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Establishing the Proper Seating Arrangement in Elevated Lecture Halls for a Faster Evacuation Process

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ABSTRACT As time is crucial in the human evacuation process during an emergency situation, several aspects related to how the humans involved in such a process act have been studied over the time, underlying that the humans' behavior is rather unpredictable and depends on social background, emotions, the degree of familiarity with the environment, age, gender, and so on. On the other hand, it has been determined that the characteristics of the environment are important in such situations as they may facilitate a shorter evacuation time. It has been shown that exits characteristics, such as width or their number, have a positive direct impact on the evacuation time. In this context, this paper aims to analyze another environmental aspect, namely, the seat arrangement, and to determine how the seats should be placed in order to reduce the evacuation time for a given configuration of the doors. On this purpose, an elevated lecture hall with two exits has been chosen, as it represents one of the most populated places within the public buildings, characterized not only by a high population density but also by a limited capacity to escape. A case study has been conducted using 97 human subjects and an agent-based model has been created considering their individual characteristics. The model has been simulated on eight different seat arrangements for 15 different positions on the two exit-doors. As a result, the proper seating arrangement for each of the 15 exit-door positions has been presented along with the study's limitations.

INDEX TERMS Agent-based modeling, seating arrangement, elevated lecture halls, evacuation process, simulation.

I. INTRODUCTION

Time is crucial in evacuation situations in case of emergency, while the people's behavior is rather unpredictable and depends of a series of factors such as: age [1], [2], emotions [1], [3]–[6], social background [7], density [8]–[10], environment conditions and localization [11], [12], the presence or absence of guidance or authority figures [1], [13]–[18], geographic features [19], the degree of familiarity with the environment [20], etc.

Among the public building evacuation research, the classroom and lecture halls evacuation hold an important place, as they represent the most populated places within the educational system, characterized by a high population density and a limited capacity to escape [21].

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The current research aims to create an agent-based model through which the evacuation behavior of the persons located in a lecture hall with elevated floor will be simulated. For this, a case study is conducted in an elevated floor lecture hall using 97 human subjects. Afterwards, their physical characteristics and their decisions are analyzed in order to extract the behavior rules to feed the agent-based model. The purpose is to determine which is the best seating arrangement within a lecture hall with two fixed exits that will allow the fastest evacuation in an emergency situation.

While there are many studies in the evacuation area that have used agent-based modeling and experimental methods, in the present study we investigate the particularities present in the situation of a lecture hall with an elevated floor, that has a direct effect on the walking speeds of the evacuees. Moreover, compared to other studies, we aim to more closely model the way in which actual humans evacuate, by employing intelligent agents, which poses different exits selection criteria, inspired by the answers received as a result of the case study performed with human subjects.

The paper is organized as follows: section 2 offers some insights on the state of the art from the crowd evacuation area and agent-based modeling, with an accent on the researches made using NetLogo, a free-software for agents' modeling and simulation. The third section presents the prerequisites of the case study and underline the data extracted through the evacuation simulation, while section 4 presents the agent-based model and the seating arrangements used in simulation. The fifth section simulates the 15 considered door placements against the 8 seating arrangements and offers the proper configuration of the seats' placement in each case. The last section draws the main conclusions of the paper and offers some future developments of the agent-based model. The paper concludes with bibliographical references.

II. THEORETICAL BACKGROUND AND STATE OF THE ART

Considering the literature related to evacuation, a series of factors have been considered over the time both related to the individual characteristics of the evacuating persons and the environmental conditions.

Among them, the emotional contagion holds an important role as it is believed that humans found in an emergency situation tend to be influenced by other humans (adults or children) found in the same emergency situation [22]–[24]. Even more, the emotion contagion between children and adults can have a higher degree. Panksepp and Panksepp [25], Nakahashi and Ohtsuki [26] and Preston and de Waal [27] believe that emotion contagion is often met in the case of mothers because they can easily recognize their children' needs by empathy, without verbal information or warnings.

Liu et al. demonstrate that the personal space (which is represented by a perimeter or some physical limits, between which a certain person feels in their comfort zone while standing or sitting in a place near another person) influences the comfort and safety feelings a person has during an evacuation, with a direct impact on reducing his/her velocity [28].

On the other side, Zheng and Cheng [29] proved that even rationality should be considered in such cases, as it has a direct impact on the evacuation time. In their study, the authors demonstrate that in an evacuation process, the time consumed by a group who manifest a high-rationality is longer that time needed to evacuate for a crowd with low-rationality [29]. The results are also confirmed by Frank and Dorso [30].

Another important aspect is given by the presence of a leader during an evacuation process. Aubé and Shield [31] discovered that the mixture between different types of leaders (peripheral and distant) lead to an efficient evacuation, while Ji and Gao [32] investigated the influence of a leader among a crowd throughout an emergency situation and the result highlighted that the crowd's period of evacuation would be shortened under a leader's guidance.

Nevertheless, exits characteristics plays an important role in the evacuation process. Daoliang *et al.* [33] prove in their paper that the exits' width represents one of the main factors which are affecting the overall evacuation time, while Nagai *et al.* [34] show that a greater number of exits has a direct and positive impact on the evacuation time reduction. Even more, the authors are underlying the fact that when two exits are available for evacuation instead of one, the evacuation time is reduced by half [34]. Even though this result may be correct in a wide range of situations, but other phenomena may appear, as concluded in Sticco *et al.* [35].

Even more, the way of choosing the exit doors is rather correlated with the daily usage, familiarity than the level of efficiency throughout evacuation process. Hofinger *et al.* [36] and Proulx and Richardson [37] have proven that people have the tendency to use the main egress, the one they are familiar with in order to enter the building on a daily basis, without considering another faster routes which can shorten the time for evacuating. Helbing *et al.* [5], using empirical observations, have shown that herd behavior represents the main point to consider in the analysis of exit selection, individuals often having the follow-the-crowd instinct.

Haghani and Sarvi [38] have observed that the decision scenario is influenced not only by the others' actions and strategies for survival, but also by some physical aspects: the former is the distance to escape exits and the latter is the visibility. The more crowded and further the exit is, the smaller the probability to choose that door will be. The authors highly emphasize that people prefer certainty to feel secure, so the exits which are visible from a longer distance are desirable without any doubts. Regarding the level of visibility, Tan *et al.* [39] studies have highlighted the same idea: the grade of visibility is very important to people when they are choosing the routes for evacuating. Ren-Yong and Hai-Jun [40] studied the route choice of pedestrians who had to escape through multiple exits, considering pedestrians' disutility and concluded that the choice was influenced by the route distance, exits' width and the number of people who wanted to use the same exit.

