Simulation of evacuation in an educational building using Agent-Based Modeling with emphasis on furnishing location

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Abstract

Agent-based modeling is helpful in simulating reality to predict the unknowns. Evacuation simulation can be effective in preventing undesirable events on actual occasions. This study aims to simulate classroom evacuation with different furnishings in two different conditions: open and closed doors. This model is developed with AnyLogic software. According to the results, the best furnishing in the classroom between a central pathway, central and sides pathways, and separated chairs are related to the second furnishing. In first furnishing, the brief delay makes people bet to master the conditions. While in other furnishings, the results show the opposite. However, it should be noted that an increase in delay time leads to an increase in reaction time.

Keywords: Evacuation, Agent-based modeling, Simulation, Classroom, Furnishing

Highlights:

- A set of agents can create new behaviors not seen in each of them.
- It is essential to know these behaviors in the evacuation process so that the necessary arrangements can be made at the right time.
- With the help of agent-based simulation software such as AnyLogic, these behaviors can be better understood.

1. Introduction

Emergency evacuation is enumerated as an essential factor in building safety. Physical barriers such as walls and doors have divided current buildings' inner spaces into enclosures. The accessibility through the buildings is determined about the position of such elements that have a vital role in the evacuation process [1]. Moreover, the population density affects the evacuation process and should be noted in the simulation of educational buildings like university or school classrooms.

The spatial accessibilities may greatly influence the evacuation process [2]. Taking the university classroom, for instance, the door of the class can be opened inside or to the corridor (outside). The evacuation situation may be different in these two conditions because the number of students and their behaviors are precisely predictable. It is essential to consider not only the physical environment of the class but also the dynamic state of the humans.

Agent-based modeling is a powerful simulation method in which a system is modeled as a collection of autonomous decision-making entities called agents. An agent-based model includes a system of agents and the relationships between them. Each agent individually assesses their situation and makes decisions based on set of rules [3]. Many computer programs are provided to model agent-based systems. NetLogo, Repast, and AnyLogic are examples of this respect.

Given the above facts, the purpose of this study was to simulate the evacuation of university classrooms, focusing on the combination of human behaviors and physical characteristics of the classrooms. This paper first describes the process of evacuation of the class. Then it presents an agent-based model to model the students of the class to assess the impact of different furnishing scenarios. AnyLogic is utilized for this purpose.

2. Literature review

Human behavior and building environment are critical bases of building evacuation [2]. Many works have mainly focused on fixed spatial constraints through the building environment, aiming at the optimization of evacuees' movement and evacuation time [4-6]. In such studies, the building is modeled with plans in which no changes can occur. Many ways can be enumerated to represent the evacuees' behavior. Some models consider the evacuees as a continuous homogeneous mass behaving as a fluid stream.

Braun et al. [7] utilized an agent-based model to evaluate virtual human crowds in emergencies. Ha et al. [8] also studied crowd behavior, focusing on its relation to building architecture in a multi-story building.

Facial to closed spaces in evacuation is another critical issue investigated by some researchers [9].

Kuligowski [10] studied human behavior in fires. He focused on a behavioral process in a building fire evacuation. He defined 4 main phases for the behavioral process of occupant response in a building fire. Perceiving cues, interpreting situations and risks, making decisions about action, and acting are respectively these phases. He believed that by identifying the factors that influence each phase, researchers can develop a comprehensive and predictive model for a building fire evacuation. Evacuation models calculate the time it takes for the building to be evacuated. Then, it can be used in an engineering safety analysis.

Chu et al. [11] modeled the social behaviors in an evacuation simulator. They provided a social agent for egress in which building occupants decide to exit based on their knowledge of the building and interactions with social groups. According to the results, not only familiarity with the building but also social behaviors have a significant effect on egress performance. The safer design of buildings requires a better understanding of agent behaviors during evacuation, which should be considered in the simulation.

Tan et al. [12] simulated the building evacuation by considering the combination of human behavior with predictable spatial accessibility. According to the results, they reported that the proposed model can evaluate the effect of spatial change on evacuation efficiency. The knowledge level of evacuees and the location of the fire safety facilities are essential parameters in this respect.

