Research on the Fire Safety Early Warning Model and Simulation of High-rise Building Based on BIM

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Abstract. With the acceleration of urbanization in China, the rigid demand for urban land has promoted the rapid rise of high-rise buildings. While affirming the application advantages of high-rise buildings, it is also necessary to focus on the huge hidden dangers of fire accidents. Disaster prevention is greater than disaster relief, the cost of actual fire simulation and evacuation practice in high-rise buildings is huge, and accidents and unexpected factors can not be controlled, so that the results are minimal. Given this, based on the practical advantages of the building information model (BIM), this paper constructs a fire safety early warning model for high-rise buildings and completes fire simulation and evacuation simulation by combining Pyrosim and Pathfinder software, to put forward corresponding optimization and rectification measures for the hidden dangers of fire accidents currently faced by high-rise buildings and effectively prevent the occurrence of fire accidents. Practice has proved that the fire safety early warning model can integrate the fire protection design and fire equipment management of high-rise buildings, and demonstrate the feasibility with the feedback of fire simulation and evacuation simulation results. Furthermore, this paper puts forward some measures, such as optimizing fire protection design and fire protection facilities and increasing safe evacuation routes, to improve the emergency management ability of high-rise buildings.

Keywords: BIM; high-rise building; fire safety warning model; fire simulation; personnel evacuation simulation

1 Introduction

At present, the new urbanization process with people as the core is developing in-depth, and the number and scale of cities have maintained an obvious growth momentum. At the same time, the coordinated development of cities, architecture,and transportation

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gradually integrates urban design with architectural design, which promotes the rapid development and application of high-rise buildings [1]. With its outstanding advantages in land use, energy conservation and environmental protection, and application functions, high-rise buildings have become a symbol of urban civilization and urban development. Based on the 14th Five-Year Plan, the development trend of high-rise buildings in China should not only turn to digitalization and intelligence but also focus on improving the ability of disaster prevention.

Because of the complexity of their height, structure, and function, high-rise buildings have great risks in actual fire prevention design, evacuation, and rescue, which can easily lead to the "stack effect" and serious fire accidents [2]. Facing the actual demand for fire risk management ability of urban high-rise buildings, it can only be tested through actual fire simulation and evacuation drills. The cost of this method is huge, and accidents and unexpected factors can't be controlled, so that the error of the test results is too large, and it can't feedback on the defects and deficiencies in the fire protection design of high-rise buildings [3]. Given this, this paper holds that the research and application of BIM technology in high-rise building fire safety in China is still in the primary stage, lagging behind the advanced level abroad. We should widely learn from the complete fire discipline system and mature scientific research achievements abroad, and adopt various simulation software to achieve breakthroughs in key fields. The fire safety early warning model of a high-rise building based on BIM technology can combine Pyrosim and Pathfinder software to transform the basic BIM building model into a fire simulation model and a personnel evacuation simulation model and complete the simulation test. By comparing the simulation results of various tests, we can quickly determine the existing safety hazards of high-rise buildings and put forward corresponding optimization measures and suggestions to improve the fire emergency management ability of high-rise buildings.

2 Model building

The fire safety early warning model of high-rise buildings takes BIM technology as the core and is extended based on the conventional model application, forming a comprehensive functional system including five sub-models: fire prevention design, fire equipment management, fire simulation, personnel evacuation, and fire safety education [4].

First of all, as a virtual and visible three-dimensional model of building engineering, BIM needs the support of a large number of computer application technologies and software engineering to complete the high integration of various parameters and information and transmit and share them in all links or processes of building projects. The specific design and implementation environment involves two parts: hardware devices and software programs. The basic hardware configuration requirements are shown in Table 1. Compared with hardware equipment, software programs need to be selected according to different design majors. Among them, Revit Architecture is selected for building model construction, Revit Structure for structural model, and Revit MEP for electrical and pipeline models.

Table 1. Hardware configuration of BIM modeling

Hardware	Configuration information
CPU	Intel Core i7-12700F@ 2.10 GHz 4.90 GHz
RAM	DDR4 3600 16 G
SSD	Kingston KC3000 1TB PCI-E4.0
GPU	GeForce RTX 3080Ti 12 G
MOBO	ASUS PRIME Z690-P

Secondly, the sub-models of fire protection design and fire equipment management can be realized based on Revit software. The sub-model of fire simulation and evacuation needs to be developed and constructed with the help of Pyrosim, Pathfinder, and other software. Figure 1 shows the research technical route of fire simulation and evacuation. Among them, Pyrosim and Pathfinder are third-party software, which is different from Revit software in model information description and storage mode. It is necessary to convert IFC and DWG file formats to realize the combination of BIM, Pyrosim, and Pathfinder [5].

