Design and Implementation of BIM-based Fire Risk Assessment System

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Abstract. Integrating BIM with fire risk assessment, this thesis adopts the fire risk index method and analytic hierarchy process to assess the risk of buildings and establish fire risk assessment index system. With Microsoft Visual Studio 2015 as the development platform and C# as the development language, the secondary development was carried out based on BIM technology, which is characterized by efficiency, reliability and scientificity, and a fire risk assessment system based on BIM was successfully designed, which can realize the fire risk assessment of four types of buildings: residential building, public buildings, factory building and warehouses. The system can directly import the fire protection data of buildings needed by fire risk assessment from BIM to complete the building fire risk assessment, which not only can make fire risk assessment process simplified with less costs, but also can enable the fire risk assessment to be widely used in all kinds of buildings, thereby further promoting the fire safety level of buildings.

1. Introduction

In pace with the high-speed economic development and rapid development of construction industry in China, China has become the country with the largest number of new buildings each year in the world, accompanied by rapidly increasing special buildings of various kinds and increasing risk factors. Accordingly, the risk and complexity of building fire significantly increases, leading to greater fire risk. Once the fire breaks out, the casualties and property losses will seriously affect people's production and life. Fire risk assessment should be carried out comprehensively according to the actual situation of buildings such as architectural structure, fire load, fire prevention measures, firefighting facilities and fire management of buildings, etc[1]. In the process of traditional assessment, the assessment personnel were required to inspect on the spot and fill in the data on the field investigation form. Fire professionals needed to investigate the building, typed the data in the field investigation form into a computer and then carried out fire risk assessment through the risk assessment software. However, this traditional fire risk assessment method has such disadvantages as low assessment efficiency, high cost, and poor management effect, making it difficult to satisfy current needs. It has become a problem that needs to be solved urgently how to reasonably conduct fire risk assessment of buildings by virtue of modern science and technology as well as advanced design ideas, and how to effectively reduce the frequency of fires and reduce the losses caused by fire.

Taking the risk assessment index system based on AHP as the theoretical basis, the BIM-based fire risk assessment system adopted the building fire risk index method and the analytic hierarchy process to conduct the risk assessment of buildings, and establish the fire risk assessment index system. Integrating the computer software development technology with BIM technology, the computing and
data acquisition tasks were completed by the computer, and the building fire data needed by the fire risk assessment was directly imported from BIM. Accordingly, the traditional field investigation was replaced by automatic collection of building information and then the computerized algorithm was used to complete the value assignment computing of the risk assessment, which helped to save a lot of manpower and material resources, quickly and intelligently compute the index value of the buildings being assessed, thereby greatly reducing the cost of fire risk assessment, and raising the efficiency of risk assessment. This BIM-based fire risk assessment system could make the fire risk assessment widely used in numerous common buildings, further promoting the safety performance of buildings, and enable the government, insurance company and fire intermediary to accurately master the fire safety conditions of the building[2].

(1) Providing assessment criterion for fire supervision department and building audit department, and providing reference and basis for fire department to determine key units and key sites;
(2) Providing a reference for insurance and intermediary companies to determine insurance rates and whether to grant insurance or not;
(3) Providing decision support for the layout of fire prevention and control system in enterprises and the decoration of civil buildings, and helping to determine the key risk sites for the strengthened layout of the fire prevention forces of enterprises.
(4) It is necessary to assess the fire risk of the whole building, formulate a perfect fire protection plan and construct an intelligent fire prevention system. The BIM technology could optimize the building fire protection system and improve the building fire protection management.

2. Index system for building fire risk assessment

2.1. Research status of fire risk assessment
At present, in terms of fire risk assessment, overseas studies mainly focus on the following aspects. The first is the fire risk assessment method based on quantitative analysis which can analyze the number and characteristics of fires, as well as the change characteristics in recent years to find the corresponding trend. The second is the development of fire simulation software, which can visualize the fire scene in a virtual way, making it easy for people to master the characteristics of fires and the probability of fire in various types of buildings. The third is the development of evacuation simulation software, such as EVACNET4, E-SCAPE, BGRAF, Building EXODUS, Legion, etc. According to domestic literature, some units, experts and scholars have already conducted studies on building fire loss prediction mainly from three perspectives. The first is the predication of the fire loss of a particular building for a period of time in the future with the method of statistical analysis on the basis of the previous fire loss data of a particular type of building in a certain area. The second is performance-based design, which aims to analyze and predict possible fire loss by virtue of fire dynamics and relevant assessment methods. The third is the study on fire loss based on the data acquired from mathematical statistics, the law of fire development and fire assessment methods, so as to further establish a prediction model for fire risk loss[3].

