Journal of Landscape Research 2024, 16(5): 19–26

Design of Barrier–free Evacuation for Diverse Crowd on Campus Based on Evacuation Simulation: A Case Study of North China University of Technology

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Abstract By using evacuation simulation technology and taking North China University of Technology as an example, the barrier-free evacuation design scheme for groups with different needs in campus environment was deeply discussed. Based on the data of building layout, population composition, road system and distribution of shelters in the school, a detailed evacuation model was constructed in the Pathfinder emergency evacuation simulation system. By the simulation during the daytime and at night, the total evacuation time of the whole school, evacuation completion time of each building, selection of evacuation paths and shelter utilization were analyzed in detail. The simulation results show that the distribution of shelters on campus is uneven, and their capacity is limited. As a result, the evacuation paths of the disabled, the elderly and children need to be adjusted frequently, which affects the overall evacuation efficiency. In view of this, the optimization strategies of road renovation and entrances of shelters and buildings were put forward from the perspective of space planning. From the perspective of emergency management, it is suggested to improve the campus evacuation infrastructure and strengthen the evacuation drill for teachers and students. These results provide a solid theoretical support for enhancing the construction of campus barrier-free environment and improving the level of emergency management.

Keywords Diverse crowd, Campus barrier-free evacuation design, Analogue simulation, Shelter

DOI 10.16785/j.issn 1943-989x.2024.5.005

The *Action Plan for the Development and Improvement of Special Education during the "14th Five-Year Plan" Period*, emphasizes the importance of "promoting the integrated education model and comprehensively improving the quality of special education". The Party's 20th National Congress further clarified the direction of "accelerating the popularization and beneficial development of special education". The *Law of the People's Republic of China on Building a Barrier-free Environment*, which came into effect on September 1, 2023, stipulates that barrier-free facilities on campus must be designed and constructed in accordance with established standards, aiming to ensure smooth evacuation of special groups such as the disabled and the elderly in emergency situations. This series of measures has laid a solid legal foundation for all types of personnel on campus to be able to quickly evacuate to safety when they are in the face of an emergency, and for comprehensively optimizing barrier-free environment on campus.

In the process of evacuation, people's behavior is different from their daily life, and they are prone to chaos, panic and crowded phenomena, but simple disaster prevention and evacuation drills can not fully show a real evacuation scene. However, general mathematical models are difficult to describe the influence of many factors such as individuals and environment on the evacuation process in evacuation models[1]. Computer simulation technology can solve this problem well.

In the research field of emergency evacuation, the academic circles at home and abroad have carried out extensive and in-depth exploration. With the help of computer simulation technology, researchers have successfully reproduced the dynamics of crowd evacuation in various situations[2-3]. These studies span multiple dimensions in scope from a single building to neighborhoods and even entire cities. On the level of individual buildings, the research focuses on large public facilities[4], medical institutions[5], educational institutions[6], subway systems[7] and high-rise buildings[8], etc., and the mechanism of crowd evacuation inside these specific buildings is analyzed in depth. In the outdoor evacuation simulation on a neighborly scale, the research perspective turns to residential areas and blocks in high-density urban areas, and the shortest path algorithm is generally used to optimize the selection of crowd evacuation routes[1, 9-14]. However, despite the fruitful research results, there is relatively little research on the evacuation of disabled people in emergencies[15-16]. The special challenges and needs faced by this group during emergency evacuation have not received sufficient academic attention. In the field of barrier-free design and construction on campus, research focuses mostly on barrier-free facilities and universal design practices on campus[17-19], while there are few systematic discussions and studies on the evacuation of diverse crowd including disabled people in response to emergencies on campus. Therefore, carrying out more in-depth and comprehensive research in this field has important theoretical and practical significance for improving the level of campus emergency management and ensuring the life safety of all types of people.

In this paper, taking the campus of North China University of Technology as an example, data of population distribution, building layout, road network, shelters and crowd attribute characteristics on campus were obtained through field investigation. By means of computer simulation and pathfinder software, campus planning layout, personnel scale and evacuation behavior were set, and the construction of evacuation simulation model was completed. The evacuation simulation was carried out during the day and at night respectively, and the total evacuation time of the campus crowd, the evacuation time of the crowd in each building, campus evacuation path and shelters were analyzed (Fig.1). From the aspects of spatial environment and emergency management, the updated strategies of barrier-free environment

Received: September 18, 2024 Accepted: October 21, 2024

Sponsored by the Innovation and Entrepreneurship Training Project for College Students in Beijing (10805136024-XN139-100); Scientific Research Foundation of North China University of Technology (11005136024XN147-56); Yuxiu Innovation Project of North China University of Technology (2024NCUTYXCX214).

construction on campus were put forward.

1 Selection of research object and setting of simulation model

1.1 Status of research object

North China University of Technology, which is located in Shijingshan District, Beijing, has a vast campus covering a total area of 30 hm^2 and a total construction area of nearly 400,000 m^2. Since its establishment in 1946, the university has experienced decades of wind and rain, and has accumulated rich historical heritage and cultural inheritance.

