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Horizontal Movement of Kindergarten Children During a Primary School Fire Evacuation Drill

Javad Hashempour[1] · **Babak Bahrani**[2] · **Michael Kinsey**[3]

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Abstract

Occupant evacuation is a critical aspect of fire safety in buildings. Most evacuation strategies and design principles are based on data from adults, leaving gaps in understanding the unique evacuation behaviours of children. This study examines the movement characteristics of kindergarten children (ages 4–7) during evacuation drills in a primary school. Speed and flow were analysed in corridors and through exit doors of varying widths using video recordings. The findings reveal distinct behaviours, such as the absence of personal space and group-based movement, which differ significantly from adults. Correlations were observed between exit door width, density, and flow rates, highlighting that density alone does not fully explain evacuation dynamics. These insights emphasize the need for evacuation models tailored to children, addressing their unique behaviours and the effects of escape route design.

Keywords Evacuation · Children · Egress · Kindergarten · Human factor

1 Introduction

Egress strategies and designing effective evacuation routes is pivotal to building fire safety and comprise a significant part of building codes. With the rise of performance-based design of fire safety applications, analysing occupant behaviour and their movement during fire events has been experiencing a great demand in the recent decade and prompted research on formulating human behaviour in fire science. The focus of the research was to evaluate movement characteristics of occupants along the egress routes, including vertical and horizontal components. As a result, analytical models have been adopted to allow fire engineers

✉ Javad Hashempour
javad.hashempour@bcu.ac.uk

1 Department of Architecture and Built Environment, Birmingham City University, Birmingham B4 7XG, England, UK

2 Emerson Graham + Associates, Roanoke, VA, USA

3 Ashton Fire, Birmingham B4 5QJ, England, UK

to estimate the flow of building occupants [1] and overall evacuation time, which are necessary for evaluation of Required Safe Egress Time (RSET) for performance-based analysis.

The early research on mass motion in buildings outlines the relation of movement with the density of building occupants and their speed, clothing, and human anthropological characteristics [2, 3]. Later works continued by collecting data on occupants' movement have been based on unannounced, semi announced and announced evacuation drills in various occupancies. As a result, evacuation parameters better formulation and essentials for occupant evacuations such as pre-evacuation decision-making time [4, 5], downward or upward [6–8] speed of occupant over stairs, movement speed in horizontal sections such as corridors and movement characteristic near exit doors [9] have been studied and helped to develop analytical and computational evacuation models which are summarized in [10].

Buildings encompass various population groups that may not share the same characteristics as populations dominated by adults, as considered in the previous works. The elderly, people with disabilities and children are among the groups with physical and mental abilities different from adults in processing emergency cues and evacuating the buildings [11]. Previous research on elderly people highlighted a different evacuation behaviour affected by floor layouts, instruction and assistance by others, and occupants' characteristics. Research on disabled people found a movement speed of much less than the ones reported for adults [12], and it may vary depending on the types of assistance provided to disabled and elderly people during evacuation. Familiarity with evacuation plans and moving as a group found to be common behaviour among disabled and elderly people [13]. In another evacuation drill conducted at a university, the authors found differences between female and male disabled individuals in terms of evacuation movement times, and familiarity with the building greatly affected the overall evacuation time [14].

Like elderly and disabled people, children are among the vulnerable groups during fire emergencies, and the research community does not well understand their evacuation abilities and behaviours due to limited data available in the literature. In recent years, attempts to learn the evacuation behaviour of children with different age ranges have been prompted. Hamilton et al. conducted a series of evacuations in schools in Ireland to evaluate the pre-evacuation decision-making time, vertical and horizontal movement of children aged 4–12 years [15, 16]. They highlighted the age dependency and effect of handrails on school children's speed. The study also found that pupils use the entire width of exit doors, and their maximum flow is higher than those reported for adults, movement speed-age dependency. Evacuation drills in schools with children at pre-school age showed that familiarity with escape routes, children's age, and environmental conditions, including instructions by staff determine factors in the evacuation behaviours of children [17, 18]. In a series of evacuation drills, the movement of children aged 1–15 years old in schools in Denmark was studied along stairs and exit doors [19–21] in which a significant discrepancy between available theories for adults' evacuation movement and children data obtained by evacuation drills was reported. Ono et al. conducted a series of evacuation drills in a Brazilian school with pupils aged 6–14 years and noted the effect of instructions by school staff as an important factor to determine children and adolescent evacuation speed [22–24]. Similar conclusions were reported by others with evacuation drills in China [25], in Spain [26], and in Russia [27, 28] that led to the same findings.

Although the previous works shed light on the overall movement behaviour of children in the school evacuation, more research should be carried out to address children's evacuation behaviour. In essence, the behaviour should be analysed under various scenarios, building layout, and egress routes design to compile a database that allows validation of models, developing development simulation methods, and analytical theories specific to children. Moreover, the current data is also geographically limited to certain parts of the world that may not represent children's populations of different backgrounds, cultures, and demography. Therefore, more data on children's evacuation must be collected to address these shortcomings in the available data. To fill these gaps, this study (1) expands the emperical database by analysing two semi-announced drills with 135 kindergarten children in Muscat, Oman - an under-represented population and (2) systematically examines how exit-route components (corridor and two door width: 75 cm vs. 105 cm) affect speed, flow, and congestion patterns. Our findings offer child-specific correlations and challenge current egress-width prescriptions (e.g. NFPA 101's minimum clear width of 810 mm), supporting the development of tailored evacuation models and design recommendations for early-education facilities. The above gaps were the motivation of current work to expand available data on children's evacuation and further scrutinise the evacuation parameters with respect to the change of escape route components layout. Current work evaluates kindergarten children's movement on horizontal components, including exit doors of various widths through semi-announced evacuation drills in a kindergarten in Muscat, Oman.