Liu et al. [13] studied classroom evacuation scenarios by agent-based simulation. They indicated that the classroom plan with two exits shortens the evacuation time of students. They also proposed some comments to achieve better similarity with reality. Investigation of different responses of students to emergencies by preparation of models based on different reaction mechanisms or adding reaction time to the model before taking any action are some of the examples they suggested.

Faroqi et al. [14] focused on emotional status in the evacuation process. They considered three kinds of agents, including Adults, Children, and security teams, with six, two, and one level of emotional status, respectively. One of the items they analyzed was the proportion between the number of security agents and the percentage of rescued people. They reported that 1/35 is the best ratio for the most rescued agents in this situation.

3. Method

This research was conducted in 4 phases. Fig. 1 shows a process of phases.

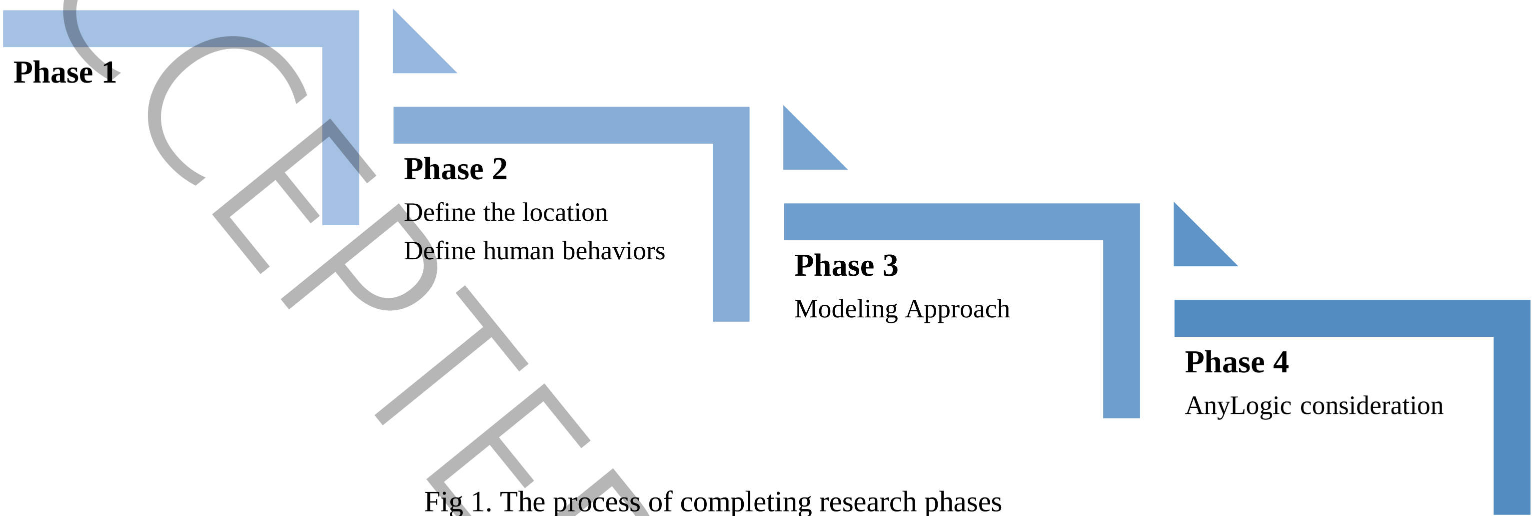

Fig 1. The process of completing research phases

3.1. Phase 1:

The initial phase was a literature review to form the model structure and categorize the needed information for modeling. According to this phase, two main characteristics of the model were human behaviors and the physical environment.

3.2. Phase 2:

The second phase includes defining the location and behavior of humans. In a classroom, factors such as overall dimensions, number of exit doors and their sizes, location of furniture, number of students, and their behaviors can be studied to improve the efficiency of evacuations. In this research, we focused on furniture location in 3 different scenarios to evaluate which kind of furnishing is more suitable for the evacuation process. (see Fig. 2). As a practical study, a multi-media classroom was designed, and its properties are mentioned in Table 1. The number of agents (students) in this simulation is 50.