The campus interior space layout is diversified, and it is clearly divided into teaching areas, living areas and staff buildings and other functional areas. Due to the relatively small spacing between buildings and the large span of construction time of buildings, some of the buildings have shown signs of aging. In addition, the road system on campus is intricate and intertwined into a dense traffic network. In this environment, people of all ages live, including students, staff and their families, etc. Hence, when emergency evacuation is needed in the face of emergencies, it is difficult to evacuate people due to the diversity of population distribution and the complexity of road system, thus increasing the risk of casualties. In a word, there are hidden dangers in campus security.

1.2 Analysis of demographic structure

In order to determine the number of participants in the simulation during the daytime, the detailed course schedule of the whole school during the third and fourth classes in the 12th week of the spring semester in 2024 has been successfully obtained. This schedule provides comprehensive coverage of a number of key elements, including but not limited to course name, co-class teaching logo, teaching location (i.e. classroom), starting week of courses, instructors and other details

At the same time, the study also carried out detailed statistics on the structural information of campus dormitories, and relevant data are shown in Table 1. Besides, a comprehensive survey on the distribution of residential buildings in the campus family areas was conducted. According to the survey, there are 14 residential buildings on the campus of North China University of Technology, of which buildings 7, 8, 9, 10 and 11 were lived by the retired staff, their children and grandchildren, while the remaining 9 residential buildings are mainly lived by young staff couples and their children. The statistics show that the total number of adult residents in the family areas is 1,350, and the elderly population is 510, while the child population is 675.

From the the analysis of the above data, it is concluded that during the daytime, the total number of participants in the evacuation simulation reached 15,627. In view of the fact that the graduate students were specially arranged to live off campus, the graduate students were not included in the simulation during the night period, so the total number of participants in the evacuation simulation at night was 15,177.

1.3 Setting of model parameters

In this study, the graphic drawings of North China University of Technology were obtained from the Open Street Map platform and accurately imported into the CAD software according to the actual scale. Subsequently, an in-depth investigation was carried out on the core area of the campus of North China University of Technology, focusing on the configuration of entrances in the main teaching buildings, dormitory areas and residential areas, and key data including the width of entrances, the number of steps and the width of barrier-free ramps were recorded in detail. Then the data was integrated into the campus CAD drawings. Finally, the processed CAD drawings were imported into Pathfinder software for evacuation simulation.

1.4 Setting of personnel parameters

According to a survey by the American College Health Association (ACHA) in 2022, 4% of students have blindness or vision loss, and 2% of students are deaf or hard of hearing; about 1% of students have mobility or flexibility problems, and around 1% of students have speech problems. Based on these empirical data, in the parameter configuration stage of the simulation experiment, the number of disabled people in the main teaching buildings and