2 Methodology

2.1 Evacuation Site and Procedure

The evacuation drill was conducted in a school with a basement in one of the neighbourhoods of Muscat, Oman. The school consisted of a three-story building and a basement that was allocated for gatherings and performances, accommodating children with a majority in an age range of 4–7 years old and a negligible number of pupils in grades 1 and 2. The total number of children in the school was 183 children aged 4 to 9 years old with a total staff of 22, resulting in a staff/children ratio of 1/9. Table 1 provides details of children's distribu-

Table 1 Details of children's distribution, age, and location in the Building

Grade	No. of children	Age (years)	Group age no.	Floor
KG-1-1	18	4–5	77	1st
KG-1-2	13	4–5		1st
KG-1-3	15	4–5		1st
KG-1-4	18	4–5		1st
KG-1-5	13	4–5		1st
KG-2-1	10	5–6	58	Ground floor
KG-2-2	10	5–6		Ground floor
KG-2-3	13	5–6		1st
KG-2-4	13	5–6		1st
KG-2-5	12	5–6		1st
G-1-1	17	6–7	32	2nd floor
G-1-2	15	6–7		2nd floor
G-2	8	7–8	–	Ground floor
G-3	5	8–9	–	2nd floor
G-4	3	9–10	–	2nd floor

tion, age, and location in the building. The evacuation drills are intended to focus only on children in the age range of 4–6 years old and exclude primary school-age children. The total number of kindergarten pupils for this study was 135, with a completely mixed gender profile in the classes. All kindergarten-age (K1 and K2) children were located on the first floor, and a few were on the ground floor.

The evacuation drills were conducted in a semi-announced manner. In this context, "semi-announced" refers to a procedure in which the school management team was informed of the drill in advance, but the exact timing and details were not disclosed to staff or children. This approach aimed to minimize the likelihood of foreknowedlge influencing behaviour while ensuring the school management could prepare appropriately for the drills. The staff did not take part in the fire drills or give the children any instruction on how to evacuate the building. The kindergarten held fire drills regularly, and it was assumed the children were already familiar with escape route. During the drill, member of the management team were positioned at key points along the route to ensure the children followed the signs and path.

Figure 1 shows the layout of the ground floor of the kindergarten. The building had two exits, one as the main entrance and the other on the west side. The latter opened toward a semi-covered football pitch with synthetic grass, which was designated as an assembly point. The exit is separated by an L-Shaped corridor from the main stairs inside the building as shown in Fig. 1. The stairs are designed as a split staircase between two floors, leading to a single stair ending on floor landing. The stairs are located on the south side of the building, passing through the entire building to the third floor. The width of stairs with and without handrails measured as 115 and 118 cm, respectively, with a handrail height of 104 cm. The stair flight length in each section was measured as 272 cm. The thread and riser of the stairs were measured as 29.5 cm and 17 cm, respectively. The main exit in the main lobby was connected to the stairs via a lobby and a long corridor with offices and two classrooms on each side. The main exit is open to the public pedestrian and the road. For this study, only the exit on the west side of the building was used for the evacuation drills, while the main exit remained closed.

Two semi-announced evacuation drills designed for this study, intending to address the width effects of exit doors in kindergarten on flow and speed of children. The first evacuation (EV-1) was scheduled on a Tuesday at 10:30 AM when all children were inside the classrooms. The second evacuation (EV-2) drill was conducted two hours after the first one at 12:30 PM. The exit door width in the first attempt (EV-1) was set to 75 cm, while it was set to 105 cm (full width) in the second attempt (EV-2). In both evacuations, only kindergarten children from the first floor and ground floor participated, using stairs, the L-shaped corridor, and the exit to reach the assembly point.

This study adhered to rigorous ethical guidelines to ensure the safety, privacy, and well-being of all participants. Consent forms were distributed to the parents or guardians of the kindergarten children through the school management, clearly outlining the purpose of the evacuation drills, the data collection methods, and the intended use of the data for research purposes. Only children whose parents provided signed consent were included in the study. The authors also obtained ethical clearances from the research and ethic committees of the first author's institution and informed the civil defence authorities about the drills. To maintain participant anonymity, no personally identifiable information was collected. All video recordings were processed to ensure individuals could not be identified, with faces and distinguishing features blurred when necessary. The videos were securely stored on encrypted

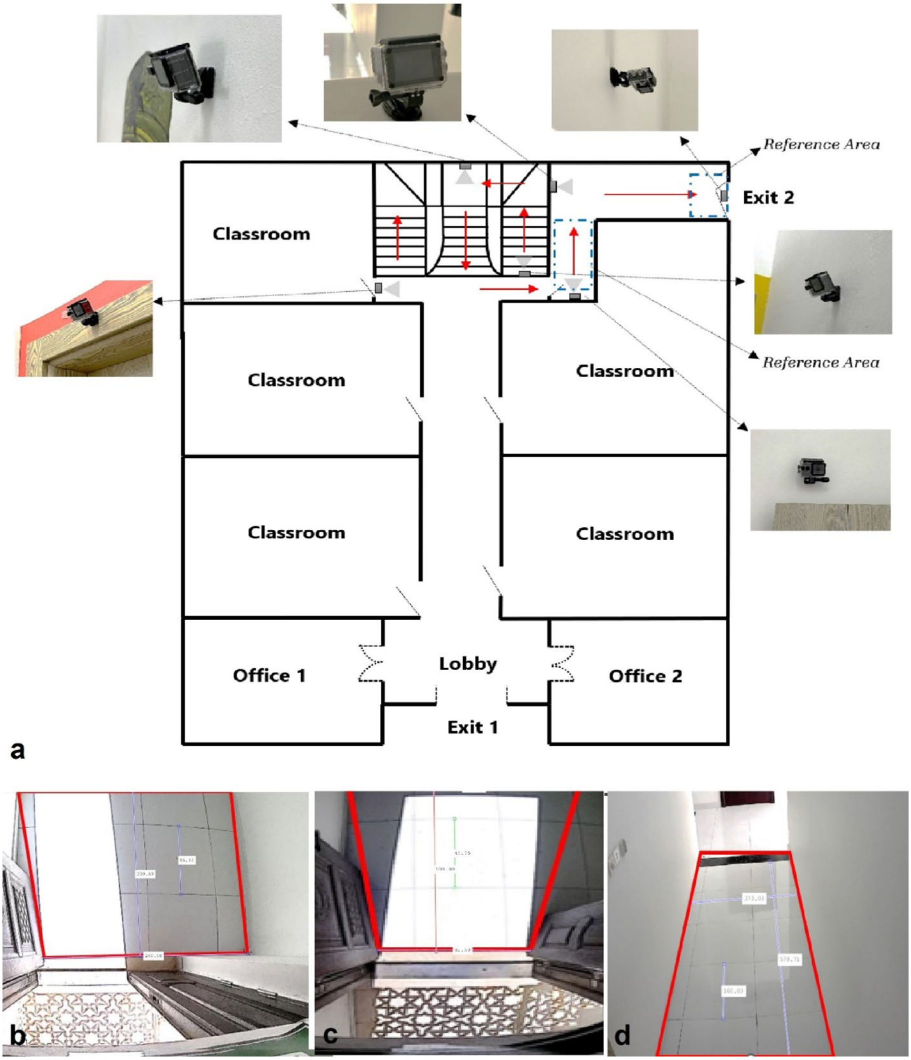


Fig. 1 **a** Floor plan of school ground floor and layout of Go Pro cameras mounted in different location; **b** reference area calculated for 70 cm width exit door; **c** reference area calculated for 105 cm width door; **d** reference area calculated for the corridor

