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ORIGINAL RESEARCH

A dynamic fire escape path planning method with BIM

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Abstract
Aiming at the current research on the escape path of complex building fires with the problem about lack of path prediction correction and multi-person escape, this paper proposes an analytical method of real-time dynamic escape path prediction based on Building Information Model (BIM). The method uses a Fire Dynamic Simulator (FDS) to simulate the spread of the fire and analyzes the simulated data of BIM model, and dynamically adjusts simulation of the spread of fire according to the real-time situation of fire. This method is designed for path planning for the single and multi-person escapes. The single-person escape path planning uses real-time dynamic methods to locate the evacuee and obtain the fire situation. The Dijkstra algorithm is used to derive the shortest escape route with BIM integration information, and the fire spread simulation data and escape speed are used to predict and correct the path to achieve the best escape path planning in real-time dynamic. The multi-person escape path planning predicts the congestion according to the single-person escape route. When the congestion is predicted, the corresponding evacuation process is carried out to avoid the hazard caused by the fire escape and crowding so as to realize rapid escape at the scene of fire. Through the BIM 3D model, the dynamic fire escape path can be visualized for the evacuees. The effectiveness of the proposed method is verified by constructing a prototype system for the analysis.

Keywords Dynamic fire escape · Multi-person escape · BIM · FDS · Fire spread · Dijkstra

1 Introduction

With the development of the economy, the progress of building technology and the trend of urbanization, the volume of use of urban land had risen sharply. Urban buildings are becoming increasingly high-rise and complex. Once a high-rise building or a large complex building are in fire, it is easy to decline in feeling and judgment of the personnel and cause panic. It is difficult for trapped people to escape safely by relying solely on the fixed escape plan inside the building (Ding et al. 2019). Therefore, it is of great significance for building disaster prevention and emergency management to study the fire escape of high-rise buildings.

In recent years, Building Information Models (BIM) have been widely used in building disaster prevention and relief management (Wang et al. 2013; Choi et al. 2014; Wang et al. 2015; Cheng et al. 2017; Zou et al. 2017). It not only provides three-dimensional space for visualizing fire conditions and displaying other emergencies (Ruppel et al. 2011; Wang et al. 2014), but also provides real-time information (Ding et al. 2016). In a building fire, the uncertainty of the fire makes every second of the fire scene crucial. With this information, users can quickly make a judgment of the escape route to deal with the fire (Zhou et al. 2019). Zou et al. introduced the application of BIM in risk management and took the BIM model as an integrated information platform to carry out risk management (Zou et al. 2017).

The current research on building fire escape usually focuses on path planning according to the current fire situation (Cheng et al. 2017; Chou et al. 2019). However, in the fire scenes of high-rise buildings and large complex buildings, due to the large number of floors and complex internal space (Ding et al. 2016; Li et al. 2014), it is difficult to get the overall optimal escape path that carries on path planning only through the current location data and situation of fire, lacking of fire spreading and using the fire spreading data to correct the path. Although there are some studies on escape paths in the case of fire spreading, they mainly focus on fire

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rendering (Chen et al. 2018a, b) and dynamic planning (Zhu et al. 2020), and lack of research on dynamically modification of escape paths based on fire spreading simulation. It will take longer time for evacuees to escape for it is easy to cause detouring in partial paths.

The fire is sprawling and uncertain, and the trapped people are in constant motion. If the escape route planning was performed only by real-time personnel location and fire information, it may cause the current route to be opposite to the previous route with the fire spread and the escape proceeded (Cheng et al. 2017; Wang et al. 2014; Chou et al. 2019; Chen et al. 2018a, b). As a result, it is hard to escape quickly from the fire scene for the problem of partial route detour. Although there have been researches on fire spread and path planning based on simulation data (Ding et al. 2016; Long et al. 2017), but there is a lack of processing to dynamically correct the escape path according to the fire spread data, so that it is impossible to ensure the real-time escape path is the optimal in the overall escape process (Wang et al. 2015; Zhu et al. 2020). Moreover, people often escape at the same time in a real fire. And it will be more difficult to escape if people are in panic. Congestion and stampede tend to occur on stairs, resulting in unnecessary casualties (Yuan et al. 2012; Ran et al. 2014).

In response to the above problems, this paper is going to make a further study on the quick and safe escape in building fire, and it will design and implement a real-time dynamic escape path planning method by taking advantage of the visualization and integration information of BIM model. With using BIM model integrating fire information to simulate fire spread, the data of fire spread can be obtained and adjusted dynamically according to the real-time situation. Through planning and using the fire spread integration data in BIM model to dynamically correct the escape path, it can predict the situation of congestion and evacuate correspondingly. In this way, real-time dynamic predictive analysis of the escape path for complex building fires can be realized and displayed in the BIM model, which helps trapped people to escape quickly.

2 Literature review

2.1 Applications of BIM in building fire evacuation management

As a structured and visual data, BIM model can not only convey two-dimensional plane and three-dimensional spatial information reflecting the general situation of fire scene to users, but also provide real-time and clear information and connect building elements. These information can be used to help users determine the relative locations of fires, people, infrastructure, and escape path, further users can make decisions quickly and correctly to deal with the fire even conduct real-time path planning predictive analysis through the information visualization and integration. For example, the evacuation personnel can judge the current situation of the fire by using the information of 2D plan and 3D space, so as to quickly find a safe path for escape, effectively reduce uncertainty and response time, and improve the probability of building fire escape (Ruppel et al. 2011). Zhou et al. integrated BIM technology and virtual reality technology to realize evacuation route guidance during building fire (Zhou et al. 2019). Wang et al. built up a virtual intelligent fire emergency evacuation system by using BIM technology and VR, and built up an adaptive immersive virtual game environment by using BIM technology in conjunction with virtual reality technology to realize real-time fire evacuation guidance (Wang et al. 2014). Wang et al. applied BIM to realize fire safety assessment and management using 3D geometric data of BIM (Wang et al. 2015). Zhang et al. proposed a fire evacuation management framework based on BIM, which can dynamically guide trapped people to escape according to the changing environment of fire (Zhang et al. 2019).

2.2 Research on escape path planning in building fire

In the study of building fire escape path, Cheng et al. used Bluetooth and smoke sensors to obtain information about fire scene (Cheng et al. 2017), and then used Dijkstra algorithm for dynamic evacuation/rescue path planning, which successfully realized real-time dynamic path planning and navigation of building fires. In the same way, Chou et al. made integrated fire protection system under multiple scenarios for evacuation and rescue was came true by using Dijkstra algorithm to carry out real-time dynamic path planning and constantly update the location nodes of trapped and rescuers (Chou et al. 2019).

