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SAFETY IN SCHOOLS: THE SIMULATION OF EVACUATION AT THE ELEMENTARY SCHOOL CAR KONSTANTIN IN NIŠ

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Abstract

Evacuation generally presents a very complex and responsible task, no matter what kind of object or location is in a plan for the evacuation. Reasons for evacuation are mostly well known. These are earthquakes, fire, overflow, tsunamis, terrorist attacks, and others. A major significant factor for evacuation is a lot of humans, particularly immobile, hard-mobile persons and children. This fact can significantly make evacuation difficult, complicated and even hard possible or impossible. The simulation software application presents many benefits because of prediction, calculation of evacuation times and determining evacuation routes.
In this paper, the evacuation time of each evacuation exit was calculated by the simulation software Pathfinder (version 2023). The results of this paper were done by an appropriate simulation model at the elementary school Car Konstantin from Niš with all potential exit doors. Simulations predicted two scenarios with occupants' speeds: 1m/s, 1.5 m/s, 2m/s, 2.5 m/s, 3m/s and 3.5 m/s. The contribution of these results is applicable because the calculation of evacuation times for every combination of potential exits facilitates potential evacuation situations.
Evacuation problems can be much better and effectively analyzed with the software. Particular benefits from the simulation software used are in the sense of safety, cheapness and prediction.

Keywords: *evacuation time, evacuation route, pupils and staff, simulation software, safety*

Introduction

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The standard and well-known definition for evacuation is that evacuation presents the moving of people, animals, and material properties from an endangered place or object to a safe location in a fast and safe way. Reasons for evacuation can be different and well-known: earthquake, fire, terrorism threat or attack, tsunami, hurricane, etc. Evacuation almost always presents a complex problem because many factors can be hard to predict or evaluate. That is particularly relevant in scenarios where individuals who require evacuation cannot move, have limited mobility, or are children. Naturally, there are numerous settings where evacuation can be challenging or unique, with a significant number of individuals present. A prime example of such a location would be a school.

Schools as objects with a lot of children are much demanded objects for evacuation. No matter how well the school was built, in an architectural sense, the evacuation of children is a task that always goes wrong. It can be challenging to anticipate how children can react in situations like fire, smoke, stress, and panic. Additionally, younger children in elementary school may not fully comprehend the gravity of their circumstances, leading to a higher likelihood of untimely reactions.

On the contrary, their unpredictable reaction and behaviour could cause even more chaos and disorder, with intense consequences, even with a tragic epilogue. Unfortunately, one of the severe and striking examples was the murder of nine children and one adult by a thirteen-year-old boy in elementary school Vladislav Ribnikar in Belgrade. This terrible accident confirmed all unnecessary needs for a fast and safe evacuation.

So, related to all noted, it is crucial to predict as much as possible potential evacuation times, evacuation routes, and evacuation procedures to evacuate children-pupils from school to a safe location or safe place. One of the best ways of task execution with a sense of safety, low cost, and precision is simulation. This software has the potential to save many lives by facilitating proper evacuation and decreasing evacuation time. Additionally, it can predict the most efficient and safest evacuation protocols to ensure the quickest and safest exit from a location. Today, there are more software on the market related to evacuation.

This paper aims to demonstrate the advantages of using the Pathfinder simulation software for predicting evacuation times and planning evacuations. The software enables the analysis of various evacuation scenarios, considering the speed of different occupants, such as students, professors, and school staff. In general, the contributions of the simulation software in evacuation are significant in many senses. The contributions of this paper present the best scenarios for evacuation with the fastest evacuation time without jams. These results are crucial in the evacuation planning and realisation [1-3].

Pathfinder Simulation Software

In this paper, the simulation method was used and realised in the simulation software Pathfinder, version 2023.2. This version is significantly improved from earlier versions and has a lot of new possibilities in the sense of demands and analysis. Reasons for the usage of simulation software are numerous and justified. Safety and the ability to predict outcomes in various scenarios are the main reasons for the value of the simulation software. This software allows for the simulation of real-life conditions without any risk involved. Pathfinder is a powerful simulator that has very great potential. Additionally, simulation software significantly reduces the needed time to calculate evacuation plans or test real-life evacuation models involving humans.

