



Multi-scale analysis of fire and evacuation drill in a multi-functional university high-rise building

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ABSTRACT

Fire evacuation drills are crucial for familiarizing occupants with building layouts and evacuation procedures. However, organizing a large drill in an educational site is rare due to the cost effort and data limitations. This paper examines a fire drill in a multi-functional university building in Hong Kong with over 800 participants. While capturing every participant's evacuation process was challenging, key location recordings allowed for a detailed analysis of corridors, staircases, and exits. The analysis revealed that nearly 50% of participants delayed responding to fire alarms, with some remaining in their rooms for over four minutes. Furthermore, exits experienced imbalanced utilization rates, and one was over 200% of design capacity, revealing occupants' preference for familiar routes. Additionally, it highlights the importance of fire drills and discusses future roadmap combining advanced techniques. Overall, this study offers valuable data on human behavior during emergencies, supporting the calibration and validation of evacuation models.

1. Introduction

Building fires are one of the top indoor emergencies to human safety and can quickly turn the built environment into a dangerous place including temperature, gas composition, luminance, and visibility (Kobes et al., 2010a; Hanea and Ale, 2009). According to the U.S. Fire Administration, there were 482,500 fires in residential and non-residential buildings in 2017, resulting in 2790 deaths, 12,025 injuries, and 10 billion dollars in damages (Sheeba and Jayaparvathy, 2019). In a fire emergency, the priority is to evacuate promptly and properly (Zhang et al., 2023). However, past fires have shown that people may be reluctant to evacuate or lack knowledge of how to do so. For example, the MGM hotel fire in Las Vegas caused over 80 deaths, with half of the fatalities found in their rooms, indicating they did not try to evacuate. These lessons emphasize the importance of proper fire education and evacuation planning in building fires (Shi et al., 2019; Uhlík et al., 2024).

Improper evacuation behavior can result in injuries during a fire due to occupants being unfamiliar with the evacuation process and increased

stress during an emergency (Wang et al., 2023, 2024; Zhang et al., 2022). To combat this, pre-training such as fire drills can improve occupants' evacuation performance (Lovreglio et al., 2019; Sriniketh et al., 2023). There are two main types of drills: field drills (Hostetter et al., 2024) and virtual drills (Smith and Trenholme, 2009). Field drills involve a real-life building and occupants evacuate when they hear alarms and broadcasts. This can provide a real environment to learn pedestrians' performance during fire emergencies, where occupants receive fire and evacuation notifications and evacuate to a safe location. For example, Rahouti et al. (2020) conducted a fire drill and found that pre-evacuation time and walking speed data collected during an unannounced fire drill in two office buildings was significantly different from current literature but still within the recommended ranges of SFPE handbook (Hurley et al., 2015). Lovreglio et al. (2019) studied two unannounced drills and two unplanned evacuations and discovered that unplanned evacuations had higher pre-evacuation times and that 29% of the variance could be explained by factors such as evacuation type and group behavior. Peacock et al. (2012) summarized the stairwell movement speed during evacuation, which was $0.48 \text{ m/s} \pm 0.16 \text{ m/s}$, with

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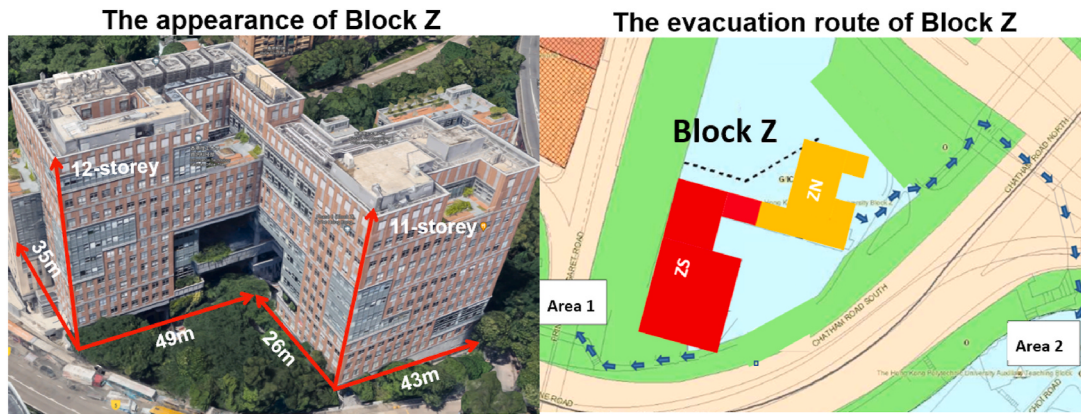


Fig. 1. The appearance and evacuation route of Block Z.

personal local movement speeds ranging from 0.056 m/s to 1.7 m/s. Kobes et al. (2010b) performed 83 unannounced evacuation drills in a hotel at night, suggesting that smoke influenced on route choice and low placed exit signs and individual knowledge of the building surroundings played a positive role.

Virtual drills, on the other hand, involve a virtual reality (VR) environment where participants experience a fire evacuation and move themselves to a safe place using controllers or a mouse (Kinateder et al., 2014; Ronchi et al., 2015; Arias et al., 2021). Studies have shown the effectiveness of VR fire drills. For instance, Ronchi et al. (2016) studied the effect of flashing lights in a VR experiment and recommended design changes for emergency exit portals in road tunnels. Kinateder et al. (Kinateder and Warren, 2016; Kinateder et al., 2018a) tested the effect of social influence on exit choices during an emergency in VR scenarios. VR drills are room-saving, controllable, and repeatable, but they also have several limitations. Participants may be aware that they are in a VR environment; there may be limited interaction among participants; and physical exhaustion is not accurately simulated. Additionally, some scenarios may not be realistically represented (Kinateder et al., 2018b; Xu et al., 2020). One specific example is the challenge that current VR technology struggles to provide real-time and authentic feedback to participants during the movement on stairs. Thus, while VR experiments are increasingly popular in learning human behavior in emergency, fire drills still play a critical role. In the future, it would be worthwhile to explore the hybrid of VR-based training in university fire drills and implement pilot educational programs among university students, especially majoring in fire engineering.

At this stage, fire drills remain the most effective method for training university students and staff in emergency response capabilities. Well-prepared and well-designed drills are uncommon and valuable, and regarded as a precious resource to study human behavior while training occupants to behave properly in a fire evacuation (Menzemer et al., 2024). While some research has applied in high-rise buildings, their findings focus on some specific parts such as staircases or exit choices but not the whole process (Yu et al., 2014; Andr  e et al., 2016). Moreover, drills are extremely essential at a university building in training occupants how to evacuate properly and orderly. Those buildings own complex layouts and structures while undertaking multiple functions such as classrooms, offices and laboratories with high density of students and staff. Fire drills are also significant for university participants to experience and train the usage of the emergency facilities and key nodes of their daily work and study places. Additionally, compared to different types of people from the public, college students and employees generally have a better knowledge of safety. Therefore, observation of evacuation behaviors of these human group is also interesting for the research of human behavior in fire.