In the research of fire escape route, Long et al. analyzed the effect of fire data on evacuation path with Pyrosim and Pathfinder (Long et al. 2017). Ding et al. proposed a dynamic planning method of indoor evacuation route based on real-time situational awareness with multi-source sensors (Ding et al. 2016). Zhu et al. solved the problem of static escape path and lack of fire spread by using simulation data to simulate dynamic fire spread, and realized the indoor escape path planning (Zhu et al. 2020). However, in the case of fire, it is impossible to ensure that the overall path can be optimal during escape under the condition that path planning based only on the fire simulation at the current moment, that lacking of the processing of using the fire spread simulation data to correct the path.

3 Dynamic fire escape path planning method

The overall research framework of dynamic fire escape path planning method is shown in Fig. 1. A BIM model is the main platform of information integration and visualization. In this method, the smoke sensors are firstly used to sense the fire, and integrate the fire data into the corresponding sensors in the BIM model according to the location of the sensors. Then the BIM model integrated with fire information is put into the Pyrosim software for the fire simulation. In the case of single-person escape, the method uses wireless sensors to sense the position of the evacuee in real time and relates it to the BIM model. The optimal escape path can be obtained using the dynamic programming method with the BIM spatial information model. Through the BIM 3D model, the dynamic fire escape path can be visualized for the evacuee. For multi-person escape, the difference is that, according to the escape paths of all evacuee, predict whether congestion will occur, and deal with the congestion accordingly.

The process is shown in Fig. 2, which mainly includes three key parts: perceptual positioning, fire spread simulation and dynamic escape path planning. The perceptual positioning perceives the location information of evacuees and fires in real time and integrates the information into BIM model. The fire spread simulation imports the BIM model with fire information into Pyrosim, and conducts fire spread simulation with FDS. In dynamic escape path planning, Dijkstra algorithm is used to process BIM model, and the fire spread data in BIM model is used to dynamically correct the path to obtain the optimal escape path, and the optimal escape path is imported into BIM model for display. In terms of dynamic escape path planning, it is divided into two planning methods: single path planning and multi-person path planning.

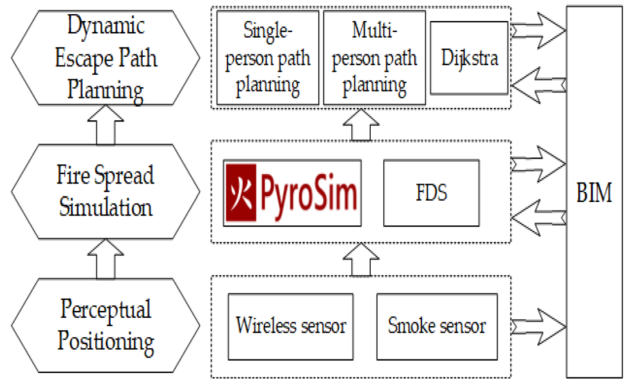


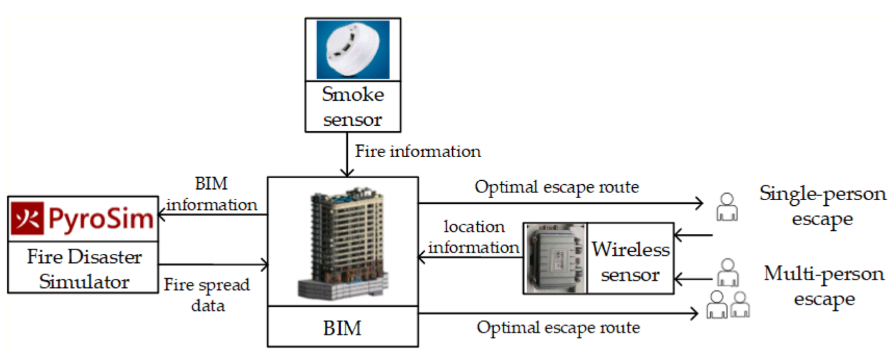
Fig. 2 Process of dynamic fire escape path planning method with BIM

3.1 Perceptual positioning

Perceptual positioning make use of wireless sensor positioning technology to form a wireless sensor network covering the whole building by properly setting up wireless sensors and smoke sensors inside the building (Li et al. 2014; Yao et al. 2018; Zhai et al. 2017). Wireless sensors could locate users in real time to determine the user position. The smoke sensors provide early warning and real-time positioning of the fire. The user location and fire location are associated with the BIM model, so the data accuracy of fire simulation and the escape path plan can be guaranteed, and the escape path can be simulated.

Figure 3 is a sensor network deployment diagram of a building. First, BIM model is used for performing plane analysis on each floor of the building. Second, wireless sensors and smoke sensors are set up according to the information such as doors, junctions, corners and rooms. Finally, wireless sensors and smoke sensors are installed in the middle of stairs and stairway entrance to form an effective wireless sensor net.

Fig. 1 Overall research framework



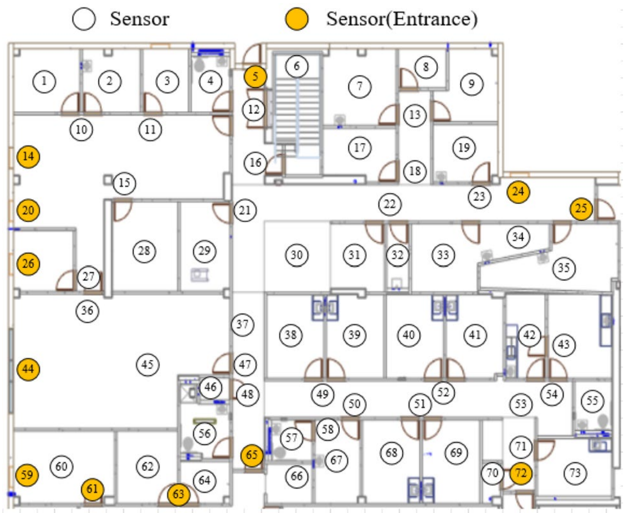


Fig. 3 Wireless sensor deployment diagram

3.2 Fire spread simulation

Fire dynamics simulator (FDS) is a computational fluid dynamics (CFD) model that describes the flow of smoke and hot gases from a fire (Shen et al. 2008; Ralph et al. 2019). FDS can facilitate the fire scene display, and it is able to compare simulation results with the actual investigation results of the fire scene. The similarity between actual data and simulation data on heat dissipation rate and smoke spread time is 80% (Xiao et al. 2018). BIM model contains building information such as the building materials and quantities, which are highly related to fire trends (Chen et al. 2018a, b). In this paper, fire spread simulation of BIM model is conducted through FDS. The simulated data is analyzed and processed to obtain the fire spread data