The current studies are mostly based on the statistical data of previous fire loss to carry out predication with mathematical methods. However, there are few studies that aim to make comprehensive use of stimulation of the fire scene, fire probability, determination of fire load, fire development rate model, influence of fire loss inducing factors and evacuation model in the field of insurance[4]. Although some software for fire loss assessment has been developed abroad, the algorithms corresponding to the software are so ideal that they are not applicable to the current building fire risk assessment.

2.2. Index system of fire risk assessment based on BIM
Having made reference to the existing overseas models, the scientific assessment method of building fire risk level has been put forward based on the actual situation of the fire assessment in China. The building risk index method and analytic hierarchy process were used to conduct a building risk
assessment and construct the fire risk assessment index system, so that the government, the public and relevant units could accurately master the fire safety situation of the building, in addition, providing decision basis for rectification of risks and hidden dangers. It was also necessary that the enthusiasm of the person in charge of fire safety be promoted to reduce the fire risk.

The fire risk index method is an assessment method first put forward in Sweden, which was originally used to know fire safety performance of wooden houses in Northern Europe. Having been tested, supplemented and revised for several times in practice, the current fire risk index method is applicable to all kinds of buildings today. This method is characterized by division of sub projects, during which each sub project will be divided in detail with different scores and weights, thus obtaining the corresponding level[5].

The range of the theoretical risk value is [0, 5]. The larger the risk value, the lower the fire risk level and the higher the fire safety level. The smaller the risk value is, the opposite is true[6]. The fire risk value of the building is calculated by formula (1).

\[
R = \sum_{i=1}^{n} X_i \cdot A_i
\]

In the formula, n is the number of risk indicators, \(A_i\) is the risk value of the \(i\)th indicator, \(X_i\) is the weight of the \(i\)th indicator, that is, the impact of the indicator on the overall building fire risk, and the value range is [0,1].

The relationship between building fire risk value and fire risk level is shown in Table 1.

| Fire risk value | Fire risk level |
|----------------|----------------|
| (4.5,5)        | V(Low)         |
| (3.5,4.5)      | IV(Relatively low) |
| (2.5,3.5)      | III(Medium)    |
| (1.5,2.5)      | II(Relatively high) |
| (1,1.5)        | I(High)        |

In terms of the weighting factor used in the system, first, a questionnaire survey was carried out to widely collect opinions from all sides. Based on this, the opinions of the experts specialized in assessment were collected and analyzed, through which a relatively reasonable weighting factor was obtained. Finally, through the sum of weight and scores, the final risk score was obtained, based on which the fire safety level of the building could be known according to the specification.

The main assessment steps include:
1. Determining various disaster-inducing factors of buildings and assessment criteria;
2. Dividing the risk value of each assessment criteria with AHP;
3. Dividing the scale of assessment;
4. Calculating the building’s risk value to determine the corresponding fire risk level.

The research and judgment data of fire risk assessment factors are collected from BIM, so the fire risk assessment index system based on BIM is shown in Figure 1.

![Index System of fire risk assessment based on BIM](image-url)

Figure 1. Index System of fire risk assessment based on BIM
3. Characteristics of BIM

Building Information Modeling (BIM) technology has attracted widespread attention and been widely used in the construction industry at home and abroad. BIM technology takes relevant information and data of the construction project as the model basis to establish building model, and simulates real information of buildings through digital information. It is characterized by visualization, coordination, simulation, optimization, figure, integration, parameterization, and information completeness. Instead of simply integrating the digital information, BIM is an application of digital information and a digitized method that can be used for design, construction, and management. As a representative of new ideas and new technology revolution in future construction industry[7], BIM can be closely connected with such new technologies as cloud computing, intelligent building, digital city, Internet of things etc.

In addition to the geometric characteristics of buildings as well as the physical information of building components such as walls, doors, windows, beams, columns, pipes, equipment and other primitives, BIM also provides a rich family library and the function of self-built family files to load firefighting equipment, such as fire extinguisher, fire detectors, fire hydrants, fire indicator lights etc. Each family file has its own information library to provide various parameters of the component, such as the detailed original information of model, status, location, supplier, and instruction. Moreover, BIM also can intuitively display the internal structure of buildings, show the location layout of the firefighting equipment and the status of the firefighting access, etc., providing information basis for the building fire risk assessment[8].

4. Design of BIM-based fire risk assessment system

According to the building fire risk assessment index system, it is necessary to collect relevant information of buildings in the assessment process, such as building space, function, structure, decoration, materials, fire load, equipment, personnel characteristics and fire management, etc.

Through importing the BIM database, the BIM-based fire risk assessment system can select the building type and automatically collect the fire data information needed by the assessment from the BIM database. The background will assign values and corresponding weights to the corresponding factors and the corresponding assessment scores and levels can be obtained with the algorithm set by the system, thereby getting the total fire risk assessment score of the building. According to the assessed risk level, the experts system will give detailed rectification measures.