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Pathfinder enables detailed simulation of human movements through different objects such as stairs, elevators, and ramps using different speeds of occupants. This software can use two different simulation mods for their calculation. The first mode is the so-called SFPE mode, while the second is the steering mode. Besides many good characteristics and benefits, this software has the potential to „import„ files from some other computer program (Pyrosim, AutoCAD or some other). This property significantly accelerates the complete simulation process because some objects are very complicated to design and draw. During simulation, Pathfinder is presented as a reliable, precise and significant engineering tool for the prediction of evacuation times and evacuation scenarios [4-6].

Simulation Method

The paper presents a simulation model created in Pathfinder software using actual dimensions of the building of Car Konstantin Elementary School in Niš, Serbia.
The reason for selecting this building for analysis and simulation is the tragic event that occurred at Vladislav Ribnikar Elementary School in Belgrade. Planning and predicting school evacuations is crucial to prevent tragic consequences.
Elementary school Car Konstantin was founded in 1962, at a location as today, in Velikotrnavska Street, but with a different name: May twenty-first. The school had its name changed in 2003. Throughout its history, it had three more advanced departments in the Ćele kula and Gabrovačka settlements, with over 2900 pupils. The school was divided several times whenever a new school was founded. Over time, the school acquired a hall for physical education, rooms for extended stay, kitchen, and dining rooms. The number of pupils was pretty changeable over time, but now the school has 1070 pupils and 103 employees, with classes held in two shifts.
In the architectural sense, the school has four entrances and exits where pupils and staff can enter/exit the school. There are two more exits, but they remain locked during normal school functioning and work. The basement has offices, a library, extended-stay rooms, a physical hall, toilets and classrooms. On the first floor are several classrooms, toilet rooms, and a large hall.
The schoolyard is large and has different sports fields: football, basketball, and volleyball. However, it is significant to note that the approaches to the school for fire truck are inaccessible, with the only great approach being from the schoolyard that borders the student dormitory. The yard's gates are very narrow. Generally, Velikotrnavska Street is a very narrow street with great traffic jams and congestion. Exterior part of the school Car Konstantin is presented in Figures 1.

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a) b)

Figure 1: The exterior of the school Car Konstantin: front side with main exit (a) and the side from the physical hall (b)

Interior part of the school Car Konstantin is presented in Figure 2.

a) b)

Figure 2: The interior of the school Car Konstantin: main hall (a) and the second floor near stairs (b)

Simulation models of the school in Pathfinder, as 2D models with marked exits: above view (a) and 3D model-side view (b) are presented in Figure 3. Main elements: desks, chairs, cupboards and others were not presented because of better visibility (HIDE function).

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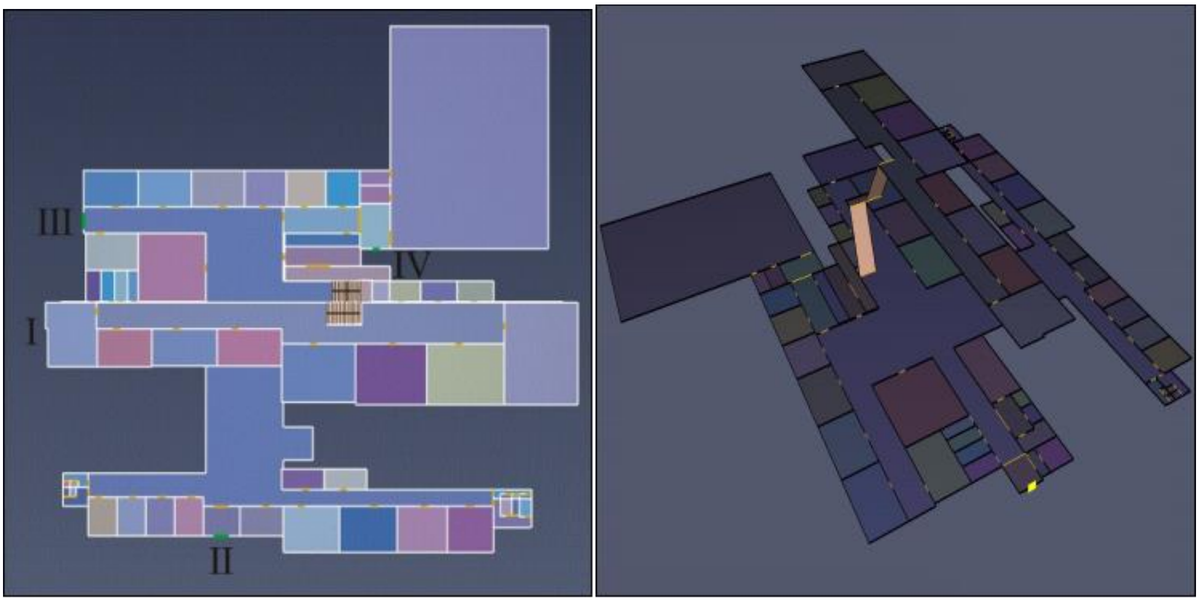