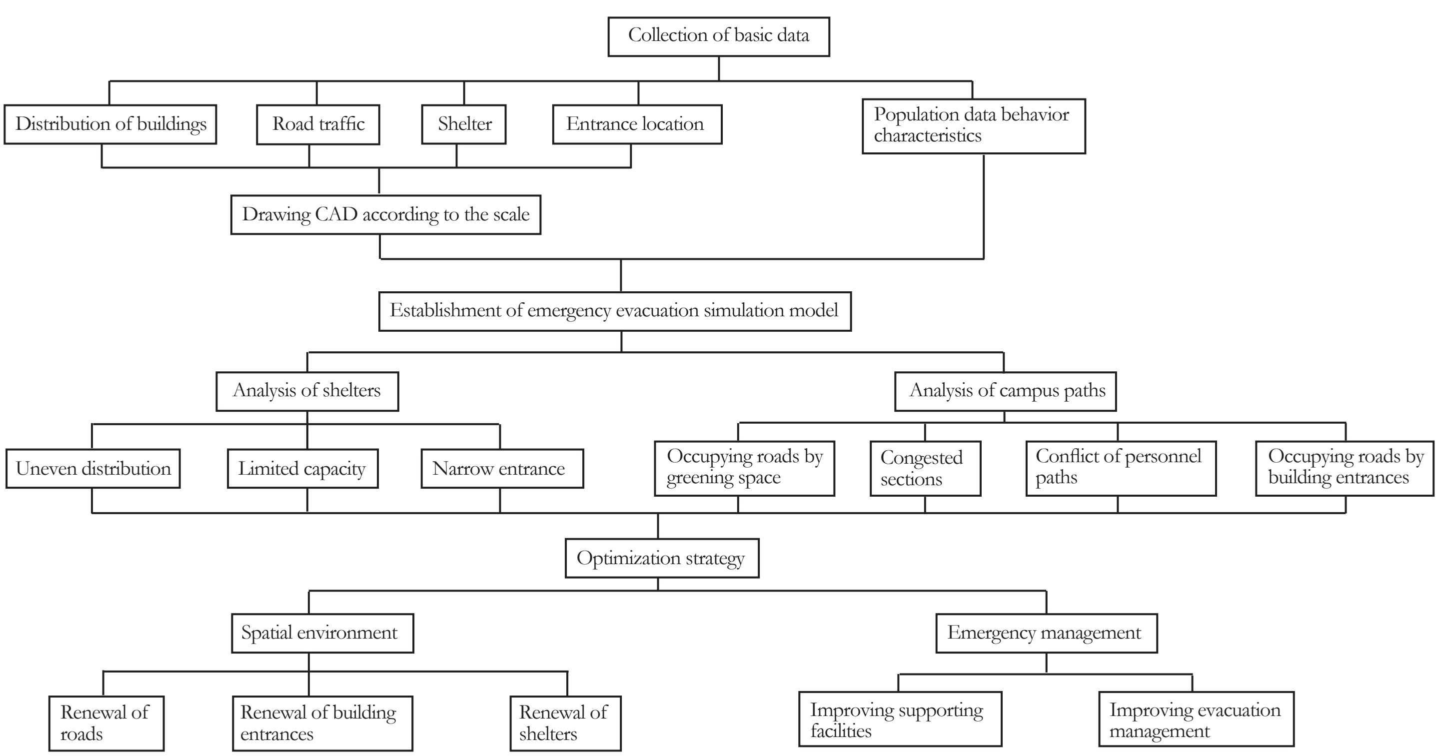


Fig.1 Research framework

dormitories was set in strict accordance with the above proportions. The configuration of various types of personnel are shown in Table 2.

1.5 Simulation of evacuation behavior characteristics

Since the objects of this study include not only ordinary adults, but also people with disabilities and other people with barrier-free needs, the general people are set as red cylinders. For disabled people, the elderly are set as yellow cylinders, and children are set as green cylinders; the people with hearing impairment are set as dark blue cylinders, and the speech disabled are set as light blue cylinders.

The special needs of students with physical disabilities are taken into account when setting evacuation behavior. In view of the difficulties such students may encounter in entering and exiting buildings and going down stairs, the planning of their evacuation path is to move first to the "Goto Rooms" (i.e. barrier-free ramps) and then to the "Goto Refuge Rooms" (refuge rooms). In contrast, for other groups of students without mobility problems, their evacuation route is uniformly set to direct to the "Goto Refuge Rooms" (refuge rooms).

For the setting of evacuation response time, based on relevant studies, it can be seen that the response time of ordinary people after receiving the evacuation signal is usually between 1 and 3 s. However, children, people with hearing and speech impairment may take longer time to receive information and make decisions in the face of emergency situations, so the initial delay time of these three special groups is adjusted to 6–8 s[16], so as to ensure that the simulation is more close to the actual situation and reflects the behavioral characteristics of different groups in emergency evacuation.

1.6 Limitations on the capacity of shelters

The simulation scenario of this study is an emergency shelter. According to the planning standard of an emergency shelter in the *Code for Design of Disasters Mitigation Emergency Congregate Shelter* (GB 51143–2015)[20], the refuge area per capita is 1 m^2. Research on the special planning of earthquake emergency shelters in Beijing[21] shows that the site size of an outdoor emergency shelter in Beijing should not be less than 2,000–3,000 m^2, and the effective area of a shelter should be converted according to a certain proportion, among which the effective refuge area of school sports land accounts for 90% of its actual area, while the effective refuge area of green space and square open space accounts for 60% of its actual area.

The six shelters selected in this study include Yuxiu Garden (S_1), Gubai Garden and a large green space around the experimental building to the north of the first teaching building (S_2), a fountain square between the fifth teaching building and the library (S_3), small squares in front of the complex building and the residential area (S_4), small playground (S_5) and large playground (S_6). Their effective refuge area and the actual number of accommodated people are shown in Table 3.

2 Analysis of simulation processes and results

2.1 Analysis of evacuation processes

In this study, a simulation experiment on the crowd evacuation process at noon and evening on campus was conducted, and the total evacuation time of the crowd on campus, evacuation completion time of various types of crowd, evacuation completion time of each building, the use of shelters and the location of route congestion were analyzed.

The time required to complete the evacuation of all types of people during the day and night is shown in Tables 4–5.

During the day, the total time for the evacuation of people is 1,121.3 s, and the evacuation process of all types of people is shown in Table 4. During the daytime evacuation, no people retrace their paths. In the early stage of evacuation (0–60 s), people in each building start to evacuate, and some exits are congested due to greening, while the evacuation efficiency is affected by the gathering of students with physical disabilities around barrier-free facilities. In the middle period (60–200 s), the people in the family area are basically evacuated, and more than half of the people in the teaching buildings and dormitory areas are evacuated, but the students with physical and hearing disabilities are still stranded in the buildings. Subsequently (200–500 s), the main shelters gradually become saturated, and congestion points are mostly caused by the backlog of people. Except for specific buildings, the rest people are evacuated before 200 s. In the later period (500–700 s), the small playground (S_5) became the main evacuation place, and the narrow entrance on the west side leads to serious congestion, among which the students with physical disabilities account for a significant proportion. After 700 s, the congestion gradually eases until the evacuation is completed after 1,121.3 s.