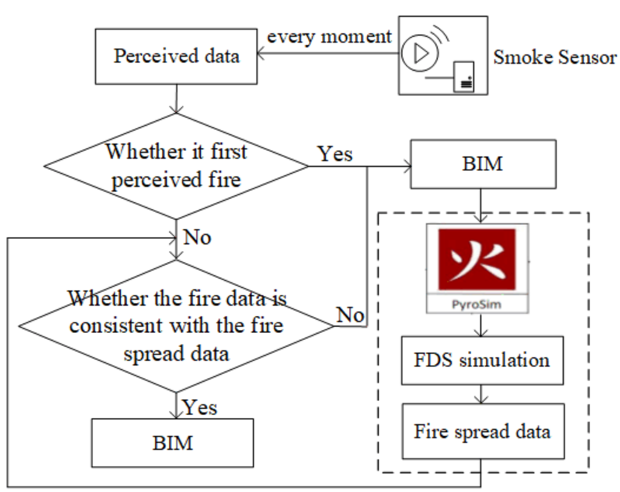


Fig. 4 Fire spread simulation

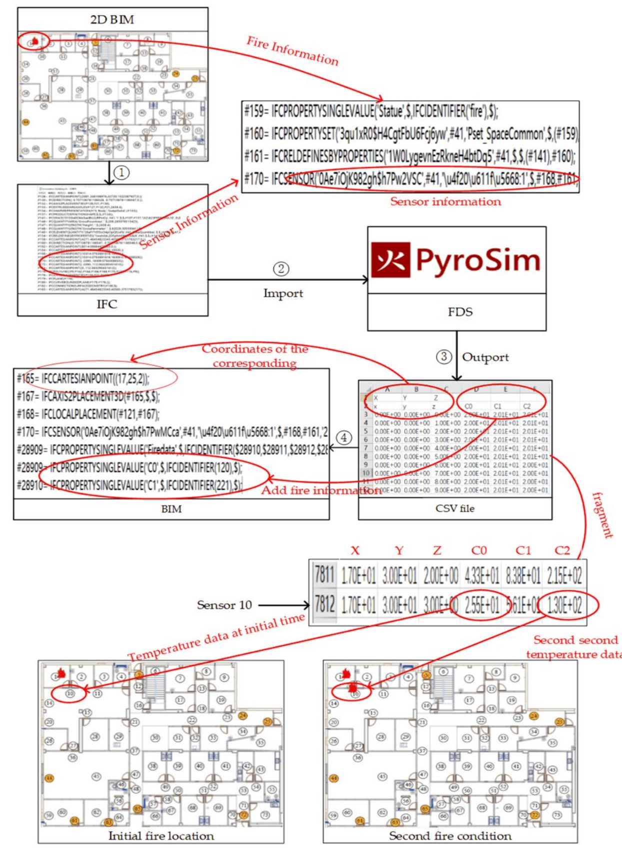


Fig. 5 Information conversion in fire spread simulation

which will be dynamically adjusted according to the real-time fire situation.

The specific process of fire spread simulation is shown in Fig. 4. The smoke sensor is used to get the perception data in each moment. If the fire is perceived, the sensing data at this moment will be used for locating the fire. Then the DXF file containing the BIM building information is imported into the Pyrosim software, and the fire is added to the Pyrosim software according to the real-time location of the fire; then, the fire simulation is carried out by FDS. Finally, the fire spread data are obtained.

The real fire is more complicated and will be inconsistent with the simulation. When a fire occurs, the sensors will continuously sense the fire state and compare the previous data of fire spread in BIM with the data at the current moment. If the data is inconsistent, it will indicate the difference between the real situation of the fire and the simulation. Then, the fire will be re-added to Pyrosim and simulated by FDS to obtain new fire spread data, based on the current time sensing data to determine the location and number of fires. Real-time perception of fire and dynamic adjustment of fire spread data can provide process of fire spread fire spread data for path predictive planning accurately.

Figure 5 shows the detail processing of information conversion in fire spread simulation. The first step, add the fire information perceived by smoke sensors to the BIM model according to the name of sensor information. The second step, the BIM model file is imported into the Pyrosim software, and the fire is added to the Pyrosim software according to the information of ignition point in BIM model. The third step, the fire spread simulation is carried out by FDS. The command line calls fds2ascii to get the fire simulation data at each moment and collect the data for analysis and processing. The fourth step, the correspondence between the CSV file information and the BIM model coordinates is used to obtain the temperature of all the sensor nodes in the BIM model at each moment, which integrates fire simulation data into the BIM model, and set the temperature above 60℃ was fire (Zhu et al. 2020).

3.3 Dynamic escape path planning

Dijkstra algorithm, as the shortest path algorithm, is able to achieve the general optimal way as well as avoid the regional optimal way in the circumstances of location is unknown by searching uniformly in all directions. Due to the short computational time, this paper applies Dijkstra algorithm as the escape path planning algorithm. Escape path planning not only needs to determine the number and location of the escape personnel and the location of the fire, but also needs to consider the internal characteristics of the building, such as whether the corridor is unblocked and whether the stairs can be used. As a structured and visualized data model, BIM is used for escape path planning. The optimal escape path is the shortest route that keeps the safety state in the escape process.

Firstly, we split BIM model according to the floors. Multi-layer buildings make the stairs as intermediate nodes for path planning. According to the location, connectivity and distance information of sensors in BIM model of each floor, a directed graph is formed. A digraph consists of nodes and edges and is commonly represented as $G=(V, E)$, where V is the set of all nodes and E is the set of all edges. The sensor position is set to the node, two connected sensor paths serve as edges, evacuee's location serves as the starting point, the security exit or stair is the target node, according to the position of the two sensors and the floor coordinate system, determine the distance between the two sensors, and take the distance as the length of the edge of the digraph. Thereafter, by using of Dijkstra path algorithm, make the shortest path planning of the directed graph based on the real-time position information acquired via the wireless sensor, fire spread array integrated into BIM model is used for Dijkstra algorithm to plan and correct the shortest path. In the escape path planning, smoke sensors sense fire information in real time. If the fire spread data in BIM model is not consistent with the smoke sensor perception data, re-simulate the fire spread and integrate the fire spread data into the BIM model. The optimal escape path is obtained by using the fire spread data to predict and correct the path. With regard to the escape of multiple people, there are more factors needed to be considered, such as whether the escape paths for all people in the building overlap, stairs with many people flow in a short time. This algorithm has considered these questions based on many people escape at the same time. Congestion can be predicted according to the escape path of each person, and corresponding evacuation can be carried out in case of congestion, and ultimately achieve rapid escape from the fire scene. The detailed process is shown in Fig. 6.

3.3.1 Single-person escape path planning

The single-person escape path planning method applies the Dijkstra shortest path algorithm to determine the shortest path according to the user position information and fire information in the real time. Dynamic adjustment and the fire spread data of the FDS simulation are obtained from the fire situation during the escape process, therefore forming the optimal escape path with the help of the individual escape speed information and fire spread information.

