Journal of Building Construction and Planning Research, 2023, 11, 27-35
https://www.scirp.org/journal/jbcpr
ISSN Online: 2328-4897
ISSN Print: 2328-4889

Pathfinder-Based Simulation and Optimization of Evacuation of Large Commercial Complexes

Jiuju Liu, Shuhan Li

School of Architecture & Fine Art, Dalian University of Technology, Dalian, China
Email: liujiuju1010@126.com

How to cite this paper: Liu, J.J. and Li, S.H. (2023) Pathfinder-Based Simulation and Optimization of Evacuation of Large Commercial Complexes. *Journal of Building Construction and Planning Research*, **11**, 27-35.
https://doi.org/10.4236/jbcpr.2023.112002

Received: March 27, 2023
Accepted: June 23, 2023
Published: June 26, 2023

Abstract

Large commercial complexes are large in scale, complex in function, and located in densely populated areas that are prone to casualties due to unfavorable evacuation. To comprehend the safety evacuation of large commercial complex buildings in China, investigate the safety evacuation problems encountered during the evacuation process and the evacuation optimization design strategy, the paper uses Pathfinder to build a simulation model based on literature research and study to simulate the evacuation of personnel in a large commercial complex in Dalian and explore its problems during the evacuation process. The results show that the type of personnel has an effect on the large commercial complex's evacuation simulation results; the total number of evacuees is non-linearly correlated with the time change curve; some staircases take a long time to evacuate and have a low utilization rate. To improve evacuation efficiency, optimization suggestions for safety exits, evacuation stairs, and evacuation channels are made based on the results.

Keywords

Commercial Complex, Safe Evacuation, Simulation, Pathfinder

1. Introduction

Large-scale commercial complexes with multiple functions are densely populated and complex, and they are critical points for preventing fires in the field of fire protection. The safety concept of commercial complex building design is the foundation for protecting the safety of consumers and staff, and its personnel safety evacuation problem is primarily affected by the layout of functional partitions, evacuation flow line organization, and other aspects.

Foreign scholars began researching building evacuation problems before domestic researchers, and early research methods were mostly questionnaire interviews and evacuation drills, which were developed to simulate the evacuation process of real scenarios with the help of computer technology, using software simulation and virtual reality experiments to bring the research closer to the real crowd evacuation situation due to the difficulties in performing full-scale evacuation. Helbing D, Farkas I, and Vicsek T [1] proposed a model based on the concept of "social force" in the early stages of research. The model can effectively simulate and predict the dynamic characteristics of fire evacuation through simulation experiments and comparing the predicted results with actual data, and it can help design and optimize evacuation strategies. Du Changbao, Zhu Guoqing, and Li Junyi [2] compared evacuation simulation software by combining theoretical research with practical simulation. They discovered that the Pathfinder simulation results were more consistent with reality, and STEPS was better suited for simulating normal personnel evacuation. Huiping Zeng [3], for a large space stadium, discovered that mass crowd evacuation is not the same as evacuating the same number of people and that real-life evacuations take longer than Exodus simulations. Tang Yu *et al.* [4] performed a fire simulation of a large shopping mall building in Shenyang, whose personnel type was determined using the ratio recommended for international general entertainment public places, calculated the safe evacuation time of each floor, identified the hidden dangers of the fire evacuation design, and proposed optimized design suggestions. He Xin *et al.* [5] simulated the evacuation process of mall personnel using Revit and Pathfinder, and the process reflected the fast-is-slow effect, proposing to select the evacuation mode of opening and closing different stairwells and improve the evacuation rate through reasonable management. The above study has reference significance for the study of influencing factors in the evacuation of large public places and the optimization of evacuation designs.

Computer evacuation models for personnel evacuation Social force models, meta-cellular automata, agent-based models, and social network models are among the evacuation models. The social force model is a continuous pedestrian model that considers how people's movement is influenced by their own dynamics and the surrounding environment, takes into account interaction forces between people and objects, and can represent crowd congestion and bottleneck effects. The social force model can predict the entire crowd evacuation procedure as well as provide decision support for practical applications. Pathfinder's exit selection is also more logical in complex situations with multiple departure environments and is suitable for large building evacuation simulations. Based on the evaluation of the simulation software's suitability by literature studies and the type and volume of usage of the research object in this paper, Pathfinder is the evacuation simulation software used in this paper. Its steering movement mode is more realistic for the situation. Based on this, this paper selects a comprehensive shopping center (in Shahekou District, Dalian) as the research object, combines the field research situation, analyzes its evacuation simulation process and results using Pathfinder, makes optimization suggestions to improve evacuation efficiency, and makes reasonable suggestions for the safe evacuation design of a commercial complex.

