Fire evacuation in complex underground space of personnel

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Abstract. As the consequences of building fire evacuation continue to be severe, some experts and scholars have proposed to combine building information modeling (BIM) technology with geographic information system (GIS) technology to construct a three-dimensional space scene of building fire evacuation. BIM has the advantages of refined three-dimensional modeling, and with the help of evacuation software, people evacuation and its characteristics are simulated, GIS has powerful spatial analysis functions to analyze the path. In this kind of evacuation simulation method, the two technologies complement each other to achieve quantitative analysis of qualitative indicators and efficient visualization of evacuation emergency management. This paper summarizes and analyzes the research on personnel evacuation in recent years by summarizing the current research situation in China, and puts forward the existing problems, hoping to provide ideas for the further research.

1. Introduction

With the continuous improvement of China's economic level, the development of urbanization continues to evolve. Since the beginning of the 21st century, the underground space of the complex has begun to be constructed and developed rapidly on a large scale, from a small-scale single-function underground project to an urban underground complex integrating commerce, entertainment, leisure, transportation, parking and other functions [1]. Effectively alleviate the contradiction between the development of urbanization and the maximization of land resources, but what follows is the evacuation of underground space in the complex.

According to statistics, the number of fires in underground space is 3-4 times that of high-rise buildings on the ground, the death toll is 5-6 times, and the direct economic loss is 1-3 times [2]. Because the underground space structure is mostly single-story, the large layout area, the gathering of people, the closed and complex space environment, the poor natural ventilation conditions and the limited evacuation exits are characteristics that cause great harm in the event of a fire. Therefore, experts and scholars use computer evacuation simulation to simulate the crowd evacuation process, which can not only reduce costs and risks, but also effectively propose emergency evacuation plans, which has great reference value and social significance. At present, simulation research on fire evacuation of people in underground space of complex is also an issue that many countries attach importance to.

2. Fire evacuation characteristics of underground space of complex

The fire hazard of the underground space of the complex is very serious. Table 1 lists the chronological underground space fires in the past 20 years. Through the analysis of the real situation of the fire accident and the characteristics of the underground space of the complex, the evacuation
characteristics of the underground space of the complex are analyzed.

Table 1 list of underground space fires in recent 20 years

| time          | place                                      | Cause of the accident | Cause of the accident | Cause of the accident |
|---------------|--------------------------------------------|-----------------------|-----------------------|-----------------------|
| 2000.10.26    | Underground parking of Peking Union Medical College Hospital | Electrical fire       | 20 people trapped, 3 people died; | 5000 yuan+ |
|               | Ball of Dongdu commercial, Luoyang         | fire                  | 309 people died, 7 people injured; | 275 million yuan+ |
| 2000.12.25    | Underground shopping mall of Zhuzhou railway station, Hunan Province | fire                  | nothing               | unknown |
| 2002.9.25     | Zhuzhou railway station, Hunan Province    | fire                  | nothing               | unknown |
| 2003.2.18     | Central Road Station of Taegu City, South Korea | fire                  | 198 people died, 146 people injured; | Two subways damaged |
| 2004.2.5      | Zhongbai commercial building, Jilin City   | fire                  | 53 people died, 71 people injured; | unknown |
| 2007.7        | People’s Square underground shopping mall, Shanghai | Electrical fire       | nothing               | Nearly 200 stores closed |
| 2013.11       | Hongqi Street underground shopping mall, Changchun | fire                  | nothing               | Stores closed |
| 2016.3.3      | Jinzhuuyuan underground shopping mall, Sichuan Province | fire                  | nothing               | unknown |
| 2017.10.8     | B1, cinding mall, Moscow                   | fire                  | nothing               | 600 million yuan+ |
| 2018.6.1      | B1, Tatuo market, Sichuan                  | fire                  | 1 people died, 1 people injured; | unknown |
| 2019.11.11    | Underground shopping mall, Hangzhou        | fire                  | 2 people injured      | unknown |
| 2020.9.12     | B1, grain and oil building, Hangzhou        | fire                  | nothing               | unknown |

Through a large number of investigations and analyses, the characteristics of fire evacuation in the underground space of the complex can be analyzed, as follows:

1. The underground space of the complex is different from the traditional high-rise buildings on the ground. It is mostly single-storey layout, and the single-storey layout area is large, so the crowd is relatively dense. When a fire accident occurs, it is more difficult for people to evacuate and escape. It caused tragic consequences such as casualties.

