standard. In addition, different disciplines have developed Model View definition (MVD), which refers to a data exchange specification defined as a subset of the IFC model. However, the BIM data validation required by MVD and the limitations of the data evaluation process has not been thoroughly investigated, which has led to syntax problems, semantic errors, and unexpected geometric transformations [5]. R-M-Nordin has developed a project-level building safety management system based on the SDM dynamic model, but the model has limitations and has fewer practical applications [6] It enables objects and devices to perceive and communicate environmental conditions. Building information modeling (BIM) is a revolutionary construction technology that integrates databases, integrates geometry into digital models, and provides a visual means for all building lifecycle management. Weng-Fong C integrates BIM and WSN into a unique system that enables the construction site to intuitively monitor the safety status through a space and color interface, and automatically remove any harmful gases. Many wireless sensor nodes are placed in underground construction sites to collect data on hazardous gas levels and environmental conditions (temperature and humidity). In any area where an abnormal state is detected, the BIM model will issue an alarm to the area and issue an alarm and the ventilator will be on-site and automatically start warning [7]. Safety barrier diagrams and "bow tie" diagrams have become popular methods in risk analysis and safety management. Zhou C described the grammar and principles of constructing a consistent and effective security barrier diagram. The relationship between the latter and other methods (such as fault trees and Bayesian networks) is discussed. Compared with others, the important advantage of the safety barrier map is that it can effectively provide risk analysis and safety management [8].

The innovation of this article is to use BIM and Internet of Things technology to build a construction safety management system, focusing on the protection of people, through technical means such as personnel activity control, hazard warning, major hazard monitoring, and multiple systems such as education, training, supervision, and protection. Coordinate and complete measures to protect workers and avoid risks during construction. Through the analytic hierarchy process, the evaluation index of the safety management system is put forward. Taking the actual project as an example, the application effect of the remote monitoring system is qualitatively analyzed [9]. On the basis of the analysis, from the three levels of policy, enterprise, and practitioners, several suggested measures that are helpful for the application of new technology to construction safety management are put forward.

2. Algorithm of Security Management System Based on BIM and IoT Technology

2.1. Statistics and Characteristic Analysis of Safety Accidents in the Construction Industry in Recent Years. The proportion of the construction industry in the national economic development can be seen. However, the safety situation of the construction industry is not optimistic. Figure 1 is the annual statistics and accident-type statistics of the number of accidents in the construction industry across the country from 2014 to 2019 (data source: National Housing and Municipal Safety Incident Bulletin) [10].

The types of accidents include falling from a height, collapse accidents, object strikes, lifting injuries, and other types of accidents. Among them, falling from height accidents rank first among safety accidents throughout the year. The number of safety accidents has risen from 536 in 2014 to 773 in 2019. Except for 442 accidents in 2015, which is slightly lower than 536 in 2014, the number of accidents in recent years has shown an upward trend year by year. The annual statistics on the number of deaths in the construction industry across the country from 2014 to 2019 are the same as the development trend of the statistics on the number of accidents. In 2019, there were 904 deaths, compared with 554 deaths in 2015, which is an obvious upward trend. In the 2014–2019 deaths, the rate of falls from height was always the largest, both around 50%, followed by object impact, accounting for about 15%.

From 2015 to 2019, the annual number of accidents and deaths in the national construction industry has shown an upward trend year by year. This is inseparable from the importance of building construction safety issues. Governments and competent departments at all levels should strengthen their attention to construction safety issues. Pay attention to and control, so the problems of the national construction industry need to be paid attention to and continuously improved for a long time, so as to effectively reduce the number of accidents and deaths.

2.2. BIM and IoT Technology

2.2.1. BIM. BIM (building information modeling) is an engineering data model based on three-dimensional digital technology that inherits various related information of construction projects. It contains not only geometric information, special features, and state information representing building components but also states information of objects other than components (such as space and behavior of movement). BIM is a digital expression of the physical and functional characteristics of engineering project facilities [11, 12]. A complete information model can connect the data, processes, and resources of different stages of the construction project life cycle. It is a complete description of the engineering object and can be commonly used by all participants in the construction project [13]. BIM has a single engineering data source, which can solve the problems of consistency and global sharing between distributed and heterogeneous engineering data, and support the creation, management, and sharing of dynamic engineering information during the life of construction projects [14, 15]. Building information modeling is also a digital method applied to design, construction, and management. This method supports the integrated management environment of construction engineering, which can significantly improve efficiency and reduce risks in the entire process of construction engineering [16, 17].

With the development of BIM technology, it has gradually been applied in some large and complex projects [18, 19]. However, there are still some problems that need to be improved: the government recognizes and promotes BIM technology but has not issued specific implementation standards related to BIM, relevant laws and regulations have not yet been formulated, and the legal responsibility boundaries of all parties in the implementation of BIM technology are blurred [20]. The cost of using BIM technology is relatively high, and the balance of benefits will make companies abandon the use of BIM technology; the national society's inherent cognition and processing concepts of things are quite different from the refined and digital management concepts advocated by BIM technology. With the development of BIM, people began to realize that only the rich information associated with the object model can fully realize the value of BIM [21, 22].

2.2.2. Internet of Things Technology. The Internet of Things is called a network that connects things to each other [23]. In 2009, IBM put forward the concept of "Smart Earth = Internet of Things + Internet", taking the continuous development of Internet of Things technology as a new technological innovation; the core of the Internet of Things technology is a variety of smart sensors and low-power