a) b)

Figure 3: 2D simulation model of the elementary school Car Konstantin in Pathfinder with marked exits (a) and 3D simulation model of the elementary school Car Konstantin in Pathfinder (b)

The evacuation of occupants at the Elementary School "Car Konstantin" was done in two different scenarios. The first scenario purported randomly arranged occupants (pupils, professors and school staff) in the big break situation. The second scenario purported exactly arranged occupants (pupils in classrooms or halls for physical education, professors in cabinets or assembly halls, and school staff in their rooms). Classrooms capacities were 25 and 20 pupils in the classroom. Evacuation started on alarm sound when occupants went to the nearest exit in both scenarios. The complete number of occupants was 638, which purported pupils from one shift and complete teaching and school staff - 535 pupils and 103 professors and school staff. For both scenarios, there were four exits where occupants were leaving the school, marked with numbers and shown in Figure 3 (a). Every potential case for different exit combinations was analyzed and simulated for both scenarios (for example, the first, the second, and the third exit was open, but the fourth exit was closed). The total number of combinations for exits was 15 (4^2-1=15) because of inconsideration for all four exits closed for any scenarios. The speeds of occupants were 1 m/s, 1.5 m/s, 2 m/s, 2.5 m/s, 3 m/s and 3.5 m/s. Thus, the entire number of realized simulations was 180 for both scenarios.

Simulation Results

For the simulation in this paper, the laptop with the following performances: Dell Latitude, with Intel® Core™ i7-1185G7 (4 Core, 12M cache, base 3.0GHz, up to 4.8GHz, vPro) processor and 16 GB of RAM, was used. Simulation software usually demands a powerful computer or laptop configuration for faster and more effective work.