The objective function of dynamic escape path planning method is as follows:

$$\min S = \sum_{i=1}^{n} \sum_{j=1}^{n} \theta \cdot d_{ij} \tag{1}$$

Decision variable:

$$\theta = \begin{cases} 1 & 0 \leq t_j^p < t_j^f \\ \infty & t_j^p \geq t_j^f \end{cases} \tag{2}$$

n is the total number of nodes, d_{ij} is the distance from node i to connected node j, t_j^f is the time the node j become the fire

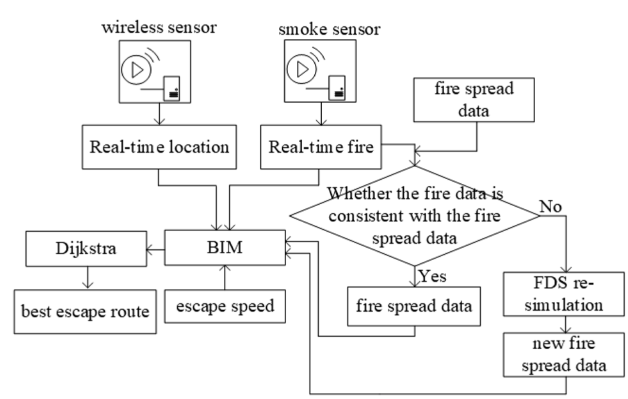


Fig. 6 Implementation diagram of escape path planning

node, t_j^p is the estimated time, which is obtained according to the shortest path from the starting node to node j and the average escape speed and fire spread information.

In the above equations, there are both optimal escape path objective function (1) and safe path constraint (2), where, formula (2) indicates whether node j is safe when evacuee reaches node j from the starting node. According to these equations, the shortest path in the case of relative safety can be well calculated and the optimal escape path can be obtained.

The single-person escape path planning method is shown in Fig. 7. The process is as follows:

(1) Acquisition of real-time data BIM integrated information into the program, including fire node, the location of the evacuee, total number of nodes, total number of edges, distance between connected nodes, escape speed and fire spread data.

(2) Information initialization: The location of the evacuee is the starting node, and the exit nodes or stair nodes are the target node.

(3) Dynamic correction of nodes: All the nodes are traversed and the estimated time t_j^p of each node is calculated. According to the fire spread data, the time t_j^f when each node becomes a fire node is obtained, the time t_j^f is compared with time t_j^p. If $t_j^p < t_j^f$, the node is safe, said the fire does not spread to the node when the evacuee reaches the node. Else the node is dangerous and the length of the edge becomes infinite.

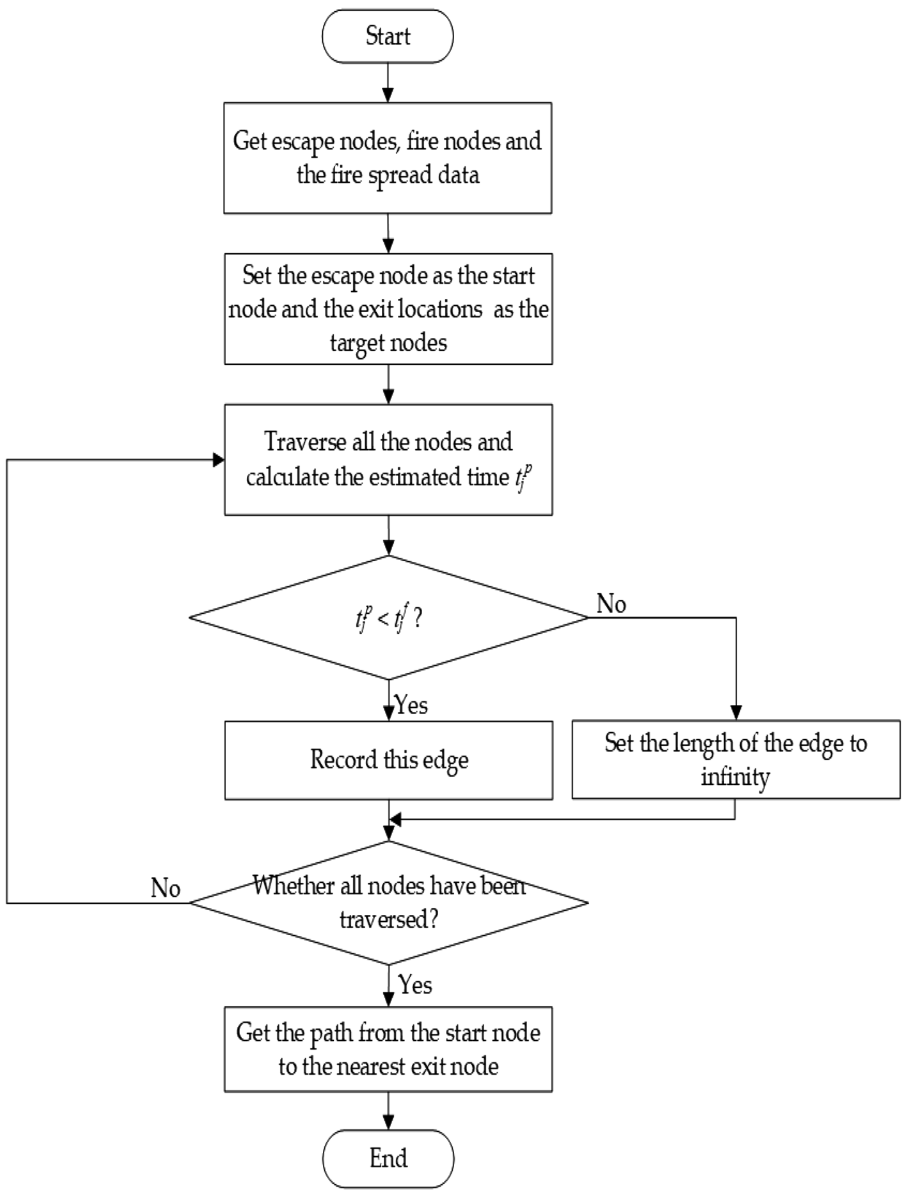


Fig. 7 Single-person escape path planning flow chart

(4) Iteration processing: If all nodes have been visited, the calculation is complete. Otherwise, repeat step 3.

(5) Get the optimal escape path. Among all the safe paths, find a path from the starting node to the nearest exit node, which is the optimal escape path. Then, according to the real-time information of the evacuee and fire, continue to calculate the new optimal escape path and realize the real-time dynamic optimal escape path planning.

For example, as shown in Fig. 8a, the fire is located at node 34 while the evacuee is located at node 17. According to the current escape location and fire location, the shortest path planned by Dijkstra algorithm is 17–18-22–23-24. However, according to the calculation of the fire spread speed and escape speed, $t_{23}^{p} > t_{23}^{f}$, when the evacuee reach node 23, the fire has already spread into node 23. Hence, this route is not safe. After the node safety prediction, the optimal escape path is 17–18-22–21-16–12-5. As shown in Fig. 8b.

