Simulation of Evacuation in Crowded Places Based on BIM and Pathfinder

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Abstract. Densely-populated public areas with high concentration of people have many potential hazards for its high difficulty in evacuation. Once an emergency occurs, it is easy to cause crowd panic and casualties. Therefore, research on the building characteristics and evacuation methods for densely-populated areas can provide reference and the emergency plan preparation for emergencies. Taking the central building of the Women and Children's Health Hospital in a certain city as the research object, the simulation and analysis of the evacuation process in the three-dimensional building scene are carried out based on BIM modeling and Pathfinder simulation software. The results show that due to the special proportion of people in the building, appropriately increasing the width of the evacuation doors near the evacuation stairs and fire elevators, clarifying the responsibilities of medical staff, and controlling the escape speed of people in different areas can significantly improve the evacuation efficiency.

1. Introduction

With the boosting economic development, the number of densely-populated areas in the cities has exploded. Once accidents or disasters occur in such places, it is easy to cause a large number of casualties and property losses[1]. Over the years, casualties around the world have often been caused by earthquakes, fires and other accidents in places where people are densely populated, such as hospitals, schools, gyms, or large commercial complexes. Large-scale public places with a high concentration of people have many potential dangers, which make it difficult to evacuate and would easily lead to panic and casualties. For instance, Harbin "8.25" hotel conflagration, Hong Kong "8.10" tall building conflagration and South Korea "1.26" hospital conflagration. Taking the Maternal and Child Health Care Center building of some city as the research object, this paper constructs a BIM-based three-dimensional model to provide basic data for the daily fire management of the building by using Pathfinder software to model the evacuation scene of this building, and analyzes the evacuation efficiency and the difficulties in the evacuation process.

2. Key Technology and Software

2.1. BIM technology

The full name of BIM is building information model. After more than two decades of research, development and promotion, BIM has been widely used in the life cycle in the construction field. As a digital technology, it has become a necessary ability for design and construction units when undertaking projects, and at the same time it has promoted great changes in the construction industry[2].
BIM not only records the geometric characteristics of the building, but also contains the entity information about the building components, such as walls, doors and windows, beams, columns, pipes, equipment, etc. Also by using digital technology, BIM provides a rich family library and self-built family files, which can load fire extinguishers, fire detectors, fire hydrants, fire indicator lights and other fire-fighting equipment, to provide a complete building information database consistent with the actual situation. It has brought significant influence for emergency evacuation plans in densely-populated high buildings[3].

2.2. Pathfinder software Introduction
Pathfinder is an agent-based evacuation simulation software. It is a personnel evacuation simulator based on computer graphics and triangle mesh, which can perform the visual motion simulation within multiple motion groups and inside-group independent individuals[4]. Pathfinder provides a quick modeling tool in the main interface, which is combined with the import modeling of graphic files in DWG, IFC and other formats to generate an evacuation model. In addition, Pathfinder can lay the floors horizontally on the XY plane, and view the personnel density, utilization rate and escape route parameters of multiple floors at the same time. Pathfinder has two personnel movement modes, including SFPE and steering, in which the steering mode can reflect the interaction relationship between personnel, which makes it closer to the real evacuation situation. The evacuation simulation of the central building will use the steering motion mode[5].

3. Model building of a city’s Maternal and Child Health Center based on BIM
The model example mainly reflects the fire protection design of the building of the Maternal and Child Health Center and simulation that supports the evacuation scene. Thus, the architectural model was selected to create the project[6]. Apart from the examples of structural components which are necessary for evacuation simulation, the model does not reflect too much about the building structure. Choosing a building model can avoid redundant collision checks to make the project conduct more smoothly. The central building is rendered into a ray-traced architectural appearance, as shown in Figure 1.