Corridors, staircases, and exit doors are the key nodes in any evacuation route in complex buildings. Many studies presented important

impact of key nodes in buildings on the evacuation process. For example, Peacock et al. (2017) analyzed 14 building fire drills to study the impacts of stair geometry on pedestrian movement during building evacuation. Heli  vaara et al. (2012) studied evacuation behavior on corridors and exit door selection in an evacuation drill. Therefore, key nodes in buildings are essential to human evacuation and multi-scale and comprehensive analysis for evacuation movements in different egress nodes are significant to understand evacuation behaviors.

Aiming to this, we have conducted a field evacuation drill in a multi-function building at the Hong Kong Polytechnic University (PolyU). In the paper, we introduced the drill in detail including the drill plan, participants, evacuation process, etc. Key parameters such as response time, route choices, moving time and speed were calculated and presented. In addition, multi-scale analysis of the evacuation performances on the corridors, staircases and exit doors were conducted emphatically. Finally, the paper discussed individuals and groups' drill process, compared drills and field experiments, and discussed fire drills' contribution and challenges. On the one hand, this study was a real and effective training to students and staffs, where they experienced the whole process of the evacuation and learned the layout of the building, the correct evacuation route, and proper response to a fire emergency. On the other hand, it contributes to an improved understanding of human behavior in a fire evacuation including response time, route choice, speed etc., which provides valuable human behavior dataset for further model development.

2. Methodology

2.1. Fire drill arrangements and participants

The drill was conducted at 11:00 a.m. on October 26, 2022. Before that, the Campus Facilities and Sustainability Office (CFSO) had sent two rounds of email notifications to all university staffs and students. The first round was sent on the 17th, October, and the second was sent one day before the drill, ensuring that the occupants were aware of the drill and its purpose. These email notices provided the necessary information to participate in the drill. The notification contained the date and time of the drill, available routes, the purpose of the drill, the suggested procedure, and the safeguard of the campus emergency teams, see Supplementary Material. In addition, due to the Covid-19 pandemic, there would not be any assembly point. There were two suggested evacuation destinations as declared on the ground floor, Area 1 and Area 2, see Fig. 1. The notification requested the following points.

The main participants in the fire drill at PolyU consisted of students and staff of the Faculty of Construction and Environment. Also, there were many visitors from other departments to some classrooms or some lab rooms. The post-drill statistics recorded over 800 participants in the building, who all successfully completed the drill, and it was apparent

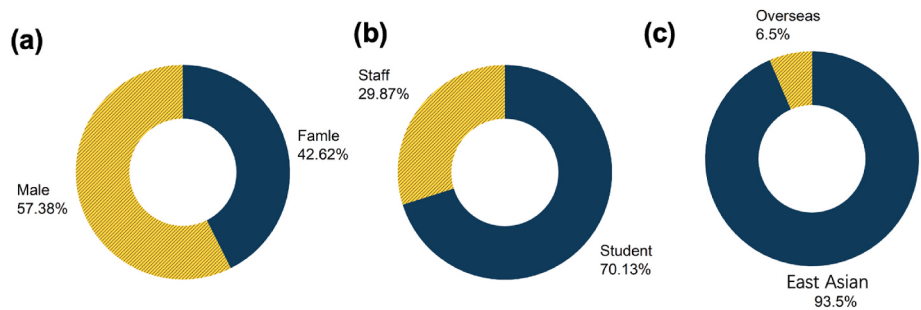


Fig. 2. The demographics of participants in the fire drill.

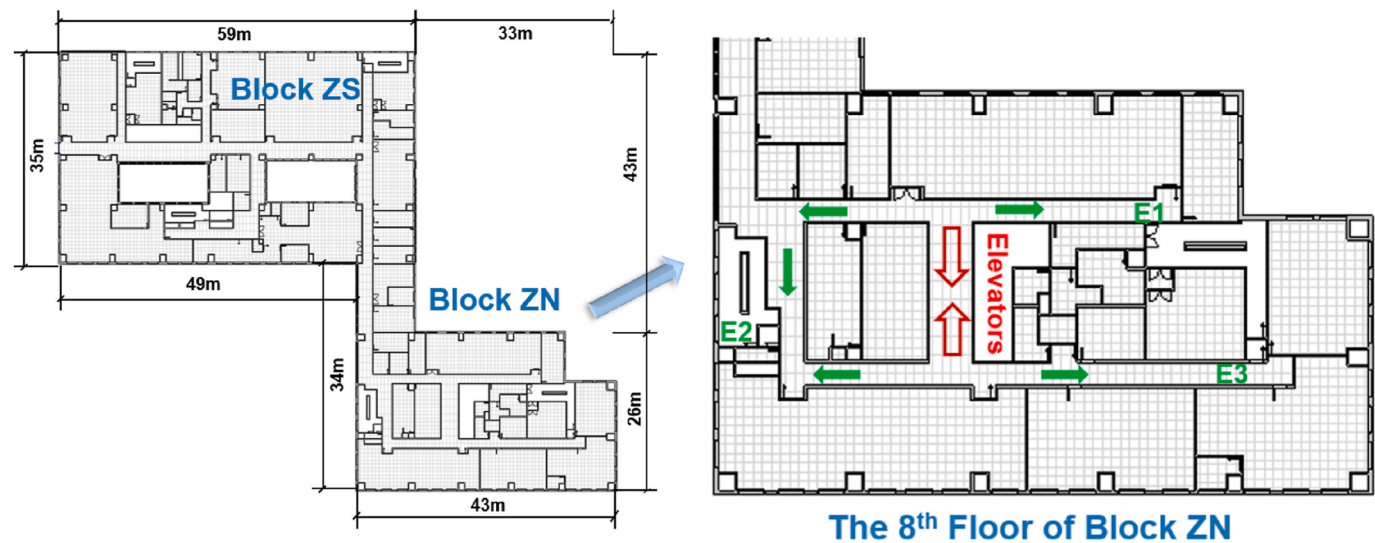


Fig. 3. The floor plan of Block ZN (the 8th floor as an example).

from the recordings to identify the demographics of 122 participants. Out of these, 52 were female and 70 were male, see Fig. 2, with the majority appearing to be students and less than 30% appearing to be staff or visitors. Most participants appeared as east Asians, while the

detailed races were not analyzed due to confidentiality considerations. The identification of demographics was not entirely precise, and the main purpose was to provide an overview of the participants' composition. Due to the Covid-19 restrictions, all people needed to wear masks