2. Due to the strong closedness of the underground space and insufficient natural lighting, in the event of a fire, it is easy to cause the trapped people to panic and impulse. Moreover, its natural ventilation conditions are poor. When the smoke concentration is large, it cannot be quickly removed, which hinders rescue work.

3. The internal structure and environment of the underground space of the complex are very complex, which makes it difficult for people to choose the route when they escape, and causes confusion in evacuation.

4. The evacuation exits are limited and the horizontal distance is long. Unlike buildings on the ground, which can use fire-fighting ladders or windows to escape[^3], and the escape route is not as clear as that of high-rise buildings, it will increase evacuation time and difficulty, and reduce evacuation efficiency.

Based on the analysis of the fire evacuation characteristics of the underground space of the complex, the necessity and importance of studying the fire evacuation of the underground space of the complex is more clear.
3. Study on crowd evacuation model

According to different research conditions and objectives, the evacuation models are classified as follows:

3.1. Macro model and micro model

Starting from the research objectives, the crowd evacuation model in emergency situations can be divided into a macro model and a micro model. The macro model considers the crowd as a whole and studies the visible clustering behavior in the crowd. The macro model mainly includes fluid model and potential energy field model. The micro model mainly focuses on the individual level, considering the behaviors, actions and decisions of individuals in the crowd, as well as the interaction between individuals. Micro models mainly include: social force models, agent-based models, cellular automata models, etc.

Because the modeling of the macroscopic model is simple and the computer capability is low, the early simulation models mostly belong to this category. With the continuous development of computer technology, researchers build better microscopic models based on computers.

3.2. Mathematical model and computer model

According to different research simulation methods, it can be divided into digital model simulation and computer model simulation. Basic digital model, by observing the flow of personnel, constructing mathematical model simulation, and then obtaining data for analysis. Such methods are widely used in the formulation of building fire protection design codes. Computer simulation, by constructing an evacuation simulation model, analyzes the existing problems, and proposes an optimized design plan. At present, the more widely used models by domestic and foreign scholars are: Building EXODUS, Pathfinder, Unity3D, Simulex, Steps, Evacnet, etc. Traditional real evacuation simulation exercises are costly, destructive, and have many hidden dangers and are difficult to implement. Computer evacuation simulation can not only reduce costs and risks, but also effectively propose a safe evacuation plan for personnel.

With the continuous development of performance-based design, the accuracy requirements of related calculations and numerical values in evacuation design have also been continuously improved. The error conditions of the previous design and calculation methods can no longer meet the relevant requirements. Therefore, the crowd evacuation simulation model that relies on computer technology has become the best choice to solve this problem.

3.3. Continuous model and discrete model

Due to the different representation methods of the three basic elements of time, space, and people, models can be divided into continuous models and discrete models.

The continuous model regards the crowd evacuation behavior as the flow of liquid or gas for research, and its calculation has the advantage that it has nothing to do with the scale of pedestrians. It mainly includes fluid dynamics and social force models. Discrete models include cellular automata model, lattice gas model, and queuing network model.

4. Simulation of underground space evacuation of complex

Due to the particularity of the underground space of the complex, construction of domestic and foreign started relatively late, so the research results on the evacuation of the underground space of the complex are less than that of the traditional ground construction. The research contents of domestic and foreign experts and scholars are as follows:

Helbing [5](2002) and others used the social force model to simulate the evacuation behavior of people, transform individual psychological responses into quantifiable forces, and study the rules of crowd evacuation movements.

Hao Shuqing[6](2009) applied risk theory to the research of fire safety evacuation technology in urban underground space, determined the influence factors of fire on the safety of personnel and the
appropriate evacuation plan, and finally verified it with engineering examples. Lawrence PJ[7](2012) and others statistically analyzed the use of escalators and stairs in the London Underground, and based on the Building EXODUS software, simulated and analyzed the use of escalators and stairs during the evacuation process. Their research strategies and results can improve the subway The efficiency of emergency evacuation on the platform.

Despina P[8](2016) et al. studied in detail the fire protection design standards and regulations of underground complexes, and proposed that the best way to reduce casualties is to strictly abide by the regulations. At the same time, they proposed the use of simulation software to improve the efficiency of emergency evacuation.

Zheng Xiafei[9](2019) established urban underground complex fire numerical model and personnel evacuation model based on FDS and Pathfinder software, and analyzed the fire evacuation safety of urban underground complex through simulation.