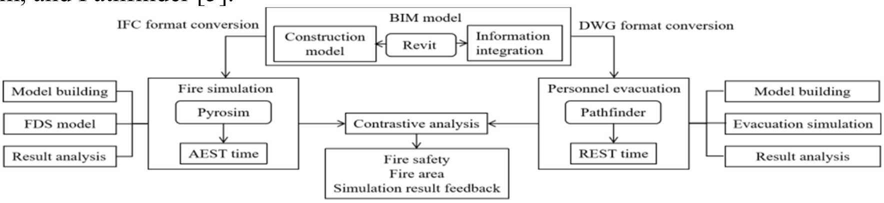

Fig. 1. Technical route of fire safety early warning model for high-rise buildings

3 Analog simulation

3.1 BIM model establishment

In the research process, this paper chooses a commercial office complex as the simulation object. This commercial office complex covers an overall area of about 7500.0 m^2, with a total construction area of about 65312.63 m^2, a building height of 95.5 m, and 27 floors (including 2 underground floors). The first to fifth floors are commercial floors, the sixth to twenty-fifth floors are office floors, and there are four evacuation stairs on the commercial floor, each with a width of 1.60 m. There are two evacuation stairs on the office floor, each with a width of 1.60 m. In addition, there are four entrances and exits on the first floor of the building, and there are two elevators for business and two elevators for office.

In the BIM model of a commercial office complex, there are many types, such as architectural model, structural model, MEP model, and so on. The fire-fighting tools and equipment, fire escape, smoke detection system, fire extinguishing system, fire power supply, and comprehensive fire management system included in the fire-fighting design of buildings will also be reflected in the BIM model [6]. Figure 2 shows the internal fire-fighting equipment and pipeline passage model of the overall structural model of the building.

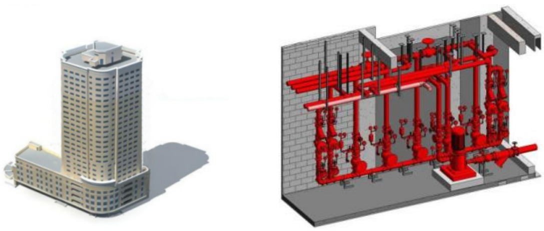

Fig. 2. BIM model renderings

3.2 Fire simulation

After the BIM model is established, the fire simulation will be carried out with Pyrosim software. The technical route of Pyrosim software is as shown above, and the specific implementation steps include definition setting, numerical simulation, and Smokeview analysis. First of all, the fire simulation in Pyrosim software will be based on the grid division and calculation of the model, that is, all components and objects in the model need to be divided into cells with standard sizes. Under the conventional division standard, the grid size near the fire source is 0.5 m, and the grid size far away from the fire source is 1.0 m [7]. After the grid division, users can create a fire-burning reaction according to the actual information of the commercial office complex. Table 2 shows the set values of various parameters in Pyrosim software, and the location of the fire is set on the west side of the second floor of the commercial building. The fire simulation results are analyzed from three aspects: temperature change, CO index concentration, and visibility distribution.

Table 2. Fire simulation parameters

No.	Heat release rate	Development rate	Temperature threshold	Visibility threshold	CO concentration threshold	Slice height
H001	10 MW	T^2	60℃	5.0 m	500 PPM	2.0 m

Temperature changes.

The high temperature generated in the fire has a great influence on the evacuation of people, and the temperature is directly related to the heat release rate of the fire. Figure 3 shows the simulated heat release rate (HRR) curve of the fire [8]. HRR reached its peak 500 s after the fire and then entered a state of fluctuation until the fire ended. According to the HRR curve, we slice the height of 2.0 m above the second floor of the commercial building to obtain the corresponding temperature change results, as shown in Figure 4. According to the temperature distribution changes of the fire floor, the temperature changes of the evacuation stairs on the second floor are shown in Table 3. The results show that the 4# staircase near the fire source reaches the temperature threshold in about 210 s, the 1# staircase farthest reaches the temperature threshold in 290 s, and the safe usable time (AEST) of the two staircases is 210 s and 290 s, respectively.