Figure 1. The ray tracing mode of the central building

4. Architectural Fire Protection Design and Safety Evacuation Analysis Method of Central Building

4.1. Basic construction background introduction
The central building of a city’s Maternal and Child Health Care Hospital belongs to first class of high-rise, civil public buildings, with a fire resistance rating of Class I, with a capacity area of 31363.82 square meters, a main body of 24 floors, and a building height of 99 meters. The central building is a comprehensive building containing multiple functions such as surgery, nursing, storage, and office.
Each floor of the central building is less than 1500 square meters, and each floor is a fire compartment with a fire compartment area of 1324.3 square meters. The pharmacy on the east side of the second floor is built on a non-evacuation passage, and the steel fire shutter is installed in the middle. Thus, no separate fire protection partition is designed.

The stairs on the east and west sides of the central building are open stairs. There are 6 fire elevators on both northeast and northwest sides. The load capacity is ≥800.0kg, which can be reduced from the 23rd floor to the evacuation floor within 51 seconds. The evacuation width of the ground stairs is 3.45 meters.

A conventional model for calculating distance can be built by using Revit's adaptive model. It is calculated that the farthest evacuation distance is 26.98 meters (<30 meters), and both ends of the walkways on all floors can lead to the evacuation stairs. The evacuation stairwell and its front room on the first floor are the farthest distance from the outdoor entrance and exit with the distance of 6.34 meters (<15 meters). The front rooms of the fire elevators on the east and west sides are directly connected to the evacuation floor exit.

4.2. Analysis of safe evacuation method

(1) Standards for safe evacuation

When an accident occurs, whether a person can escape successfully depends on the values of two characteristic time variables [7]. The first is the period from the occurrence of the accident to the time when the accident is about to cause personal injury, which is called the Available Safety Egress Time, shorted as TASET. The second period is when accident happens, time used after the life of the person is threatened and before he moves to the required safe area, that is, Required Safety Egress Time, shorted as TRSET. The required safe evacuation time can be divided into three stages: detection time TAWA, reaction time TRES and escape time TEVA, so TRSET = TAWA + TRES + TEVA. By comparing the two time variables of TASET and TRSET, it can be judged whether the people in the building can escape safely when the accident happens. The timeline composed of two characteristic times forms the internationally used safety evacuation standard, as shown in Figure 2. The central building researched in this paper is equipped with an automatic alarm system, in which the value of TAWA is 60 seconds, the central building is equipped with a broadcasting system, and the value of TRES is 120 seconds.

![Figure 2. The relationship changing between accident and safe evacuation over time](image)

(2) Calculation expression of personnel evacuation time

In the field of safe evacuation, many classic evacuation time calculation expressions have been discovered, and they are still used today:

1. Pauls empirical formula

March Pauls carried out long-term calculation and analysis on the experimental evacuation data, proposing that in the calculation of the safe evacuation time in high-rise buildings, it is necessary to reduce the sides of the stairs by 15cm, and the remaining part is calculated as the effective staircase width [8]. As the result, the following formula (1) is sorted out:

$$ f = 0.206p^{0.27} $$ (1)
Togawa empirical formula

After a large amount of data research and comparison, Togawa came up with a formula used for the safe evacuation time in a multi-exit building. The formula has two items: the first item represents the safe evacuation time for all persons passing through the exit with a constant flow coefficient, and the second item is, the time for the person closest to the exit to complete the evacuation when the evacuation starts[9]. As the result, the following formula (2) is sorted out:

\[ T = \frac{Q}{NB} + \frac{L}{V} \] (2)

5. Building model of the central building based on Pathfinder

5.1. Model import and generation

Import the created model from Revit into Pathfinder. When setting the generated version, this paper uses "IFC 2×3 Coordination View 2.0". Compared with the IFC 2×2 standard, IFC 2×3 is similar to a container, in which Revit components are mapped to IFC one by one, allowing more Revit components to be adaptive in Pathfinder.