By analyzing the research of domestic and foreign experts and scholars, they mainly use models to simulate evacuation to study evacuation plans, safe evacuation time, evacuation influencing factors, evacuation behavior characteristics, etc. Moreover, Chinese researchers are mainly based on the results of foreign theories, and on the basis of them, they propose more intelligent models or software for the study of personnel evacuation models.

5. Comparative study of evacuation simulation software

After a lot of research and analysis, scholars at home and abroad have widely used Pathfinder software, Building EXODUS software, Unity3D software and other software in evacuation simulation. Now I will briefly describe the above three software and compare and analyze their functions.

5.1. Pathfinder software

Pathfinder software supports two motion simulation modes, SFPF mode and Steering mode. In the SFPF mode, pedestrians will not influence each other, that is, they will not avoid each other and can penetrate each other; the Steering mode uses a combination of path planning, guidance mechanism and collision handling to control the movement of pedestrians, and will automatically choose other routes when congestion occurs. Since the Steering mode is closer to reality, it is more suitable for the simulation of emergency induced evacuation in public gathering places.

Through a lot of research, it can be found that the evacuation applications of Pathfinder are mainly focused on applications in fire scenarios. At present, many experts and scholars combine the BIM building information model with the Pathfinder personnel evacuation simulation model to make the simulation scene more realistic and accurate.

5.2. Building EXODUS software

Building EXODUS is a fine-grid process simulation software. The model consists of 5 interactive sub-modules, namely personnel, movement, behavior, toxicity and danger. The biggest difference between this software and other software is that it considers the interaction between people, between people and fire, and between people and building structures[10]. Therefore, it can simulate evacuated persons and the details of the evacuation process more realistically. As a simulation software widely used in commercialization, it has certain advantages in simulation accuracy and operational convenience.

5.3. Unity3D software

Unity3D's embedded evacuation model is based on A*'s navigation grid pathfinding algorithm. Through reasonable values of character model parameters, embedded character movement, and other scripting languages, it can simulate the evacuation process well and obtain a similar commercial evacuation software. At present, it has gradually become the mainstream virtual reality technology implementation platform.

The three softwares are widely used in various evacuation simulation studies, each with different
characteristics, shortcomings and scope of application. Through this survey and summary, it is hoped that the efficiency of future evacuation research can be improved. The specific function comparison research results are shown in Table 2:

| project            | Pathfinder     | Building EXODUS | Unity 3D       |
|--------------------|----------------|-----------------|----------------|
| Evacuation model   | Agent based model | Agent based model | Agent based model |
| Model type         | motion model    | motion model    | Motion optimization model |
| Modeling method    | Internal modeling, CAD or FDS import | With the help of DXF format | With the help of FBX model file |
| Grid structure     | Continuous grid | Fine grid       | Continuous grid |
| visualization      | 2D/3D           | 2D              | 3D             |
| Scope of application | It is suitable for evacuation simulation of large buildings. | It is suitable for supermarkets, hospitals, theaters, railway stations, airports, high-rise buildings and schools. | It is suitable for buildings, natural artificial scenes, etc. |
| advantage           | (1)The 3D effect is real, flexible and accurate; (2)Multiple simulation mode; (3)The assessment results are strong, showing the escape routes and distribution of personnel in real time. | (1)It is suitable for all kinds of buildings; (2)Arguable building code; (3)Immersive experience of escape scene; | (1)High modeling requirements; (2)Increase the modeling workloa; (3)There is deviation in simulating the actual problems. |
| shortcoming         | 1. There are few studies on complex space; 2. The parameter setting is lack of practical basis and the research is relatively rough. | 1. There are differences in body shape and movement characteristics. |  |
(2) In the actual evacuation, due to individual differences and some unpredictable environmental factors, the difficulty of evacuation simulation is bound to increase, and the requirements for the model are more stringent.

(3) Due to the complex structure and diverse functions of the underground space of the complex, the evacuation plan is less targeted and the research strategy is not applicable.

(4) There must be a gap between foreign personnel parameters and habit parameters and other country's. When using foreign crowd evacuation simulation software, the accuracy of the evacuation results will be reduced to a certain extent.

The outlook for future evacuation simulation research is as follows:

1. The current evacuation simulation software is gradually accurate and beautiful, making the simulation process and results clearer and more intuitive, providing a lot of convenience for the evacuation simulation work, and continuous development and innovation should be carried out in the future.

2. Continuously improve relevant codes and standards to provide theoretical basis and technical support for guiding fire protection work.

3. In the research process, individual differences and the particularity of environmental factors should be considered to make the simulation effect closer to reality.

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