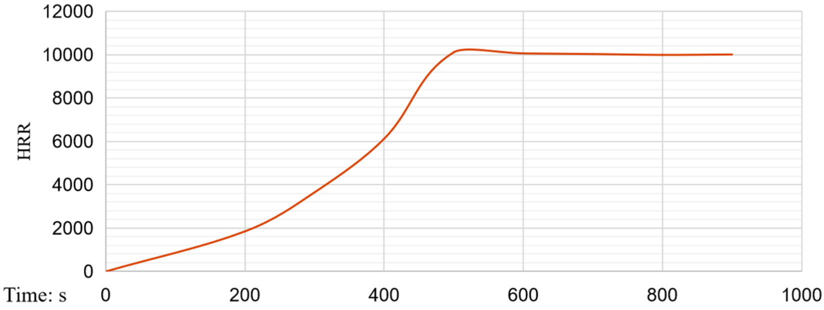

Fig. 3. Simulated fire heat release rate

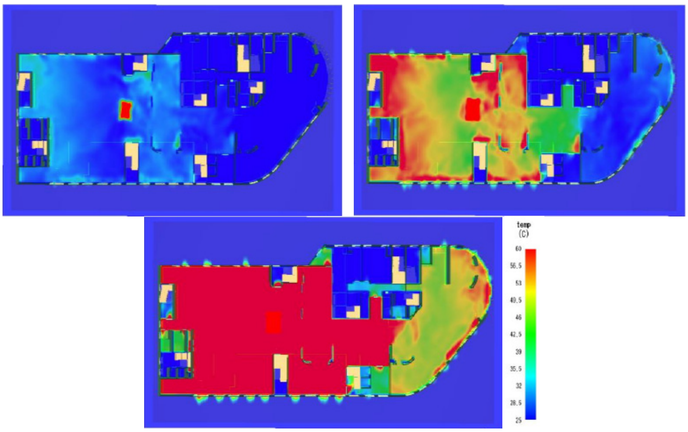

Fig. 4. Temperature change process of the second floor of a commercial building at 180 s, 300s, and 600 s after the fire

Table 3. Temperature changes of two evacuation stairs on the fire floor

Evacuation stairs	T=60 s	T=100 s	T=180 s	T=300 s	T=600 s
1#stairs	25°C	28.5°C	34.5°C	65°C	110°C
4#stairs	25°C	30.5°C	44°C	110°C	195°C

CO index concentration.

CO produced in fire is the main component that causes dizziness, coma, and dyspnea. When the concentration of CO in an indoor environment exceeds 500 PPM, it will pose a threat to human health. The simulation test results of the CO index of the fire layer in Pyrosim software are shown in Figure 5 [9]. The results show that the indoor CO concentration on the second floor exceeds the threshold of CO concentration by 500 PPM at 490 s after the fire. Relative to the indoor space of the fire floor, the CO concentration of other stairwells reached the predetermined threshold after 800 s, and the safe available time (AEST) of the two stairwells was 800 s.

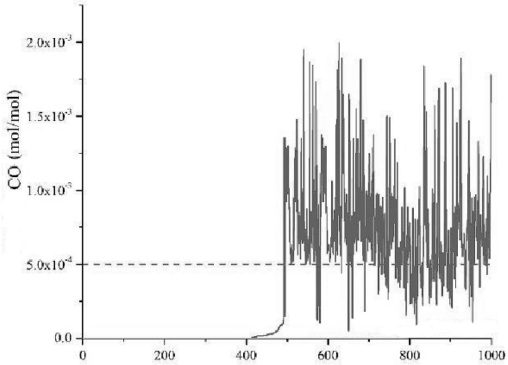

Fig. 5. Variation curve of CO concentration in fire floor

Visibility distribution.

In this paper, the indoor space of the second floor of the commercial building on the fire floor is relatively open, and the visibility threshold is set at 5 m. Figure 6 shows the visibility slice results of the fire layer visibility simulation test. The results show that the influence of smoke on visibility is mostly concentrated on the fire floor, and only some areas on the third and fourth floors have influence, but the influence on the office floor is very small. At 150 s, the visibility of some parts of the wall on the second floor began to decrease, and after 300 s, the visibility of most areas of the fire floor was less than 5.0 m, so the safe usable time (AEST) of the fire floor was 300 s.