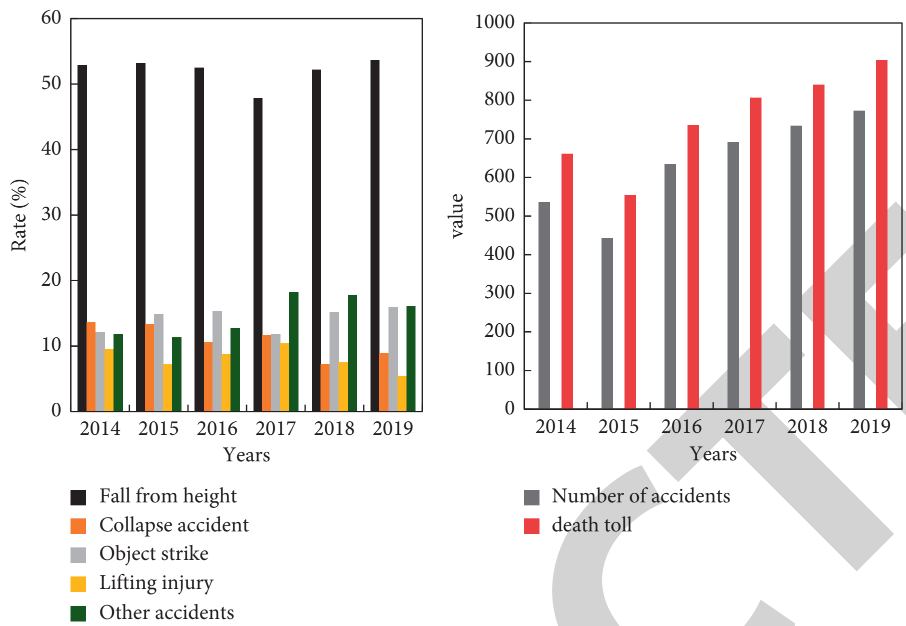

Figure 1: The occurrence of construction safety accidents in 2014–2019.

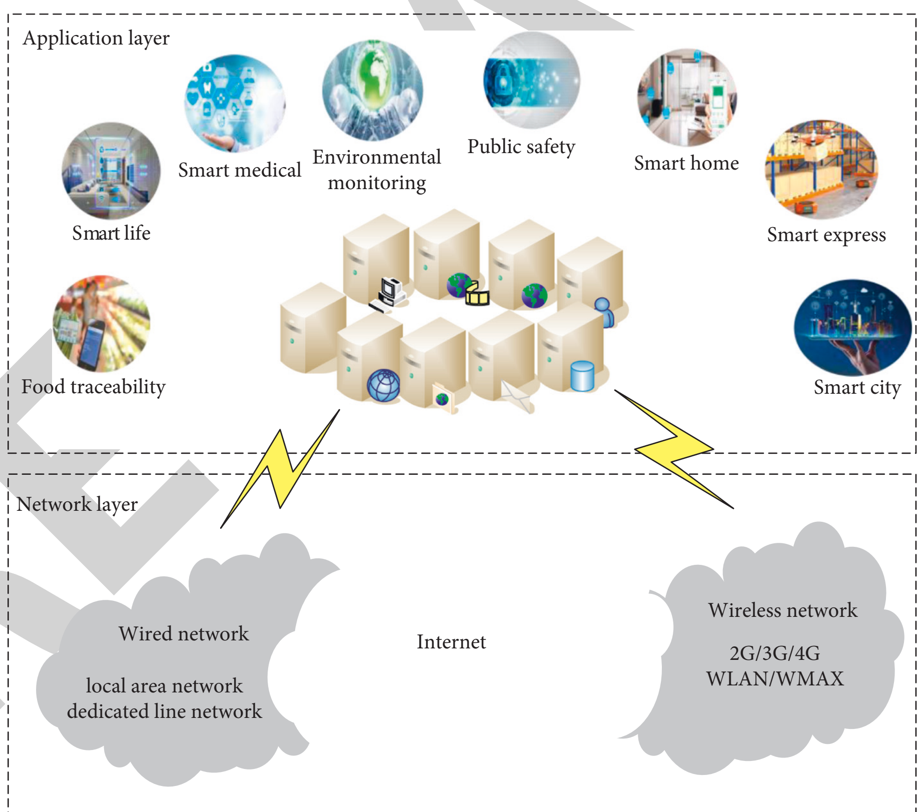

Figure 2: Schematic diagram of IoT system architecture.

wireless transmission technology to classify with a pyramid level structure [24, 25], as shown in Figure 2:

At present, the Internet of Things technology is applied in a small range of industries such as smart buildings and smart homes. Take the monitoring of the interior of the building as an example. Internal, the sensor transmits information and data such as the measured environmental temperature, gas composition, and concentration back to the main console, and performs data analysis to determine whether the measured environment is harmful to the human body, or

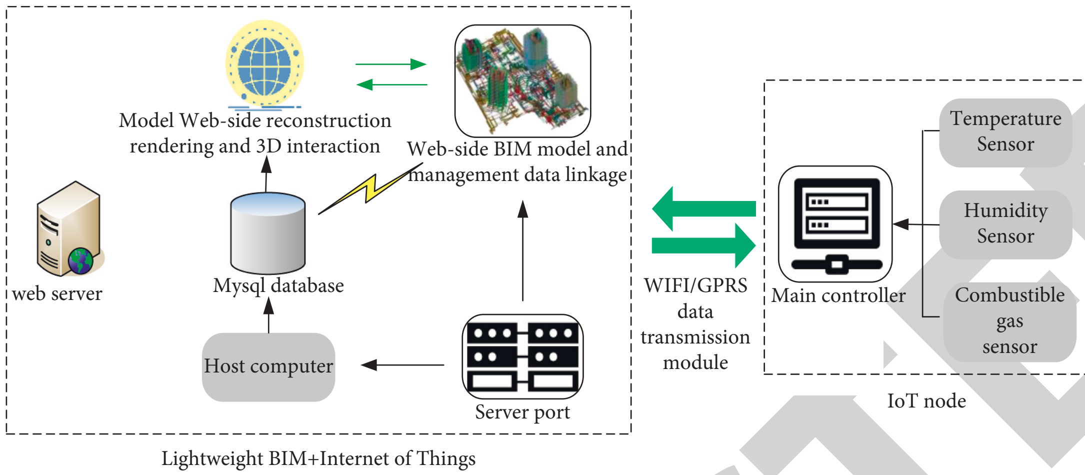

Figure 3: Design of BIM + Internet of things-based building construction safety management system.

whether there is a safety hazard, and realizes the monitoring of the internal environment of the building function.

The Internet of Things is hot and has become one of the hot research topics in this era [26, 27]. The development of the Internet of Things is inseparable from the deep integration with other fields, and it is inseparable from the applications of all walks of life. They develop in integration with each other. Therefore, once the Internet of Things is widely used on a large scale, it will bring convenience to the operation of social economy and people's daily life. Scientific research and other aspects have brought unprecedented changes [28, 29].