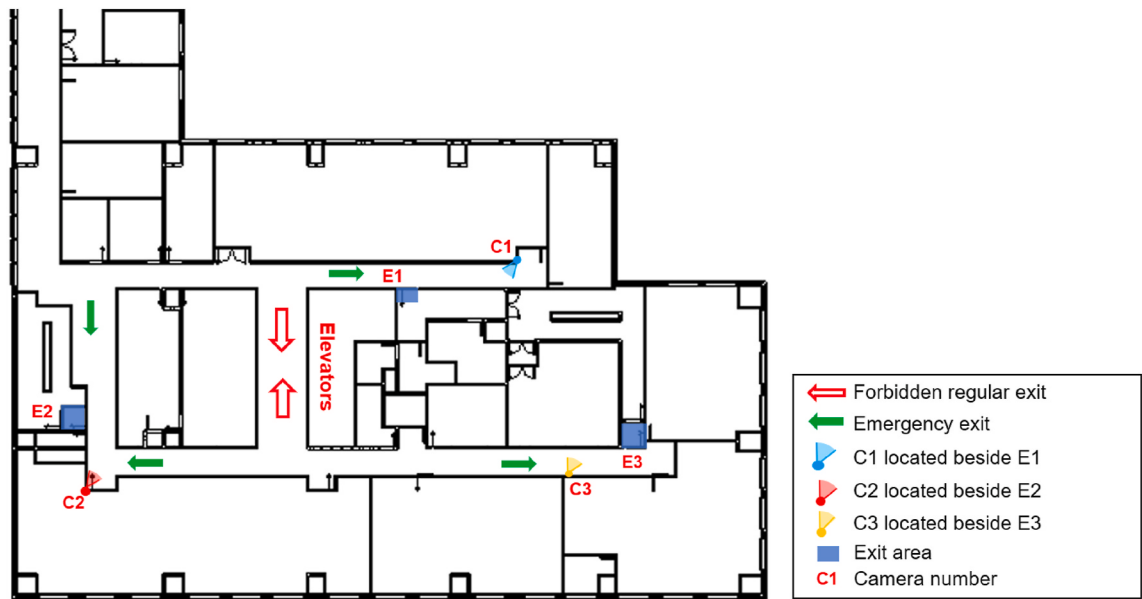


Fig. 4. The layout of cameras and exits on the 8th floor.

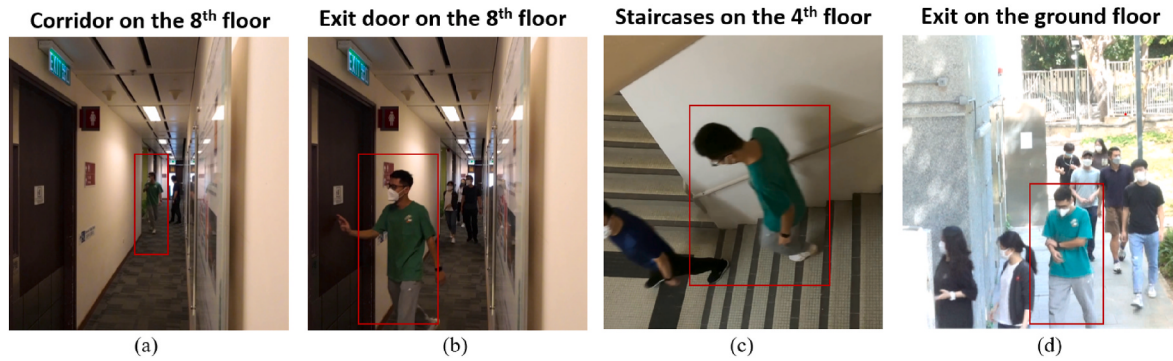


Fig. 5. Evacuation process, take the participant in the red box as an example (a) Participants heard the alarm, went outside the corridor on the 8th floor. (b) Participants found the exit door on the 8th floor, chose the targeted exit, and evacuated towards the exit. (c) Participants travelled to the ground via staircases (the 4th floor). (d) Participants escaped from the assumed dangerous building through emergency exits on the ground floor, and reached safe areas.

in public area, which applied to the whole drill process.

2.2. Building specifications

The fire drill was conducted in a multi-functional building called Block Z at the PolyU campus in Hong Kong, China. The building serving as a teaching, research and office space for the Faculty of Construction and Environment. The site area is 0.96 ha, and the construction floor area is 46,000 m². This high-rise building consists of two parts, Block ZN (North part) with 11 floors and Block ZS (South part) with 12 floors. The 0th (ground) floor is used for building equipment and maintenance, the 1st to 5th floors are used for teaching, the 6th to 9th for research and offices, and the 10th to 12th for various teaching and research laboratories (e.g., environmental lab and fire lab). In addition, there are another two levels of basements for teaching labs and research offices. The location and dimensions of Block Z are illustrated in Fig. 1. The floors are connected by multiple staircases and elevators following the construction requirements. Specifically, Block ZN owns three emergency exits (E1-E3) shown in Fig. 3, while elevators are forbidden in emergencies.

2.3. Recording approaches

The recording system consisted of six fixed video cameras covering key nodes of evacuation routes. Three cameras were installed on the 8th

floor, such as corridors, exit doors, and staircases of Block ZN, see Fig. 4; one on the junction of the staircases of the 7th and 8th floor; and one on the 4th floor. In addition, one camera was fixed outside the building to cover the exit to Area 2 (see Fig. 1). To minimize interference with participants' movements and ensure natural behavior, discreet GoPro cameras were selected for their compact size and easy mounting on handrails, providing unobstructed footage. These cameras captured the entire evacuation process, including preparation time, movement time, and evacuation trajectories. However, limited camera coverage meant that some areas, such as individual rooms or crowded sections, were not fully visible, potentially impacting data on individual response times and movement paths. Despite these limitations, the video data offered valuable insights into social behavior, such as movement patterns, interactions among participants, and social distancing during evacuation.

2.4. Ethical considerations

The research group worked closely with the CFSO at the Hong Kong Polytechnic University to ensure the safety of participants in the evacuation drill. All evacuation routes were cleared and free from obstacles, and medical staff were present to aid if needed. To avoid any physical or mental harm, proper health care measures were put in place. Two rounds of email notifications were sent in advance to inform participants, and the research group received PolyU Institutional Review Board (IRB) approval to the fire drill such as video recording and analysis for