2. Project Overview

According to the scale of commercial complex classification, a comprehensive shopping center (in Shahekou District, Dalian) with a total construction area of about 120,000 m^2, is classified as a large commercial complex. The commercial complex was built in 2005, and it has five floors above ground and one underground floor for small stores.

The commercial complex, including the evacuation staircase, has a total of 20 safety exits and 14 groups of evacuation stairs, with No. 1 and No. 7 having four scissors stairs and the rest having two. In addition to the evacuation stairwell safety exits, there are six direct outdoor safety exits evenly distributed on the ground floor (**Figure 1**). According to the distance between the location of the evacuation stairs and the nearest safety exit, it can be seen that the commercial complex follows the building code and uses the covered walkway model to address the requirement that some of the evacuation stairs do not meet the requirement that the stairs on the ground floor go straight to the outdoors. According to Article 5.3.6 of the Code for Fire Protection Design of Buildings, when the evacuation staircase cannot go directly outdoors on the ground floor, it can go directly to the pedestrian street on the ground floor, but the walking distance from any point in the pedestrian street to the nearest outdoor safety location cannot exceed 60 m.

3. Model Construction and Parameter Selection

3.1. Model Construction

The model is established in Pathfinder based on the CAD drawings of the building, the building profile is simplified in the model, and the general layout of the building, the safety exits, and the location of the evacuation stairs between floors are input into the software, and the basic model of the mall is established. Because the actual commercial complex environment and personnel interact with one another, and the evacuation environment is complex, the steering personnel movement model was chosen to present the simulation process and results in a more realistic manner. Furthermore, the model has not yet considered the impact of store layout and crowd psychological factors on evacuation results.

3.2. Evacuation Number Calculation

When the scale of the building is large (total construction area greater than 20,000 m^2), the lower limit of the personnel density specified in Table 5.5.21-2 of the Code for fire protection design of buildings can be used. The building scale is large in this study, with a total construction area of 120,000 m^2 and a personnel density of the lower limit value. When calculating the number of evacuees based on the number of evacuees per floor = floor area of the business hall on each floor × area conversion value × personnel density, the above-ground area conversion value is 0.6 and the underground area conversion value is 0.7, and the total number of evacuees inside the shopping center is 29,477.

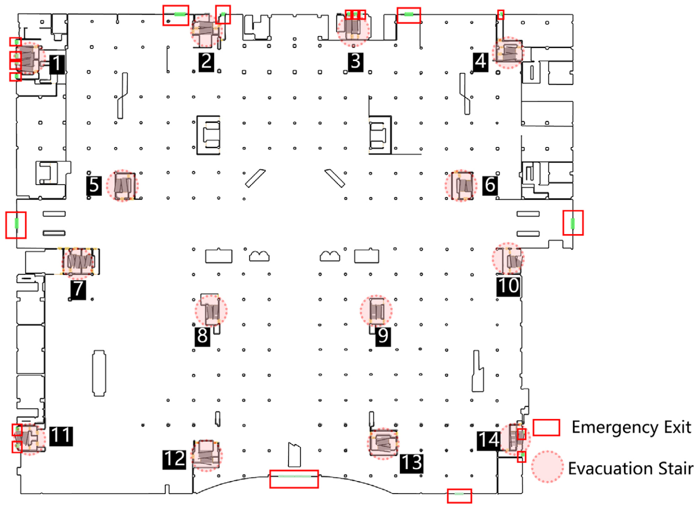

Figure 1. Location map of evacuation stairs and safety exits on the ground floor.

3.3. Setting Personnel Parameters

The crowd composition in a large commercial complex is complex and relates to the nature of the building. Before conducting the simulation, in order to make the evacuation simulation more realistic, field research on the composition of the population in the commercial complex (in Shahekou District, Dalian) was conducted. The gender and age distribution of 200 people was randomly sampled and analyzed, and it was discovered that adult females occupied a high proportion of the population in the commercial complex, while the elderly and children were relatively few. To set the specific parameters of people types in the building, the proportion of people types was determined using the Dalian field questionnaire and combined with other references [6] [7] (**Table 1**).