devices and accessed only by the research team. Data analysis focused solely on collective movement characteristics rather than individual behaviours.

2.2 Data Collection and Measurement

Six GoPro cameras were mounted in various sections of the building to monitor the movement of children during the evacuation. Figure 2 provides the layout of mounted cameras and a picture of their orientation on the walls. Overall, one camera was on top of the exit door, two cameras along the L-shaped corridor before the exit, two on stairs and one on land-

Fig. 2 Snapshots of children's behaviour along the corridor and near the exit door during evacuation drill

ing platforms before the corridor. Nonetheless, the cameras on the stairs were distorted by one of the participants during the evacuation, making it difficult to calculate reference areas and track children's movement on the stairs. Therefore, the investigation team decided to exclude the stair data from the current study. The cameras were mounted half an hour before the first evacuation started to keep the drill unnoticed as much as possible. The recorded videos are then imported to a computer for processing and analysis.

The videos manually have been reviewed to identify any odd or unusual behaviour during the evacuation drill to report. Video files were imported into a frame-by-frame analysis tool to extract evacuation parameters. It also used to calculate evacuation parameters, including children's speed, flow, and total evacuation times. For calculating speed and flow near and through the door and corridor, the density of evacuees was obtained by defining a reference area in front of the door and in the corridor, as given in Fig. 1. The area obtained by converting distances measured in pixels and using a reference scale in the images. The reference areas were defined via pixel-to-meter calibration: 3.56 m^2 for the corridor, and 3.07 m^2 (EV-1) and 2.28 m^2(EV-2) for the doorway reference zones. For the corridor, the reference area has been found to be 3.56 m^2. Further details about speed, flow, and density calculations as well as measurement uncertainties are elaborated in [29] and used here to obtain the parameters.

For flow calculations, the effective width is defined as the full width of the corridor and the exit door. This was based on analysing the movement of children reviewing videos and analysing children's movement along these two exit components. The majority of children ignored the effective boundary near the wall or edge of the door and used the entire width to either walk toward the exit or leave the building. Hence, the authors found that using a full width as an effective width ideally represents children participating in the drills.

3 Results

3.1 Observations

A review of videos recorded during evacuation drills revealed notable differences in the behaviour of kindergarten children compared to other age groups. Most notably, children moved along egress routes without adhering to privacy zones typically observed among adults [3] and, to a lesser extent, teenagers. In many video frames, children were observed in close contact with one another, often holding hands, pulling, pushing, or otherwise interacting physically. Figure 2a illustrates this behaviour, showing children holding hands as they navigate a corridor, a common practice among most of participants. Near doorways, the evacuation movement demonstrated unusual patterns of behaviours. For example, in Fig. 2b, four children are seen moving toward an exit door when one child from behind trips their friend in front. In Fig. 2d and e, four children pause near the exit door to chat. The pause appears to be triggered by one of the children being upset after the tripping incident. The group lingers as another child attempts to comfort their friend, and they eventually move slowly toward the exit door before leaving the building.

On another occasion, a girl paused at the exit door, leaned against it, and even pushed some participants to encourage them to move out more quickly, as shown in Fig. 2f and g. This behaviour partially blocked the exit and disrupted the flow of others, potentially affecting the overall evacuation pattern. After some time, she eventually decided to leave with the rest of the group. In Fig. 2i, a boy is seen turning around to talk to a female friend, standing in the way of others and creating congestion near the doorway. He later decided to move slowly with the crowd, facing backward and reversing towards the exit. Observations confirm that he continued talking to his female friend all the way to the door. A common behaviour observed near the exit door was children waiting for their friends to catch up before leaving together. In Fig. 2k, l and a girl is seen waiting by the door, looking back for her friends. After they reach her, she takes one friend's hand, and they all leave the building together. This behaviour was frequently observed across participants in this study.

The observations highlight some certain behaviours of kindergarten children, which are not observed to this extent in other age groups. The video reviews demonstrate that children under the age of seven do not maintain any personal privacy zones while evacuating and appear more relaxed about being squeezed during congested movement. Kindergarten children's movement patterns and behaviours significantly influence mass movement during evacuation, yet these factors are not adequately addressed. Furthermore, the uncertainty associated with current theories for estimating evacuation parameters in such scenarios remains unknown.

3.2 Evacuation time

Figure 3 illustrates the exit flow of participants passing through the exit door and the total number of evacuees leaving the building over time. The delay between the fire alarm activation and the first participants appearing at the exit door was calculated as 68 s in both cases. The total evacuation time for EV-1 was recorded as 246 s (approximately 4 min), while for EV-2, it decreased to 194 s (approximately 3 min). The exit flow rates in the two cases also exhibit notable differences in patterns and peak values. In EV-1, the continuous