2.3. Scheme Design Based on BIM and Internet Technology. Construct a three-dimensional model of the construction site and carry out research on the lightweight of the model. The BIM + Internet of Things construction safety management system scheme is shown in Figure 3:

The system scheme is divided into two parts: the first part is the reconstruction of the original data of the BIM model, the reconstruction of the Web-side model and the three-dimensional interaction, and the writing of the server program. First, according to the computer three-dimensional graphics theory, traverse the triangle mesh vertices of the original data of the BIM model to obtain the number of vertices and their coordinates, find the vertex normal vector and the triangle normal vector, calculate the model surface texture mapping coordinates, and obtain the color value. After the geometric information is extracted, it is reconstructed into the data available on the Web side and then reconstructed on the Web side. The third-party library Three.js of WebGL is used to render the 3D graphics to realize the Web side reconstruction of the BIM model. Secondly, according to the ray picking, orbital space control, first-person control, and flight control theories are developed on the Web to realize three-dimensional interactive functions such as selection, drag and drop, zoom in and zoom out, and perspective conversion, laying the foundation for its subsequent integration with the Internet of Things; finally, PHPStorm based on IntelliJ. The platform writes web server-side programs, relies on ThinkPHP5 framework, uses Apache lightweight web service tools to connect front and back, uses MySQL database system, and relies on Qt development platform to write data receiving, parsing, and storage programs. The second part is the hardware design of the IoT node and the writing of the node driver. The STM32F103RCT6 is used as the main controller of the IoT node, and the MQ-2 gas sensor and the DHT11 temperature and humidity sensor are used as the core of the information acquisition and perception layer. The sensor data is transmitted to the server through the Wi-Fi module ESP8266 and stored in the database to display the building operation and maintenance status in the form of 3D visualization [30].

2.4. Web-Side Reconstruction and Rendering of Bim Model. The reconstruction and rendering design scheme of the BIM model on the Web is shown in Figure 4.

Based on the theory of computer three-dimensional graphics, reconstruct the original data of the BIM model into JSON format data available on the Web, build an HTML5 framework, add a scene in the Three.js renderer, and add light sources, texture objects, and 3D camera models to the scene. The main purpose is to make the BMI model construction more realistic and convenient to display. Elements, read the locally reconstructed model data through jQuery, use Three.js through the GPU 3D graphics rendering pipeline, go through the vertex buffer, triangle assembly, frame buffer, and other steps, and then go through the model space, world space, camera space, and cropping. The transformation of space and projection space will finally display the BIM model on the Web.

2.5. BIM Model Data Reconstruction Method. BIM model data reconstruction is to reconstruct the original data into JSON format data available on the Web, and traverse the triangle mesh vertices of the original data of the BIM model.

2.5.1. Triangular Mesh. Triangles play a very important role in graphics and three-dimensional modeling. Two-

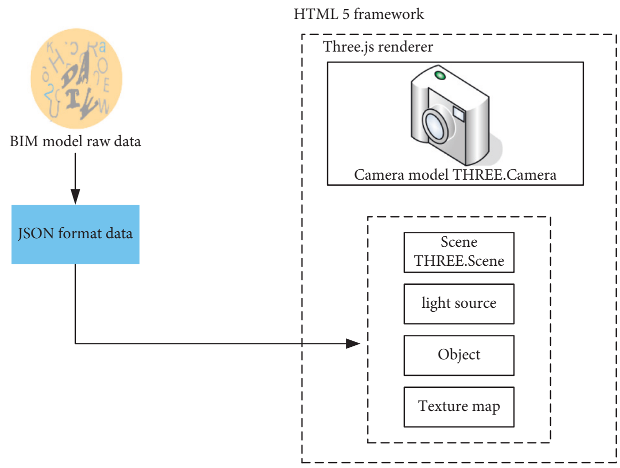

Figure 4: BIM model web-side reconstruction overall scheme design drawing.

dimensional graphics and complex three-dimensional models, such as complex curved surfaces and human body models, can be generated by triangle simulation. The operation of triangular meshes is convenient, so through computer graphics a large number of triangular meshes are used to simulate the surface of the object. Graphics, also known as computer graphics, is a discipline that studies the input of graphics, the construction and representation of models (graphics objects) et al. It includes several aspects of graphics system hardware (graphics input-output devices, graphics workstations), graphics software, algorithms, and applications. In the index triangle mesh, the triangle vertex table and triangle table are used to store the mesh information: the vertex table mainly contains the three-dimensional coordinates of the vertices, and can also add surface normal vectors, texture mapping coordinates, etc.; the triangle table is divided into two parts, the triangle information contains a list of vertices, and can also add vertex normal vector, material information, etc. The indexed triangle mesh table contains the number of triangles and the number of vertices. According to the grid information, the two-dimensional or three-dimensional graphic surface can be simulated.

2.5.2. Vertex. Triangular mesh can intuitively simulate the surface of three-dimensional objects, but the graphics processing unit (GPU) cannot directly index the triangular mesh, so it is necessary to index the vertices that make up the triangular mesh. The vertex is the core of the data, and the vertices are connected in the form of triangles. Vertex data are divided into three categories: the first category is position data such as 2D screen coordinates or three-dimensional coordinates with depth information; the second category is lighting and fog data determined by the vertex normal vector; the third category is texture mapping information. The number of vertices directly determines the complexity of the two-dimensional or three-dimensional graphics because the complexity naturally increases as the number of rows, edges, vertices, and segments of the graph increases.