5.2. Creation of fire elevator

Pathfinder supports the simulation of the fire elevator in the exit operation mode. The operation of the fire elevator is based on the quasi-measurement of the elevator used in the fire. In this paper, the elevator shaft has been arranged in the Revit modeling. The floorslab is generated by default during the process of importing Pathfinder from the IFC format file, and the relevant parameters are defined to create the fire elevator[10]. In the evacuation simulation process, the elevator will follow the rules defined by the parameters, and the priority of the elevator is determined by the priority of the group or movement group. Once the elevator picks up passengers, it will not go to other floors to pick up more passengers, but directly to the release floor.

5.3. Group creation and addition

In order to meet the real situation of the center building of the Maternal and Child Health Center, this paper will construct four groups, namely, children, adult women, adult men and the elder. Patients are included in children and adult women these two groups. During the evacuation process, patients have the highest priority, followed by healthy children and the elder, then followed by healthy adult women, and finally adult men. In order to make the evacuation simulation closer to reality, after all groups are placed, the individual coordinates and parameters are modified according to the room function and personnel density indicators. The behaviors mainly include going to the exit, going to the waypoint, going to the room, escaping through the elevator, and waiting. The modified object can be an individual or a sports group. The distribution of behaviors is assigned to individuals and will not be cancelled due to the addition or merging of groups or sports groups.

6. Evacuation simulation and result analysis

6.1. Overview of evacuation parameters in the central building

(1) Fire safety evacuation calculation

As shown in Figure 3, the green line indicates the door that leads directly to the outdoors. There are 10 exits that lead directly to the outdoors on the first floor of the central building, and there is a corridor entrance and exit between the buildings on the west side of the third floor. is calculated. The total width for evacuation is 18.2 meters, the total clear width of the two evacuation stairs is 3.28 meters, and the evacuation passages on each floor are ≥1.6 meters.
Figure 3. The first-floor plan of the central building based on Pathfinder

Regarding the personnel density parameter, this article refers to the "Japan Refuge Safety Verification Act", determining that the personnel density of the physical therapy room, the registration fee office and the medicine collection area is 3 people/㎡. The number of inpatients is equal to the sum of the number of inpatient care units and ICU beds. The number of patients is twice the number of escorts. The ratio of male to female staff in the hospital is approximately 1:3. Classrooms and conference rooms are valued according to the number of seats. Operating rooms with a single operating table is arranged, and the total number of staff and patients are valued for 12 people. At present, there is no standard for calculating the density of staff in the office area of hospitals and ward buildings in China. The density of medical staff in the office area refers to the "Code for Design of Office Buildings", in which it takes 0.25 persons/㎡. Combining the room tool and area tool of Revit, the number of evacuated persons on each floor of the central building is calculated, as shown in Table 1.

Table 1. Number of evacuated persons on each floor of the center building

| Floor number | Evacuated persons number | Main functions of the floor                                      |
|--------------|--------------------------|-----------------------------------------------------------------|
| 1F           | 163                      | Central supply center, hospital lobby, fire control center     |
| 2F           | 83                       | Intravenous drug configuration center                           |
| 3F           | 150                      | Operating room                                                 |
| 4F           | 105                      | Operating room office area, surgery supporting room            |
| 5F           | 96                       | ICU                                                             |
| 6F           | 210                      | Delivery room                                                   |
| 7F           | 103                      | General prenatal care unit                                     |
| 8F-9F        | 65                       | Prenatal VIP nursing unit                                      |
| 10F-11F      | 122                      | Postpartum nursing unit                                        |
| 12F          | 150                      | Postpartum rehabilitation, functional examination               |
| 13F-15F      | 113                      | Gynecological nursing unit                                     |
| 16F          | 110                      | Pediatric surgery nursing Unit                                 |
| 17F          | 114                      | Breast care unit                                                |
| 18F          | 114                      | Reserved pediatric surgical nursing unit                        |
| 19F          | 131                      | Assisted reproduction center                                    |
| 20F          | 64                       | Eugenics and genetic diagnosis center                           |
| 21F          | 51                       | Laboratory                                                      |
| 22F          | 88                       | Pathology, blood transfusion center                             |
| 23F          | 273                      | Conference center                                               |