In the early stage of the evacuation process

Table 1 Information of dormitories

Name	Four-bed room	Six-bed room	Highest floor	Maximum capacity
Qizhai	10	10	7	700
Dezhai	42	0	6	1,008
Xinzhai	0	42	12	3,024
Yazhai	0	26	10	1,560
Huizhai	14	14	12	1,680
Yuezhai	14	44	11	3,520
Hongye Apartment	0	15	5	450

Table 2 Setting of personnel parameters[16]

Type	Average speed//m/s	Size
Students/teachers/staff	1.45	0.44 m×0.44 m×1.70 m
The old	1.28	0.44 m×0.44 m×1.70 m
Children	0.90	0.30 m×0.30 m×1.25 m
Students with language barriers	1.45	0.44 m×0.44 m×1.70 m
Students with hearing impairment	1.45	0.44 m×0.44 m×1.70 m
Students with visual impairment	0.86	0.60 m×0.80 m×1.70 m
Students with physical disabilities (independently using a wheelchair)	0.89	0.80 m×1.20 m×1.00 m
Students with physical disabilities (using a wheelchair with assistance)	0.89	0.80 m×1.20 m×1.70 m
Students with physical disabilities (using crutches)	0.94	0.75 m×0.70 m×1.60 m

Table 3 Information of campus emergency shelters

Emergency shelter	Actual area//m^2	Effective refuge area//m^2	Effective refuge area per capita//m^2	Number of accommodated people
S_1	8,278	5,268	1	5,268
S_2	2,757	1,654	1	1,654
S_3	4,572	2,743	1	2,743
S_4	5,366	3,220	1	3,220
S_5	7,472	6,724	1	6,724
S_6	20,418	18,376	1	18,376

at night (0–60 s), people in each building start to evacuate. Similar to the daytime, the roads around family buildings 4–6 are narrow and congested due to greening. At 12.2 s, some students had arrived at the shelter. During 60–100 s, except Yuezhai, people are mainly evacuated to the nearby small square in front of the family courtyard (S_4) and Yuxiu Garden (S_1). In the middle period (100–400 s), the small square in front of the family courtyard and Yuxiu Garden have reached the limit of accommodation, and people are evacuated to other refuge places. The congestion at the exits of Xinzhai, Yuezhai and Yazhai continues. After 250 s, the people who has not been evacuated move to Gubai Garden (S_2), and the people in Yuezhai go to the small playground (S_5) and Fountain Square (S_3) respectively. The congestion in the small playground (S_5) is aggravated because of its narrow entrance. During 400–700 s, Gubai Garden (S_2) also becomes saturated, and all the remaining people flock to the small playground (S_5), forming a new congestion point. In the later stage of evacuation (700–1,400 s), the intersection near the small playground (S_5) becomes a new congestion area, and especially the west entrance is heavily congested due to the concentration of people. The congestion gradually eases after 1,100 s, and the evacuation is finally completed before 1,465.5 s.

2.2 Analysis of shelters

2.2.1 Uneven layout of shelters. The six shelters on campus are distributed unevenly, that is, they are dense in the north and sparse in the south. Yuxiu Garden (S_1), Gubai Garden and a large green space around the experimental building (S_2), and the small square in front of the residential area (S_4), which are adjacent to the family area, dormitory area and teaching area, are densely distributed but have limited capacity. With 10 min as the emergency evacuation standard, when the evacuation lasts for 600 s, the three small-capacity shelters are full, but about half of the disabled, the elderly and children have not been evacuated. As shown in Fig.2, the playgrounds at the edge of the campus have the largest capacity, but their utilization is insufficient because they are far away from evacuation demand points. In general, the total capacity of the six shelters can meet the demand, but their distribution is unbalanced: the middle small-capacity shelters have high accessibility and utilization rate; the surrounding large-capacity shelters are poor in accessibility and insufficient in utilization.

2.2.2 Evacuation paths have been adjusted several times due to the limited capacity of shelters. The evacuation time of people from a single building is shown in Fig.2. In the evacuation time of all buildings during the day, Boyuan Building has the fastest evacuation due to the small number of people and its proximity to the large playground (S_6) (having the largest area and the most entrances among the evacuation shelters). At night, the teaching area is empty, and the evacuation time of building 1 in the family area is the shortest, only 77.6 s, because it is close to the small square in the family area (S_4). As shown in Fig.3–Fig.4, in the process of emergency evacuation, after the capacity of the small square in the family area (S_4), Yuxiu Garden (S_1), Gubai Garden (S_2) and fountain square (S_3) reached the maximum, the remaining people who are not settled in time will tend to concentrate in the small playground (S_5), which has the nearest evacuation distance and relatively abundant remaining capacity. For instance, Huizhai is the farthest from the small playground. During the evacuation process, some students including the disabled move slowly due to their limited mobility. When the capacity of other shelters reached the maximum, the evacuation route of the students has to be adjusted several times, and finally they are evacuated to the small playground.