Helbing *et al.* [41] provides a good picture of the mass behavior in crowd dynamics, underlines the main factors that influence the presence of crowd turbulences and how they can be reproduced in computer simulations. Also, a series of challenges which derive from the moral behavior of the evacuees are discussed by Capraro and Perc [42] and by Perc *et al.* [43].

III. CASE STUDY: A LECTURE HALL EVACUATION

For simulating the lecture hall with elevated floors evacuation, we have conducted a case study in one of the lecture halls that our university has, located in Piata Romana, Bucharest, which can be seen in Fig. 1.

FIGURE 1. View from the front of the lecture hall (one of the two exits is visible in the back).

FIGURE 2. Subjects' seat placement in the analyzed lecture hall (view from the front).

A. PREREQUISITES

The lecture hall is composed by 3 vertical columns of seats, each of them being able to accommodate 6 persons per row. The number of rows on each column is 23. As it can be observed from Fig. 1, the lecture hall has 4 vertical aisles, 2 of them between the 3 columns of seats and the other 2 between the seats and the room's walls. Also, the lecture hall has 2 exit doors, one located in the middle-back and another one, which is also the main entrance to the lecture hall, located in the front-left side of the room, on the long wall. The elevation degree is 9.83°.

In order to extract some of the key features related to lecture hall's evacuation, we have made a simulation using 97 human subjects which were attending one of the classes offered by our university. The human subjects have been spread almost evenly across the lecture hall with the purpose of evaluating as much as possible the evacuation behavior of persons located on each area of the lecture hall. Fig. 2 depicts the subjects seat placement.

In the first stage of the simulation, the course attendees were asked to fill in a form in which they gave their accord to be a part of this study and they offer the information regarding a series of personal data such as name, gender, age have, approximate height and weight. Also, the subjects have been asked if they have participated in the past to an evacuation simulation and whether they have taken in the past courses related to how to act in an evacuation case. A copy of the questionnaire is presented in Fig. 15 (translated from Romanian).

Along with the information related to the personal data, the subjects have been asked to mark their exact position within the lecture hall, indicating it through an ''x'' on the grid of rows and columns depicted in the form.

The next step was to ask the subjects having a smartphone or a digital hand-wrist watch to measure the actual time between the start of the simulation (marked by the moment they were standing in their initial position) and the moment they have reached the outside area of the lecture hall.

At time zero, the simulation begun and each of the subjects has chosen one of the two exits in order to evacuate. During the evacuation, a series of photo and video recordings have been made by our team in order to better extract the subjects' behavior during the simulation. One of the team members has been responsible with giving the start and counting for the time needed until the last person has left the room. Fig. 3 depicts the evacuation process seen from the front and from the back of the lecture hall.

In order to ensure an evacuation process that is as close as possible, to real-world emergency situation, the participants to the study were instructed to evacuate from the lecture hall as fast as possible and to behave in a natural manner. A similar experiment design was used by Lu *et al.* [44].

After the last person has evacuated, the subjects were asked to return to their seats and to fill-in the time they needed for evacuation and to draw on the form the path they have chosen in this process. Last, at the end of the form, there was an empty field in which the subjects were asked to name the criterion / criteria they have used in order to choose their path and whether they have changed their mind related to the door choosing. In the case in which they have answered with ''yes'' at the following question: ''Have you decided to evacuate on a particular door, but, in the end you have evacuated on another door?'', the subject had an additional field in which they were asked to explain what was the cause that made them change their minds.

B. DATA ANALYSIS

The population structure is: 19.59% males and 80.41% females, having ages between 18–23 years old.

Analyzing the inter-group characteristics, it has been observed that most of the subjects have the height and the weight close to the average values, thus, not significant differences have been recorded in terms of physical characteristics. Also, it should be mentioned that none of the analyzed subjects were subjects with disabilities or with reduced mobility.

(A)

(B)

FIGURE 3. Snapshots during the evacuation process. (a) View from the front of the lecture hall. (b) View from the back of the lecture hall (the front exit is visible).

For determining the average evacuation time, we have divided the subjects into four groups depending on their gender and on their chosen path for evacuation. As we are dealing with an elevated floor lecture hall, we have assumed that the time and the speed will be different for the subjects who have decided to evacuate through the door located in the upper side of the room (in our case, in the back of the lecture hall) than the time and speed of the subjects evacuating through the door located in the lower side of the room. As a result, the average time has been calculated in Table 1. Even though the average evacuation time for men in the lower side door seems slightly higher than the value recorded in the case of women, we should also consider the men position within the lecture hall, depicted in Fig. 16. By analyzing it, it has been observed no man has been encountered in the first three rows of chairs located in the first two columns near the lower side door. This might be one of the reasons why the women have scored smaller average values when evacuating on the lower side door.

As for the speed, we have determined it based on the video recording we have made, by randomly selecting 6 males and 6 females. Among them, half (3 males and 3 females) have chosen the upper side door, while the other half the lower side door. We have considered the speed only on a part of the path they have chosen, the one that consists on stairs. As a result, it has been observed that on average, a male had an average speed of 0.99 m/s when heading up and 1.06 m/s when heading down, while a female had 0.97 m/s when ascending and 1.02 m/s when descending.

TABLE 1. Average evacuation time based on gender and chosen evacuation door.

Gender	Chosen door location	No. of persons	Average time (s)
Male	Upper side	11	14.91
	Lower side	8	23.63
Female	Upper side	31	18.71
	Lower side	47	23.49

Considering the question in which the subjects have been asked if they have participated before in any simulation for evacuation, it has been observed that more than half of the participants have been involved before in a simulation or have taken a first aid course, 55 subjects have marked that they have taken part in some courses regarding what to do in an evacuation situation, representing 56.70% from the considered population. This high number of recorded persons who have taken part in the past in evacuation courses might be due to the fact that our university has organized free courses of first-aid in the last few years.