Mainly consisting of various functional modules such as system management, BIM information collection, fire risk assessment, query of historical data, output of assessment report, expert system etc., the BIM-based fire risk assessment system has realized the risk assessment, data collection, report output, data query and system operation and maintenance management of four types of buildings, including public buildings, residential buildings, factory buildings and warehouse buildings. The system function structure is shown in Figure 2.

![Figure 2. System function structure](image-url)
It is the BIM information collection module and fire risk assessment module that are the core functions of the system.

4.1. BIM information collection module
Fire risk factors of four different types of buildings are collected in BIM database.

(1) Risk factors of residential buildings. Namely, it can provide the basic information of residential buildings and assessment basis of fire risk factors, including 26 items such as gas usage, personnel quality, electrical equipment, interior decoration, building height, etc.

(2) Risk factors of public buildings. Namely, it can provide basic information of public buildings and assessment basis of fire risk factors, including fire load, personnel density, electrical equipment, interior decoration, building height, etc.

(3) Risk factors of factory buildings. Namely, it can provide basic information of factory buildings and assessment basis of fire risk factors, including material risk coefficient, material quantity, electrical equipment, interior decoration, number of floors of the factory, etc.

(4) Risk factors of warehouse building. Namely, it can provide basic information of warehouse buildings and assessment basis of fire risk factors, including: material hazard coefficient, material quantity, electrical equipment, interior decoration, warehouse floors, etc.

4.2. Fire risk assessment module
This module is composed of four sub-modules, that is, the respective risk assessment module for residential buildings, public buildings, factory buildings and warehouse buildings. Options will be set in the assessment interface for the collected building risk factors, and the selection will be branched and judged to calculate the comprehensive risk level. The risk assessment flowchart and the risk assessment data flowchart are shown in Figure 3.

5. Function implementation of BIM-based fire risk assessment system
The system was designed to realize the following basic functions: first, users can conduct information collection and risk assessment of four types of buildings, determine the fire risk level of buildings, and achieve the corresponding assessment results; second, administrators can manage the system, manage users, set assessment parameters, maintain basic information etc.; third, the output and printing of assessment results can be realized.

The system implementation includes database design, interface design and module design.

(1) It is required in database design that the physical structure meeting the application requirements should be selected for the logical data model. At this stage, two tasks are required to be completed: one is to determine the physical structure of the database, that is, access method and storage structure; the other one is to assess it from the perspectives of time and space efficiency.

(2) In terms of interface design, the simplicity, appearance and user friendliness of the software should be taken into consideration so that the interface can be friendly to users and be in line with users’ using habit. The human-computer interaction interface shall keep consistent, provide meaningful feedback, and allow cancelling most operations. As shown in Figure 4, the interface displays the risk assessment, importing corresponding BIM model into the system, collection of the fire risk factors, selection of the data needed by the assessment index system, and achieving the corresponding total risk value and risk level through the set score and weight with the set algorithm.
6. Case analysis

Taking an administration building belonging to a public building as an example, whose model structure is shown in Figure 5, the fire risk assessment system was introduced to detect and extract relevant fire data of the building, including water supply system of indoor fire hydrant, fireproof door, firewall, fire resistance rating, fire compartment, fire separation, ventilation and smoke control and exhaust system, etc. After selecting the data needed by the index system according to specification standard, the background automatically assigned values to the data and obtained the corresponding assessment score and level through the set algorithm, thereby completing the fire risk assessment of the administration building. According to the result, the total score of the building was 4.86 and the fire risk level was V (low). In addition, it was also found through the report that the distance between the evacuation indicators on the top floor of the administration building was too big and the evacuation indicators were located too high, which was not in line with the specification standard and needed to be rectified.

Figure 4. Assessment interface

Figure 5. Architectural model of the administration building
7. Conclusion
In this thesis, the fire risk index method and the analytic hierarchy process were used to establish the building fire risk assessment index system. With Microsoft Visual Studio 2015 as the development platform and C# as the development language, a fire risk assessment system was designed and developed based on BIM technology, whose operability and application value have been verified through case analysis. With friendly interface and easy operation, the system can realize objective, systematic and scientific assessment results, thus effectively solving the problems of low efficiency, poor scientificity and high cost existing in the field investigation and assessment mechanism in the process of fire risk assessment. The risk assessment results can also enable users to find and solve the existing problems in fire protection in time, so as to greatly reduce the probability of fire, and promote the fire safety level of buildings. However, this study also has certain limitations, for example, what the assessment mainly consider is the building itself and the firefighting equipment, failing to comprehensively take the fire management and firefighting rescue forces etc. into consideration. With the BIM technology being further applied in the field of fire protection, intelligent buildings with Internet of things and cloud computing will further integrate all aspects of fire protection, accordingly, the BIM-based fire risk assessment system will be better developed and applied.

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