2.5.3. Surface Normal Vector. In the indexed triangle mesh, the surface normal vector information is stored in the triangle vertex table, which is used for lighting calculation, surface removal, and simulation of particle surface bounce effect and collision acceleration detection. The surface normal vector is divided into two types: triangle-level normal vector and vertex normal vector. It can be calculated according to formula 1. The discontinuity of the surface cannot be directly obtained. In fact, the normal vector at the vertex is not defined. Therefore, the triangle-level normal vector of the adjacent triangles is averaged and then standardized. The approximate method will theoretically make the calculation result coplanar. The offset of the triangle vertex will have an impact in practice within the allowable range.

$$x = \frac{\vec{a}_3 \times \vec{a}_1}{\left\| \vec{a}_3 \times \vec{a}_1 \right\|} a_2. \quad (1)$$

For the triangle color texture, the relationship between the point coordinates and the parameters is established in the form of an affine transformation between the texture space and the polygon space:

$$(x, y, z) = (a, b, c) \begin{pmatrix} i_1 & i_2 & i_3 \\ i_4 & i_5 & i_6 \\ i_7 & i_8 & i_9 \end{pmatrix}. \quad (2)$$

In formula (2), specify the three vertices of the triangle; the values of a, d, and the value of each parameter in the parameter matrix can be obtained from the formula. Using surface normal vector perturbation to form bump texture, then:

$$S'(a, d) = S(a, d) + T(a, d) \times F(a, d), \quad (3)$$

where $F(a, d)$ is the normal vector of the ideal smooth surface at a, d, and the new normal vector is calculated by taking the cross product of the partial derivatives of a, d:

Among:

$$S'a = \frac{bS'}{ba} = \frac{b(S + FT)}{ba} = Sa + FaT + FTa, \quad (4)$$

$$S'd = \frac{bS'}{bd} = \frac{b(S + FT)}{bd} = Sd + FdT + FTd. \quad (5)$$

Since the value of F is negligible compared to the other quantities in the formula, formulas 5 and 6 can be simplified to:

$$\begin{aligned} S'a &\approx Sa + FaT, \\ S'd &\approx Sd + FdT. \end{aligned} \quad (6)$$

Then,

$$
\begin{aligned}
T' &\approx (Sa + FaT)(Sd + FdT),\\
&= Sa \times Sd + Fa(T \times Sd)\\
&\quad + Fd(Sa \times T) + FaFd(T \times T),\\
&= T + K.
\end{aligned}
\tag{7}
$$

The sum of the perturbation vector K and the original normal vector T changes the normal vector of the original ideal smooth surface, that is, it produces a disturbance and forms a bumpy texture.

2.6. Ray Picking Method. The ray picking method enables users to click on three-dimensional objects on the screen to select. The key of the ray picking method is to obtain the vector of the ray. To obtain the vector of the ray, the inverse transformation of the graphics rendering pipeline is required.

The coordinates of the point S (X, Y, Z) are inversely transformed into the coordinates of the projection space through the window, and the z-axis depth is set to 0.5, and the window inverse transformation formula is obtained from the geometric operation:

$$
\begin{cases}
x_{S'} = \dfrac{(x - WS/2)}{(x - WS \times 2)},\\[2ex]
y_{S'} = -\left(y - \dfrac{QS}{2}\right)QS \times 2,\\[2ex]
z_{S'} = 0.5.
\end{cases}
\tag{8}
$$

Suppose that the point R is the origin of the projection space, which is also the point of view of the user interacting with the screen, and the S' in the projection space is transformed into a point in the view space through the inverse projection transformation.

$$
s\text{Matrix} = \begin{bmatrix} w & 0 & 0 & 0\\ 0 & g & 0 & 0\\ 0 & 0 & K & 1\\ 0 & 0 & -KR & 0 \end{bmatrix},
$$

$$
\begin{cases}
w = \cot\left(\dfrac{\text{ang}}{2}\right) \times \left(\dfrac{1}{asp}\right),\\[2ex]
g = \cot\left(\dfrac{\text{ang}}{2}\right),\\[2ex]
asp = \dfrac{WS}{QS},\\[2ex]
\dfrac{K = R_t}{\left(R_t - R_f\right)}.
\end{cases}
\tag{9}
$$

Ang represents the angle between the projection origin R and the edge of the near clipping plane; asp represents the ratio of the width to the height of the actual screen; and R_t represents the relationship between the coordinate points in the projection space, which can be expressed by the following equation:

$$
s\text{Matrix}_n = \left(x_{S'} \times R_t, y_{S'} \times R_t, z_{S'} \times R_t\right).
\tag{10}
$$

Since the depth of the z-axis is 0.5, the calculation formula for the point S$'$ in the view space can be obtained as:

$$
\begin{cases}
S''_x = \dfrac{x_{S''}}{R_t},\\[2ex]
S''_y = \dfrac{y_{S''}}{R_t},\\[2ex]
S''_z = \dfrac{z_{S''}}{R_t}.
\end{cases}
\tag{11}
$$

The ray vector required by the ray picking method is obtained by the above method, and the vector of the above ray can be converted into the vector of the ray in the world space through the transformation matrix of the view space. The object closest to the origin of the space is used as the picking target to complete the picking.

2.7. Analytic Hierarchy Process. The purpose of construction safety management is to implement effective management measures to avoid risks in the construction process, prevent safety accidents, and reduce personal injuries and property losses caused by accidents. This paper will use Analytic Hierarchy Process (AHP) to evaluate the established construction safety management system based on the Internet of Things. The analytic hierarchy process is a commonly used evaluation method combining qualitative and quantitative aspects. It can be applied to a target system with hierarchical and interlaced evaluation indicators. In the process of building construction, there are many factors that affect the safety management of building construction, and there are problems that are difficult to accurately judge. Using the Analytic Hierarchy Process, through the combination of qualitative and quantitative methods, the system is used to comprehensively evaluate the two dimensions of reducing the possibility of accidents (preventing accidents) and reducing accident damage. Through theoretical calculations, the applicability of the construction safety management system based on the Internet of Things is analyzed.

(1) The establishment of analytic hierarchy model

To establish a hierarchical structure model, we must first analyze the characteristics of the system, as well as the target requirements, and decompose the influencing factors into components. Then, according to the affiliation relationship between the constituent factors, they are combined at different levels to form a multi-level structural model, including the top, middle, and bottom layers.

(A)	B_1	B_2	B_3	$\cdots$	B_n
B_1	b_{11}	b_{12}	b_{13}	$\cdots$	b_{1n}
B_2	b_{21}	b_{22}	b_{23}	$\cdots$	b_{2n}
B_3	b_{31}	b_{32}	b_{33}	$\cdots$	b_{3n}
$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$
B_n	b_{n1}	b_{n2}	b_{n3}	$\cdots$	b_{nn}

Figure 5: The general representation of the judgment matrix.