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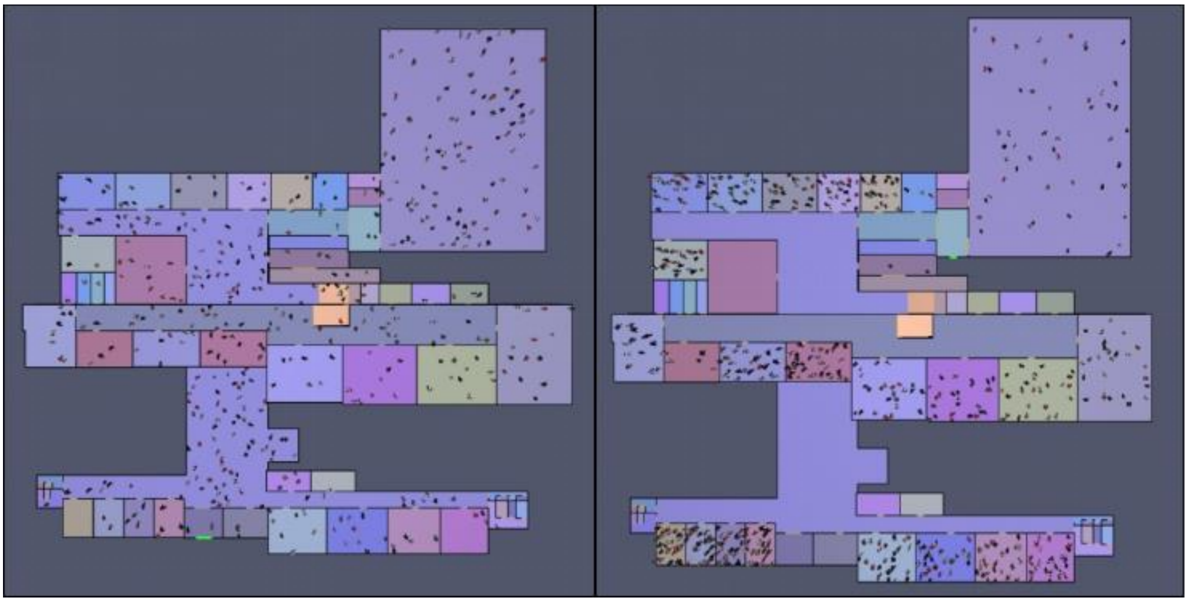
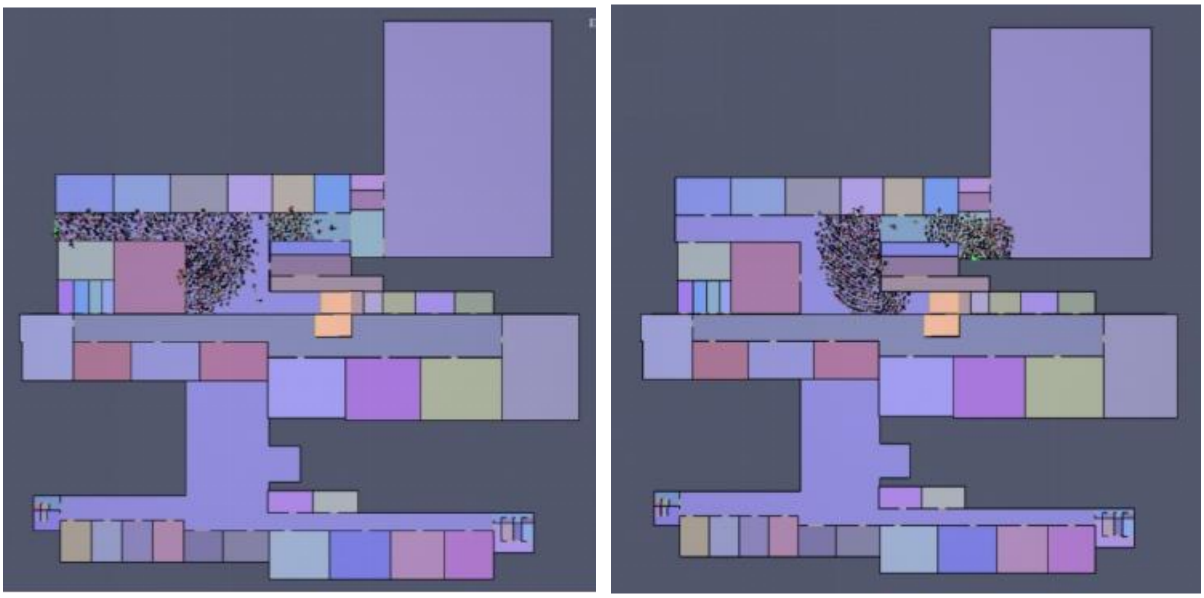


a) b)

Figure 4: 2D simulation model of the school in Pathfinder with: randomly arranged occupants (a) and precisely arranged occupants (b)

Simulation models of schools with randomly and precisely arranged occupants are presented in Figure 4, (a) and (b), respectively.



a) b)

Figure 5: 2D simulation moments for the first scenario where all exits except the third exit was closed and speed of occupants was 3.5 m/s (a) and 1 for the second scenario where all exits except the fourth exit was closed and speed of occupants was 1.5 m/s (b)

