Simulation Study on Kindergarten Evacuation Based on the Experimental Data

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Abstract: This paper studies the children evacuation behaviour, and the evacuation effect of kindergarten safety in emergency situations. The research studies the evacuation simulation via Pathfinder with experimental behavioural data. The research object is the latest issued standard drawings of nine-class kindergarten in China. With different values of the walking speed parameters for each evacuation route, the flow at each exit, evacuation time and other data are presented. The method and results of this study enrich the database of the standard drawings and provide evidence of kindergarten architectural design and developing evacuation strategies.

1. Introduction
Kindergarten building is different from other buildings due to the particularity of users. Many countries attach great importance to the safety of kindergarten buildings and have established relatively building code, standards and regulation to ensure the safety of kindergarten building. In China, the first Code for Design of Nursery and Kindergarten Buildings [2] was established in 1988, the second one [3] was issued for update in 2016. In January 2019, Ministry of Education of the PRC and Ministry of Housing and Urban-Rural Development of the PRC released a document about the establishment of Standard Design Drawings of Kindergarten Buildings (Hereinafter referred to as standard drawings) [1]. That reflects the high attention to the kindergarten architectural design from the government.

There is few research on the children evacuation in the environment of kindergarten. To solve the difficulty of real experiment, the simulation experiment method is appropriate for the privacy of children. There are many kinds of simulation software for fire evacuation in the building [9]. In this study, the fulltime nine-classroom kindergarten standard drawings were simulated via Pathfinder. One of the most important input parameters is walking speed, it will influence the accuracy of the simulation results. However, this speed parameter was discrete in the previous researches [9-13]. In this study, the definition of speed parameters was obtained from the real experiments and calculated in each evacuation route separately. The research methods and conclusions are innovative.

2. Evacuation simulation

2.1. Introduction of fulltime nine-classroom kindergarten standard drawings
The fulltime nine-classroom kindergarten standard drawing is a two-storey building (Figure 1). The floor area of the ground floor is 1,731.70 m², and the floor area of the first floor is 1,449.35 m². There are three classrooms and one general activity room on the ground floor. On the first floor, there are six classrooms on the ground floor. According to the Code for Design of Nursery and Kindergarten
Buildings [3] and Working Rules of Kindergartens [4], the simulation experiment setting as following: 30 children in each class, 270 children in total; And 53 staff in total, including 6 teachers in each class, 2 presidents, 2 health physicians, 2 accountants, 7 kitchen staff, 2 security personnel and 2 cleaners.

There are four stairwells in the kindergarten (Figure 1), which are respectively called S1, S2, S3 and S4. There are six exits for evacuation, which are respectively called E1, E2, E3, E4, E5 and E6. The width of the all safety exits is 1.8m except the E5 (3.6m).

2.2. Simulation model settings
There are SFPE mode and Steering mode in Pathfinder. Due to the children evacuating orderly under the teachers’ leading. The Steering mode is more suitable for the evacuation simulation of kindergarten buildings. Where, the value of operation correction interval was set as 0.1s.

In the simulation model, the number of 118 agents on the ground floor, 205 agents on the first floor, and 323 people in total were set. Due to the most of the children in kindergarten were 3-6 years old. With the relevant documents [5-7], the average height of children was input 1.07m, the average shoulder width was set as 0.26m. Due to the most of staff are female in kindergarten, the average height was set as 1.65m of the staff and the average shoulder width was 0.40m [8]. Under the children evacuation strategy in China, children escaping needs the guidance and assistance of teachers, so the walking speed of teachers in the simulation model was set to be the same as that of children.

With the analysis of the floor plan, E5 is used for the staff evacuation. In this study, the research is focus on the exits E1, E2, E3, E4 and E6. The evacuation routes are presented in Table 1. According to the age composition of children, and the difference of horizontal and/or vertical moving distance in each evacuation route. The parameters of this simulation were determined from the author's previous studies.
on children's evacuation behavioural data (horizontal walking speed and vertical travel speed). The comprehensive travel speed as the speed parameter in Pathfinder were calculated from the horizontal walking speed, the vertical travel speed and each evacuation distance through weighted sum method (Table1).

| Exit | Section | No. of agents (n) | Comprehensive travel speed (m/s) |
|------|---------|------------------|---------------------------------|
| Route 1 | E1 | 51 | 1.05 |
| Route 2 | E2 | 51 | 0.91 |
| Route 3 | E3 | S2 | 52 | 0.83 |
| Route 4 | E4 | S3 | 52 | 0.80 |
| Route 5 | E6 | S1 | 51 | 0.91 |

3. Results

3.1. Flow at the exits
According to the simulation results and the width of the exits, the flow rates of each safety exit were calculated (Figure 2). With flow rates analysis, the agents at E1 and E2 evacuated faster than others, because most children who pass E1 and E2 are on the ground floor do not use stairs, the evacuation routes (Route 1 & Route 2) were unobstructed. The agents passing E3, E4 and E6 all need to evacuate through the stairwells, and the instantaneous speed was slightly slow, which affected the flow rates of these three exits.

3.2. Evacuation time
The evacuation time in this study is defined as the time from the first person out of the classroom to all agents arrived at the outdoor safety area. According to the simulation data, the longest time was determined as the evacuation time. According to the statistical analysis, the total number of agents was 323 and the evacuation time was 101s. Figure 3 shows the relation between the number of remaining evacuees and the evacuation time, from which presents the whole process of evacuation.
According to the simulation data in Figure 3, the equation between remaining agents and evacuation time was established as:

\[ Q = -3.8148t + 366.86 \]  

(1)

Where, Determination coefficient: \( R^2 = 0.9853 \);
- \( Q \) is the number of remaining agents (n);
- \( t \) is the evacuation time (s).

The number of agents evacuated linearly with time (Formula 1) basically, which presents the evacuation process was relatively smooth.

4. Conclusion

In this paper, the Pathfinder evacuation software was used for an evacuation simulation study on the fulltime nine-classroom kindergarten in the newly issued kindergarten architectural design standard drawings [1] in China.

At present, in the operation of the kindergarten simulation for using Pathfinder, the value of speed parameter is relatively discrete [9-13]. To improve the accuracy of the kindergarten evacuation simulation results, the parameters were obtained from the real experiments, especially the walking speed. The evacuation results provide the method of kindergarten evacuation simulation, and support the wider popularization and application possibility. From the literature reviews, the researches of children evacuation simulation were not reasonable to input the same speed parameter for the multiple evacuation routes in the same case. Based on the previous experimental research conducted by authors, this paper proposes to value the walking speed (comprehensive travel speed) of the children in different ages evacuating on each route, which improves the accuracy of the simulation results of kindergarten evacuation.

With the statistical analysis of the simulation results, the flow of each exit in the kindergarten was obtained. It was found that the average flow rates of the exit which the agents located on the ground floor evacuating through was higher, indicating that the evacuation route was relatively unobstructed without descending stairs. The relation between the remaining number of agents and the evacuation time was established, which provides the basis of the whole kindergarten evacuation process to optimize the kindergarten building design and evacuation strategies in the future.

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