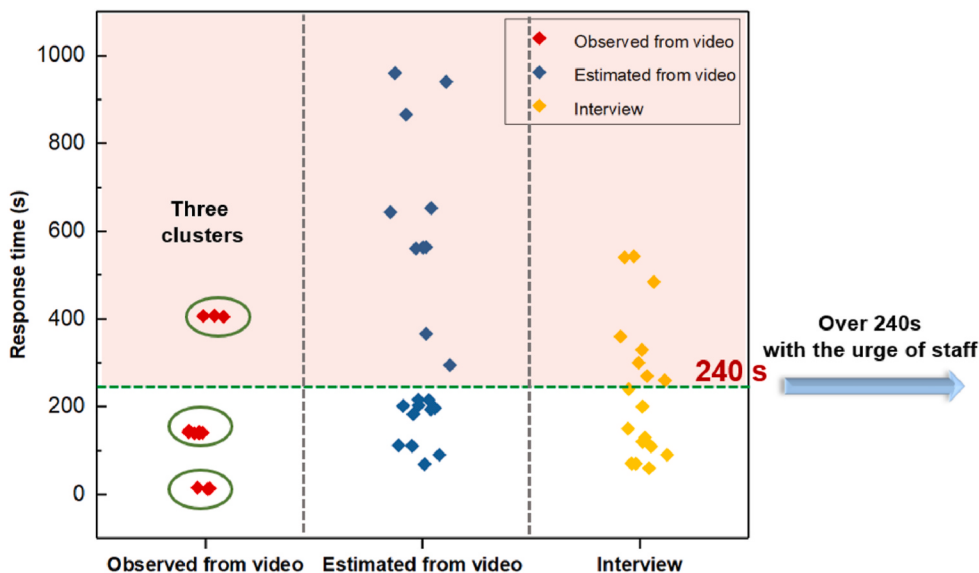
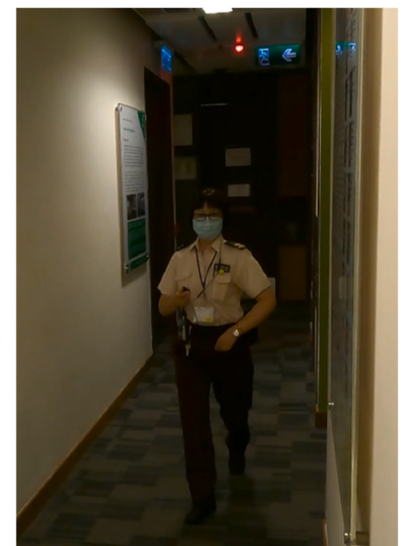


Fig. 6. Response time distribution.



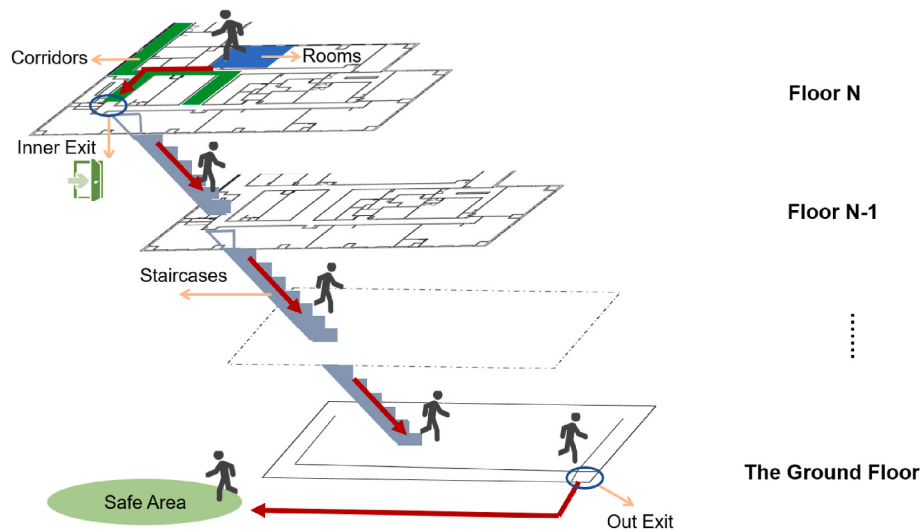


Fig. 7. Evacuation routes with exit doors, corridors and staircases.

academic purposes.

3. Drill results and analysis

The whole fire drill lasted for 22 min till all people (over 800 participants) evacuated from the building and arrived at the safe area (Area 1 or Area 2). No injuries or accidents occurred throughout the drill. To point out, it was difficult to cover the whole building with cameras and trace each occupants' full evacuation process. Thus, the results below were extracted and processed from part of participants based on the recordings. The drill was conducted as planned following the process below, see Fig. 5.

- (1) The staff for this drill fixed the recording systems and switched them on before the drill.
- (2) The electronic alarm system with sharp voice operated at 11: 00a. m., 26th October 2022 to notify the occupants in the building, and it repeated till all people evacuated.
- (3) When the alarm was activated, some students and staff evacuated immediately via the nearest exit and staircase, while some others waited for a couple of minutes. Generally, the crowd gradually evacuated to the nearest exits on their floors from 30s to more than 10 min.
- (4) The participants then crossed the stairs to the ground level, passed through the emergency exits and eventually reached Area 1 or Area 2.

3.1. Response time through room doors

Generally, response time refers to the time from the start of the fire alarm till one occupant starts to move. However, the limited number of cameras and lack of central monitoring systems made it challenging to monitor all occupants. Considering the original aim is to evaluate people's willingness and starting point to evacuation, we extracted the time point as people left their rooms as a replacement. Thus, to estimate response time, three methods were employed: direct extraction, estimation of walking on corridors, and interview. The results obtained through these methods helped to assess the effectiveness of the fire alarm systems and the evacuation preparation of the occupants, ultimately ensuring their safety in the event of a fire, shown as Fig. 6.

- (1) 12 occupants' response time were observed from the recording video directly when they left their room, see Fig. 6. Though the

exact response time should exclude the time they moved in their rooms, it is difficult to monitor the movement in rooms, and the response time here was the time they left the rooms, as stated above. The video captured 12 occupants from three rooms with three people, three people, and six people respectively, and the average time were 14s, 141s, and 406s for three rooms. After 240s of the fire alarm, a staff of CFSO went to all rooms to urge occupants to evacuate, and they evacuated from the room afterwards. The response time showed apparent three clusters of response time corresponding to three rooms. This suggests people's response time are similar to their surrounding people, and their response to fire alarms are likely to be affected by each other.

- (2) 21 occupants' response time were estimated from the recording videos according to their appearance at the floor's exit (the 8th floor) and walking distance. It was hard to distinguish their room number, but they appeared in the cameras when they exited from the floor's exit, and their walking on the corridors could be mostly tracked. The total time ranged from 77s to 975s from the alarm till they arrived at the exit door. The longest distance was around 50m, and the shortest was around 10m. Considering their normal walking speed, the estimated response time could be adjusted to 69s–960s. The longest response time was over 5 min, which was a long time in normal evacuation. Generally, in a fire emergency, the first few minutes are critical and delays in response time can largely obstruct evacuation safety.
- (3) Apart from the above, some response time were obtained via interview after the drill. Among interviews of 17 occupants, six of them stated that they heard the fire alarm, and prepared to leave the room promptly, and their self-evaluated time were within 2 min, see Fig. 6. The rest of them waited for a moment (2 min to 6 min), and they claimed:

I heard the fire alarm. It was really clear, but I assumed there would be many people near the exit, so I waited till one staff walked into my room and asked me to leave immediately.

The alarm got my attention. I read the email before, and I knew it was for a drill. I was busy replying to an email, and I left my seat until I finished it.

To be mentioned, they all expressed that they would react faster if it was not a drill alarm. However, only 12 observations of response time in this drill may induce variability and error to a certain extend.

Table 1
Comparison of corridors, staircases and exit doors.