4. Results of Simulation Analysis

4.1. A Comparison of the Effect of Whether or Not to Consider Personnel Type

The outcomes are analyzed by simulating parameter settings with and without taking into account the types of people. When the simulation parameters are set to consider the personnel type (as shown in **Table 1**), the total evacuation time is 1062.8 s; when the personnel type is not considered (the walking speed is set to 1.19 m/s, the shoulder width is 45 cm, and the height is 178 cm), the total evacuation time is 907.2 s, and the relationship between the number of evacuees and the time is compared between the two (**Figure 2**). Without taking into account the type of personnel, the total evacuation time is 155.6 s slower, which will have an impact on the evacuation simulation results of large commercial complexes. Because the structure of personnel composition in large commercial complexes has certain unique characteristics, personnel type parameters are important influencing factors for the safe evacuation of commercial complexes and should be as close to the actual situation as possible.

Table 1. Parameter settings for the person in question.

Personnel type	Percentage/%	Height/m	Shoulder width/m	Walking speed/(m/s)
Children	14%	1.30	0.32	1.05
Adult Male	19%	1.78	0.46	1.35
Adult Female	59%	1.65	0.43	1.15
Elderly	8%	1.60	0.44	1.00

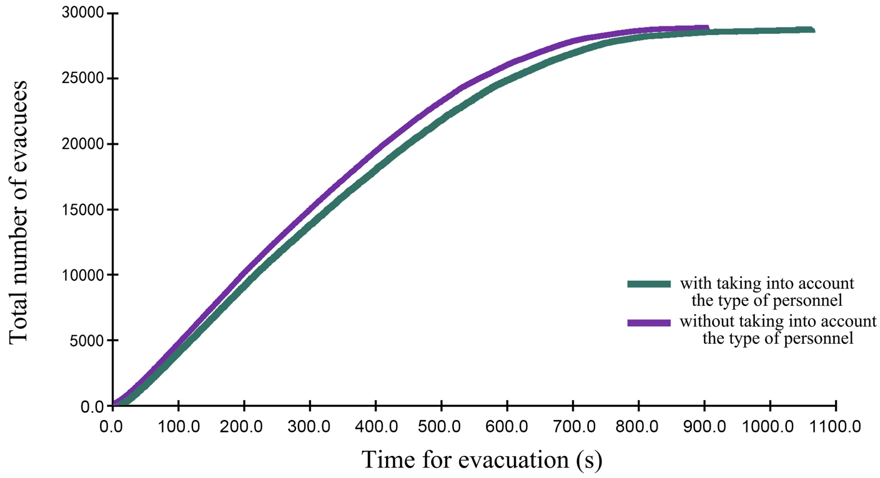

Figure 2. Plot the number of evacuees versus time, with or without taking into account the type of personnel.

4.2. Overall Simulation Results Analysis

The commercial complex's total evacuation movement time is 1062.8 seconds. The number of evacuees in the large commercial complex is non-linearly related to time, resembling a logarithmic growth curve, with faster growth at the beginning and slower growth at the end, as shown in the relationship between the number of evacuees and time (**Figure 2**).

The graph of the remaining number of people versus time on each floor (**Figure 3**) shows that 2F, 3F, 4F, and 5F evacuations ended faster, and the upper floors all completed the majority of the crowd evacuation in the 300s, whereas 1F and -1F evacuations were less efficient and ended later.

The overall curve can be divided into three stages when combined with the evacuation status of the ground floor at each moment (**Figure 4**). The first stage is 0 - 600 s, which is a rapid growth period, and the relationship between the number of evacuees and time tends to be positive proportional. The evacuation rate is fast during this period, and most of the evacuation is completed, but serious congestion occurs at some of the safety exits in the 30 - 480 s of this stage. The second stage is the 600 - 800 s, which can be described as a slow growth period, as the evacuation rate began to significantly reduce the phenomenon of the long tail at this time. The third stage is after the evacuation of the 800 s, and this stage is known as a platform period. The evacuation rate growth is slow compared to the previous and significantly reduced, as shown in Figure 4 (800 s), only a portion of the remaining evacuation stairs.