Regarding the door selection, it has been observed that 43.30% of the subjects have chosen the door located in the back of the lecture hall, while the rest of 56.70% have chosen the door located in the front. We shall mention that the door located in the front side of the lecture hall was also the main entrance and was in the visual area of the participants. Thus, one of the questions that may arise here is related to which were the main criteria that the participants have used for deciding the evacuation door. For analyzing the answers to this question, we have first extracted the persons which have declared that they have taken evacuation courses in the past, dividing the population into two major groups. As a result, the data in Table 2 has been extracted.

Analyzing the number of criteria mentioned by each of the persons in each group, it has been determined that, on average, the persons who have participated in evacuation courses in the past have mentioned more criteria (an average of 1.55 criteria) than the persons without any course (an average of 1.19 criteria). Also, regarding to the data in Table 2, it should be mentioned that 2 persons from the group without any evacuation courses have mentioned that they have evacuated with a friend as a second criterion to the closeness criterion, while 2 persons from the group that have previously taken first-aid or evacuation courses have mentioned that they have selected the door located in the lower side of the lecture hall as it was positioned at an inferior floor which would have shortened their building evacuation

TABLE 2. Criteria for selecting the evacuation door.

Groups	Chosen door location	Criteria	No. of times mentioned	Percentage
Persons without any evacuation courses	Upper side	Closeness	17	62.96%
		Less congestion	9	33.33%
		Making the same decision as a neighbor	1	3.70%
	Lower side	Closeness	21	91.30%
		Door visibility	1	4.35%
		Making the same decision as a neighbor	1	4.35%
Persons with evacuation courses	Upper side	Closeness	17	54.84%
		Less congestion	14	45.16%
	Lower side	Closeness	33	61.11%
		Door visibility	19	35.19%
		Downstairs location	2	3.70%

time compared to the situation in which they would have selected the upper door.

Based on these data it can easily be observed that the persons which have participated in the past to evacuation training courses, have demonstrated an increased awareness related to the evacuation situation, knowing how to better evaluate the situation by considering a higher number of criteria in order to decide their position and the door for evacuation, having also a reduced evacuation time by 6.34%.

The overall evacuation time has been equal to 53 seconds. The last person leaving the lecture hall has evacuated using the front door. Meanwhile, the evacuation on the back upper door has been completed by second 37. Even though there has been a 16 seconds difference until the evacuation on each of the two doors has been completed, none of the persons evacuating on the lower side door has changed his / her mind.

As also mentioned by Haghani and Sarvi [45] it can be argued that observations collected during evacuation simulations can be considered to present a laboratory nature. However, data obtained from fully naturally-occurring evacuations is extremely rare

Due to the aim of creating a ‘‘laboratory in the field’’, the current experiment has a series of inherit limitations, such as sample size, contextual realism, environmental realism, etc. However, all of them are common to any ‘‘evacuation drill’’ experiments and ‘‘controlled experiments with human group subjects’’, as mentioned by Haghani and Sarvi [46]. The authors are also stating that ‘‘certain topics related to emergency behavior, the experimenter is restricted by ethical considerations and need to make a reasonable balance between the realism and invasiveness level of their design’’ [46]. Thus, in the current study, for both ethical and safety concerns, we have decided to inform the participants that they are taking part in an experiment. This choice is in line with the studies conducted by [44], [47]–[49].

The data presented in this section have been used for creating the agent-based model in NetLogo, by giving to the agents the characteristics that are as close as possible to the subjects we have used in the case study, as presented in the following.

IV. THE AGENT-BASED MODEL

Agent-based modeling and NetLogo have been the first choice of the researchers in different areas such as: air transportation [50]–[52], evacuation [1], [13], [19], [39], [53]–[55], wireless networks simulation [56], medical field [57], learning [58], etc. as they offer the possibility to proper model and analyze the micro-behavior of the agents and to draw some conclusions related to their behavior at macro-level, as a group. Also, NetLogo [59] provides all the advantages brought by the agent-based modeling approach and offers an integrated GUI (graphical user interface) which allows the visualization in real time of the agents' behavior and decisions. A comparison between NetLogo and other agents based modeling platforms can be found in [60]–[65].

The proposed agent-based model in NetLogo has been created starting from the characteristics of the lecture hall presented in the case study and by considering the individual properties of the analyzed subjects.

NetLogo offers, besides the programming language, a very intuitive interface in which one can easily observe at each moment of time (called tick) the decisions and the steps taken by each of the agents for a faster evacuation.

As for programming the agents to act as real human beings, 2 types of agents have been used: the turtles which are the agents endowed with human characteristics in terms of evaluating the surrounding world and making needed evacuation decisions and the patches which are small pieces of ground, used for dividing the lecture hall into squares which allows the turtle agents to walk around and find their path.

A. ASSUMPTIONS

As it has been observed that the space occupied on the floor by a man and a woman has similar values and also that the distance between two subsequent row of seats is 0.75 m, we have used an average space of 0.4m x 0.4m, which will be associated to the size a patch in NetLogo. This choice is consistent with the personal space used in other simulations involving human behavior [66], [67]. In this context, the distance between two subsequent rows will be of 2 patches.

Also, from the simulation it has been noticed that on the vertical aisles between the groups of sets 2 persons could evacuate in parallel – see Fig. 4 - the space in NetLogo

FIGURE 4. Parallel evacuation on the aisle (it can be observed that the aisle is wide enough to allow the evacuation of two persons in parallel).

between the group of chairs is made of 2 patches, allowing the agents to evacuate in parallel.

In NetLogo, the turtle agents have been divided into two groups: male and female which respects the percentages of male and female encountered in our population, namely 19.59% male and 81.41% female. As it has been observed from empirical measurements, the average speed of the two categories is different and assuming that, even within groups, the population is heterogenous, each turtle has been endowed with an own-value for the speed, which is determined based on the speed distribution of the category it belongs to. For example, for the male-agents heading through the door located in the upper side, the speed has been normally distributed with a mean of 1.06 m/s and a standard deviation of 0.1, while for those going through the lower exit door, the speed it normally distributed with a mean of 0.99 m/s and a standard deviation of 0.1. In the same way we have proceed for the female-agents: the speed is normally distributed with the mean of 0.97 m/s and a standard deviation of 0.1 when they are ascending and with a mean of 1.02 m/s and a standard deviation of 0.1 when descending.