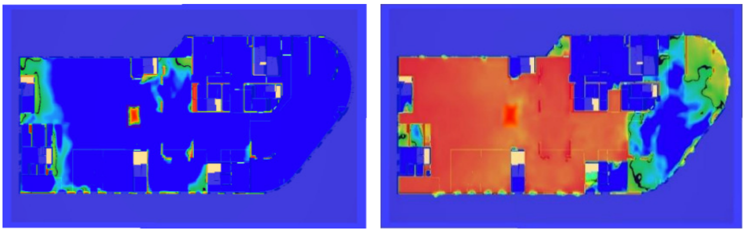

Fig. 6. Visibility distribution results of fire layer at 150 s and 300 s

Based on the results of temperature change, CO concentration index, and visibility distribution, it is finally determined that the available time for safe evacuation when the second floor of the commercial office building is on fire is 210 s.

3.3 Personnel evacuation simulation

According to the technical process of Pathfinder software in the previous article, after the BIM model is imported, we can set the behavior pattern of people, that is, set the threshold of the crowding degree during evacuation, to obtain the simulation model of evacuation. In addition, the number of people and basic characteristics need to be preset. Table 4 shows the characteristics and distribution of personnel [10].

Table 4. Characteristics and distribution of personnel

Floor	Male	Female	Subtotal	Total
First floor	211	503	714	5207
second floor	231	669	900	
Third floor	135	440	575	
Fourth floor	195	270	465	
Fifth floor	75	91	166	
The sixth to twenty-fifth floors	1130	1257	2387	
*Male height: 1.54-1.85 m, shoulder breadth: 415 mm, translational speed: 1.02-1.80 m/s *Female height: 1.44-1.70 m, shoulder breadth: 386mm, translational speed: 0.96-1.71 m/s				

The final evacuation simulation result is shown in Figure 7. At 200 s after the fire, all the people in the four staircases near the fire source area basically entered the stairwell, and there were no people in the third and fourth staircases. Therefore, it can be judged that people can complete the evacuation within 210 s and 290 s of the safe available time of the stairs. At the same time, at 240 s, due to the influence of the fire floor temperature, the number of evacuation stairs decreased, and people began to queue up, especially those on the 6th and above office floors. At 880 s, the personnel on floors 1-5 were evacuated, and at 1760 s, all personnel were evacuated. The results show that the fire protection design of the current building can meet the evacuation requirements under this fire simulation.

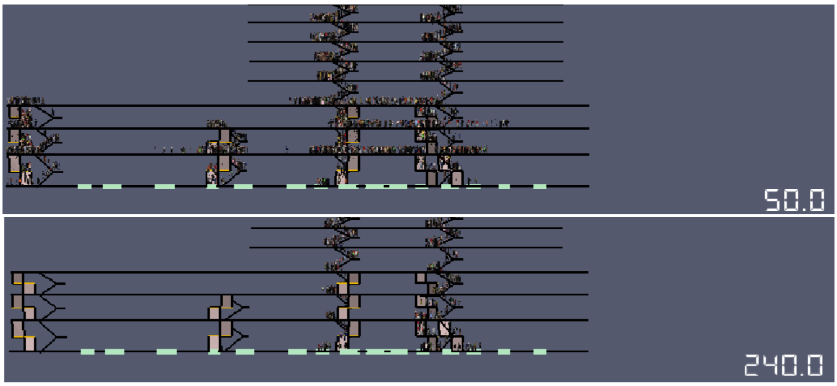

Fig. 7. Distribution of people evacuation on each floor

3.4 Optimization measures

According to the overall simulation results, it is necessary to install smoke exhaust devices and fire doors on the commercial floors of buildings to reduce the influence of temperature and smoke on stairwells. Secondly, it is necessary to increase auxiliary evacuation routes, speed up the evacuation of people on office floors, and avoid the problem of congestion.

4 Conclusions

Based on improving the emergency management ability of high-rise buildings, this paper puts forward the construction scheme of fire safety early warning model of high-rise buildings based on the current practical application requirements. The whole safety early warning model takes BIM technology as the core and completes fire simulation and evacuation simulation by combining Pyrosim and Pathfinder software. To deal with all kinds of fire accidents, the author puts forward corresponding optimization and rectification measures, which effectively avoid the occurrence of fire accidents. In the follow-up research, the overall accuracy of the BIM model will be further improved, and more fire model cases will be added to contribute to the intelligent fire protection construction of high-rise buildings.

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