2.2.3 The narrow entrances of shelters and buildings lead to evacuation congestion. In addition to the small square (S_4), Gubai Garden and a large green space around the experimental building (S_2), the entrances of other shelters are small in number and relatively narrow. When arriving at the roads outside a shelter, people gather at the entrances, so that only one or two students can pass through the entrance and exit each time because their overall volume is too large and move slowly, which seriously affects the evacuation time. For example, the small playground is only equipped with three entrances, and the width of each entrance and exit is

Table 4 Time required to complete the evacuation of all types of people during the day

Type	Number	Earliest ompletion time//s	Latest completion time//s	Average evacuation time//s	Average walking distance//m
Students/teachers/staff	13,470	12.4	1,120.8	195.2	228.7
The old	510	72.0	323.7	169.0	216.9
Children	675	46.1	1,088.2	351.3	281.9
Students with language barriers	120	45.8	1,119.4	247.6	271.8
Students with hearing impairment	247	32.5	1,098.2	216.3	244.6
Students with visual impairment	499	52.3	1,112.5	594.9	390.2
Students with physical disabilities (independently using a wheelchair)	25	70.2	1,110.0	549.9	463.0
Students with physical disabilities (using a wheelchair with assistance)	25	113.9	1,106.5	602.5	184.5
Students with physical disabilities (using crutches)	56	64.4	1,110.5	483.6	358.5

Table 5 Time required to complete the evacuation of all types of people at night

Type	Number	Earliest completion time//s	Latest completion time//s	Average evacuation time//s	Average walking distance//m
Students/teachers/staff	12,999	12.2	1,464.0	317.0	286.3
The old	510	74.6	1,314.1	198.3	215.4
Children	675	46.2	1,465.3	457.9	328.0
Students with language barriers	124	32.3	1,138.1	291.0	274.5
Students with hearing impairment	251	29.0	1,461.9	336.1	304.8
Students with visual impairment	504	29.8	1,464.4	710.1	423.7
Students with physical disabilities (independently using a wheelchair)	27	51.7	1,440.3	721.8	435.5
Students with physical disabilities (using a wheelchair with assistance)	27	127.3	1,415.1	701.8	416.6
Students with physical disabilities (using crutches)	60	102.8	1,403.3	650.5	394.5

limited to 3 m. Moreover, it has an unbalanced distribution of double doors on the north side and a single door on the south side. The southern entrance is far away from the main gathering area of evacuation personnel, so people tend to use the two closer entrances on the northern side in an emergency evacuation situation. However, the width of the two entrances seriously restricts the evacuation rate of the crowd, so that a large number of people are unable to enter the shelter in time, resulting in congestion near the entrances and on the road leading to the shelter. It not only intensifies the congestion at the entrances of the shelter, but also leads to traffic congestion on the surrounding roads, greatly weakening the evacuation efficiency. Similarly, this phenomenon also occurs around the entrances of some buildings.

2.3 Analysis of campus paths

2.3.1 Excessive greening encroaches on roads and then affects evacuation. The excessive greening design on campus has a significant limiting impact on the actual passing width of roads, and then affects the overall evacuation efficiency of the campus. For instance, excessive campus greening encroaches on road space at the north gate of Lixue Building, the north side of Xinzhai, buildings 4, 5 and 6 in the family area, and the entrance and exit on the east side of Yazhai, which directly leads to the congestion in the evacuation process and prolongs the evacuation time.

2.3.2 The design of building entrances affects the evacuation. Roads or stairs are set at the entrances of some buildings on campus to deal with the possible significant terrain height difference between the interior and exterior of buildings. These ramps or steps are too long and occupy the main roads on campus, so that roads become narrow suddenly during the evacuation process, which hinders the smooth evacuation of people.

2.3.3 The evacuation paths of disabled students conflict with other people. In the evacuation process, some disabled students, such as those with physical disabilities, are often followed by a large number of ordinary students when they are evacuated from a building. Because there are too many people at this time, even though the evacuation speed of ordinary students is set at 1.45 m/s at the beginning, in the actual evacuation process, their speed has to be consistent with that of disabled students (0.8 m/s), which directly leads to a significant decline in the evacuation efficiency of a large number of ordinary students, and in turn adversely affects the overall evacuation time.

2.3.4 Congestion points during evacuation. Regarding the definition of evacuation congestion, the academic community has widely discussed the relationship between crowd density and traveling speed: when the crowd density is <0.29 p/m^2, the crowd can be freely evacuated, and the walking speed is not affected; as the crowd density is 0.29–0.50 p/m^2, the crowd evacuation is limited, and the walking is slightly affected; when the crowd density is 0.50–0.74 p/m^2, the crowd evacuation is greatly restricted, and the walking speed is slowed down; as the crowd density is 0.74–2.0 p/m^2, the crowd evacuation conflict is large, and the walking speed is seriously affected; when the crowd density is $\geqslant$ 2.0 p/m^2, there is large congestion[13]. Therefore, when the crowd density reaches or exceeds 2.0 p/m^2, the simulation is judged as congestion, which affects the walking speed and direction.

By comparing the evacuation situation of people on campus during the day and at night, it can be found that in the evacuation process, congestion often occurs at the intersection of