Based on these assumptions, it has been calculated that a second is equivalent with 2.5 ticks (a tick is the time unit in NetLogo).

Additionally, the turtle agents possess some criteria they may use for evaluating which door to choose for evacuating, inspired from the answers obtained through the case study: closeness to the doors (C1), less congestion (C2), making the same decision as a neighbor (C3) and door visibility and downstairs location (C4). The probabilities for each of the criteria to be selected are in accordance to the data in Table 2. – namely C1 has a probability of 65.19%, C2: 17.04%, C3: 1.48% and C4: 16.30%. These values have been determined by dividing the number in each category: 88 in C1, 23 in C2, 2 in C3 and 22 in C4 by their total number, 135.

At the beginning of the simulation, time equals zero, the agents select based on the probability distribution the criterion to be used for evacuation. Each agent has its own criterion / criteria. The probability for each criterion to arise, previously determined empirically, is used in the agent-based model to better simulate the observed human behavior.

The subjects located at the end of the rows which have selected the "make the same decision as a neighbor" will adopt the same decision as the agents located in diagonal on lower row of chairs, while the ones located in the first row will have only the closeness to the doors criterion as this was encountered as the criterion used by all our human subjects located on the first row of seats. Also, as all the human subject which have mentioned the C4 criterion (door visibility and downstairs location) have selected the door located in the lower side of the lecture hall, even in the case of the agents, when this criterion arises (with the given probability), the agents will choose to evacuate on the door located in the lower side of the lecture hall. In the case in which both exit doors are located in the front of the lecture hall, these agents will receive a second criterion (C1, C2 or C3) which will make them properly choose among the exit doors. Even in this case the percentages of each criterion is used for determining which will be the second criterion (thus, C1 has a probability of 7.88%, C2 of 20.35% and C3 of 1.77% - these values have been determined by dividing the number of cases in which they have been mentioned, namely 88 for C1, 23 for C2 and 2 for C3 by their total number, 113). After each agent has its own criterion / criteria, the speed of the agent is settled in accordance with the rules mentioned above and the evacuation simulation begin.

During the evacuation process, the agents are heading towards one of the exits according to the selected criterion, using only the permitted aisles among the blocks of chairs or the spaces within the desks. The agents cannot jump over the seat rows in their way to the exit door. At each moment, an agent is occupying a space equal to 0.4m x 0.4m, making personal space to be at its lower limits.

The simulation ends when all the agents have evacuated from the lecture hall. Last, considering the purpose of the paper, namely to proper identify the seats arrangement within a lecture hall, a series of layouts in terms of seat placement have been considered as depicted in Fig. 5-12.

As for the exit doors' placement, 8 situations have been considered possible, as depicted in Fig. 5-12. The doors have been noted with: A (the door located in the left-bottom side of the lecture hall), B (left-top), C (top-left), D (top-center), E (top-right), F (right-top), G (right-middle), H (right-bottom).

According to ASSIST (Australian School Science Information Support for Teachers and Technicians) [68], in the case a classroom or a lecture hall has more than one exit, the distance between them should not exceed 12.5 m or 20% of the perimeter of the room, whichever is the lesser. Thus, for the considered doors positions, during the simulations, we will not consider the following door combination: (B, C) nor (E, F) as they are not possible in reality due to the imposed regulations. On the other hand, the situations in which we

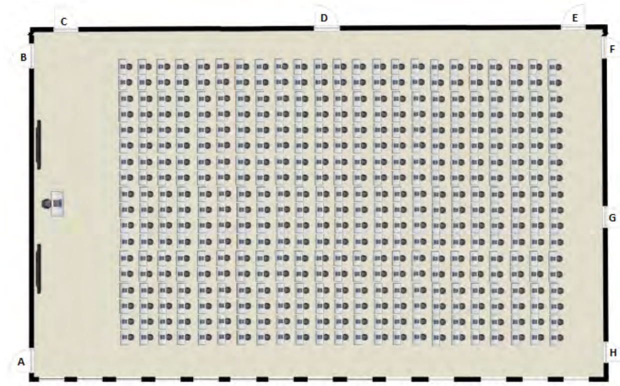


FIGURE 5. One-block seat arrangement.

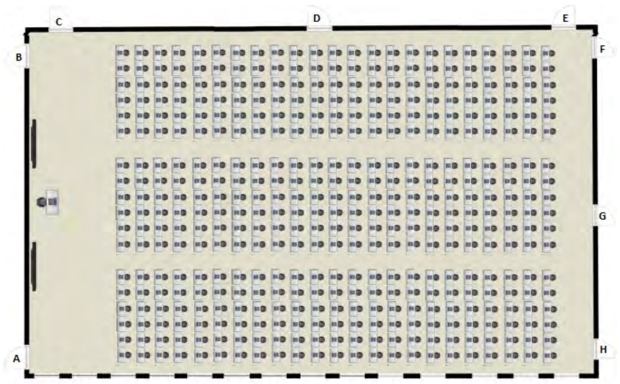


FIGURE 8. Three-even-column-block seat arrangement.

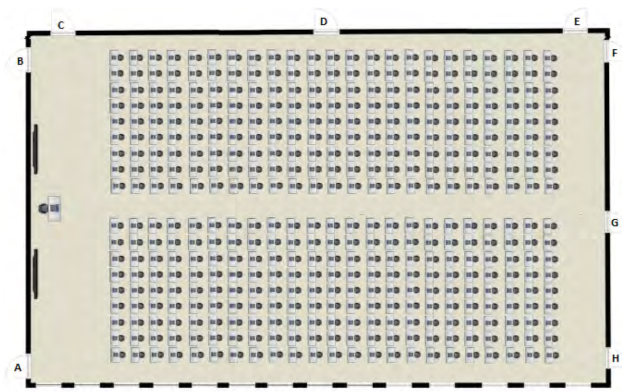


FIGURE 6. Two-column-block seat arrangement.