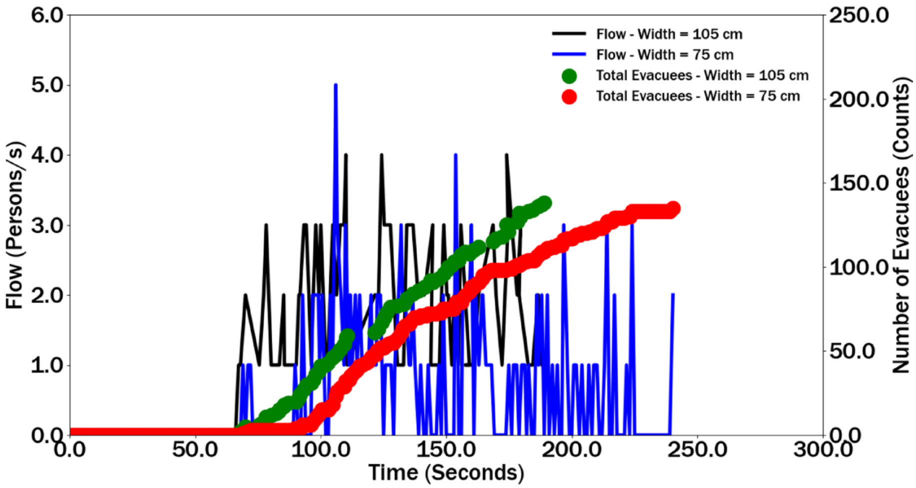


Fig. 3 Flow of children leaving through the exit door and Number of total evacuees versus Evacuation time

flow of participants leaving the building began after a delay compared to EV-2. The flow rate in EV-2 was predominantly between 2 and 3 people per second, whereas in EV-1, it decreased to between 1 and 2 people per second. During certain moments of the evacuation, maximum flow rates of 5 and 4 people per second were observed for EV-1, with a similar peak of 4 people per second for EV-2. The differences in evacuation patterns through the exit door highlight the impact of door width on both flow rate and evacuation time. These findings align with previous studies on evacuation dynamics near exit doors, emphasising the significant influence of door design on evacuation efficiency and flow.

3.3 Movement Speed and Flow in the Corridor

Figure 4a and b show the relationship between children's speed and area density (persons/m^2) as well as occupied density (m^2/m^2), calculated within the reference area outlined in Fig. 1. As shown in Fig. 4a, children's speed decreases proportionally with increasing area density. The maximum recorded speed was 1.68 m/s at an area density of 0.42 persons/m^2, while the minimum speed was 0.39 m/s at an area density of 1.55 persons/m^2. Most children's speeds fall within the interval of 0.5–1 m/s. The mean speed of children moving inside the corridor was calculated as 0.68 ± 0.04 m/s. Three correlations were plotted along the fitted curve to the collected data. Of these, only the correlation between Kholshevnikov et al. [28] showed a good fit. The data from Kholshevnikov et al. [28] was based on the relaxed walking of children in their study, which aligns with the observed behaviour in these evacuations, except for two or three children who were running. The correlations presented by Najmanová and Ronchi [18] and Fang et al. [25] also captured the overall trend of the data in relation to area density. However, the slope of their trends suggests full congestion in the corridor at lower area densities than those observed in this study.

The discrepancy between the correlations for horizontal speed and the data collected in this study is more obvious in Fig. 4b. For calculated occupied density, speed data was plotted against the corrected occupied density using values reported by Najmanová and Ronchi

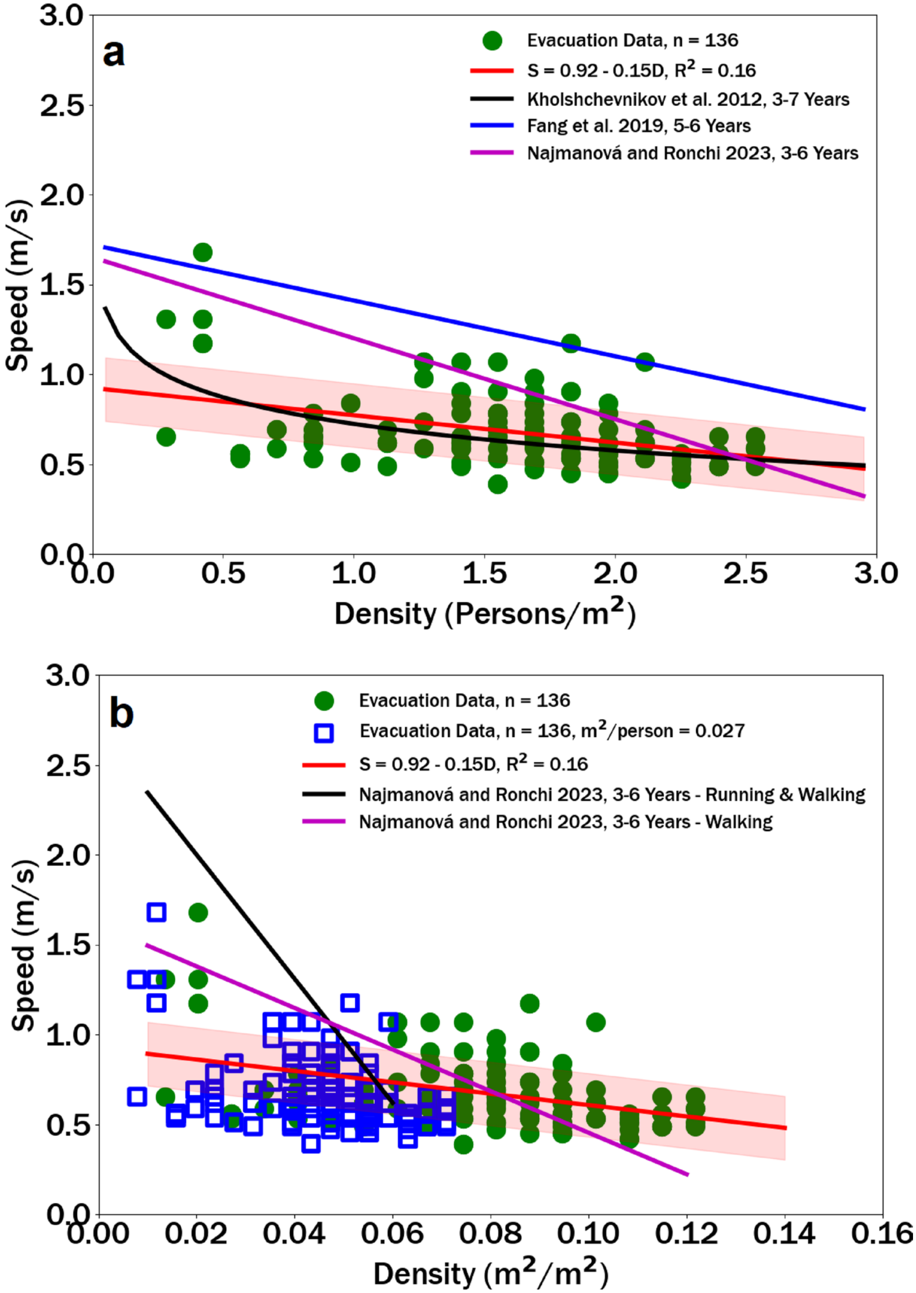


Fig. 4 **a** Children speed in corridor versus area density; **b** speed of children in corridor versus occupied density (CI: 0.95)