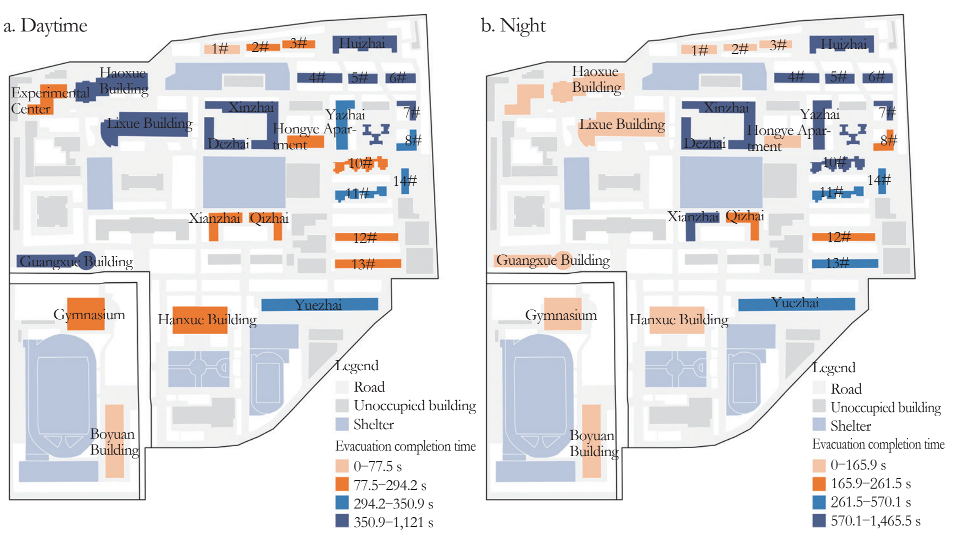


Fig.2 Time of evacuating different types of people from a single building

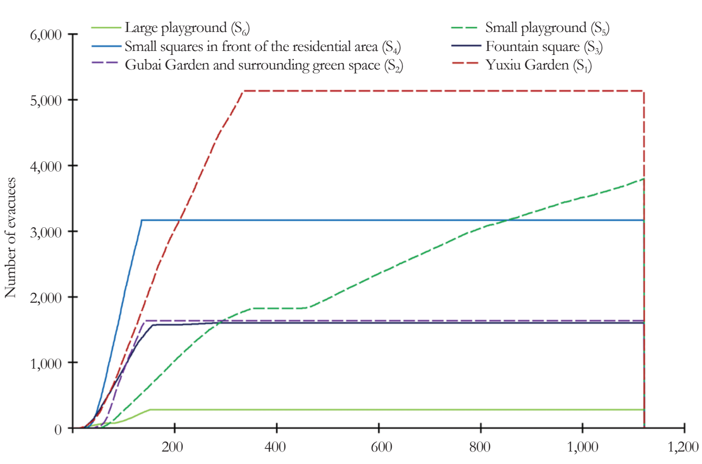


Fig.3 Relationship between time and the number of evacuees from each shelter during the day

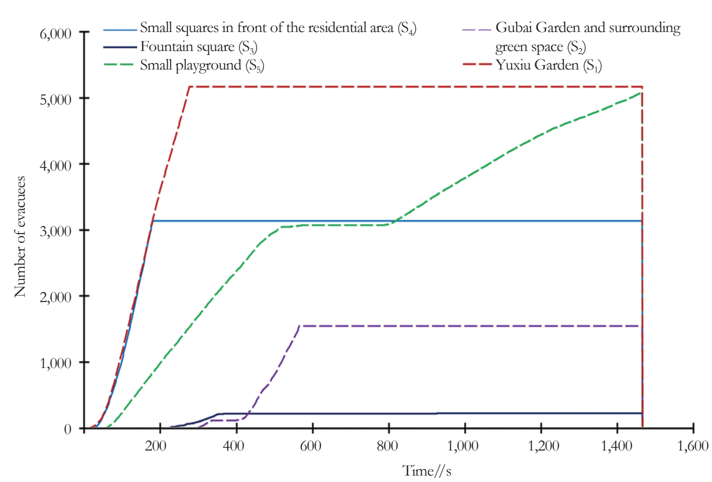


Fig.4 Relationship between time and the number of evacuees from each shelter at night

people flow, the turning point of campus passageway, the sudden narrowing of a road, the entrance of a shelter and the narrow part of a road (Fig.5).

3 Optimization strategies

Based on the analysis of campus evacuation during the daytime and night, some optimization strategies are proposed from the aspects of space environment and emergency management.

3.1 Optimization strategies of spatial environment

3.1.1 Renewal design of roads.

(1) Reducing the green area beside roads. Due to the narrow passage space caused by excessive vegetation greening along campus roads, the greening layout on both sides of roads should be appropriately adjusted and optimized according to Table 6. Green areas should be reduced to decrease the physical obstacles of vegetation to evacuation paths. In addition, as the key nodes of the intersection of people, intersections are prone to congestion. For such areas, it is needed to adjust greening, widen roads, and add passenger flow buffer areas to effectively reduce the duration of road congestion and further improve the fluency and efficiency of the campus evacuation process. During the transformation of campus roads, the campus landscape aesthetics, ecological environment protection and road functional requirements and other factors should also be comprehensively considered to not only improve road passage conditions but also protect the overall ecological environment and landscape style of the campus.

(2) Renovating building entrances. As for the excessively long ramps designed at the entrances of some buildings, optimization and reconstruction measures should be implemented to make them parallel to buildings by shortening their length or change their direction, so as to broaden the actual available width of roads, make evacuation passages unimpeded, and avoid adverse effects on emergency evacuation efficiency.

3.1.2 Renewal design of shelters.

(1) Improving the accessibility of shelters.