	Corridors	Staircases		Exit doors	
		S1	S2	Inner door	Outside
Location	Every floor	5th-12th floor	1st-4th floor	Every floor	Ground floor
Width	1.2 m	1.0 m	1.4 m	1.0 m	1.5 m
Effective width	0.90 m–1.12 m	0.70 m–0.93 m	1.10 m–1.33 m	Not applicable	Not applicable
Flows	2–3	2	3	2	3
Function	Lead to the floor's exit doors	Lead to the 4th floor	Lead to the ground floor	Lead to staircases	Lead to safety areas

3.2. Effective width of key nodes: corridors, staircases and exit doors

There are three main parts to move through for an occupant's evacuation to the safety zone, namely exit doors, corridors and staircases. Those three parts connect to others and serve as whole evacuation routes to support occupants to reach the safety zone, see Fig. 7. Those three parts play different roles in evacuation, and their performance varied in the drill. The characteristics and comparison are listed as Table 1.

- (1) **Corridors:** The design of corridors is of utmost importance in ensuring the safety of building occupants in the event of an emergency (Ren et al., 2019). As the first passage for occupants to navigate to exits, corridors serve as crucial conduits connecting rooms to exit doors and staircases. To aid in prompt and correct egress, corridors should be equipped with clear and visible exit signs, such as directional arrows or "EXIT" patterns, to guide occupants towards the nearest exit. The width of a corridor is a crucial consideration in evacuation scenarios, as a narrow corridor may lead to congestion and stampedes, while a wide corridor incurs high cost and low space utilization. To balance cost-effectiveness and functionality, corridors in this building are designed with a width of 1.2 m, and the effective width can be calculated using Eq. (1) (Li et al., 2022; Lovreglio et al., 2015; Fujiyama and Tyler, 2011):

$$w(v) = W - 0.62 \cdot \frac{v}{v_M} \cdot w_0 \quad (1)$$

where:

W is the physical width of a structure;
 w_0 is the body width of an occupant, and choose 0.4 m;
 v is the walking speed of the occupant, ranging from 0.5 m/s to 2.0 m/s;
 v_M is the free speed, and choose 1.69 m/s in urgent occasions.

Thus, the effective width varies from 0.90 m to 1.12 m, and it could accommodate two people walking side by side at least, see Fig. 8(a). In addition, the current width is capable to accommodate if one more stream come directly opposite and meet face to face, and potential conflict could be avoided.

- (2) **Staircases:** Staircases are the specific vertical routes to evacuate in a fire emergency when elevators are forbidden (not in operation). In this building, two distinct types of staircases were constructed to accommodate the different densities of occupants on different floors. The first type, referred to as S1, are the staircases located above the 5th floor and have a width of 1.0m. The second type, referred to as S2, are the staircases located below the 5th floor and have a width of 1.4m. This design considered that the 5th floor is filled with classrooms and would have a larger flow of students, while the upper floors, mostly consisting of office rooms, have a lower density of occupants. According to Eq. (1), the effective width for S1 ranges from 0.70 m to 0.93 m, making it difficult for occupants to form two flows on the staircase due to the general width of a human body and potential social distancing, though the designed physical width of 1.0m looks like fit for two flows, see Fig. 8(b). Things will get worse if firefighters or other staff need to move in the opposite direction. However, the effective width for S2, which ranges from 1.10 m – 1.33m, is able to accommodate two flows easily as observed in Fig. 8(c). An increase in the width of the staircase can result in a stronger capacity for flow.
- (3) **Exit doors:** In this drill, two types of exit doors were utilized: the inner door, which connects the corridor on each floor, and the outer door, which separates the interior from the exterior of the building. The inner door is a one-sided, left-open door with an inner width of 1.0m, which automatically closes without external force. This door type is consistent for all inner exit doors leading to evacuation staircases. Observation from recordings showed that individuals passed through the inner door one by one, while they walked side by side on the corridors. Although the width was not sufficient for two people to pass through simultaneously, the maximum width of 1.0m could accommodate two flows, serving both as an evacuation route for occupants and as an entry point for firefighters during emergency operations. On the other hand, the outer door has a width of 1.5m, which can accommodate multiple flows and facilitate the entry of firefighting equipment if necessary (Cao et al., 2018; Haghani et al., 2020).

Despite emails instructing "No use of lifts," about 40% of occupants initially headed for lifts. They observed the lifts out of operation and subsequently found alternative exits.

3.3. Route choice on the specific doors

The results and analysis of route choices were from the recordings on



Fig. 8. Evacuation flows in corridors and staircases.

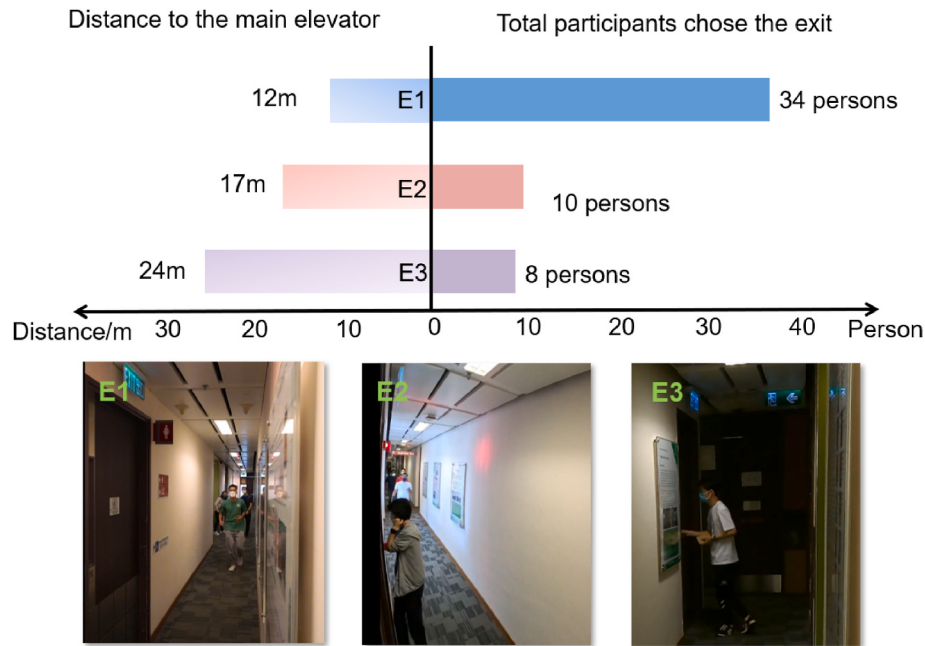


Fig. 9. Participants' exit choices.