[18] for comparison purposes. Two trends introduced by Najmanová and Ronchi for children aged 3–6 years, depicting walking and running along a corridor, are given with the current data in Fig. 4b. Both trends show a significant difference compared to the current data's fitted trend. In the Najmanová and Ronchi correlations, the slope of the trends decreases as the children's movement state shifts from a mix of running and walking to solely walking. The slower trend observed in the current data may suggest a more relaxed walking state among the children compared to those noted in the literature.

Figure 5a and b show the flow of children moving through the reference area in the corridor in relation to area density and occupied density. Also, flow estimations based on the correlations by Fang et al. [25] and Najmanová and Ronchi [18] are presented alongside the recorded data. The maximum flow of participants in the corridor was recorded as 3.42 persons/s/m at an area density of 2.11 persons/m^2, while the minimum flow was calculated as 0.28 persons/s/m at an area density of 0.28 persons/m^2. The mean flow of participants was found to be 1.59 ± 0.32 persons/s/m. The recorded flow of children in the corridor shows a consistent increase, with no indication of reaching a peak. The estimations using the Fang et al. correlation [25] align closely with the observed data. In contrast, the predictions by Najmanová and Ronchi exhibit a narrower distribution, with a peak flow occurring at a density of 1.8 persons/m^2.

In Fig. 5b, children's flow through the corridor is depicted by calculating the occupied density in the reference area using two different horizontal projection values: the average projection reported by Najmanová and Ronchi [18] and that provided by Predtechenskii and Milinskii [2]. The flow versus occupied density trend demonstrates a strong relationship with the horizontal projection values, as shown in Fig. 5b. The maximum flow was observed at an occupied density of 0.12 m^2/m^2 when using Najmanová and Ronchi's horizontal projection [18], whereas it shifted to a density of 0.07 m^2/m^2 when using the values from Predtechenskii and Milinskii [2]. The predictions based on the Najmanová and Ronchi correlation aligned more closely with the data corrected by their horizontal projection values than with those provided by Predtechenskii and Milinskii. This discrepancy highlights the critical role of horizontal projection area when considering occupied density as a variable. Incorporating horizontal projection as a factor may provide a more accurate link between flow, speed, and occupied density rather than relying solely on occupied density as the primary variable.

3.4 Flow at the Exit Door

Children's speed versus area density and occupied density near the exit door are presented in Fig. 6a and b, respectively. The mean evacuation speeds with a 75 cm exit door width were recorded as 0.33 ± 0.04 m/s and 0.34 ± 0.12 m/s, indicating no meaningful difference between the two evacuation exit door scenarios. This was supported by a two-sample t-test found no signficant difference ($p=0.63$) based on the null hypothesis that assumed a significant difference between two samples with p-value < 0.05 threshold. The maximum speed of evacuees for EV-1 was recorded as 1.57 ± 0.04 m/s at an area density of 0.33 persons/m^2. This increased to 2.09 ± 0.12 m/s at area densities of 0.44 and 0.66 persons/m^2 when the door width was set to 105 cm in EV-2. The minimum speeds for EV-1 and EV-2 were recorded as 0.06 ± 0.04 m/s and 0.08 ± 0.04 m/s, respectively, at area densities of 3.42 persons/m^2 and 6.14 persons/m^2. The trends in both drills clearly illustrate the effect of the