Firstly, the existing fences around the small playground (S_5) and the large playground (S_6) should be rationally planned and dismantled to speed up and optimize the evacuation process by breaking down physical barriers and significantly improving the accessibility of shelters. Besides, it also promotes the diversification of evacuation routes, and provide more diversified and flexible evacuation plans for campus teachers and students in emergency times.

(2) Increasing the number of entrances to shelters.

In view of the serious congestion that often occurs on the north side of the small playground in the evacuation process, it is suggested to add more entrances (Fig.6), so as to balance the use of different entrances and reduce the pressure caused by crowd concentration. At the same time, it is also necessary to properly widen the roads around the current entrances, enhance its traffic efficiency, and ensure that people can pass quickly and orderly. This measure can not only greatly improve the evacuation rate and reduce the evacuation time, but also further enhance the campus's response capacity and overall safety in emergency situations.

3.1.3 Renewal design of building entrances. During the design of some buildings, the designers neglect to provide necessary barrier-free evacuation facilities for disabled people, especially students with physical disabilities. The lack of barrier-free ramps greatly hinders the evacuation of such groups in emergency situations. In addition, the setting of building entrances has also become a key factor affecting the evacuation efficiency, because they are less and small. Such a design not only slows down the flow rate of personnel, but also easily causes congestion inside a building in an emergency. Especially for students with physical inconvenience and limited mobility, their physical condition and movement mode often make the congestion at the entrances more prominent, thus further delaying the overall progress of evacuation.

In view of the large number of people gathering at the entrances in the process of building evacuation, the primary measure is to expand the specifications of existing entrances to allow more people to pass smoothly during emergency evacuation. Secondly, it is suggested to reasonably increase the number of building entrances, or adjust the layout orientation of entrances, so that they are directly connected to evacuation paths and evacuation areas, so as to simplify evacuation routes and accelerate evacuation process. This will significantly enhance the fluency of evacuation operations, speed up evacuation, and create safer and more efficient evacuation conditions for all evacuees, especially those with disabilities.

3.2 Optimization strategies of emergency management

3.2.1 Improving campus evacuation facilities.

(1) Improving barrier-free signage system. During the evacuation process, barrier-free signs should be set up at important nodes such as evacuation paths and emergency shelters on campus to facilitate the evacuation of people with disabilities, the elderly and children.

Because there are different types of people on campus, the emphasis of barrier-free signs designed for different groups is also different. For barrier-free signs for visually impaired people, the background should be clearly distinguished from the pattern sign, and the font should be larger. They should be placed in a bright place as much as possible, and can also be suggested by touch (such as braille) or sound. The hearing impaired should use clear visual signs or light cues[22]. Considering the vision, hearing and mobility problems of the elderly, the design should integrate the above elements to achieve universality. For people with mobility difficulties and children, it is necessary to pay attention to the accessibility and understanding of the signs, and appropriately reduce the height. The signs for children should be intuitive, easy to understand and full of childlike interest to promote rapid memory and recognition, and optimize the efficiency of emergency evacuation.

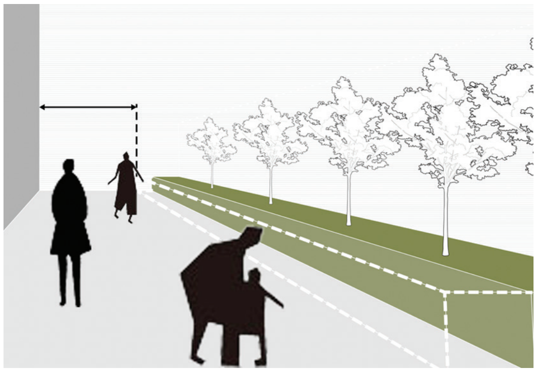
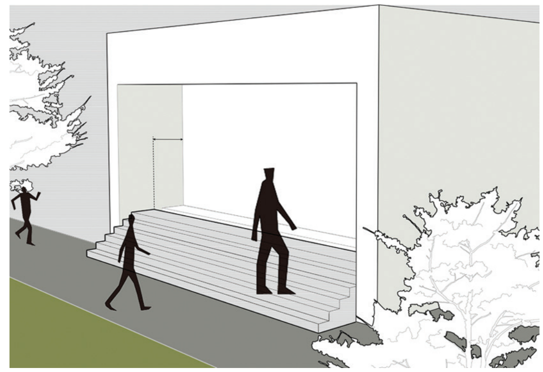
(2) Upgrading lighting facilities. Evacuations at night faces unique challenges compared to daytime, mainly due to the lack of ambient light. Therefore, it is particularly critical to strengthen the setting of lighting system along evacuation paths. Ensuring adequate lighting and proper layout can not only effectively reduce the fear caused by the disaster itself and the dark environment, but also greatly decrease the incidence of evacuation accidents caused by limited sight.

At key points such as the entrances of buildings, the turning position of roads, the intersection of people and the entrances of shelters, special lighting enhancement programs need to be adopted. These areas are obstruction points or turning points in the evacuation process, and improving their lighting conditions is of great significance to ensure the safety of all evacuees. Especially for students, the elderly and children with visual impairments, increasing lighting facilities can greatly reduce the possibility of accidents for them, thereby improving the efficiency and safety of the entire evacuation operation.