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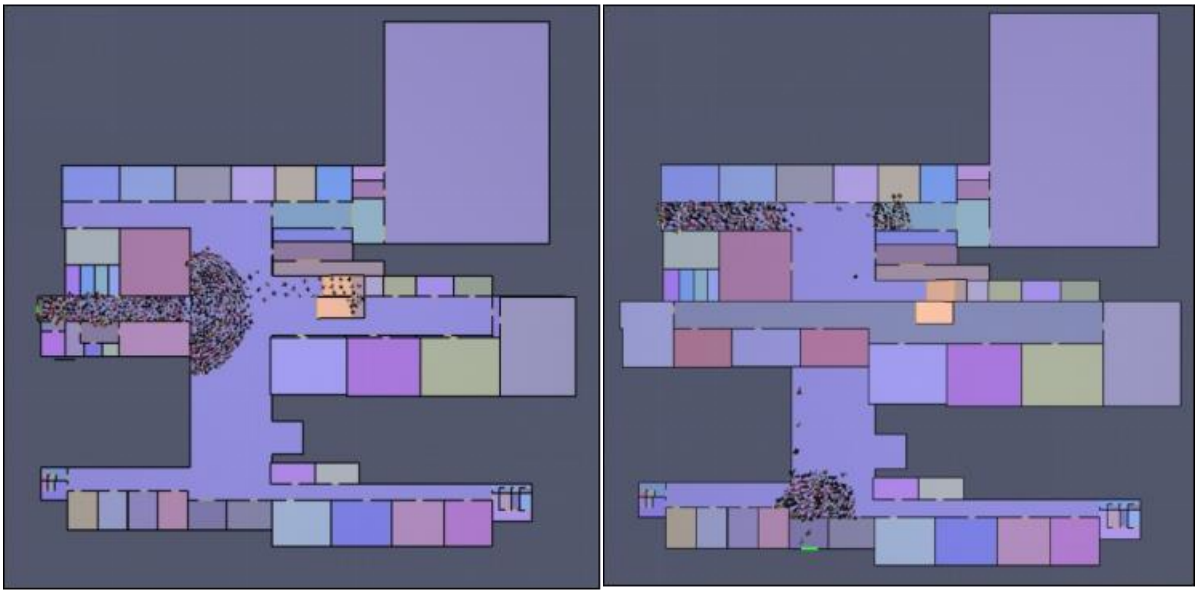
a) b)

Figure 6: 3D simulation moments for the first scenario where all exits except the first and the were closed and speed of occupants was 1.5 m/s (a) and for the second scenario where all exits was open and speed of occupants was 2.5 m/s (b)

Because of the paper's limitations, only some 2D and 3D simulation moments are presented in Figures 5, 6 and 7.



a) b)

Figure 7: 2D simulation moments for the first scenario where all exits except the first exit was closed and speed of occupants was 2.5 m/s (a) and 1 for the second scenario where the second and the third exits were open while the first exit and the fourth exit were closed and speed of occupants was 1.5 m/s (b)

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The complete number of realised simulations for the first scenario was 90. The first scenario is the evacuation of the school's purported random occupants (pupils, professors, and school staff). How four exits (marked with I, II, III and IV in Figure 3 (a) were available for evacuation, the maximal number of combinations was 15.