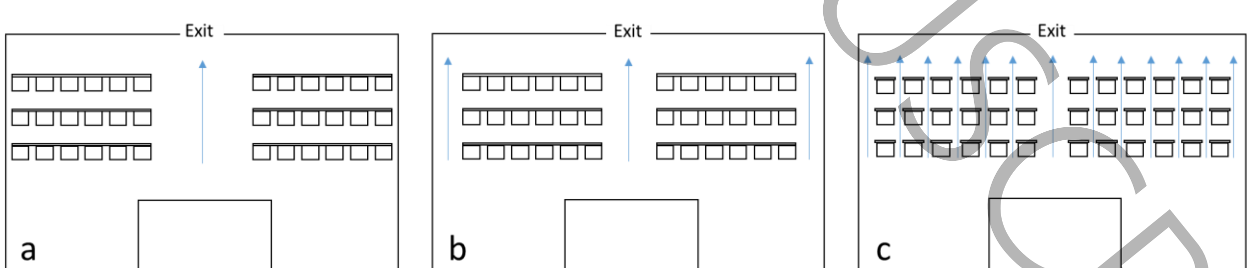

Fig. 2. Schematic furnishing of a classroom ((a). a central pathway (b). a central and sides pathways (c). multi pathways with separated chairs)

Table 1. Classroom specification

Dimensions (X-Y)	6×10 m^2
Number of rows	3
Total student number	50
Number of exit doors	2
Location of exit doors	On the right and left corner

Human behavior is considered from two aspects: first, equal share of the same conditions, and second, following the majority in choosing the exit route. In general, due to the symmetrical location of the exit doors compared to the classroom exit, students do not prefer any of the exit doors to the other, and the chance of choosing each one is considered the same. In a state of panic, people's decision-making power decreases. Therefore, they follow the majority in choosing the exit route.

3.3. Phase 3:

In this phase, the information from the literature review and map of the environment were used to develop the model. This process includes the specifications of the model's initial condition, decision rules, and tests for the scenarios, which must be examined in order to reach the aim of this study. The general approach in evacuation modeling consists of two main categories: building environment and human behavior (see Fig. 3)

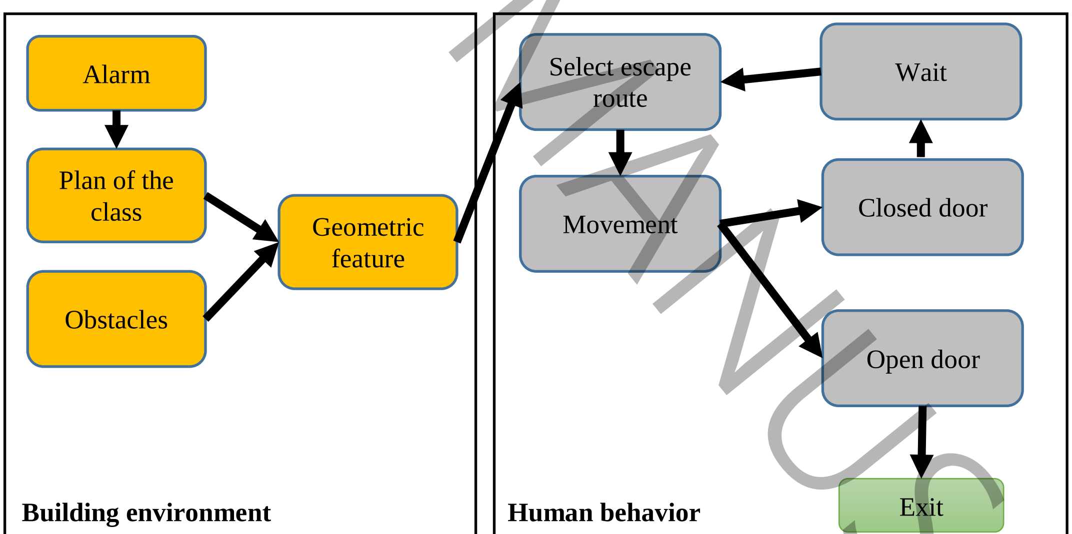

Fig. 3. The evacuation system framework

It has been assumed that the evacuation alarm starts the simulation process. In order to implement the evacuation, the plan of the class was imported to AnyLogic software. Walls and chairs are, respectively, two main external and internal obstacles considered. Different furnishing determines the geometry of the classroom. After environmental preparation, humans should select the escape route based on specified behaviors. The rules of motion make people move in an area to reach the output. At this moment, humans face two conditions: open and closed doors. If the door is open, evacuation is done by going to the exit corridor. However, closed-door situations lead humans to wait until the door will open. Finally, exiting towards each staircase terminates the evacuation process.