After 3 s of escape, the second fire occurs. As shown in Fig. 9a, the fire spread simulation is repeated according to the fire location, and then all the nodes on the shortest path are predicted and processed. After calculation, it is found

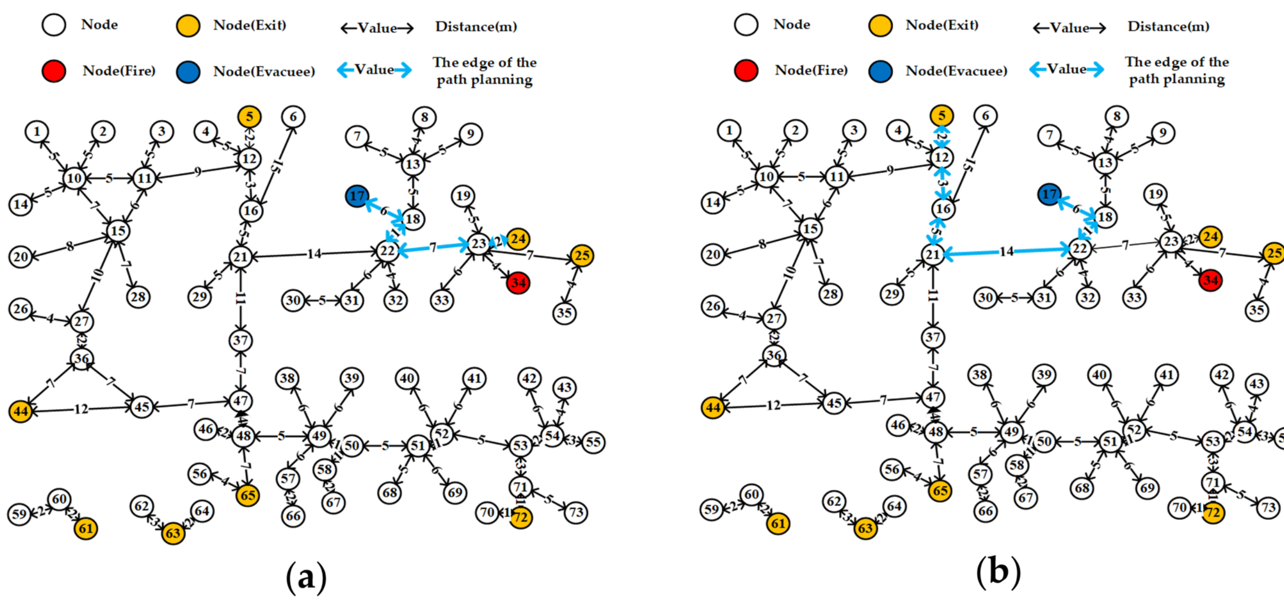


Fig. 8 Single-fire path planning: (**a**) Dijkstra shortest path; (**b**) The optimal escape path

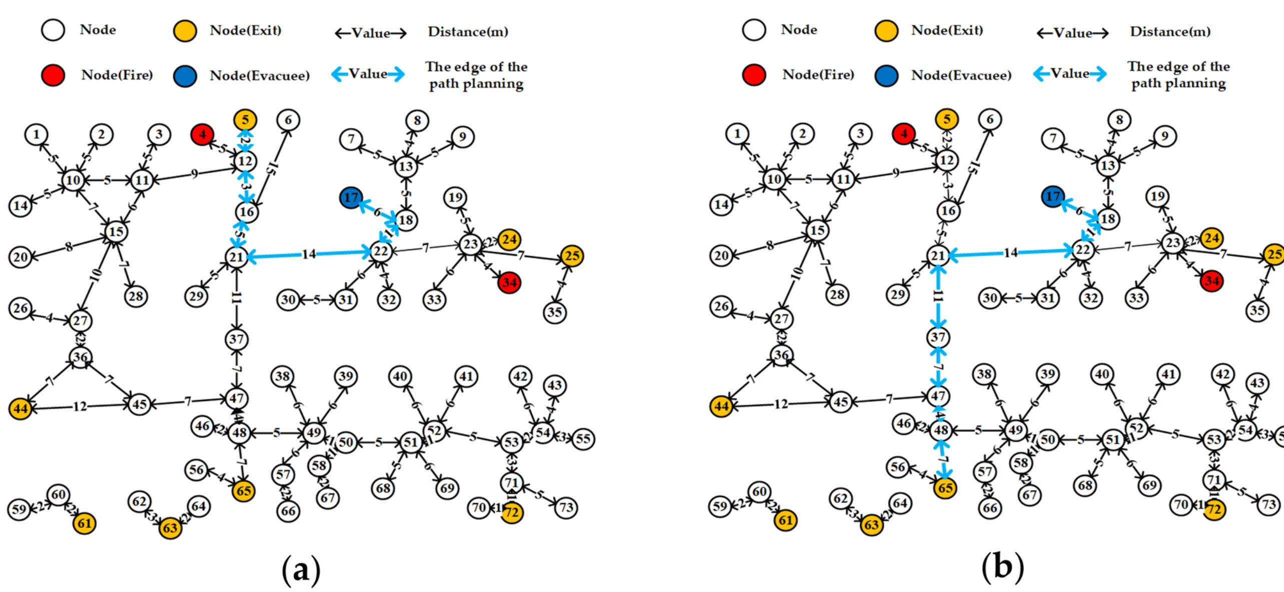


Fig. 9 Multi-fire path planning: (**a**) Initial paths of two-fire; (**b**) The optimal escape path

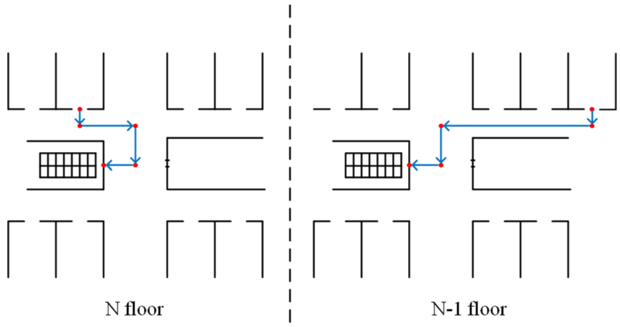


Fig. 10 Cross-floor stair congestion

that when the evacuee reaches node 12, the fire in node 4 has spread into node 12, so the edge becomes infinite, keep looking for a path. As shown in Fig. 9b, the optimal escape path is 17–18-22–21-37–47-48–65. The single-person escape path planning method dynamically plans the optimal escape path by taking advantage of the fire spread data and the escape speed to achieve rapid escape from the fire scene.