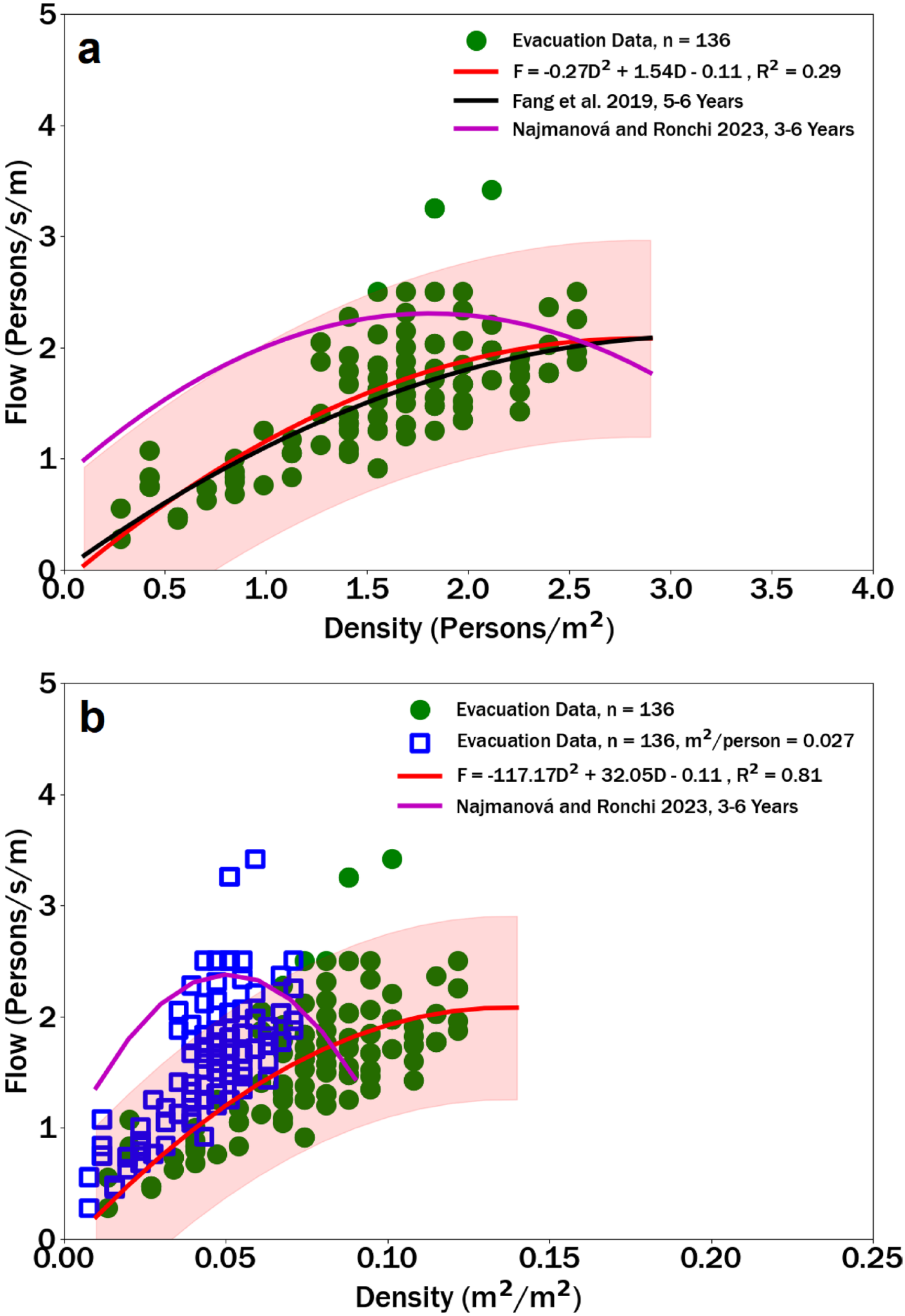
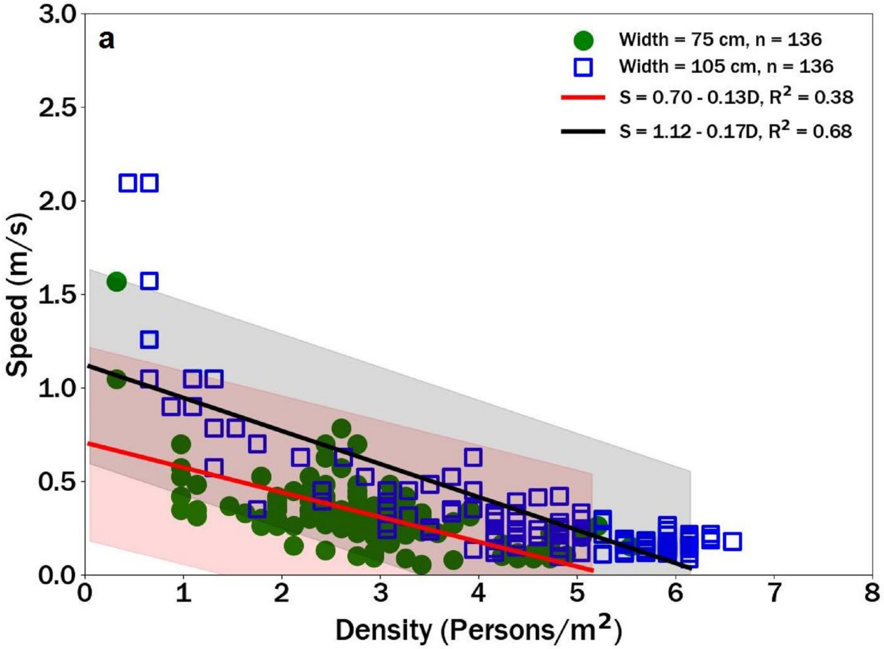


Fig. 5 **a** Flow of children in corridor versus area density; **b** flow of children in corridor versus occupied density (CI: 0.95)



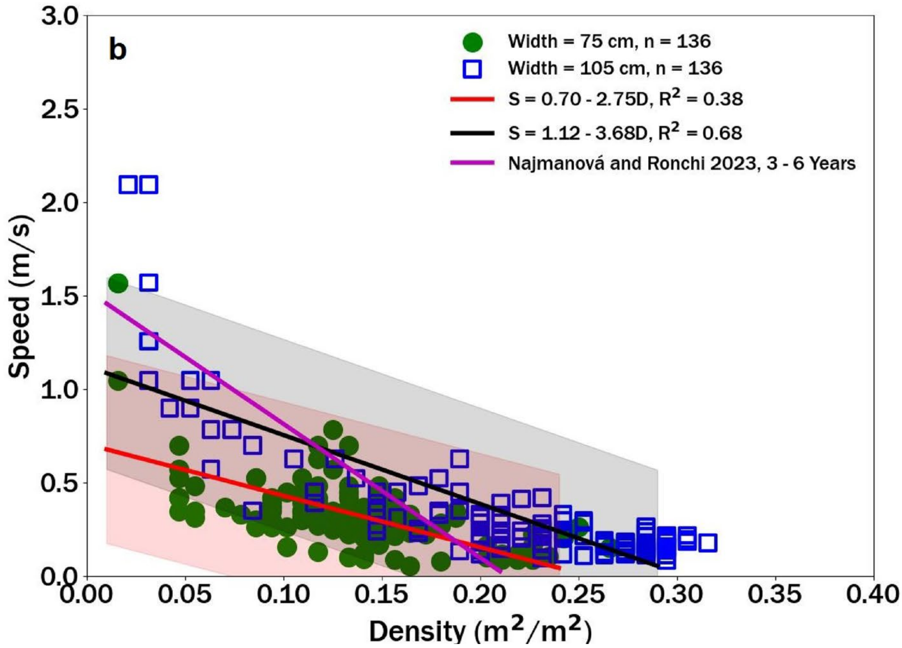


Fig. 6 **a** Speed of children in front of exit door versus area density; **b** speed of children in front of the exit door versus occupied density (CI: 0.95)

exit door on the movement of children in front of it, particularly during the jamming event, where movement halts. The area density at which the jamming occurs decreases with the reduction in door width. However, the results show no indication that door width affects the slope of the change in speed, as seen in Fig. 6a and b. In Fig. 6b, the near-jamming densities were recorded as 0.16 m^2/m^2 for EV-1 and 0.29 m^2/m^2 for EV-2. The maximum speed recorded for children in front of the door occurred at a density of less than 0.05 m^2/m^2. Predictions based on the Najmanová and Ronchi correlations [18] for children aged 3–6 years show a steeper slope, with jamming appearing to occur at lower occupied densities. However, this may not be conclusive, as it falls within the confidence bound.