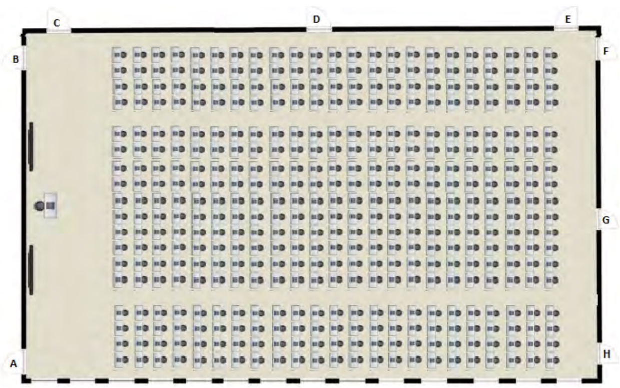


FIGURE 9. Three-uneven-column-block seat arrangement.

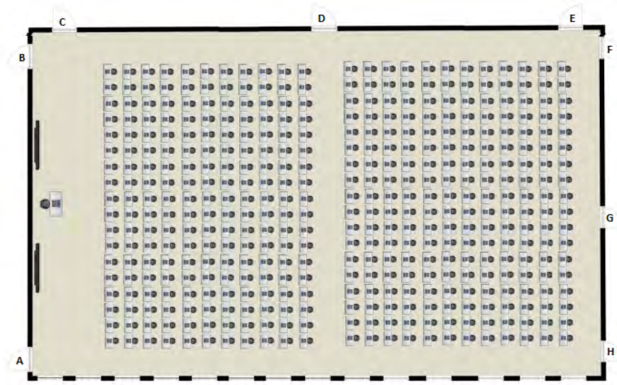


FIGURE 7. Two-row-block seat arrangement.

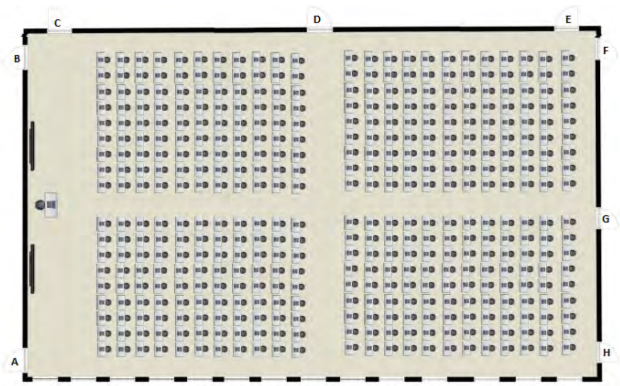


FIGURE 10. Two-column-and-two-row-block seat arrangement.

have a door located in either of B, C, E or F points and another door located in any of the other locations, such as A, D, G or H is possible and it will be analyzed in the simulations' section.

B. IMPLEMENTATION

An agent-based model in NetLogo has been created, which has similar dimensions to a lecture hall. The GUI (graphical user interface) is presented in Fig. 17.

The lecture hall's characteristics are configurable and easily adjustable from the sliders or code, while the number of turtle agents, representing the persons seating in the room can be modified using a slider available in the interface (''number-of-students'').

Each agent is able to evaluate the distance to the nearest exit when its door choosing criterion is C1 (closeness to the doors). In order to do so, we have used the ''cone exit'' approach proposed by [69] and used in a previous work by [53]. In this approach each patch receives a certain number based on how close the patch is to one of the exits. When arrived on a patch, the agent will be guided to the nearest exit

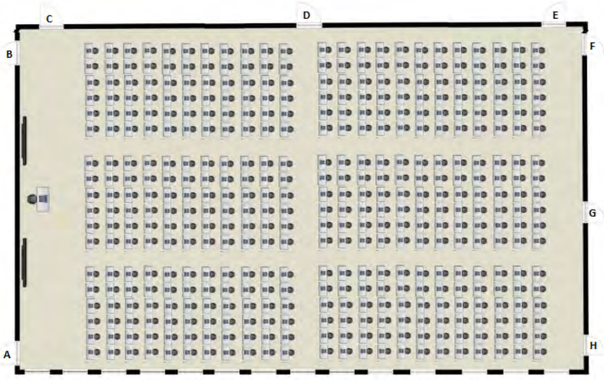


FIGURE 11. Three-even-column-and-two-row-block seat arrangement.

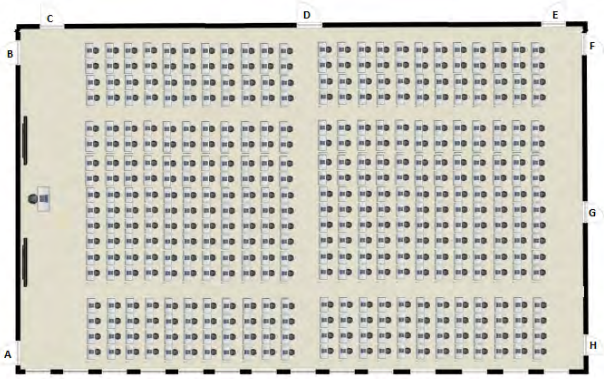


FIGURE 12. Three-uneven-column-and-two-row-block seat arrangement.

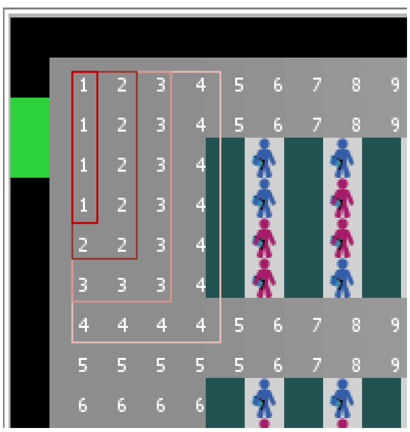


FIGURE 13. The "cone exit" approach.

by selecting at each step a patch with a value smaller or equal than the one retained by the current patch. A section from the model which depicts the cone exit approach is presented in Fig. 13.

The turtle agents possess the characteristics mentioned in the assumption subsection and are colored in blue (male) or red (female) and disposed randomly in the lecture hall at the beginning of each simulation. An example of a turtle agent and its characteristics is given in Fig. 14.