3.3.2 Multi-person escape path planning

When a fire occurs in a high-rise building or a large complex building, it is difficult to judge the safe path during the escape on account of the complicated path, the large number of floors, and the spread of the fire. Moreover, the evacuees are prone to be panic, which may lead to congestion and stampede at the stairs or doorways. Ultimately it is resulting in a failure to escape safely. Because of the complexity of the fire scene, every moment is critical. Therefore, the method of single-person escape path planning is used to predict the optimal escape path for each evacuee. Then it is to be predicted that whether congestion will occur. If congestion occurs, evacuation should be carried out according to congestion, otherwise navigation should be carried out according to the original path. By predicting the congestion situation in the process of multi-person escape to solve the problem of unable to escape safely and quickly due to congestion and stampede during a fire, it is possible to achieve safe and rapid escape for multi-person in building fires.

1) Judgement of congestion

Firstly, the method of single-person escape path planning is used to obtain the single escape path for each evacuee. Then, according to the location and speed of the evacuees at each moment, it can be calculated that when they reach the node of staircase or floor. If more than three people arrive at the node within one second, there will be congestion. Congestion includes two kinds of situations: cross-floor stair congestion and same-floor distance congestion.

(1) Cross-floor stair congestion: The main reason is the time difference of arriving at the node between the evacuees from upper floor and the evacuees from the same floor is within 1 s, which results in the overcrowding in the stairs at this moment. As shown in Fig. 10.

(2) Same-floor distance congestion: The main reason is that people on the same floor fled from multiple locations, and the time difference between them reaching the stair nodes is less than 1 s, that is to say, they arrive at the stair nodes almost simultaneously, which causes the staircase to be overcrowded instantly. As shown in Fig. 11.

2) The evacuation process

When congestion occurs, it is necessary to evacuate the evacuees. Due to the complexity of the fire scene, each kind of congestion should be evacuated accordingly. For the first kind of cross-floor congestion, as it is more difficult to escape at the upper floor. If the escape path navigation for low floor people takes much longer to escape from the floor through other path than the original one or there is no other path to avoid the staircase node, the lower-floor people still follow the previous path to escape. Otherwise, they will be navigated according to the new escape path. For the second kind of same-floor congestion, when the time difference between the people on the same floor arriving at the stair node is no more than 1 s, new path should be re-planned for people in congestion to avoid the congestion nod. If it takes much longer for people on the same floor to escape than original path or there is no other path to avoid the staircase node, people in congestion should be navigated as the previous path and messaged to watch out the congestion. Otherwise, it should be navigated according to the new path to evacuees. If congestion still occurs in the new path, the process is repeated to avoid congested nodes to escape quickly and safely, the process is shown in Fig. 12.

Step1: Provide single-person escape path planning for all survivors.

Step2: Calculate the time *t* of evacuees arriving at the stair nodes in their floor, in which starting from the top floor.

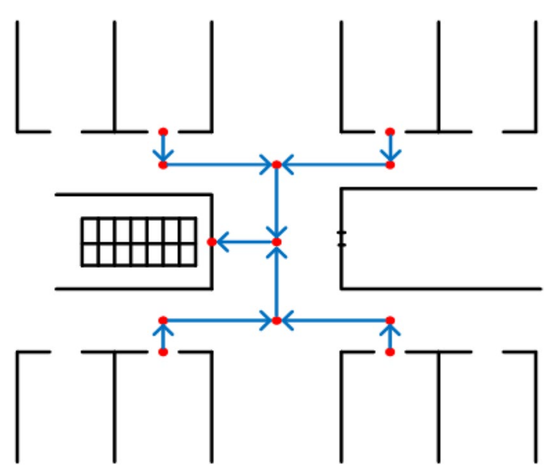


Fig. 11 Same-floor distance congestion

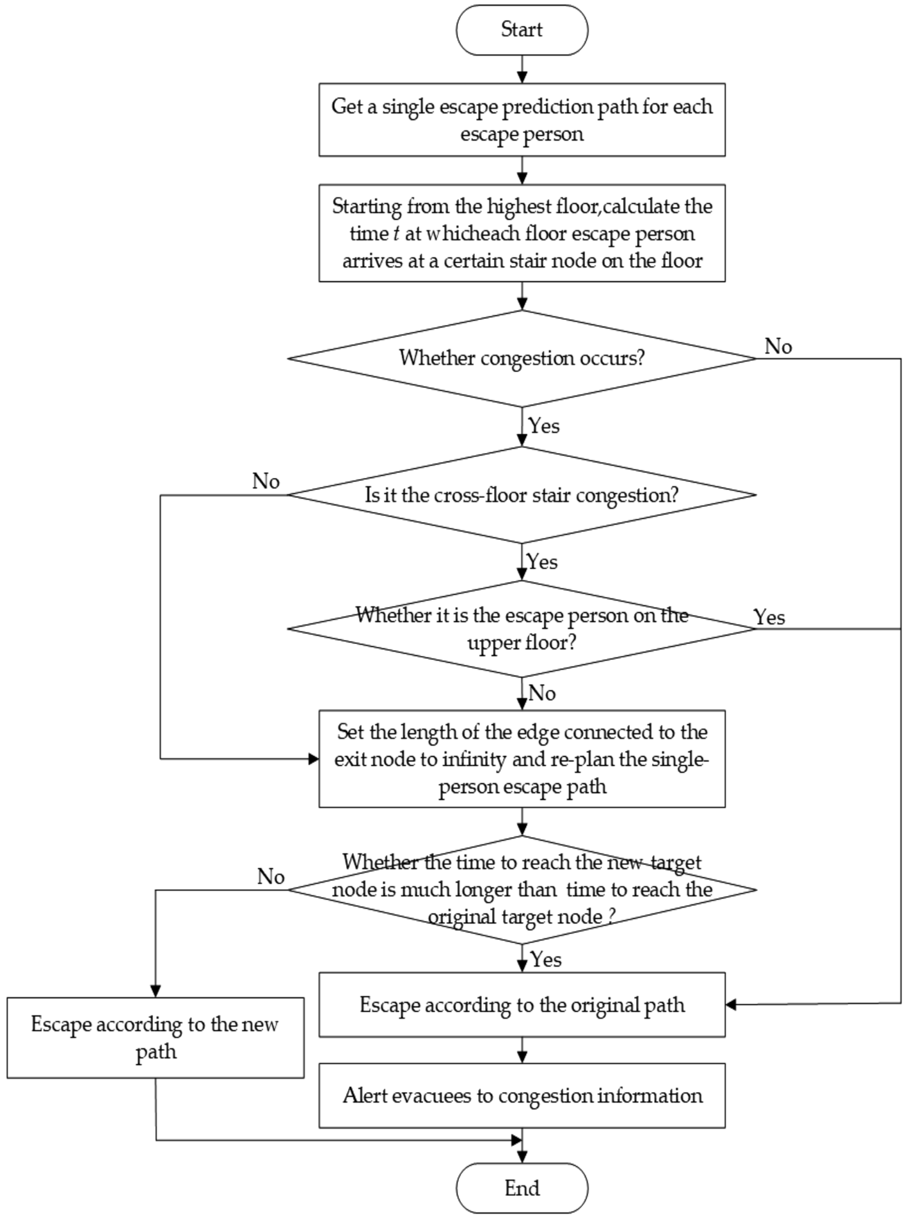


Fig. 12 Multi-person escape path planning flow chart

Step3: Determine whether the time difference of the evacuee reaching the stair node is within 1 s, that is, whether congestion occurs. If yes, jump to Step4; if not, jump to Step8.