The results of children's flow through the exit door in the two evacuation drills are presented in Fig. 7a and b. The mean flow through the exit was measured at 1.16 ± 0.22 persons/s/m for the 75 cm door and 1.01 ± 0.11 persons/s/m for the 105 cm door. Considering the variation in the average values, this suggests a noticeable difference in flow rate. This finding is supported by the results of a t-test, which gave a t-value of 2.741 and a p-value of 0.006. Since the p-value falls well below the null hypothesis of 0.05 threshold, the differences are considered statistically significant. It is evident that the peak flow is related to door width, as the maximum flows occur at lower densities with a door width of 75 cm. The maximum flow in EV-1 was recorded as 2.92 persons/s/m at an area density of 2.61 persons/m^2, while in EV-2, the maximum flow was 2.36 persons/s/m at an area density of 3.95 persons/m^2. The trend correlations fitted to the results in both cases clearly reveal the effect of door width on the changes in flow patterns relative to the densities. The Lárusdóttir correlation predictions [21] capture most of the flow data in Fig. 7a, but it shows a peak value at a higher area density than those recorded here. In contrast, the predictions from the correlation introduced by Najmanová and Ronchi [18] show a different trend than those fitted for flow versus area density and occupied density in Fig. 7a and b. In both cases, the Najmanová and Ronchi trend decays at lower densities than those shown by the fitted correlations for the current flow data.

4 Discussion

The semi-announced evacuation drills were conducted with over 135 kindergarten participants aged 4 to 7 years old. The evacuation times recorded for both EV-1 and EV-2 are consistent with the ranges reported in the literature for school buildings with 2 to 4 storeys. Cuesta et al. reported evacuation times ranging from 70 to 114 s for 70 to 162 children aged 6 to 16 years old [26]. Ono et al. noted evacuation times of 267 to 368 s for a population of 393 to 906 children aged 6 to 14 years old [22]. A study among children in a Finnish 3-storey school found an evacuation time of 228 s for 249 participants [30]. Kholshevnikov et al. reported an evacuation time of 630 s for 220 children aged 7 to 17 [27]. Najmanová et al. recorded evacuation times for children aged 3 to 6 in a kindergarten, with times ranging from 81 to 186 s [31].

The 68-second delay calculated for the arrival of children at the exit door following the fire alarm cue falls within the range reported in previous studies. Najmanová and Ronchi documented a range of 57–164 s for the first participant's arrival at the exit door in a school building [31]. Lárusdóttir reported a pre-evacuation time ranging from 10 to 545 s for children aged 3–6 years, with an average of 114 s [21]. Similarly, Cuesta et al. observed

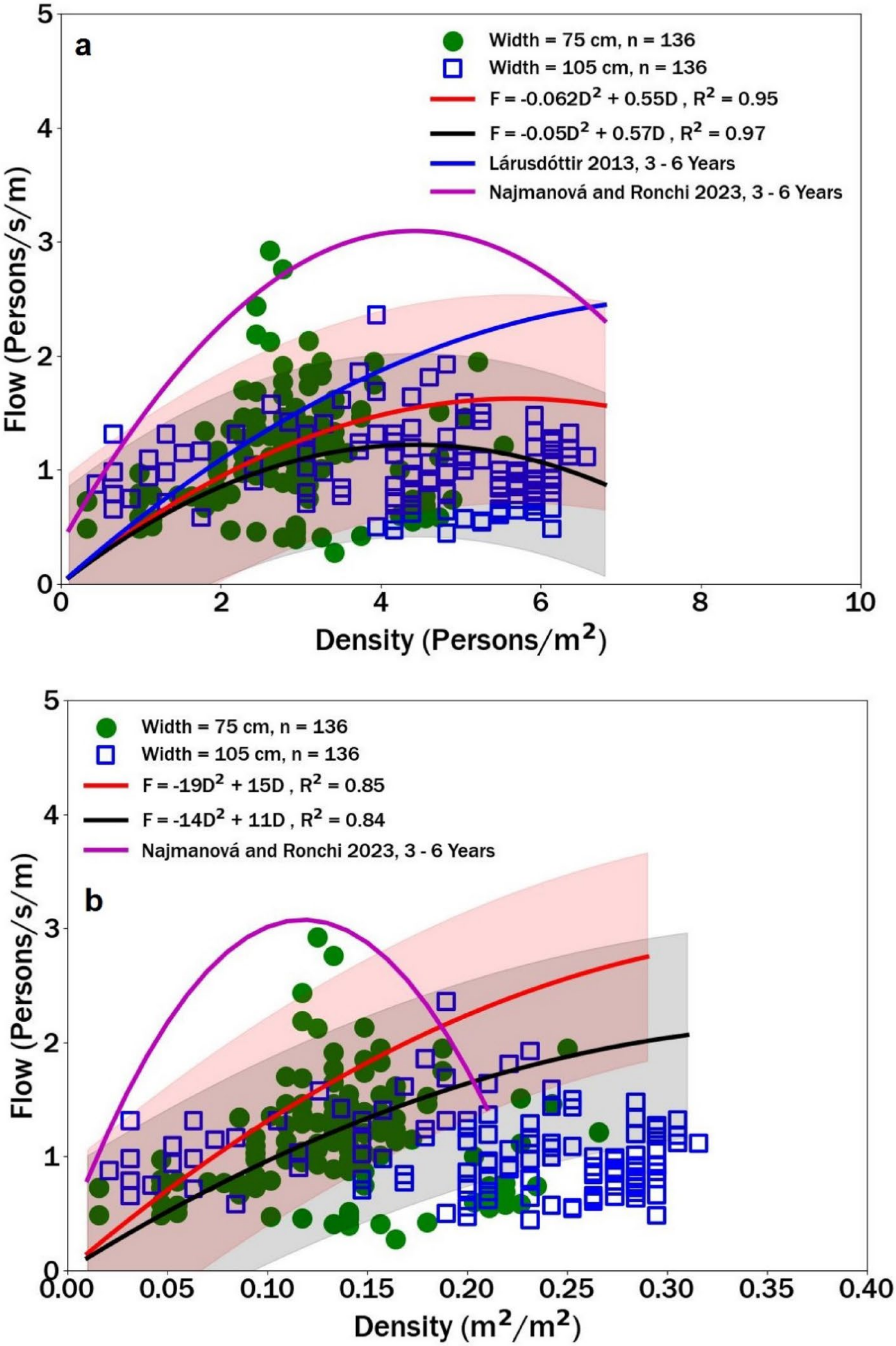


Fig. 7 **a** Flow of children through the door versus area density; **B** flow of children through the exit door versus occupied density (CI: 0.95)

pre-evacuation times of 4–166 s for children aged 6–16 years based on five evacuation drills conducted in a Spanish school [32]. Although the definition of pre-evacuation time and the delay time noted here are not identical, the wide range highlights that delay times can vary significantly depending on numerous factors, including the type of warning systems, instructions provided by staff, the layout of the building, and the ages of the children involved.