(2) Construct a judgment matrix

The relative importance of each element in the same level under the criterion of the previous level is compared in pairs, and a score is assigned to form a judgment matrix, as shown in Figure 5.

(1) Calculate the eigenvalues and eigenvectors, and finally check the consistency, as follows:

Calculate the product of each row element of the judgment matrix:

$$G_i = \prod_{j=1}^{m} B_{ij}, \quad i = 1, 2, 3, \ldots, n. \tag{12}$$

Calculate the nth square root of $G_i\overline{G}_i$.

$$\overline{G}_i = \sqrt[n]{G_i} B_{ij}, \quad i = 1, 2, 3, \ldots, n. \tag{13}$$

Normalize the vector $\overline{G} = [\overline{G}_1\, \overline{G}_2 \ldots \overline{G}_n]^T$.

$$G_i = \frac{\overline{G}_i}{\sum_{i=1}^{n} \overline{G}_i}, \quad i = 1, 2, 3, \ldots, n. \tag{14}$$

Calculate the feature vector $G = [G_1\, G_2 \ldots G_n]^T$ of the judgment matrix, where G_i represents the weight of the i-th element.

Calculate the largest characteristic root $\gamma_{\max}$ of the judgment matrix.

$$\gamma_{\max} = \sum_{i-1}^{n} \frac{(AG)_i}{nG_i}, \quad i = 1, 2, 3, \ldots, n, \tag{15}$$

where: $(AG)_i$ represents the i-th element of the vector AW.

(2) Basic Consistency Test

A method is introduced to check the integrity of the crisis table to ensure that the weighting and classification results of each indicator are valid. If the test results are inconsistent, you need to modify the original crisis matrix until they are consistent.

Table 1: Random consistency index value result table.

Order	RS1	RS2
1	0	0
2	0	0.41
3	0.36	0.55
4	0.85	0.93
5	1.14	1.08
6	1.25	1.19
7	1.33	1.24
8	1.40	1.38
9	1.48	1.42
10	1.56	1.54

Calculate the consistency index KS.

$$KS = \frac{\gamma_{\max} - n}{n - 1}. \tag{16}$$

Calculate the average random consensus index KR.

$$KR = \frac{KS}{RS} n - 1. \tag{17}$$

When the calculation result $KR < 0.1$, it means that the judgment matrix meets the consistency, otherwise it does not.

In the formula, RS is the average random consistency index, and the specific values are shown in Table 1.

3. Building Construction Safety System Experiment Based on BIM and Internet of Things

3.1. Construction of Safety Management System

3.1.1. Principles of System Construction

(1) System integration. In the process of applying the Internet of Things to construction safety management, it is not just the application of a certain technology to the management of a certain operation; the overall management of machine and environment works together to prevent accidents and effectively prevent risks.

(2) Uniqueness of Execution. The various systems of the constructed system should be unique in the implementation process, not ambiguous. In the formulation of the management system, full consideration is given to the selectivity that personnel may face during the implementation of the system. Try to minimize the selectivity of implementation and ensure the uniqueness of system implementation.

(3) Dynamics of Operation. Building construction projects are in a dynamic process of change, and the environment and equipment in the construction area will change all the time. Therefore, the various indicators of the management system need to be dynamically changed according to the changes of the project to ensure that they can truly reflect the on-site situation, update various risk indicators in time, and ensure the timeliness of management.

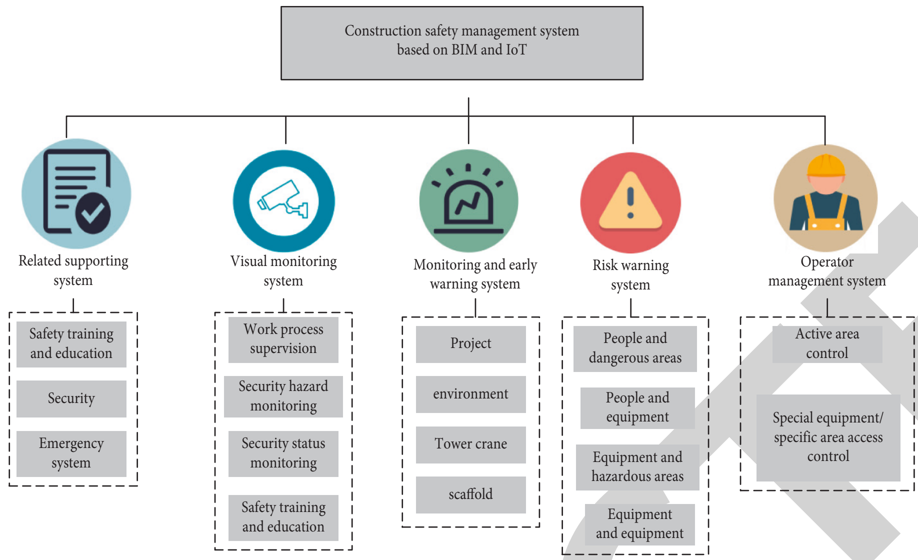

FIGURE 6: Comprehensive evaluation index of safety management system.

TABLE 2: Evaluation index of construction safety management system.

First level indicator	Definition	Secondary indicators	Definition
Operator management	A	Active area control Special equipment	A1 A2
Monitoring and early warning	B	Project Environment Tower crane Scaffold	B1 B2 B3 B4
Risk cross-warning	C	People and dangerous areas People and equipment Equipment and hazardous areas Equipment and equipment	C1 C2 C3 C4
Visual monitoring	D	Work process supervision Security hazard Security status Safety training and education	D1 D2 D3 D4
Supporting system	E	Safety training and education Security Emergency system	E1 E2 E3

3.2. Construction of Safety Management System Evaluation Indicators. Taking the prevention of accidents and reducing the possibility of accidents as the evaluation principle, the comprehensive weight calculation and ordering of various measures and functions in the established system are carried out. According to the structure of the construction safety management system based on BIM and the Internet of Things, the construction and formation of various indicators and evaluation systems are shown in Figure 6.