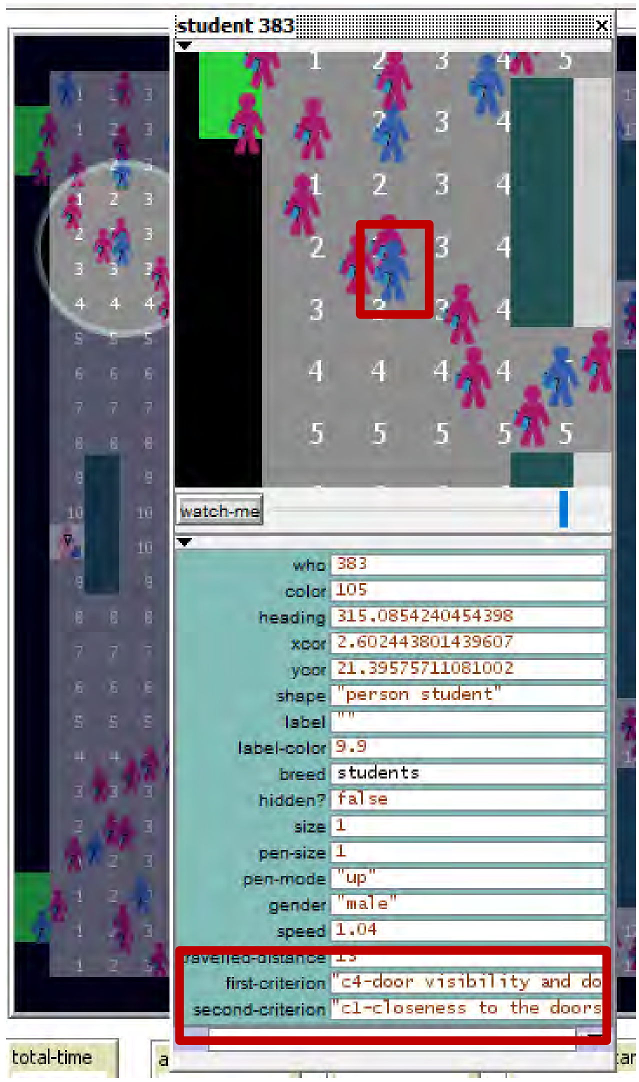


FIGURE 14. Example of a turtle agent in NetLogo, having the first criterion c4 and the second criterion c1.

In order to calibrate and validate the model, we have created a test version of the agent-based model and we have placed manually the agents in the same seats in which the participants to our simulation have seated. In this stage we have been mainly concerned if each agent is using the proper criterion in order to evaluate its decision regarding the door the agent would choose for evacuation. We have not been interested in making the agents as rationale as possible, but rather we tried to make them act as the persons we have used for the evacuation simulation. Also, in this step we have adjusted the speeds, by allowing the agents not to take only the speed values which were observed for the 12 randomly selected persons, but to have their own speeds, each of them ranging among some limits. The limits were the same as presented in the Assumptions section. After running several situations and adjusting the variables, we have noted that, in the model, there are still small differences in terms of evacuation time when compared to the real-life situation (ranging between −1.26% and 2.79%). These differences between the evacuation time in the model and in the real simulation using the students are unavoidable as even though at each simulation, the males and females have been placed on the exact same places, the speed has taken different values each time due to the randomness imposed in speed. Even though this can be mainly seen as a disadvantage of the agent-based simulation, we think that it is not entirely the case. If we consider that the same students have been attended the same class in another week, it would have been very likely that they wouldn't have stayed on the exact same places and their speed could have been slightly different due to other subjective aspects. Therefore, we have concluded that the model is able to simulate as close as possible the considered population and we have proceeded further with using it on a larger sample of agents.

V. SIMULATIONS AND RESULTS

The simulations have been made using the BehaviourSearch 1.10 tool offered by NetLogo, which is a specially designated tool for conducting complex experiments over a given model [50], [51], [59].

The 8 seat-placement in the lecture hall depicted in Fig. 5–12 have been considered, each of them representing a case. For each case, a two-door combination has been used and simulated 1.000 times. Having eight cases in which the two exit doors could have been placed, 28 possible situations are available [from (A, B), (A, C), …., (G, H)]. Considering the ASSIST regulation, the (B, C) and (E, F) case is not possible, reducing the number of possible door-placing situations to 26. Moreover, as door B is very close to C and E is also very close to F, the cases in which we are considering any other door and B it will be equivalent to the case in which we are choosing that door and C as it won't make a significant difference in the evacuation time [53]. The same situation happens when we are selecting a door and E or the same door and F. Thus, the number of the possible situations for the door placement is reduced to 15.

The simulations have been conducted considering a full lecture hall, consisting in 414 participants, all of them seating. This situation might frequently arise in the case of different events organized by the university (invited speakers, university opening festivity, etc.) or in tutorial classes.

The average evacuation time over the 15 situations considered has been determined by making the mean of the 8.000 simulations made in each case, with a total of 120.000 simulations.

The smallest evacuation time is listed for each of the doors combination in Table 3. On the third column of the table, the best seat arrangement is listed.

Depending on the two evacuation doors' position and knowing the lecture hall with elevated floors dimensions, one can easily decide which is the best seat placement that insures the fastest evacuation process in case of emergency.

Based on the simulations, it can be observed that the smallest evacuation time is encountered in the case in which the doors are positioned in an A and E/F configuration or B/C and H, conducting to an average evacuation time of 196 seconds. These two are also the cases in which the two exits are positioned in diagonal. Even though it is a desirable positioning of the doors, with a proper seat arrangement, this is also a very unlikely situation to be encountered in real lecture halls as the building should have different spacing configuration at each level.