The following two conditions will reduce the efficiency of crowd evacuation during the evacuation process. First, because there are a large number of evacuated people on the ground floor, there will be a crowd gathered at the safety exit (Figure 4), and because individual behavior cannot be unified, if someone speeds up, the overall evacuation time increases but evacuation efficiency decreases; "fast is slow". Second, because the carrying capacity of the evacuation stairs is limited over time, the entrance of the evacuation stairwell on the second and higher floors will produce a bottleneck arch phenomenon, leading to congestion here, and after the upper floor crowd reaches the ground floor stairwell position, congestion occurs in the front room of the stairwell when leading to the safety exit, greatly slowing down the person's evacuation efficiency.

4.3. Analysis of the Use of Evacuation Stairs

The evacuation time and the number of people in each group of evacuation stairs (Figure 5) show that evacuation staircase No. 9 takes the shortest time to complete evacuation, 458 s, and evacuation staircase No. 11 takes the longest time, 1062 s. The evacuation staircases No. 1 and No. 7 have four scissors stairs each, and the rest have two in each group. Data analysis of the two figures shows that the utilization rate of evacuation staircase No. 8 is the highest, and the utilization rates of evacuation staircases No. 9, 11, 12, and 13 are relatively high. The utilization rate of evacuation staircase No. 5 is the lowest, and that of evacuation staircase Nos. 1, 4, and 6 is also low. Combining Figure 4 and Figure 5, it is discovered that fewer people choose No. 5 to evacuate, and at 800 s, No. 11 evacuation staircase becomes the last staircase to end evacuation, while its average number of evacuees per part is the highest, indicating that the evacuation efficiency of this stairwell is slower and the congestion is more severe.

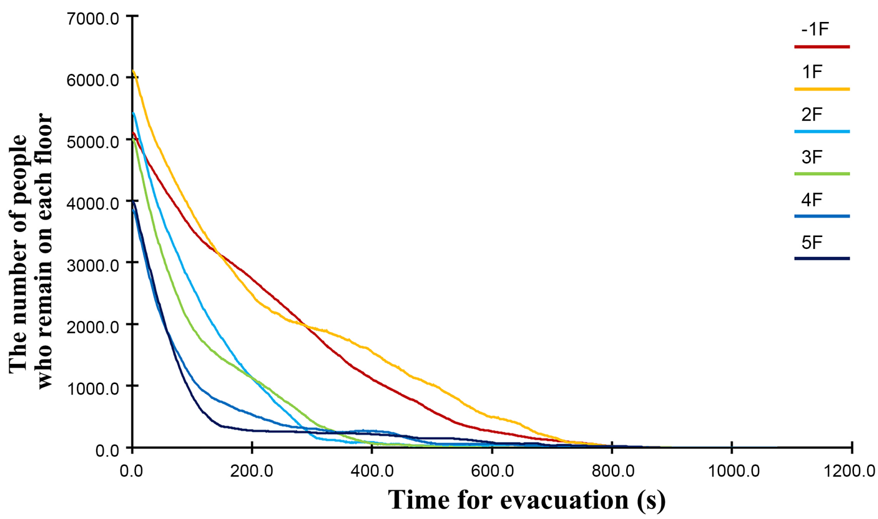

Figure 3. Plot of the number of people in each tier remaining versus time.