Step4: Judge whether it is the cross-floor stair congestion. If so, skip to Step5; if not, then it is the same-floor distance congestion, skip to Step6.

Step5: Judge whether it is the evacuee of the upper floor. If yes, jump to Step8; if not, then it is the same-floor, jump to Step6.

Step6: Set the length of the edge connected to the exit node to infinity, and re-plan the single-person escape path for the evacuee.

Step7: Judge whether the time to reach the new stair node is much longer than time t according to the new path, that is, whether the time to leave the floor is much longer than time t. If so, skip to Step8; otherwise, skip to Step10.

Step8: Navigate according to the original path.

Step9: Send evacuees messages to watch out the congestion.

Step10: Navigate according to the new path.

Step11: The path predicts of multi-person escapes completed.

4 Experimental case analysis

This paper develops a prototype system using the above key technologies with PHP. The BIM model of the innovation building is created using Autodesk Revit Architecture 2015.

In the planning of the second floor and above, only the stair node is used as the exit of the floor for path planning. The path planning is relatively simple. The first floor has more safety exits and the path planning is relatively complicated. Therefore, the first floor of the innovative building is taken as experimental scene mode for an example to verification. Figure 13 shows the deployment location of the wireless sensors and smoke sensors. The entrance is marked with yellow, and the path node is created according to the wireless sensor network. Each wireless sensor is numbered for calculation and identification. In this case, a total of 73 nodes are deployed, among which nodes 5, 24, 25, 44, 61, 63, 65 and 72 represent 8 exits of the building. The escape speed is set to 2 m/s.

4.1 Scenario 1: one fire with one evacuee

In scenario 1, it is assumed that there is only one source of fire at the scene of the fire and the number of evacuee is 1, which tests the effectiveness of the single-person escape route planning method.

The problems are described as follows: suppose there is only one fire with one evacuee, smoke is released at node 19 to simulate the occurrence of a fire. The experimental results show that the optimal escape path at the initial moment is 29–21-16–12-5, as shown in Fig. 14.

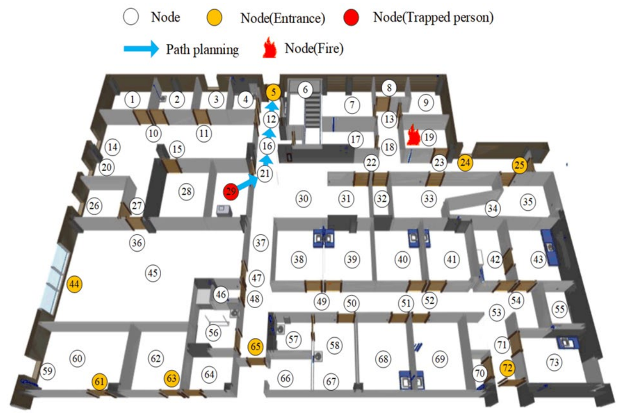


Fig. 14 3d visualization of single-person optimal escape path planning

4.2 Scenario 2: mutli- fire with one evacuee

In scenario 2, assume that there are multiple fire sources in the fire scene, and the time of fire sources is inconsistent, and the number of evacuee is 1. This scheme tests the effectiveness of the single escape path method in case of unexpected situation in the fire scene as the fire progresses.

The problems are described as follows: as scenario 1 progresses, at the third second, a second fire occurred at node 4. According to the estimated time and fire spread data, it can be known that: when the evacuee reach node 12, the flame at node 4 has spread to node 12, so the escape path is not safe. Now the optimal escape path is 29–21-37–47-48–65, as shown in Fig. 15.

4.3 Scenario 3: mutli-fire with mutli-evacuee

In scenario 3, when a fire breaks out, there are often a large number of people escaping from the building, It may lead to congestion in staircases, doorways and other places, which may easily lead to stampede accidents, which is not conducive to safe escape scenarios. 3.

The problems are described as follows: three fires occurred at nodes 51, 40 and 34. At this time, there were