3.4. Phase 4:

Finally, the scenarios have been analyzed and specified in detail. Two main conditions can be investigated, each of which contains 3 different furnishings. In the first condition, the door will be closed to evacuate other parts of the building with minimum congestion. The second condition is related to the open door. Therefore, in this situation, evacuation starts as soon as the bell rings.

In this respect, the most essential items that are used in AnyLogic software to simulate the model are discussed here briefly. In this section, the most used items of AnyLogic software that need to implement the model are mentioned in Table 2.

Table 2. Most useable items of AnyLogic software for evacuation simulation [15]

Item	Description
PedSource	To generate pedestrians (start their movement based on requirements)
PedSink	To discard pedestrians at the end of the flow
PedGoTo	To direct the flow of the pedestrians to go to a particular location
PedWait	To make the pedestrians wait for a specified period of time in a particular location
PedSelectOutput	To select routes from available pathways
PedEnter	To organize the pedestrian groups and set their parameters
PedExit	To direct pedestrian flow to another location

4. Results and Discussion

The results of the 3 mentioned scenarios can be drawn as Table 3, 4, and 5 for normal and waiting mode, respectively. It should be noted that each scenario runs more than 100 times to be sure of the accuracy of the results.

According to the results, as all the agents should exit the building until the evacuation process terminates, we consider the time when both left/right stairs have been evacuated (maximum time). As seen in each Table, the second scenario in which the agents can pass through the central and side pathways has generally devoted the lowest total exit time. So, the total exit time in the second scenario is 14.4 and 10.4% less than the first and third scenarios, respectively. Therefore, this furnishing has better performance in the evacuation process in comparison with the others. As a justification, it can be said that although separated chair furnishing provides more escape routes for agents to exit, creating spaces between chairs actually reduces the width of the sides and central paths. On the other hand, it appears that increasing the routes leads to more irregularities in the exit from the classroom compared to the sides and central pathways scenario. According to the results, this scenario can promote evacuation time by up to 14% (see Table 3, Fig. 4).

Table 3. Evacuation results in each furnishing scenario for normal mode

Results	Scenarios		
	A central pathway	A central and sides pathways	Multi pathways with separated chairs
First one exit time (sec)	28	30	27
Net reaction time (sec)	28	30	27
Total exit time (sec) of each pathway (right/left)	(91, 111)	(95, 92)	(100, 106)
Total exit time (sec)	111	95	106
Total exit time (net) (sec)	111	95	106
Number of agents exit from (right/left) door	(25, 25)	(25, 25)	(25, 25)

Table 4. Evacuation results in each furnishing scenario for waiting mode (20 seconds delay)

Results	Scenarios		
	A central pathway	A central and sides pathways	Multi pathways with separated chairs
First one exit time (sec)	48	50	51
Net reaction time (sec)	28	30	31
Total exit time (sec) of each pathway (right/left)	(104, 123)	(120, 126)	(114, 136)
Total exit time (sec)	123	126	136
Total exit time (net) (sec)	103	106	116
Number of agents exit from (right/left) door	(21, 29)	(22, 28)	(20, 30)

Table 5. Evacuation results in each furnishing scenario for waiting mode (50 seconds delay)

Results	Scenarios		
	A central pathway	A central and sides pathways	Multi pathways with separated chairs
First one exit time (sec)	79	76	78
Net reaction time (sec)	29	26	28
Total exit time (sec) of each pathway (right/left)	(138, 165)	(147, 151)	(139, 168)
Total exit time (sec)	165	151	168
Total exit time (net) (sec)	115	101	118
Number of agents exit from (right/left) door	(19, 31)	(21, 29)	(20, 30)

Fig. 4 also shows the total exit time (s) in terms of the delay in opening the exit doors. By examining it, the previous results can be deduced.