The construction safety management system based on BIM and the Internet of Things builds a comprehensive evaluation index system, including related supporting systems, visual monitoring systems, risk cross-warning systems, monitoring and early warning systems, and operator management systems.

Taking the role of reducing the possibility of accidents as the criterion, the importance of each index in the system is compared pairwise to form a judgment matrix. The results are shown in Table 2. Calculating weights is a common analysis method; however, it must be chosen in the context of the data's characteristics. For example, if the volatility between data is a type of information, consider using the CRITIC weight method or information weight method.

3.3. Construction and Evaluation Analysis of Construction Safety Management System Based on BIM and Internet of Things

3.3.1. Evaluation Indicators of Construction Safety Management System. Take the five indicators A, B, C, *D*, and *E* of the control layer as the evaluation criteria, compare the indicators of each subsystem one by one, and score the importance of all the first-level indicators and the second-level indicators. After the scoring is finished, we can check the SD. If the consistency check result of the software operation is less than 0.1, the matrix is accepted (if IR < 0.1, accept); otherwise, it is not accepted. The result is shown in Figure 7.

The hierarchical total ranking refers to the comprehensive ranking of the relative importance weights of all factors to the highest-level elements in the same level. According to the results of the calculation of the weight of each judgment matrix, the comprehensive weight calculation of each index is performed, and the overall ranking is performed. The matrix calculation function of the MATLAB software is used to calculate the judgment matrix and check the consistency.

On the basis of the results shown in Table 3, under the principle of preventing accidents, avoiding contact between dangerous areas and dangerous equipment is the most effective measure to prevent accidents. Foundation pit engineering, as operation engineering with potential damage such as falling from height, collapsing, and object hitting, is a key point in construction safety management that needs to be managed.

According to the proportion of weights in Figure 8, most of the indicators are in the first interval, but there are still several indicators that have relatively prominent weights: safety protection (A), operation process supervision (B), equipment and equipment (C), formwork engineering (D), etc. As a passive safety measure, safety protection can effectively protect workers in potentially dangerous working environments and avoid accidents. Figures 9 and 10 are the distribution diagrams of the secondary index weights of the safety management evaluation system.

From Figures 9 and 10, we can see the weight distribution of various secondary indicators. The weight values are relatively large in their respective intervals, including indicators such as A1, B3, and C1. In the two dimensions, the dangerous area, foundation pit, formwork, and special equipment/special areas are major hazards during the construction process. The control of major hazards is a necessary measure to reduce accident injuries.

The supervision of the operation process ensures that the operators wear protective measures as required and carry out construction operations as required. While strengthening prevention, they avoid the appearance of unsafe behavior; equipment and equipment and formwork projects belong to the human-machine-environment. "Machine" and "environment," human beings are the main objects of accidental injuries. The supervision and monitoring of "machine" and "environment" can avoid accidental energy release and cause personal injury. The remaining index weights are not much different, but they still play a role in preventing accidents.

By analyzing the impact of changes in safety investment on the level of construction safety management and construction site safety productivity, it can be seen from Figure 11 that (1) with the increase of safety investment, the efficiency of construction site safety management will also improve, and it is expected to achieve the desired safety production goals. Therefore, the construction unit should

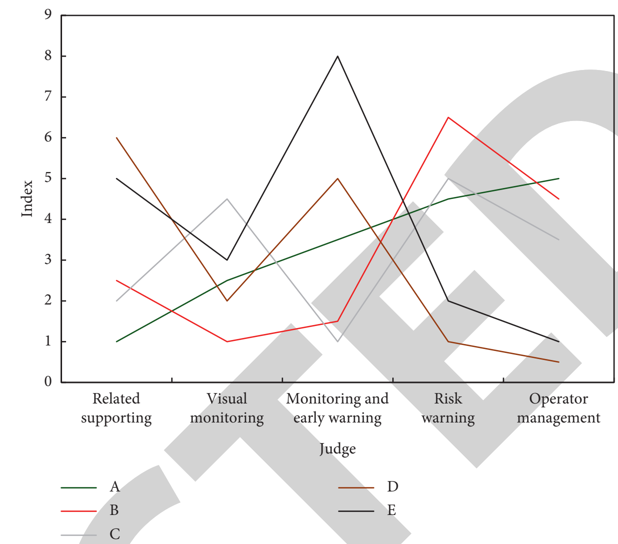

Figure 7: The first-level judgment result of the dimension of preventing accidents.

Table 3: The overall ranking of the dimensions of accident prevention.

Target layer	Middle layer					Sort
	A	*B*	*C*	*D*	*E*	
A	0.673	0.8215	0.4399	0.5649	0.7198	0.725
B	0.8126	0.9538	0.2625	0.6531	0.6636	0.4376
C	0.767	0.5549	0.7446	0.4031	0.8248	0.1479
D	0.5563	0.4051	0.3661	0.9497	0.6917	0.3392
E	0.3316	0.9671	0.3611	0.6088	0.6739	0.8562

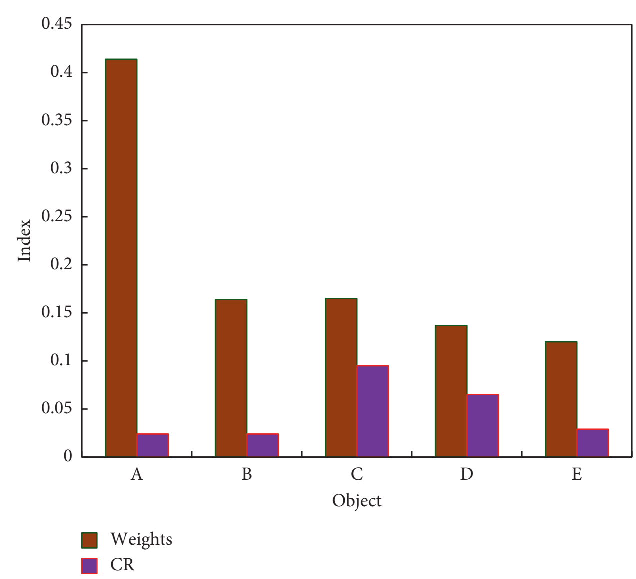

Figure 8: Distribution of the weight of each indicator under the dimension of accident prevention.