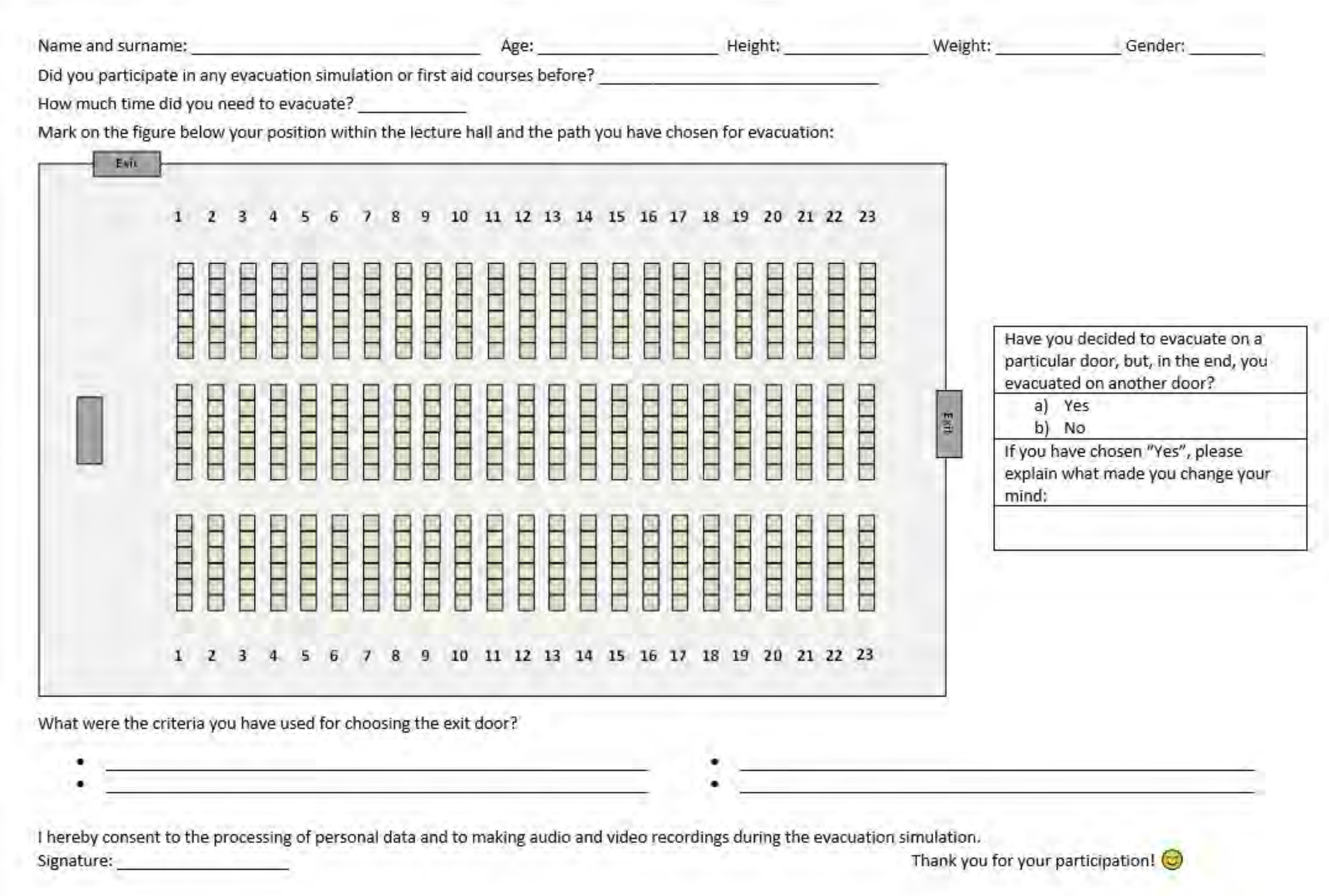
TABLE 3. Simulations' results.

First door location*	Second door location*	Seating arrangement	Time (seconds)
A	B/C	three-even-column-block	197
A	D	three-even-column-and-two-row-block	203
A	E/F	three-even-column-and-two-row-block	196
A	G	three-even-column-block	207
A	H	three-even-column-and-two-row-block	204
B/C	D	two-column-and-two-row-block	201
B/C	E/F	three-even-column-and-two-row-block	204
B/C	G	three-even-column-block	207
B/C	H	three-even-column-and-two-row-block	196
D	E/F	two-column-and-two-row-block	210
D	G	three-uneven-column-and-two-row-block	211
D	H	three-even-column-and-two-row-block	211
E/F	G	three-uneven-column-and-two-row-block	216
E/F	H	three-even-column-block	217
G	H	three-uneven-column-and-two-row-block	216

The most encountered seat arrangement among the 15 possible doors configurations considered in the paper is "three-even-column-and-two-row-block" and it offers a series of advantages due to the numerous aisles running in both (vertical and horizontal) directions.

Even though the data in Table 3 presents for each case the best seat arrangement, looking more in depth at each situation, it has been observed that for some doors-combination, there are multiple good solutions, which are producing almost the same evacuation time as the best solution proposed in the table.

For example, it has been observed that all the situations in which the "three-even-column-and-two-row-block" produces best results, the next-best seat arrangement is "three-uneven-column-and-two-row-block", this being, on average, at only 2.53 seconds distance. Also, for all the cases in which



Name and surname: ______ Age: ______ Height: ______ Weight: ______ Gender: ______

Did you participate in any evacuation simulation or first aid courses before? ______

How much time did you need to evacuate? ______

Mark on the figure below your position within the lecture hall and the path you have chosen for evacuation:

Exit

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23

Exit

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23

Have you decided to evacuate on a particular door, but, in the end, you evacuated on another door?

a) Yes
b) No

If you have chosen "Yes", please explain what made you change your mind:

What were the criteria you have used for choosing the exit door?

- ______
- ______
- ______
- ______

I hereby consent to the processing of personal data and to making audio and video recordings during the evacuation simulation.

Signature: ______

Thank you for your participation!

FIGURE 15. **The evacuation questionnaire.**

the best seat arrangement has been marked as "two-column-and-two-row-block", the second-best choice was "two-row-block" – this seat configuration leads to an increase in the evacuation duration with only 3.11 seconds (when compared to "two-column-and-two-row-block"). Regarding the "three-even-column-block" seat arrangement, in all of the four cases in which it has produced the shortest evacuation time, the second-best seating arrangement has been "three-uneven-column-block", which produced on average an increase in the evacuation time of only 2.86 seconds.

Considering "three-even-column-and-two-row-block" seat arrangement and the positions of the two doors in the cases in which this seat arrangement has produced the best evacuation times, it can be observed that in most of them one of the doors is located in the front of the elevated lecture hall, while the second one is located in the back, which justifies the presence of a large number of aisles, that could allow the agents to shorten their path to the nearest exit door. Also, in two of the cases in which "three-uneven-column-and-two-row-block" has been listed as the best seat arrangement, one of the evacuation doors is located at the top-center (door D) of the lecture hall, while the second one is either in the front (door A) or in the back (door H), which justifies the need of having a horizontal aisle in the seat arrangement. Nevertheless, the need of having a horizontal aisle is encountered in all the configurations in which one of the evacuation doors is located at the top-center (door D), as it can be observed by analyzing the simulations results included in Table 3.