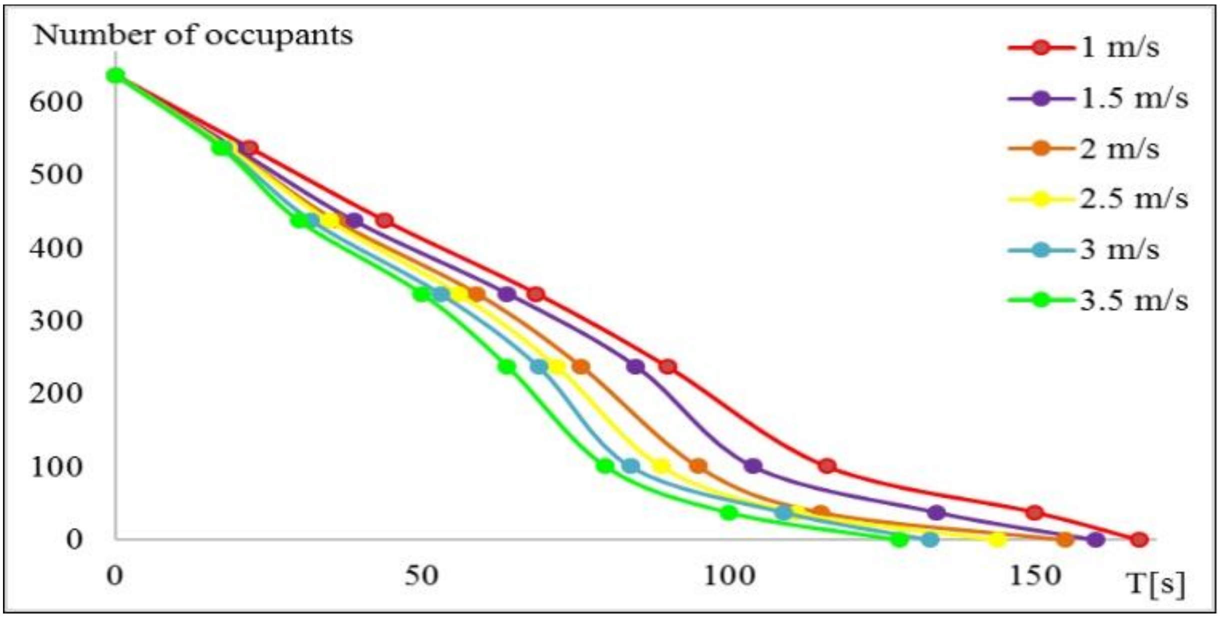

Figure 8: Simulation results for the fastest case for the first scenario

The complete simulation results for the fastest and the slowest case for both scenarios are presented in Figures 8 to 11.