3.2.2 Improving campus evacuation management.

(1) Strengthening evacuation drills for teachers and students on campus. Students are encouraged to take the initiative to participate in evacuation drills organized by the school regularly, so as to enhance the emergency response ability of the campus and the self-protection ability of students. Through frequently participating in evacuation drills, students can not only be familiar with and master correct

Table 6 Evacuation strategies of each congestion point

No.	AC, E, H, I, J, G, L, N, P, O	B, D, M
Characteristic	Greening area is too large and roads are narrow	The slope or steps at the entrance of a building are too long
Strategy		
	Reducing the greening area of roads and the plant elements hindering evacuation Widen the actual usable width of the road by shortening the length of ramps or steps or changing the direction of ramps or steps to make them parallel to the building	Making too long ramps parallel to buildings by shortening their length or change their direction, so as to broadening the actual available width of roads

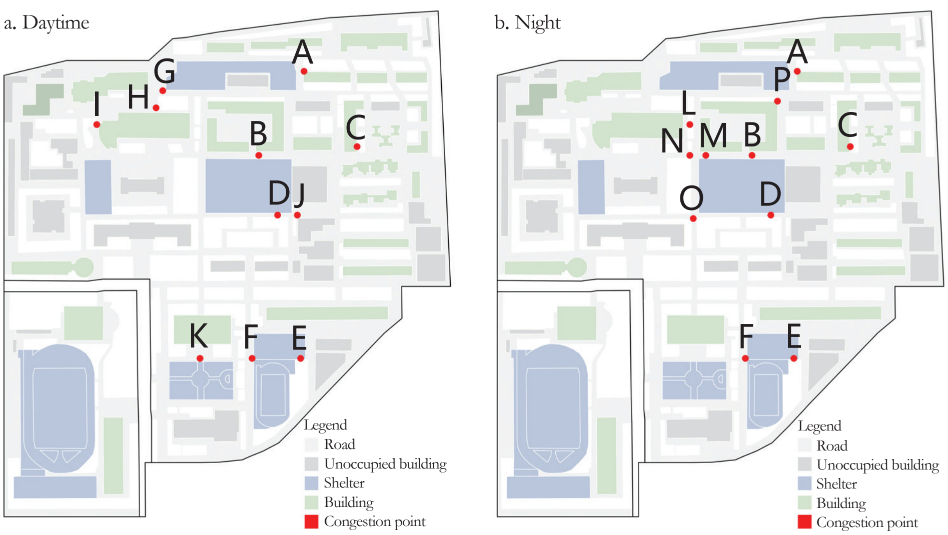


Fig.5 Congestion points during evacuation

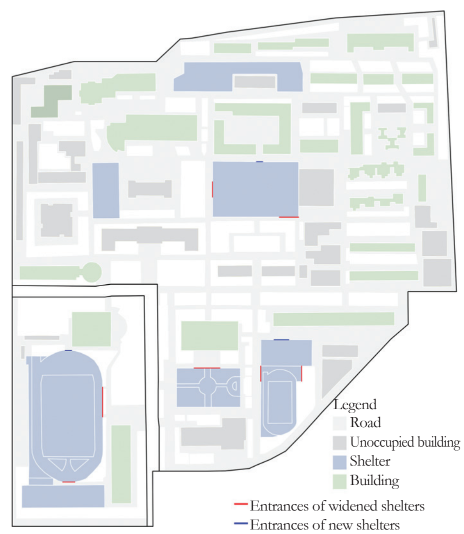


Fig.6 Location of entrances of shelters after modification

evacuation steps and skills, but also show a high degree of organization and rapid response ability when a real disaster occurs, so as to be evacuated quickly and orderly. This approach is of great significance to prevent the unknown risks brought by disasters and mitigate their possible consequences.

(2) Reasonably planning evacuation paths. In order to improve the barrier-free evacuation strategies of the campus, the district evacuation plan should be scientifically planned, and the personnel in a specific area should be clearly guided to the pre-set safe evacuation place. In this process, it is necessary to classify the evacuated crowd in detail, especially to distinguish the disabled, the elderly, children and other special groups from ordinary adults and ordinary students, and effectively avoid the possible adverse interference between different groups through reasonable allocation of road space. The purpose of this measure is to improve the overall order of evacuation action, avoid the increase of evacuation time caused by conflicts or accidents in the evacuation process, so as to ensure the efficiency and safety of evacuation to the greatest extent.

4 Conclusion

In this paper, taking North China University of Technology as an example, combined with field investigation and computer simulation technology, the problems encountered by various groups of people in campus emergencies were comprehensively discussed. Through field investigation, key information about campus population distribution, building structure, road system and shelters were collected, and Pathfinder software was used to simulate and analyze evacuation scenarios. The results of the simulation experiment during the daytime and at night show that there are obvious differences in the evacuation time of different people in various time periods. Some strategies of spacial environment optimization and emergency management were discussed.

However, this study also has several limitations: firstly, it considers the indoor and outdoor evacuation process of campus as a unified system, but ignores the possible problems in the evacuation of a single building; secondly, the specific proportion of pregnant women in special groups on campus has not been collected; thirdly, the difference of evacuation behavior between daytime and night is not fully considered.

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