increase safety investment in the early stage of construction, so that the construction site can reach the safety production goal as soon as possible, reduce production accidents at the construction site, and strive to achieve "zero" casualties. The

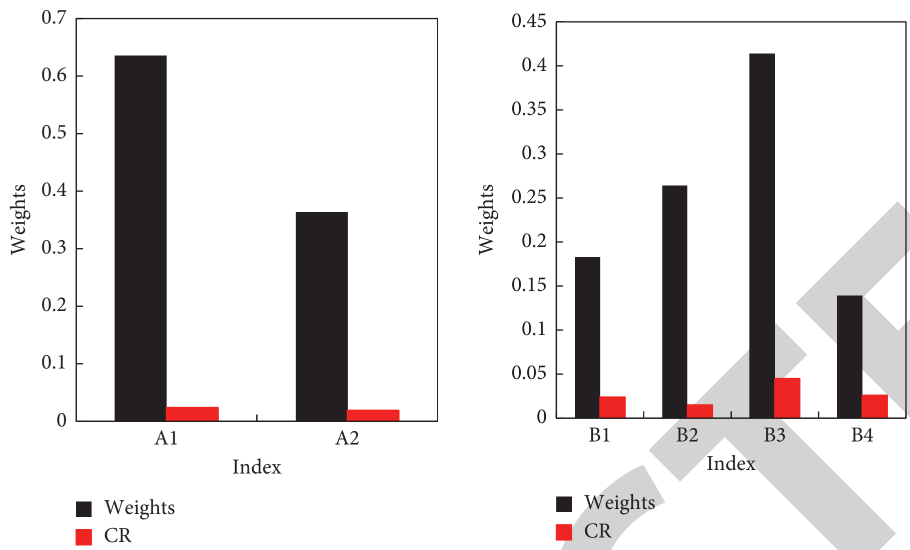

Figure 9: Operator management and monitoring and early warning index weight.

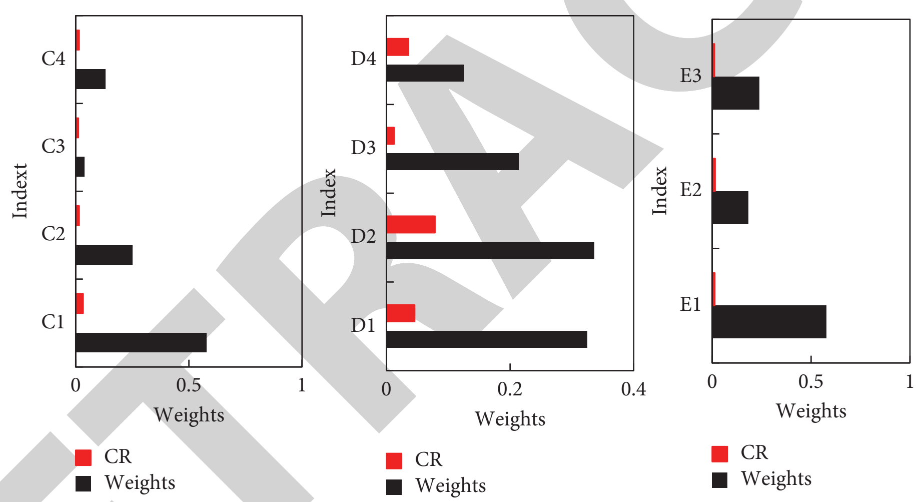

Figure 10: Risk cross-warning, visual monitoring, and supporting indicator weight distribution.

safety productivity of “zero” accidents is set to 1. (2) The improvement of the safety level of construction sites is a long-term and slow process. But there are some ways to speed up the process, like with the increase of investment, the speed of the improvement of safety management level and the growth rate of safety productivity gradually accelerate. Through a large amount of literature and investigation and analysis, it is concluded that it is because with the increase of investment, the improvement of safety awareness, the increase of work skills, and the effect of management all have a process. If you want to improve the safety management level and safety productivity of the construction site faster, you need to choose a team with high construction technology and management level when selecting a construction team, so as to shorten the process and achieve the required goals as soon as possible.

3.3.2. Implementation of the Construction Safety Management System. Use monitoring equipment to monitor the construction site in an all-round way. The location is selected in the construction area, such as the entrance and exit of the construction site and tower cranes, and the monitoring scope should cover the entire construction site as much as possible because the personnel in this position are more mobile and have a wider field of vision. In addition, it has less impact on the site construction and will not cause monitoring loss. Therefore, it is installed at high places, as shown in Figure 12:

Through the camera equipment in the construction site, the situation of each location in the construction site can be obtained, and the management center can supervise the operation process through the monitoring screen (Figure 12(d)). When unsafe behaviors or irregular operations are discovered, operators can be immediately required to make rectifications to avoid causing greater accidents; at the same time, safety inspections can also be carried out on the construction site to improve inspection efficiency.

The application of remote monitoring system improves the level of construction safety management. Here, we

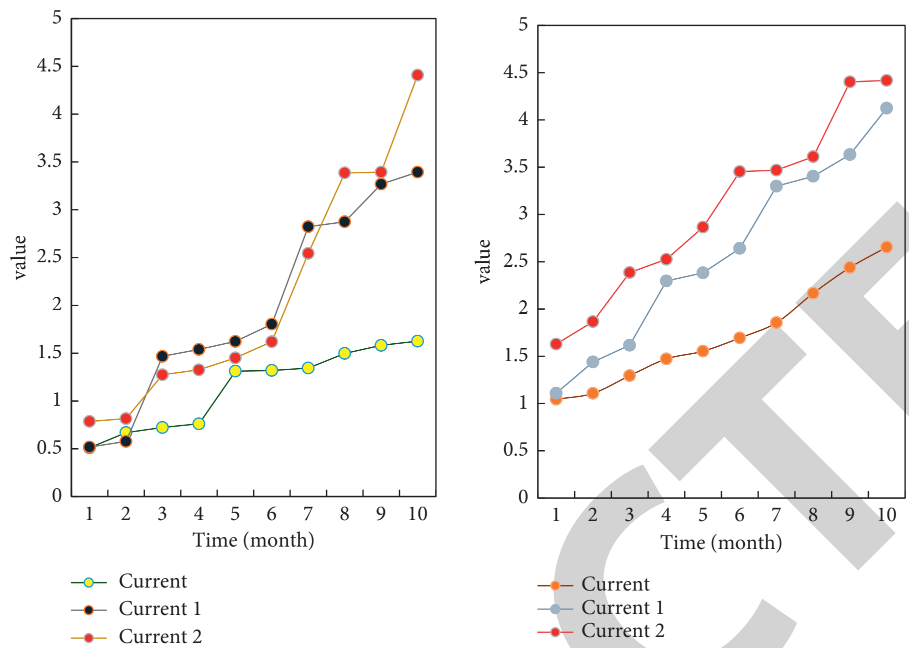

Figure 11: Safety management comprehensive level and productivity simulation.