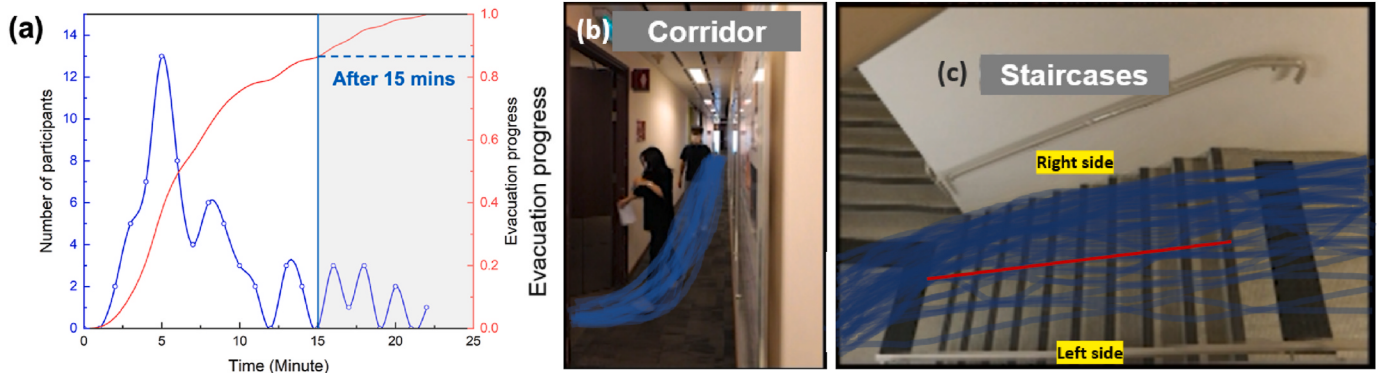


Fig. 10. Evacuation process (a) Number of occupants and corresponding evacuation process (b) Evacuation trajectories on the corridor, and (c) Evacuation trajectories on the staircases.

the 8th floor. There were three available routes towards three exit doors namely E1, E2, and E3, see Fig. 3, and we identified 52 people evacuated from E1 to E3 on the 8th floor. E1 locates on the northeast corner of the building and E3 on the southeast, which are connected after a flight of staircases. E2 locates on the southwest of the building, leading to individual staircases. Their distances to the main elevator refer to Fig. 9. Among 52 people on the 8th floor, 34 of them chose E1, 10 chose E2, and 8 chose E3.

More than half occupants chose E1, and some of them even walked over 20 m to approach E1. Some occupants stated that there was a small kitchen with a refrigerator and a microwave oven near E1. They went there frequently and were familiar with the layout there, which was the main reason for their route choice. For those people who chose E2 and E3, most of them expressed that their offices were near to the exit door, and they knew the evacuation route well. E1 had the nearest distance to the elevator while E3 had the longest. Though it is not fully convincing to conclude there is a negative relationship of participants and distance to the elevator, people are more likely to get familiar with layouts around the common access, the elevator. Thus, it suggested that familiarity was the most significant factor to make their evacuation route choices.

3.4. Movement process through the whole building

The drill started at 11:00 a.m., with the alarm ringing immediately. The occupants in Block Z walked out of their room, went downstairs and reached the safety zone on the ground floor (Area 1 or Area 2). From the video recordings, 72 people evacuated from the exit door in Block ZN and reached Area 2. The first person took 127s to leave the building and reached the safety zone with the guidance of CFSO staff. Nearly half occupants left the building successively within the next 4 min after the first person left the building. The whole evacuation process showed a fast period at the first few minutes and then decreased rapidly. After 15 min, over 80% occupants have finished the process, and only 10 people evacuated from the 16th min to the end, see the red line as evacuation people accumulated, Fig. 10(a).

Trajectories were collected and showed from one end of corridor to E1, see Fig. 10(b). Apparently, there was no bias of left and right along the corridor when they walked towards the exit. It could result from a mixture of traditional walking-left culture in Hong Kong and walking-right culture in other places like mainland, China and the United States.

Trajectories on the staircases then were extracted from videos on the fourth floor's staircases. The average speed of all people through the

Table 2

The exit usage rate of E1, E2 and E3.

	E1	E2	E3
ActualEUR	0.65	0.19	0.15
IdealDesignEUR	0.33	0.33	0.33

staircases was about 3–4 steps/s, and the speed ranges for each person were mostly from 0.5 m/s to 1.2 m/s.

We define the bias to left side or right side as following.

- (1) The space of the staircases is divided into left and right parts evenly.
- (2) If more than 70% length of the moving trajectories is on the left side, we regard the occupant has a moving bias on the left side.
- (3) If more than 70% length of the moving trajectories is on the right side, we regard the occupant has a moving bias on the right side.
- (4) Otherwise, the occupant does not show a strong bias to the left or the right side.

Based on the bias rule, all moving trajectories were processed see Fig. 10(c). 56% showed the bias on the right side, 37% showed no bias, and only 7% showed the bias on the left side. We then extracted no bias trajectories, and we found it mostly appeared when friends or colleagues walked together with side by side.

4. Discussion

The fire drill at a university campus provides valuable hands-on emergency experience for students and staff. Despite regular drills being encouraged or required in many higher education institutions, the participation of hundreds of individuals and the recording of the event through cameras made this drill particularly noteworthy in terms of fire safety education and human behavior investigation.

4.1. Evacuation performance on key nodes

Reviewing the evacuation performance on different building nodes (corridors, exit doors and staircases), we find the unbalance of exit utilization and the necessity of arranging guidelines in some key locations. For example, it is reasonable to provide manual guidance or specially labelled signage in the intersections of corridors or exit doors, which derives from the multi-scale analysis of route choices (Fig. 9). In this fire drill (the 8th floor), most evacuees tended to select their most familiar exit door rather than the shortest one. We can use the criteria of Exit Usage Rates to quantify the utilization of exits, shown as Eqs. (2) and (3) (Kubicki and Park, 2023).

$$ActualEUR = \frac{N_o^i}{\sum_i N_o^i} \quad (2)$$

$$IdealDesignEUR = \frac{N_a^i}{N_d} \quad (3)$$

where, N_o^i is observed number of occupants using exit i , $\sum_i N_o^i$ represents observed number of occupants using all exits, N_a^i number of occupants proportionally assigned by effective width of exit i , N_d represents design occupant load on the same floor.

In this drill, three exit doors are the same width (1 m) and the supposed design occupant load on 8th floor is 300. Therefore, the exit usage rate of E1, E2 and E3 can be calculated as Table 2. The ActualEUR of E1 is significantly larger than E2 and E3, and also exceeds the IdealDesignEUR. In contrast, the ActualEUR of E2 and E3 are both lower their IdealDesignEUR. It means that E1 is overused, while E2 and E3 are underused. The route to E1 is close to the main elevator and the pantry inducing to most evacuees using it rather than other egress route, which undoubtedly caused a certain amount of congestion around E1 and space resources wastage of other routes. Therefore, it is necessary to set extra guidance at the corridor to lead some evacuees toward E2 and E3.