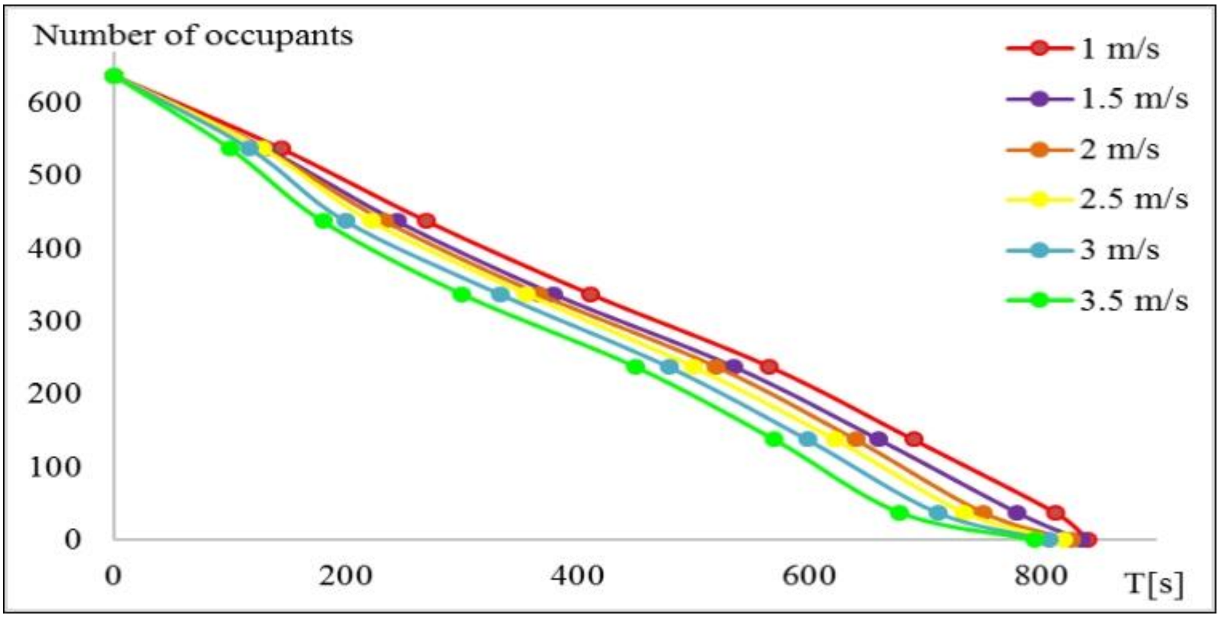

Figure 9: Simulation results for the slowest case for the first scenario

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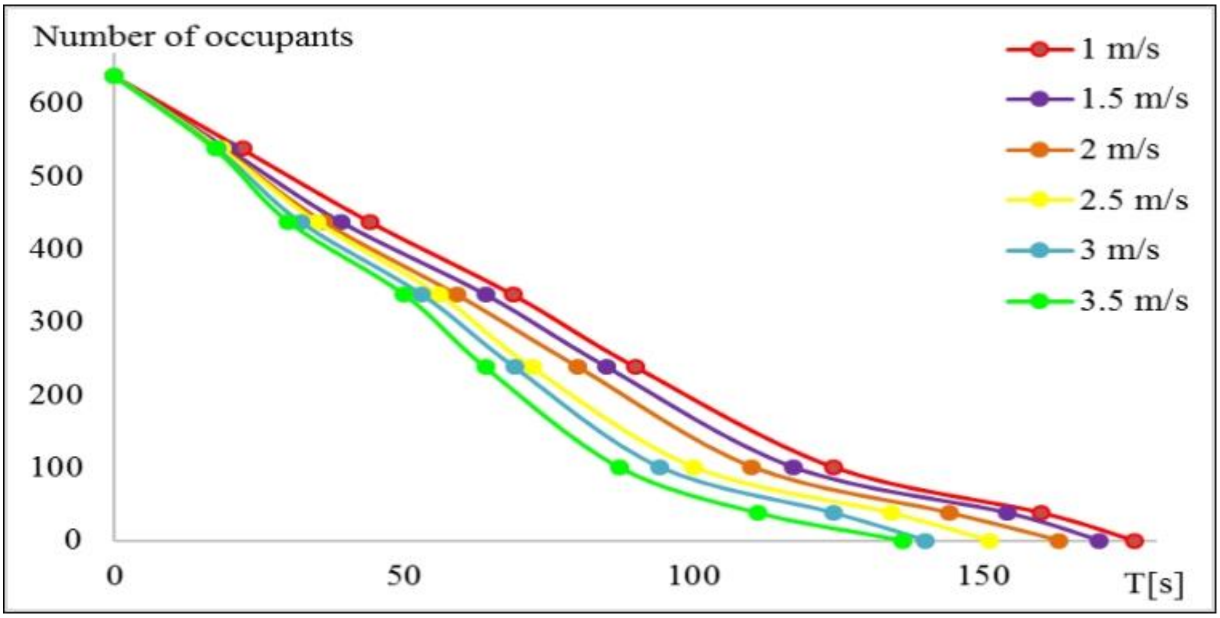

Figure 10: Simulation results for the fastest case of the second scenario

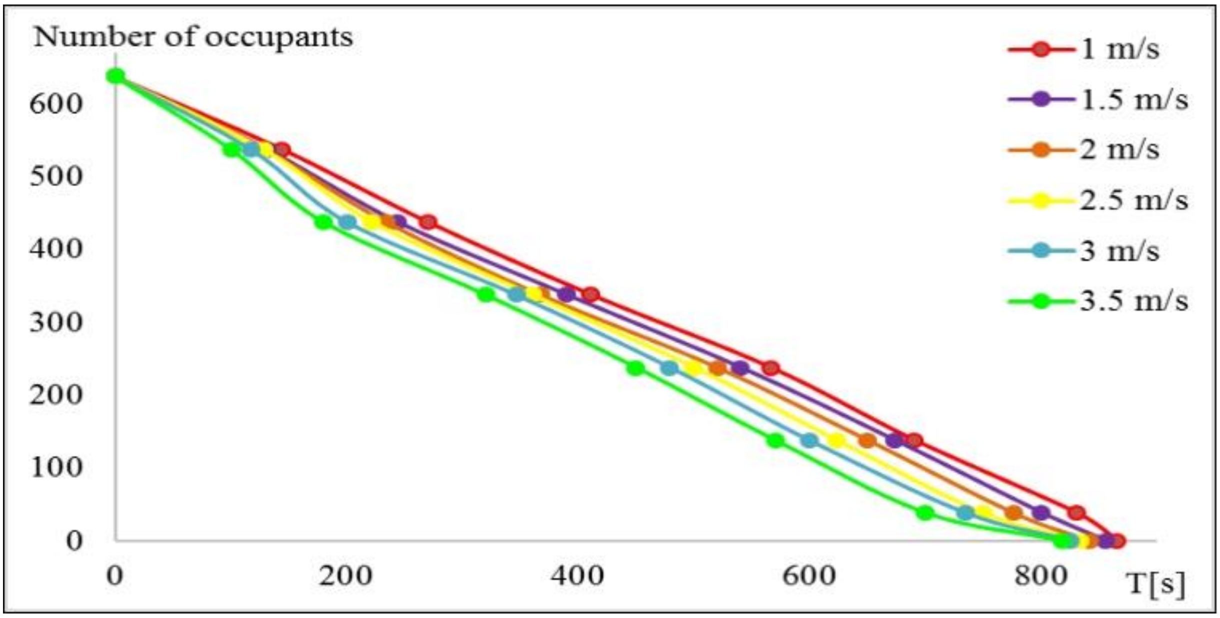

Figure 11: Simulation results for the slowest case for the second scenario.