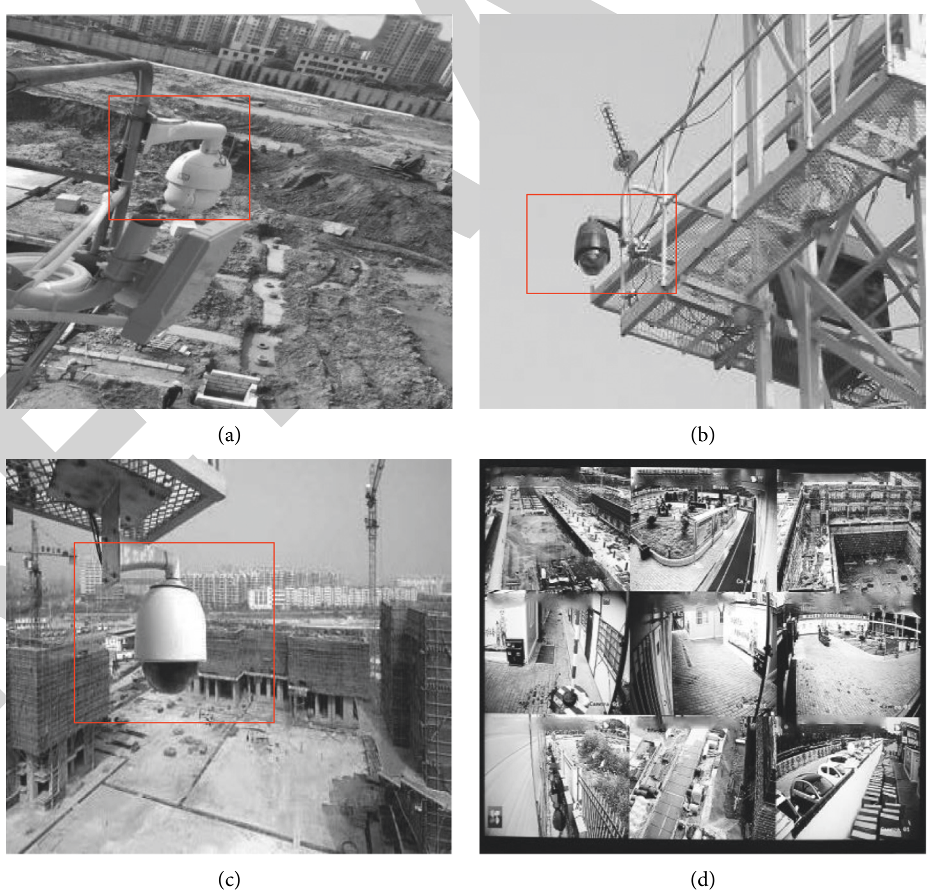

Figure 12: Construction site monitoring.

analyze it from two aspects. The application of the remote video monitoring system for the management effect of the construction unit has strengthened the supervision of the construction operation process and the implementation of various systems, which is specifically reflected in: the camera in the construction area can monitor the operation process in real time. For safety managers, the supervision of the whole process can promptly discover and remind people of unsafe behaviors in the operation project; for operators, camera equipment replaces the traditional on-site supervision of personnel, invisibly improving their attention and vigilance, self-discipline, and unsafe behavior. Remote video surveillance replaces human-made daily inspections, reduces the intensity of safety inspections, and improves inspection efficiency. The scope of video surveillance can also cover locations or areas that the inspectors cannot reach, and can realize safe inspections of the construction site without blind spots. The implementation of the pre-job disclosure system has been strengthened, the supervision of the operation process has been strengthened, the efficiency of safety inspections have been improved, the implementation of the supervision system has been strengthened, and the transparency of safety supervision has been improved.

4. Conclusions

The overall safety level of the country's construction industry has improved significantly, but there is still room for improvement. Statistics on the number of accidents and deaths in the construction industry nationwide in recent years have been decreasing year by year. It shows that with the continuous improvement of various systems and management measures across the country, as well as the application of new technologies, the level of national construction safety management has been effectively improved. But from another data analysis point of view, the mortality rate of the construction industry has remained basically unchanged in recent years, and the types of high-incident accidents and accident sites are too concentrated. The proportion of falls, collapses, object hits, and lifting injuries remained constant, and the proportions of various injuries remained basically unchanged. The entrances and borders, Earth and stone, foundation pits, etc., have always been the places where accidents occur frequently. It shows that the risk of construction in the country has not changed significantly, and there is still a lot of room for improvement and the need for improvement in the safety management of construction.

This article builds and evaluates the construction safety management system based on BIM and Internet of Things technology. The constructed safety management system can help control the occurrence of accidents. The shortcomings of the article are that it focuses on the research on the level of construction safety management systems and measures, and does not elaborate on technical issues such as various monitoring and early warning technologies and safety threshold setting; because of the actual construction safety management, there are restrictions due to the current technology and input cost issues, and there is no relevant system that requires the construction unit to use various technologies. Therefore, in engineering case analysis, there is no appropriate practical application case to support it. Only taking the application of monitoring system as an example, a qualitative analysis is made. On the basis of qualitative analysis, suggested measures are put forward, hoping to be improved in the follow-up research [31].

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The author(s) declare no potential conflicts of interest with respect to the research, author-ship, and/or publication of this article.

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