As for the evacuation performance in the staircase of this drill, it appears that participants were able to maintain order and evacuate rapidly down the stairs. Since the staircases are equipped with normally

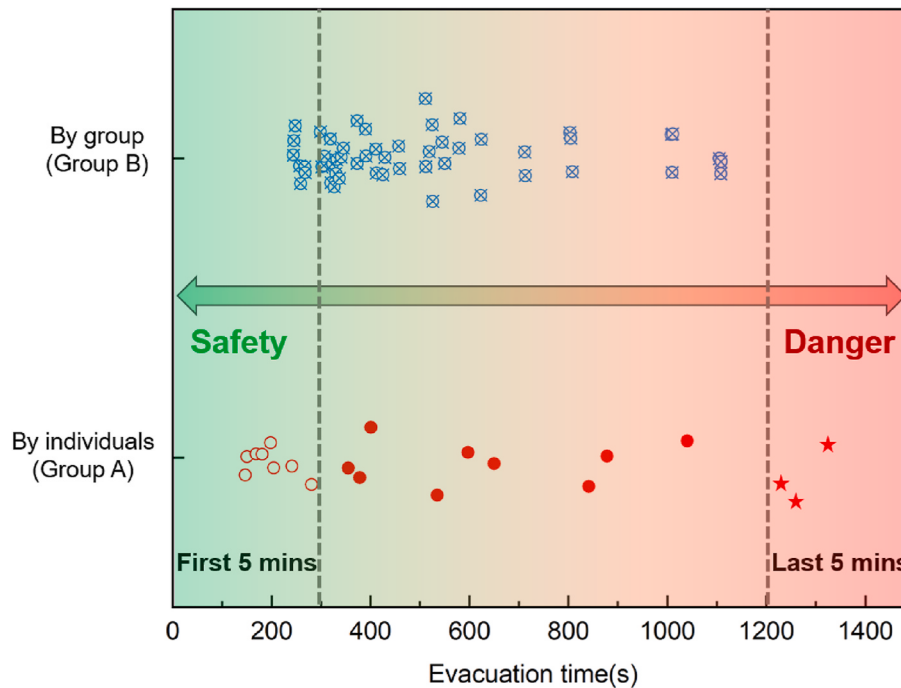


Fig. 11. Evacuation time by individual and by group. Group A refers to people evacuated by individuals (lower zone), and Group B (upper zone). Individuals are then divided into three types: evacuation time within 5 min (open circle), evacuated till the last 5 min (red star), and between them (filled circle).

closed fire doors, it is assumed that there would be no influx of smoke or flames entering the staircase during fire. Therefore, it is not necessary to arrange extra guidance besides basic signage on the staircases with good visual condition.

4.2. Evacuation process by individual and group

The evacuation behavior in a fire drill can be fulfilled from two forms: by individual and by group. Individual evacuation pertains to the act of single individuals leaving the building on their own, without supervision or aid from others. This process requires each individual to take accountability for their own safety and includes tasks such as making the decision to evacuate, identifying the evacuation route, and exiting the building expeditiously and safely (Li et al., 2024; Templeton et al., 2024). There are two scenarios for individual evacuation, either the occupants evacuate independently without the presence of other individuals or in the presence of others, yet without interaction or communication.

Group evacuation, on the other hand, refers to the process of individuals within a building evacuating together. With the guidance or assistance of others (Fu et al., 2019; Moussaïd et al., 2010). This process typically involves the use of designated evacuation leaders, who are responsible for guiding and assisting others in their evacuation or some voluntary leaders, who tend to lead a group or provide suggestion in emergency due to some social interaction and influence. Group evacuation entails individuals within a building leaving together with guidance or assistance from others. Group evacuation may include specific procedures such as the “buddy system,” where individuals are paired for mutual safety, or the use of “stairwell marshals” who assist individuals in the stairwells. In this scenario, individuals’ evacuation behavior is significantly impacted by the group dynamic, leading to similar evacuation choices in response time, evacuation route, and pace of movement.

From video recordings, evacuation forms of 72 occupants are distinguished and classified, see Fig. 11. It is apparent to distinguish about 30% occupants evacuated individually (Group A), 50% evacuated by group (Group B), and 20% were hard to distinguish either by group or by individual. The below discussion aims at Group A and Group B.

One third of the individual occupants finished evacuation within the first 5 min. These individuals were among the first to leave their rooms and quickly proceeded downstairs. In contrast, the remaining two thirds of the occupants displayed a slower reaction time, ranging from several minutes to over 10 min, and many started to evacuate after being prompted by the staff. The last three occupants (red star in Fig. 11) who evacuated in the last 5 min all evacuated independently. It indicated a lack of proper reaction or disregard for the warning alarm, presenting a significant risk of injury in a real-life fire evacuation scenario. The average total evacuation time was 553s, with a standard deviation (SD) of 405s.

For occupants who evacuated as a group, their evacuation time was moderate, with all completing the process within 20 min. Interviews revealed that some individuals took the lead, prompting colleagues to evacuate and waiting to ensure everyone gathered before leaving. Although group evacuation resulted in slightly slower times than faster individual evacuations, it helped encourage others to evacuate earlier, reducing delays. The average evacuation time for the group was 507 s, 8% faster than individual evacuations, suggesting group evacuations are generally more efficient. Additionally, the standard deviation (SD) for group evacuations was 251 s, 38% smaller than for individuals, indicating more stable evacuation times. This suggests that group evacuations lead to more coordinated and predictable outcomes, with less variation in evacuation times compared to individual efforts.

4.3. Comparison of data collection from fire drill, field experiment, and real life

Fire drills are crucial components in ensuring the safety of building

Table 3

Comparisons of drills, field experiments and real-life scenarios.

Subjects	Drills	Field experiments	Real-life scenarios
Place and scene	Design by human	Design by human	No human intervention
Scenarios	Emergency scenarios	Multiple scenarios like daily life, fire, earthquake, congestion	Daily life/ Accidents
Participants	Residents/ Occupants	Recruited volunteers	Residents/ Occupants
Objectives	• Test evacuation capacity of a building • Train occupants • Optimize evacuation strategies • Human behavior research	Vary largely such as • Test new design • Test new facilities • Human behavior research	• Daily life: Learn moving patterns • Accidents: No intention to have an accident
Data collection	Video, sensors, and GPS tracking devices	Video, sensors, and GPS tracking devices	Videos, social media, and interview

occupants. It is beneficial for people to practice proper evacuation procedures and familiarize themselves with the building’s fire safety systems and procedures in a real fire emergency. Fire drills are served as a platform for educating and training building occupants on fire safety protocol help to educate occupants on how to respond in case of a real emergency. Moreover, they provide building management with an opportunity to assess the effectiveness of fire safety systems and identify any potential shortcoming including evaluating the response time of fire alarms, assessing the efficiency of evacuation routes, and verifying the availability of fire safety equipment such as fire extinguishers. In addition, the data collected from these drills can provide valuable insights into human behavior in fire emergencies, allowing researchers to study and improve evacuation strategies and protocols.

Apart from the fire drill, field experiment and collection from real life are both used to obtain the information of human behaviors and movements, which help researchers and planners gain a better understanding of human movement behavior in emergency scenarios. It also could be applied for the design of spaces and systems that support safe and efficient evacuation. Table 3 listed comparisons of drills, field experiments and real-life scenarios.

Both drills and field experiments are human-designed approaches and involve the collection of data through techniques such as video cameras, sensors, and GPS tracking devices. The data collected can be used to analyze a wide range of topics, including pedestrian flow and crowd dynamics in different building nodes, the multi-scale impact of built environments on movement patterns, and the influence of social factors on evacuation behavior. The distinction between drills and field experiments lies in their objectives, scenarios and participants. Drills often refer to simulated or controlled scenarios that are used to test a building’s safety capacity and practice occupants’ response to certain situations. Thus, drills are mostly conducted in a real environment, and the participants are mostly residents of the building or working/studying/living in this environment. For example, the drill described in this paper aimed to test the fire alarm systems, the evacuation route performance in different building nodes, students and staff’s response to a fire emergency, and to train occupants to evacuate properly.