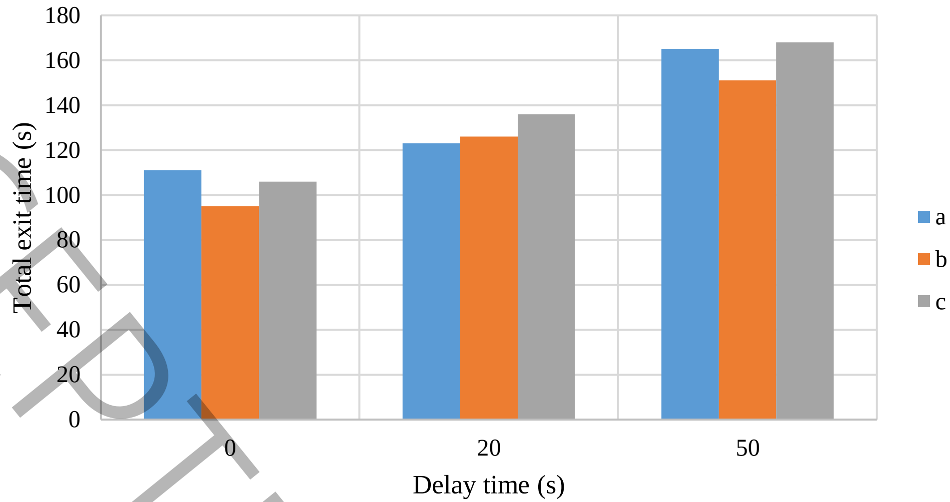

Fig. 4. Total exit time in terms of delay time (s), in different scenarios.

In the first condition in which the class door is always open, it is supposed that choosing the runway between each of the right and left stairs has equal probability because the plan is symmetric (see Table 3). Considering panic conditions, people lose their decision-making power and consequently follow the mass population. Therefore, differences in the number of agents exiting from each stair can be observed in this situation. In general, as the delay time increases, this discrepancy is increased too. In such a way that the distribution of exiting people in the condition with 50-sec delay is more than other conditions. Of course, there is no difference in the scenario with multi-pathways. The minimum difference is devoted to the second scenario in a 20-sec delay, which equals 0.12%, while the maximum difference is 0.24% for the first scenario in a 50-sec delay. Therefore, it is suggested that the width of each staircase is considered to be 1.12 to 1.24 for normal users in building architecture design, to prevent people from falling back when exiting and gathering. It also meets the minimum width of different standards for the width of the staircase [16, 17].

As seen in the Tables 3-5, to compare the reaction time of agents in panic conditions the exit time of the first one is recorded in each scenario, and the delay is considered to highlight, the reaction time. In the first scenario, with a 20-sec delay in opening the exit door, the reaction time that has been saved is about 8 sec (111-103=8). It may be said that the brief delay makes people better able to master the conditions. However, an increase in delay time to 50 sec leads to an increase in the reaction time (115>103). This can be due to an increase in people's confusion. Although the delay in opening the door can pretty help more efficient egress in the first scenario, it should not be neglected that a closed door delays the overall evacuation time. In the second and third scenarios, delays generally lead to an increase in the reaction time of egress. In the second and third scenarios, the more dispersion of agents in classroom space before opening the door can be the reason for this.

5. Conclusion

In this study, the effect of different furnishings on classroom evacuation is investigated. In this respect, 3 furnishing scenarios, including the central pathway, central and sides pathways, and multi pathways provided with separated chairs, are considered in two different situations: open and closed doors. AnyLogic is a friendly software that is used in this study to simulate the classroom evacuation process with consideration of the limitations. According to the prepared model of evacuation, the following results can be drawn based on the agent-based simulation:

- According to the results, it is necessary to evaluate the appropriate method for the evacuation and exit of people from buildings, especially with a large gathering of people, and it should be followed proactively.
- By choosing the right arrangement of furniture and optimizing the delay in opening exit doors, it is possible to improve the direction and evacuation of people in unexpected and sudden situations.
- Among the different furnishings, the central and side pathways scenario generally devotes the minimum total egress time. So, this arrangement provides more regularity at the exit during unexpected conditions.
- The presence of panic conditions can cause a mass population during exit of up to 24%. This situation is aggravated when there is a delay in opening the exit doors.
- Temporary closing of the doors of specified locations is an alternative to have more efficient evacuation. Simulation shows that in this situation, the total evacuation time will be increased. However, a brief delay may even reduce the agent's reaction time, as seen in the central furnishing scenario.

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