(2) Staff distribution and parameter setting at each level
Combining Morgan's fire protection design manual in SFPE mode and the real situation of the functions of each floor of the central building[11], the personnel characteristics and the distribution of each floor are obtained, as shown in Table 2.

|                  | Children | Adult women | Adult men | The elder |
|------------------|----------|-------------|-----------|-----------|
| Shoulder width(cm) | 31.0     | 38.5        | 41.7      | 40.0      |
| Pace(m/s)        | 0.92     | 1.02        | 1.20      | 0.82      |
| Simulation cylinder model color | Yellow | Red | Blue | Green |
| Personnel composition ratio in 1F(%) | 20 | 50 | 25 | 5 |
| Personnel composition ratio in 2F(%) | 0 | 75 | 25 | 0 |
| Personnel composition ratio in 3F(%) | 0 | 76 | 24 | 0 |
| Personnel composition ratio in 4F(%) | 0 | 75 | 25 | 0 |
| Personnel composition ratio in 5F(%) | 3 | 74 | 20 | 3 |
| Personnel composition ratio in 6F(%) | 1 | 73 | 25 | 1 |
| Personnel composition ratio in 7F(%) | 1 | 80 | 18 | 1 |
| Personnel composition ratio in 8F(%) | 1 | 76 | 22 | 1 |
| Personnel composition ratio in 9F(%) | 1 | 76 | 22 | 1 |
| Personnel composition ratio in 10F(%) | 1 | 78 | 20 | 1 |
| Personnel composition ratio in 11F(%) | 1 | 78 | 20 | 1 |
| Personnel composition ratio in 12F(%) | 1 | 68 | 30 | 1 |
| Personnel composition ratio in 13F(%) | 1 | 78 | 20 | 1 |
| Personnel composition ratio in 14F(%) | 1 | 78 | 20 | 1 |
| Personnel composition ratio in 15F(%) | 1 | 78 | 20 | 1 |
| Personnel composition ratio in 16F(%) | 45 | 35 | 18 | 2 |
| Personnel composition ratio in 17F(%) | 1 | 78 | 20 | 1 |
| Personnel composition ratio in 18F(%) | 45 | 35 | 18 | 2 |
| Personnel composition ratio in 19F(%) | 3 | 67 | 27 | 3 |
| Personnel composition ratio in 20F(%) | 0 | 75 | 25 | 0 |
| Personnel composition ratio in 21F(%) | 0 | 75 | 25 | 0 |
| Personnel composition ratio in 22F(%) | 0 | 75 | 25 | 0 |
| Personnel composition ratio in 23F(%) | 0 | 75 | 25 | 0 |

Groups are added through the Add Occupant Group tool. According to the data in Table 2, four groups(Random Placement) are randomly placed on each floor, as shown in Figure 4. The shoulder width, height, and walking speed of all individuals are assigned by a random allocation method. At the same time, all group models are set to select random evacuation methods to make the scene more realistic.
6.2. Evacuation simulation scene setting
The evacuation simulation scenes were all carried out under the extreme total number of 2,718 people. In terms of motion simulation parameter settings, the Runtime Output Freq, 3D Output Freq and CSV output Freq of the two scenes are all set to 1 second, and the simulation time limit and the simulation time step are set to 0.025 seconds.

1) Evacuation scene without using fire elevator
When accident occurs, full consideration should be given to the failure of UPS (Uninterruptible Power System) and other dedicated power supply circuits in the building. Therefore, evacuation simulation without fire elevators can provide data support for the hospital’s evacuation plan. If the disaster is uncontrollable, the evacuation rooms at the ICU level and the inpatient level are normally not used. The evacuation priority adopts the scheme mentioned in this paper. All individuals in the building will go to any exit.