Children's speed and flow through the corridor revealed a clear discrepancy between the correlations fitted to the current data and those reported by [18]. Similar differences are observed for flows near the exit door in Figs. 6 and 7, where the correlations deviate beyond the confidence bounds of the data scatter and fitted trends. Several factors may explain the evident differences between the two studies. The data in Najmanová and Ronchi's research are based on a mix of evacuation types, including unannounced, semi-announced, and announced drills. These variations could influence the behaviour of children and staff during evacuation, particularly their movement speeds. Furthermore, in Najmanová and Ronchi's study [18], the movement of children in the corridors was categorised based on their state, such as walking or running. In contrast, no such categorisation was applied in this study, as most pupils were observed walking. This distinction likely resulted in slower speeds for comparable densities. Moreover, the evacuation drills in this study were conducted without staff assistance, whereas in some evacuations studied by Najmanová and Ronchi, staff provided instructions and support to participants. Such assistance could significantly affect the speed and flow of movement through corridors and doorways.

The width of the exit door significantly influences the distribution of speed and flow both near and through the exit. Wider exit doors allow higher movement speeds and increased flow rates across various densities. Existing empirical formulas, such as those presented by the Society of Fire Protection Engineers Handbook, typically assume a linear relationship between door width, after deducting a boundary width, and flow through the exit door. Although some researchers, such as Gwynne et al. [9], have criticised these models and recommended incorporating additional door parameters, such as design features, into flow calculations, the method remains widely used in fire engineering practice. The relationship between exit width and participant flow is evident in the present study. By comparing the exit width ratio between EV-1 and EV-2, a value of 0.66 was obtained. Similarly, averaging the flow rates at a density of 3.07 persons/m^2 for EV-1 and 3.09 persons/m^2 for EV-2, and then calculating the flow ratio yielded a value of 0.60. The ratio of these two values yields approximately 1, confirming a strong correlation between exit width and flow for the children participating in these drills.

From a practical perspective, the findings suggest that minimum exit door widths prescribed by codes may not always ensure optimal evacuation efficiency for kindergarten and primary school settings. For instance, while NFPA 101 [33] recommends a minimum clear door width of 810 mm, the results of this study indicate that narrower exits could lead to congestion, particularly in scenarios involving young children. In the UK, Approved Document B (ADB) sets a minimum width of 750 mm for a maximum number of 60 people and increases to 850 mm for a maximum number of people of 110 or an alternative of 5 mm per person [34]. These observations highlight the importance of considering occupancy-specific evacuation needs when setting regulatory standards. The exit door width attempted in these drills corresponds to the minimums mandated by fire safety codes in different countries. Considering the evacuation times in this study, the evacuation times with minimum width noted by the codes may surpass the ideal evacuation times of less than 3 min, at least for the context of kindergarten and primary schools. This shows the minimum width may not be applicable for different occupancies, and it may yield different performances, with the potential to cause complete congestion at the exit doors.

When using the current results for comparison or modelling purposes, several limitations of the study should be considered. The evacuation drills may not be fully comparable to actual events involving fire emergencies in buildings. Therefore, caution is advised when comparing the presented results with real-life incidents. Additionally, the uncertainties associated with the repeatability of evacuation drills remain unknown, as only a single evacuation was conducted in this study. However, conducting evacuation drills in a single school for data collection is not uncommon, and similar approaches have been used in previous studies [25, 26], which are generally considered to provide an acceptable level of accuracy within the research community. Factors such as staff engagement, the frequency of drills in a building, and the methods of warning can introduce variability and should be accounted for when comparing results across studies. This study made every effort to ensure that children and staff were unaware of the evacuation drills beforehand. However, the possibility that some participants may have been alerted by pre-evacuation activities or management cannot be ruled out. This could have influenced their perception of the emergency cues and movement speeds. It was assumed that all children participating in this study were healthy and physically capable of movement over vertical and horizontal egress components. Nonetheless, it is possible that some participants may have had undisclosed disabilities or conditions that could have affected their movement, which was not revealed to the research team.

5 Conclusion

Children represent a vulnerable population during fire evacuations, with behaviours and movement patterns that differ significantly from those of adults. This study investigated the evacuation behaviours of kindergarten children (ages 4–7) through semi-announced drills in a primary school. By analysing movement speed, flow, and behaviour in horizontal components, including corridors and exit doors of varying widths, the study highlighted several unique characteristics of young children during evacuations.

Key findings reveal that children do not adhere to the privacy zones typically maintained by adults and exhibit strong group dynamics, such as waiting for friends or moving in clusters. These behaviours often lead to congestion and slower evacuation times, particularly in high-density scenarios or at narrow exit doors. The study also underscores the critical influence of exit door width on flow rates and evacuation efficiency, aligning with prior research while emphasizing the need to tailor evacuation models to account for behavioural factors specific to children.

The results have practical implications for fire safety engineering and building design. Regulatory minimums for exit widths, such as those prescribed by NFPA 101, may not always suffice for optimal evacuation performance in schools, particularly for younger children. Design standards should consider both physical and behavioural factors, ensuring egress routes accommodate the unique needs of child occupants.

This study contributes valuable data to the limited body of knowledge on children's evacuation behaviours but also highlights the need for further research. Future studies should investigate a wider range of scenarios, including unannounced drills, diverse building layouts, and different cultural contexts. Incorporating staff-assisted evacuations and exploring the impact of environmental and psychological factors on children's behaviour can provide deeper insights to refine evacuation models and improve fire safety strategies.

Data Availability The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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