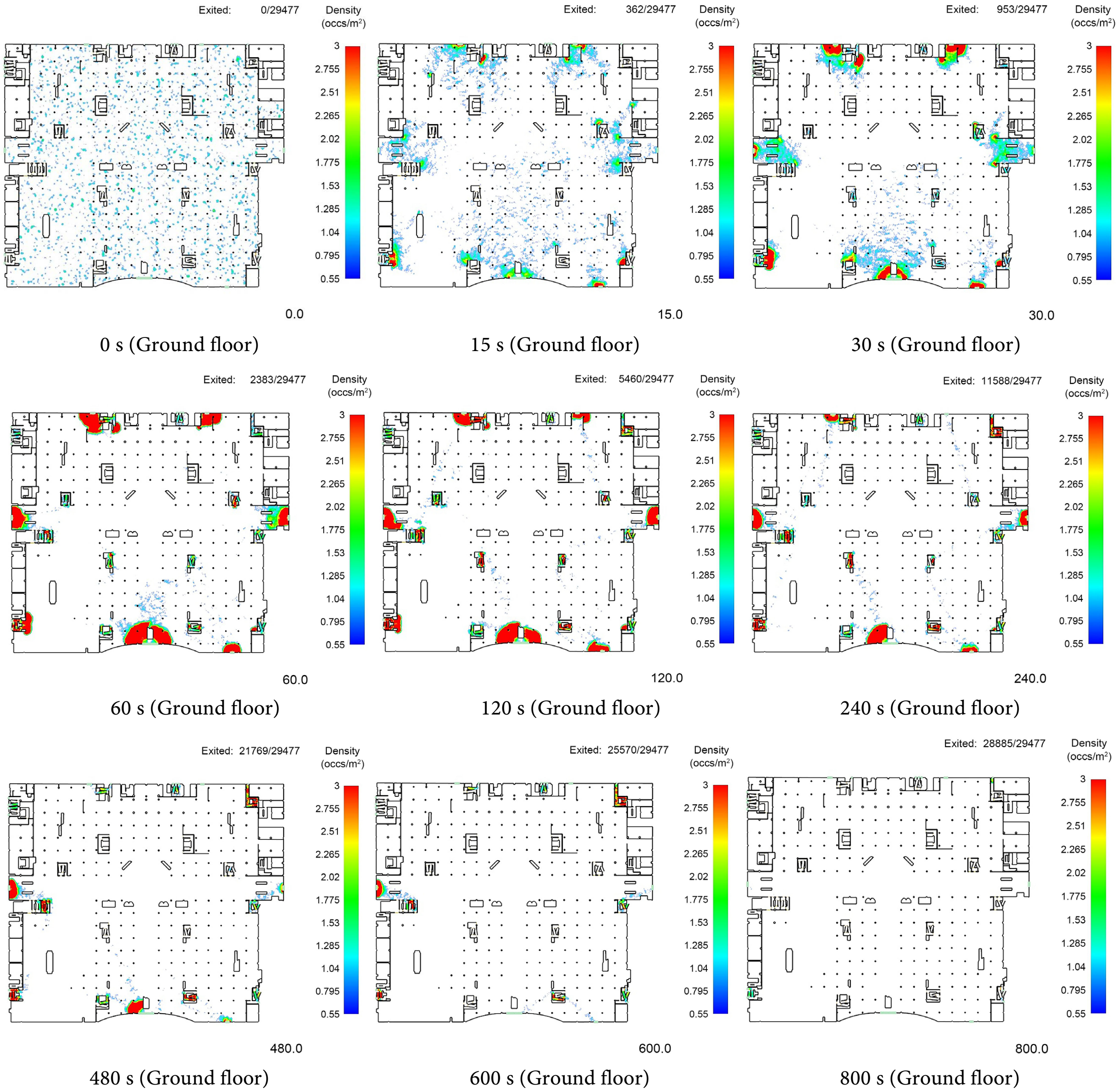

Figure 4. People's evacuation status on the ground floor at any given time.

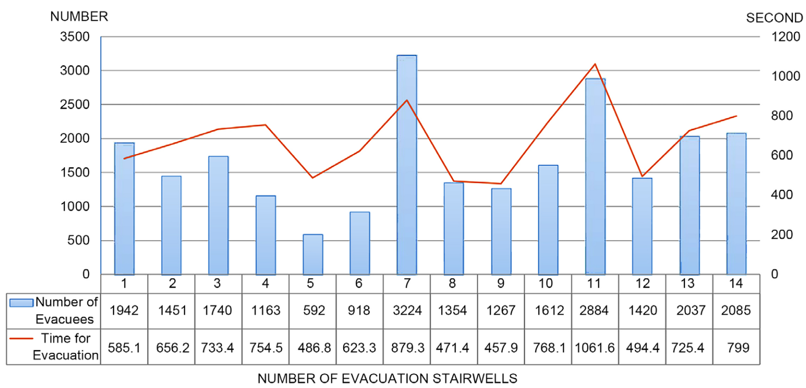

Figure 5. Number of evacuees at each evacuation staircase and end evacuation time.