2) Evacuation scene using fire elevator
With the premise that the equipment uses electricity to support the operation of the fire-fighting elevator, this scenario sets the behavior of all patients to go to any elevator first, then to any exit, and all other individuals are set to go to any exit. It should be noted that other individuals may also use elevators to escape when planning their paths. Therefore, on the basis of the proposed priority scheme, higher priority is given to hospitalized children. However, the software temporarily does not support excluding other individuals from responding to taking the fire elevator during the escape.

6.3. Results and analysis
(1) Results and analysis of evacuation scenarios without fire elevator
Without consideration about the trampling accident, the shortest simulation time of the evacuation scene without fire elevator is 376.4 seconds, and the shortest evacuation time is 1112.0 seconds. Both sets of data are from the same running test. The simulation results are shown in Figure 5.
Based on the results, at the beginning of the simulation, the longest individual evacuation distance is only 291.3 meters, which means that at least 725 people have changed paths. During the evacuation process, the individual’s maximum congestion time is 649.25 seconds, and the single longest congestion time is 189.35 seconds. The congestion time in the evacuation building is much longer than that of being congested between floors. It can be seen that the biggest bottleneck for escaping in the central building is the blockage of the evacuation stairs. Secondly, based on the distribution of people on each floor, the evacuation pressure on the east stairs is greater. If individuals choose the shortest distance to escape, more people will go to the east. But there are more exits and fire elevators on the west side of the first floor.

(2) Results and analysis of evacuation scenarios using fire elevators

After many experiments and constantly adjusting the group behavior, the shortest simulation time of the evacuation scene using the fire elevator is 332.5 seconds, and the shortest escape time is 863.0 seconds. Both sets of data come from the same running test. The simulation results are shown in Figure 6.

The simulation results show that the fire elevator effectively alleviates the use pressure of the evacuation stairs. Most of the individuals who take the elevator for a long time of congestion can complete the escape within 700 seconds, and the congestion time of the individuals whose escape time
exceeds 700 seconds is less than 100 seconds. During the simulation process, it was observed through the three-dimensional dynamic model that, in addition to patients, a small number of individuals who needed to escape through the fire elevator were hesitant to choose between going to the elevator and going to the exit when planning their route. The fire elevator on the east side has a low usage rate, but experiments have shown that if low-rise individuals are set to escape from the east side fire elevator, congestion will form in the front room, which will increase the evacuation time of the east stairs. If the high-rise individuals are set to escape from the east side by using the fire elevator, due to factors such as priority and delay of opening and closing doors of the elevator, they finally would choose to escape through the stairs.

The evacuation time is calculated as 1635 seconds by substituting the basic data of the central building into the Togawa formula, and the simulated evacuation time is around 1000 seconds. Based on the experimental results, it can be known that the average speed that an individual can actually achieve during the evacuation simulation process is only about two-thirds of the preset speed, so the experimental result is close to the theoretical calculation value.

7. Conclusion
Based on BIM and Pathfinder, the building information model construction and evacuation scene modeling of the central building of a city’s Maternal and Child Health Care Center are carried out. The safe evacuation design of the central building is studied. The feasibility of safe evacuation and the impact of personnel behavior are analyzed, and the evacuation simulation of the central building could calculate the utilization rate of evacuation exits, evacuation stairs and fire elevators, which is similar to evacuation drills for people in buildings. As the staff ratio of maternity and child health care hospitals is more special than that of general buildings, simulation analysis shows that daily real-time statistics of the flow of people on all floors should be recorded, the width of evacuation doors close to evacuation stairs and fire elevators should be appropriately increased, and the responsibilities of related medical staff should be clarified. By controlling the escape speed of people in different areas, evacuation efficiency can be significantly improved. Three-dimensional evacuation simulation scenes and data reports play a more guiding role in safe evacuation. Relevant responsible units and individuals can test a variety of preset escape plans, and formulate feasible evacuation plans by data analysis and comparison.

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