In contrast, experiments could either conduct a whole process of evacuation to the designated area, or a part of the whole evacuation such as making exit choices, going downstairs, route trajectories etc. These experiments often involve collecting data on the behavior of people or systems in specific environments, such as public spaces, transportation networks, or buildings. The environment could either be in accordance with the real world, or modified considering difference aims and purposes. Different from manual intervention of previous two methods,

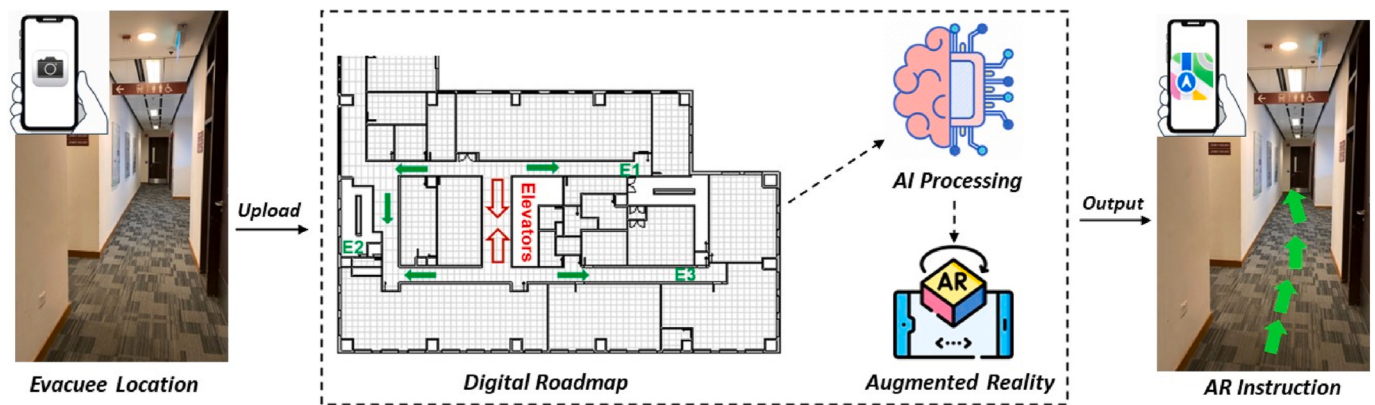


Fig. 12. Illustration of intelligent roadmap based on AI and AR.

occupants' movement parameters in real life always show the most authentic situation. On the one hand, the data could be derived from pedestrian's movement in daily life. On the other hand, it is rare but valuable to obtain data from evacuation in a real fire accident.

4.4. Perspective of the intelligent roadmap of fire evacuation

In Section 4.1, the necessity of guidance around key route nodes, i.e., exit doors and surrounding corridors is discussed. The results also show the unbalance of exit usage and route choices due to people's unfamiliarity with all access and routes. Some approaches such as intelligent roadmap application could solve the above issue by providing real-time evacuation route guidance (Zhang et al., 2024a). An illustration of the intelligent roadmap framework is shown as Fig. 12, combining artificial intelligence (AI) algorithms (Zhao et al., 2020; Zhang et al., 2024b) and augmented reality (AR) technology. AR is an interactive technology enhancing the real world with computer-generated perceptual information, which enables to overlay digital content onto real-life environments and objects (Huang et al., 2019; Ding et al., 2023). Using AR and its supporting application, the real-time route signage could be shown for the evacuee user to rapidly identify the egress route and exit door combining the original built-in 3D map in advance (Templeton et al., 2024; Zhang et al., 2024c; Balboa et al., 2024). In addition, AI algorithms play a role of intelligent computing engine for optimal path planning according to onsite evacuation conditions, i.e., spatial distributions of evacuees (Ding et al., 2024, 2025) and fuel hazards (Ding et al., 2024), flame and smoke development, usage rates of all exits, and crowd density of each corridor (Naser, 2022). In practice, evacuee users launch the intelligent road map application and upload a surrounding photo of current location, and the AI engine could rapidly recognize the user's location and compute the optimal route and display it by AR instruction.

Fire drills would be suitable to test the performance of the above intelligent applications or other evacuation systems. Other relevant emergency scenarios could also be designed according to the testing demands of these systems, and the participants enable experiencing the efficiency or inconvenience from using the evacuation system in immersive fire drill and providing their real feedback. However, how to ensure the working efficiency and accuracy of the system in smoke-filled environments is also a tough issue currently. In future work, it requires more advanced multimode perception technologies, i.e., millimeter wave radar or infrared for AR system to identify the user's relative positions in the fire building. Additionally, the dynamic distribution of smoke and fire movements also could be inserted into the AR environment to strengthen the immersive feeling for more authentic fire drill training.

5. Conclusions

This paper conducted a multi-scale analysis of a fire drill at a multi-functional building at the Hong Kong Polytechnic University. Upon activation of fire alarm bells at 11:00 a.m., about 800 occupants evacuated from the buildings either independently or with the assistance of our emergency team within 22 min. The study successfully recorded some evacuation process at key nodes of university buildings such as corridors, staircases and exit doors, and multi scale analysis from structure layout, evacuation choices, group behavior etc. are conducted. Some main conclusions are as following:

- 1) The drill was completed successfully without any injuries. The drill, on the one hand, tested the firefighting facilities such as fire alarms; on the other hand, was a chance for university occupants to experience how to respond in case of a real emergency, and the data were rare and valuable to study human behavior in fire as a field drill in educational settings.
- 2) Video recordings captured evacuation behavior data, revealing a delayed response by nearly half occupants who did not leave their rooms until reminded by staff. This highlights the need for further evacuation training in universities.
- 3) During the evacuation process, occupants performed apparent intimacy. They tended to wait for colleagues in the same room and evacuated together. Group evacuation showed a shorter time and a stable time distribution than individuals.
- 4) Occupants' performance of the corridors, staircases and exit doors were extracted and analyzed. They preferred to choose familiar exits as evacuation routes in their daily life, and the unbalance usage of exits are discovered and quantified.

In summary, human behavior in this fire drill was recorded and analyzed including response time, route choice, time and speed, etc. Moreover, thorough discussion of fire and evacuation drills were presented in key nodes in buildings, by individuals or by group, comparing to field experiments and real life. The paper fully explained the necessity and outcome of fire drills and is expected to call on more fire drills in educational settings to enhance the research of human behavior in fire in the future.

CRediT authorship contribution statement

Yuxin Zhang: Writing – original draft, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Yifei Ding:** Writing – original draft, Methodology, Investigation, Formal analysis. **Mohcine Chraïbi:** Writing – review & editing, Methodology, Conceptualization. **Xinyan Huang:** Writing – review & editing, Supervision, Investigation, Funding acquisition, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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