Analysis and Discussion

The occupant's speeds were with the following values: 1 m/s, 1.5 m/s, 2m/s, 2.5 m/s, 3m/s, and 3.5 m/s, so related to that fact, the maximal number of simulations was 90.
The fastest case for the first scenario was for all four exits to be open, and the scenario for all speeds of occupants is presented in Figure 8.

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The most necessary evacuation time for the occupant's speed of 3.5 m/s was 128.5 seconds, while the longest needed time was when the occupant's speed was 1m/s and time was 167.4 seconds.
The slowest scenario in the first case was when only the fourth exit was open, and the other exits (I, II, and III) were closed. Figure 9 presents this scenario for all occupant speeds. According to the simulated results, the shortest evacuation time was when the occupants moved at a speed of 3.5m/s, and it took 795.23 seconds to evacuate. On the other hand, the longest evacuation time was recorded when the occupants moved at a speed of 1m/s, and it took 841.3 seconds to evacuate.
In Figure 10, the scenario where all four exits were open proved to be the swiftest in the second scenario across all occupant speeds. According to the simulation results, the shortest evacuation time occurred when occupants were moving at a speed of 3.5 m/s, taking only 136.4 seconds. Conversely, the longest evacuation time occurred when occupants were moving at a speed of 1 m/s, taking a total of 176.89 seconds.
In the first scenario, the slowest evacuation occurred when only the fourth exit was open while the other exits (I, II, and III) were closed. Figure 11 illustrates this scenario for all occupant speeds. Based on simulated results, the shortest evacuation time was achieved when occupants moved at a speed of 3.5 m/s, taking 817.45 seconds. On the other hand, the longest evacuation time occurred at a speed of 1 m/s, taking 865.11 seconds. Interestingly, the times required for evacuation were marginally shorter when occupants were randomly arranged compared to when they were precisely arranged. This finding held for every case in both scenarios.

a) b)

Figure 12: Simulation moment of crowd at the entrance/exit of hall for physical education (a) and at the stairs that leads to the second floor (b)

It is significant to note that analysis showed that critical points can be the hall for physical education and the stairs that lead to the second floor. In the case when the number of pupils and professors in the hall for physical education exceeds 42, there will be crowd and

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congestion for almost any speed of occupants. The reason for that is the proximity of the fourth exit.
There is a moment when the entrance/exit of the physical education hall becomes crowded, as shown in Figure 12 (a). Stairs are often a bottleneck in most places, and our analysis showed that speeds greater than 3.9 m/s can cause congestion and blockages on the stairs due to their size and flow capacity; this crowding moment on the stairs leads to the second floor, as shown in Figure 12 (b).
Of course, in the case of this school, a great advantage and help in the potential evacuation is an atrium in the front part of the school, which could provide additional needed time, space, and air.
Related to Pathfinder software, all of the occupants had the same speed. It would be hard to realize because panic, stress presence, potential crowds, and jams would be too difficult to resolve. Stress and panic have an intensive influence on human behavior, especially children. Children are hard to organize even in a calm state, but with the presence of stress and panic, the end of evacuation very probably could be tragic. It is necessary to note that the hard mobile or immobile occupants (pupils, professors, and school staff) significantly complicate evacuation and make it more difficult for successful execution because of longer evacuation times and almost possibilities for collision, jams, and other complications. Of course, there are always evacuation causes of smoke, flame, water, and the like, which further complicate the evacuation and make it more difficult. The calculations and results achieved in this paper are in the order of similar papers and research [7-13].

Conclusion

The safe and fast evacuation of occupants, especially children, is crucial in schools. Simulation software can help test and analyze evacuation cost-effectively and safely, determining optimal evacuation routes and predicting potential issues. This paper calculated evacuation times and analyzed adequate combinations of opened/closed doors/exits. Results realized in this paper showed the evacuation times for two different evacuation scenarios where the first exists with randomly arranged occupants and the second one with precisely arranged occupants. The simulation software in evacuation calculations and analyses presents an enormous advantage for safety and efficiency and should be standard practice in engineering. The future directions will focus on determining optimal evacuation scenarios and utilizing new resources.

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