5. Suggestions for Design Optimization

Large commercial complexes with existing fire safety regulations generally calculate the number of evacuees based on the fire compartment area, then determine the evacuation stairs and evacuation width. Existing commercial complexes may still exhibit certain issues in evacuation simulations despite compliance with regulations due to their densely populated and complex spatial characteristics. According to the above analysis, the impact of personnel type on evacuation simulation must be considered by controlling the variables to investigate, then using the determined number and type of personnel parameters for evacuation simulation, analyzing the simulation results and data situation, and finally proposing suitable optimization strategies for this project.

1) Reasonable safety exit placement and width. The simulation allows for further optimization of the safety exit width. In the evacuation simulation, safety exits with a high volume of people and congestion should be appropriately spread out or increased in width. The current safety exit distribution is fairly uniform, but some safety exits carry both the upper floor's evacuation flow through the evacuation stairwell and the flow of people on the ground floor, which is prone to blockage and cannot evacuate directly and quickly to the outdoors. An independent safety exit near staircase No. 11 can be added to disperse the two flows of people in the stairwell and on this floor, avoiding congestion and reducing the pressure of evacuating the exit of the evacuation stairwell and the adjacent safety exit.

2) Reasonable evacuation width allocation. According to the simulation results of the evacuation time and the number of evacuees of each group of stairs, as the research project of this paper has been completed, the stairs with a longer evacuation time and a larger number of people (such as stairway No. 11) can be appropriately increased in evacuation width, or a group of evacuation stairs can be added here. Furthermore, if the project is in the program phase, the stairs with shorter evacuation times and fewer people can have their evacuation width appropriately reduced, which not only improves efficiency but also certain security.

3) The layout of the store and evacuation channel is reasonable. The evacuation channel should be convenient for customer flow; its width should match and be evenly distributed; it should be straight and smooth; it should not turn several times; and it should be conducive to evacuation flow organization and guidance. After accounting for the fall of the fire shutter, the evacuation channel should avoid forming the end as much as possible, and it is preferable to form a circular walkway in the fire prevention zone that goes as far as possible straight to the safety exit to facilitate evacuation.

6. Conclusion

Using a large commercial complex as the research object, we use Pathfinder to perform crowd evacuation simulation analysis, analyze the problems in this example's safety evacuation from the perspective of parameter setting, both overall and locally, and propose optimization strategies. This can improve the evacuation efficiency and reduce the total evacuation time of a large commercial complex in a targeted manner, achieve evacuation optimization, and ensure the safety of the crowd in the commercial complex from the design level as much as possible.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Helbing, D., Farkas, I. and Vicsek, T. (2000) Simulating Dynamical Features of Escape Panic. *Nature*, **407**, 487-490. https://doi.org/10.1038/35035023

[2] Du, C.-B., Zhu, G.-Q., Li, J.-Y. (2015) Comparative Study on Evacuation Simulation Software STEPS and Pathfinder. *Fire Science and Technology*, **34**, 456-460. https://doi.org/10.3969/j.issn.1009-0029.2015.04.012

[3] Tserng, H.P., You, J.-Y., Chang, C.-Y. & Hsiung, K.-H. (2012) Comparison Analysis of Emergency Evacuation between Computer Simulations and Real Exercises for Large-Space Buildings. *Journal of the Chinese Institute of Engineers*, **35**, 779-792. https://doi.org/10.1080/02533839.2012.701914

[4] Tang, Y., Biao, X.F. and Ma, F.S. (2019) Research on Fire Evacuation of Shopping Malls Based on Pathfinder. *Journal of Shenyang Jianzhu University* (*Natural Science*), **35**, 858-866.

[5] He, X., Chang, L., Xie, F., Song, W.H. and Li, L. (2016) Study on the Safety Evacuation of the Shopping Mall Building Based on the Revit and Pathfinder. *Acta Scientiarum Naturalium Universitatis Nankaiensis*, **49**, 14-20.

[6] Yao, Y.S. and Lu, W. (2020) Children Evacuation Behaviour Study in One-Storey Kindergarten Via Pathfinder. *Architecture & Culture*, 66-67.

[7] Liu, Y. and Liu, Z.M. (2021) Study on Crowd Evacuation Simulation of Small and Medium-Sized Gymnasium Based on Pathfinder. *Low Temperature Architecture Technology*, **43**, 6-10.