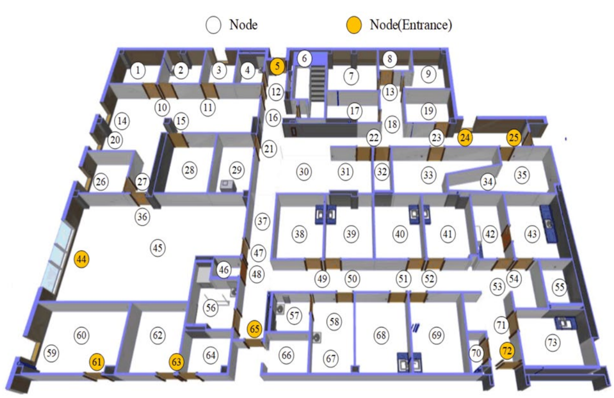


Fig. 13 Sensor floor layout on the first floor of the Innovation Building

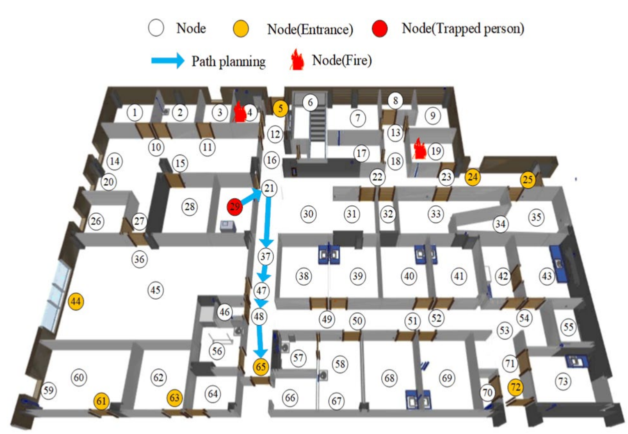


Fig. 15 3d visualization of multi-fire optimal escape path planning

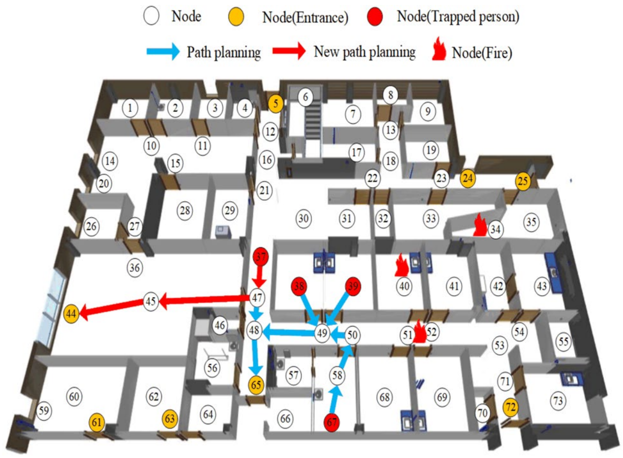


Fig. 16 3d visualization of multi-person optimal escape path planning

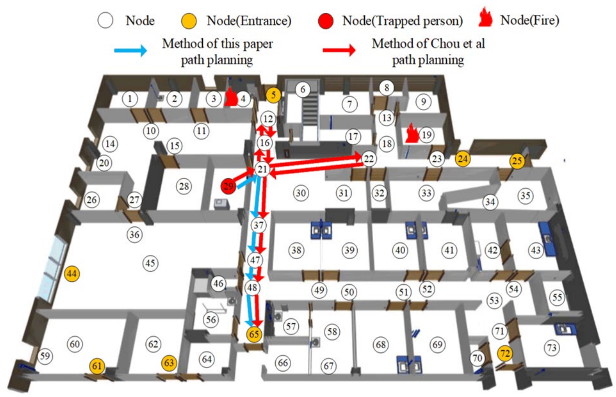


Fig. 17 Overall escape route

four evacuees at node 37, 38, 39 and 67 respectively. At this point, it is found by calculation that the time for the four evacuees to reach the exit node 65 is within one second. That is, congestion would occur at the exit. The new escape path of the evacuee at node 37 is 37–47-45–44, and the escape time of the new escape path is not much different from that of the original path, so the evacuee at node 37 of the escape route are 37–47-45–44. At this time, the new escape path of the evacuees at node 38, 39 and 67 the escape time of the new escape path is much longer than that of the original one, so display the original path, as shown in Fig. 16.

5 Discussion

Under the same condition, the method designed in this paper is compared with the evacuation method of Chou et al. using the innovation building model. In this paper, nodes 4 and 19 are set as fire source nodes, the evacuee is located at node

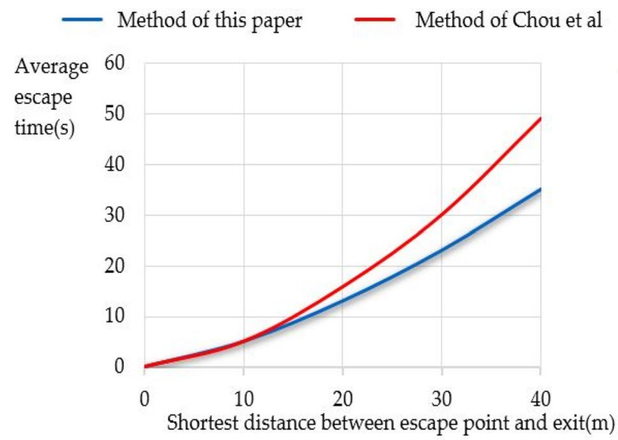


Fig. 18 Comparison of escape time

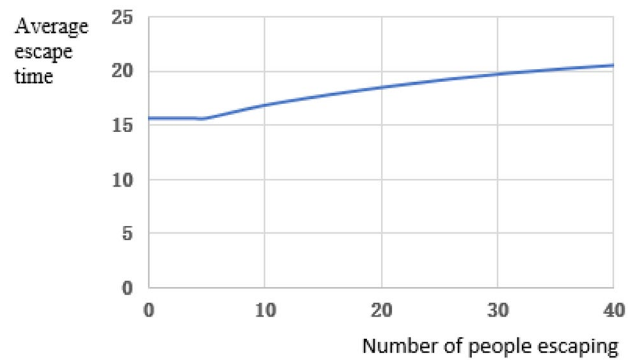


Fig. 19 Escape time and number of people

29, because the different age and escape speed of escaped people, the average escape speed is 2 m/s, and FDS is used to simulate the process of fire spreading over time, as shown in Figs. 17 and 18.

The general escape route is drawn according to the route that the evacuee uses the two methods to plan the escape route to the exit. The result shows that the current traditional method only focuses on the current situation, resulting in a roundabout escape route, and the total escape route is comparatively longer. The method of this paper achieves the optimal overall path in the escape process by predicting and correcting the shortest path. As the distance between escape node and exit gradually increases, the escape path increases. The average escape time of the escape path predicted and planned in this paper is relatively short, which is more conducive to the scene of fire safety and rapid escape.

In Fig. 18, the abscissa is the shortest distance from the escape to the exit, this distance does not consider the fire, according to the shortest path calculating distance between two points. The vertical coordinates is the average escape time, the blue dashed line is mentioned in this paper, the orange solid line is the research methods of Chou et al. (Chou et al. 2019), the experimental results show that as node distance increases gradually, and export to escape route to increase, the escape route forecast planning in this relatively short average survival time, more conducive to the scene of the fire escape safely and quickly.

When many people escape, the method proposed in this paper was analyzed in the aspects of number of escape people and escape time. The result is showed in Fig. 19, the abscissa is number of escaped people, the vertical coordinates is average escape time. When the number of escaped people less than 5, since the number of people is small and no conflict among them, the average escape time remains the same, with the increase of the number of escaped people, and constant number of exits, the average escaped time grows gradually smooth, thus the many path planning method mentioned in this article works effectively for situation of congestion for many people escape at the same time.

6 Conclusions

Aiming at the lack of predictability of fire escape routes in complex buildings, this paper proposes a real-time dynamic fire escape path prediction analysis method with BIM. First, wireless sensor network is deployed to obtain the information of evacuee location in real time. Then the smoke sensors are used to obtain real-time fire information, and then the information is integrated into BIM model. This article designed the single and multi-person escape route planning method according to different situations. FDS is used to conduct fire simulation on BIM model, and dynamic adjustment is made according to the real-time fire information obtained by smoke sensors to obtain the fire spread data and integrate it into BIM model. The shortest path is planned by Dijkstra algorithm, and the path is dynamically corrected by fire spread data to realize the optimal escape path at every moment. Multiple-person escape path planning by predicts whether there will be congestion according to the escape speed, if congestion occurs, the corresponding evacuation process will be carried out. In the end, the method of dynamic fire escape path planning is verified by a concrete example. The experimental results demonstrate the effectiveness of the method. This method can solve the need of high-rise building fire escape and will play a greater role in the trend of urbanization and high-rise building. This method only considers the spread and proliferation of fire, there will be a large amount of smoke during the fire, the smoke have a major impact on both escape and rescue, so next step we need to consider to add smoke analysis, optimize the escape path, which is more conducive to fire emergency escape and rescue operations, next study need to focus on the influence of smoke on fire escape path.

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