Among all the considered cases, it has been observed that the "one-block" seating arrangement produces the longest evacuation times, with 27.14 seconds more, on average, than the best-ranked seating configuration. This might happen due to the fact that some of the agents need to spend more time on each row of seats until getting to an aisle and their speed depends more on the speed of all the other agents located in front of them.

The results gathered through the NetLogo simulations are applicable to an elevated lecture hall having similar dimensions and elevation degree with the one considered in the present case study. For different scenarios, the NetLogo model is configurable, allowing other researchers to adjust the dimensions of the lecture hall, the agents' walking speed ranges, the number of agents, the percentage of males and females, the width and location of the exit doors and the general configuration of the desks in the lecture hall.

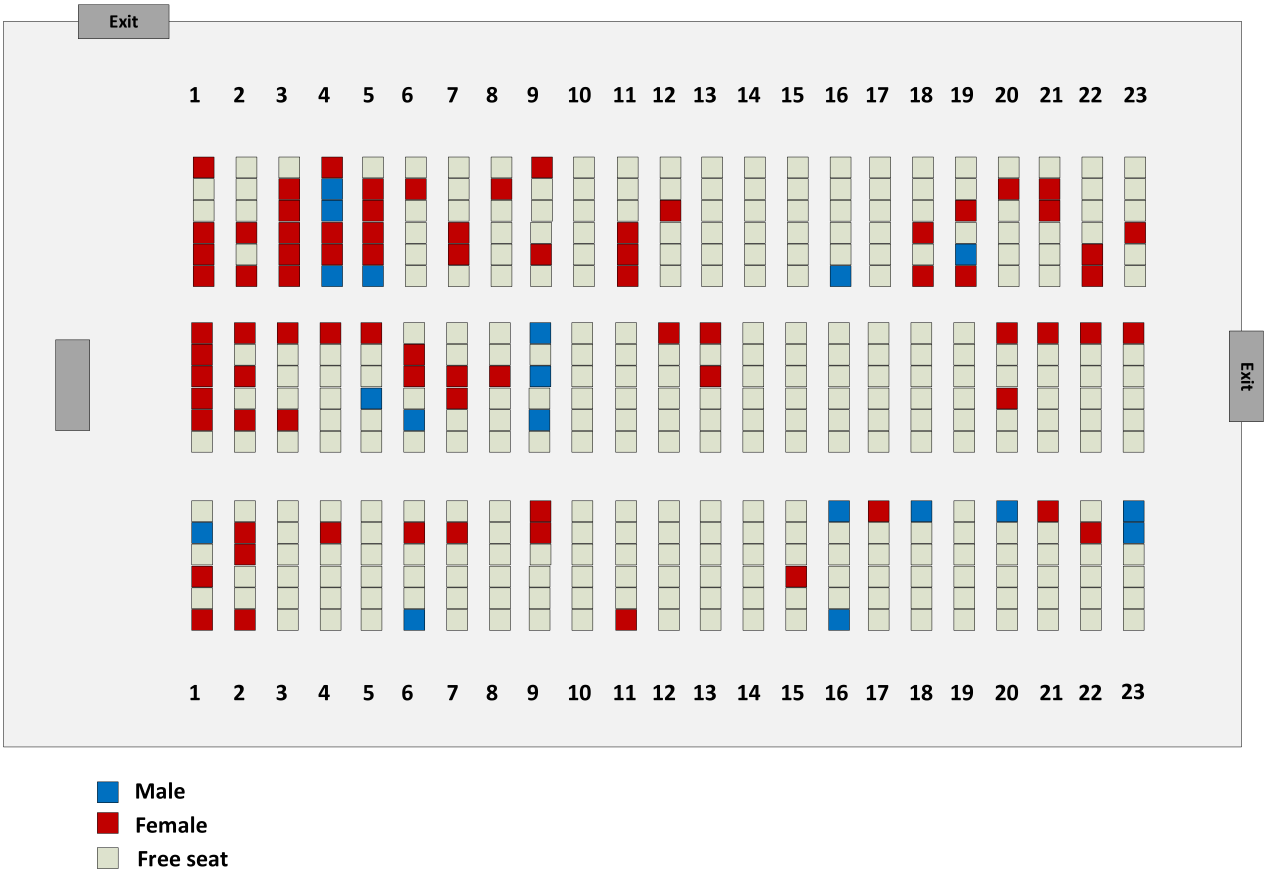


FIGURE 16. Students (male and female) positions within lecture hall.

VI. CONCLUDING REMARKS

The study of seat arrangement within lecture halls can give some insights on how the seats should be placed in order to facilitate a faster evacuation in an emergency situation.

In the present paper we have considered the case of a lecture hall with elevated floor and we have built an agent-based model in order to simulate the people's behavior when confronted with an emergency.

A case study has been conducted on a lecture hall made by 23 row-seats and 18 column-seats divided into three individual columns. A series of data have been extracted related to the profile of the persons under investigation and the decision they have made in order to evacuate.

By observing their behavior and reading which have been the criteria they have considered when deciding on which door to evacuate, we have been able to create a model with agents in which some of the personal characteristics of the human subject have been transferred to the agents. Keeping the same population structure, the model in NetLogo has been used on a series of situations in which the doors could have been placed in a lecture hall, identifying eight possible situations (left-bottom, left-top, top-left, top-center, top-right, right-top, right-middle, right-bottom). The combination between some of the doors' position was not feasible as the two-doors were to close one to another, while other situations were similar in terms of evacuation time, which reduced our cases from 28 to 15.

Using 1.000 replications for each case, the best seat arrangement has been determined for a given placement of the doors.

As the agent-based model is configurable, it can be easily adjustable to other dimensions of the lecture hall. Also, the different characteristics of the agents are adjustable, allowing to the model to be adapted to different types of audiences (e.g. persons with a different age, body size, speed, etc.).

The case study has some limitations due to the fact that it has been conducted in a controlled environment and even the subjects were aware of the gravity of the situation and they tried to act as they were involved in a real emergency evacuation, it is still possible that, when confronted to a real situation, to act differently based on many other factors which can be more or less related to their or the other persons' state. Nevertheless, the agent-based model has some limitations due to not considering some extreme situations in which some of the agents decide to jump over the seats in order to shorten their path to the exits or in which some of the agents are injured and may fall over the floor. We aim to add all these

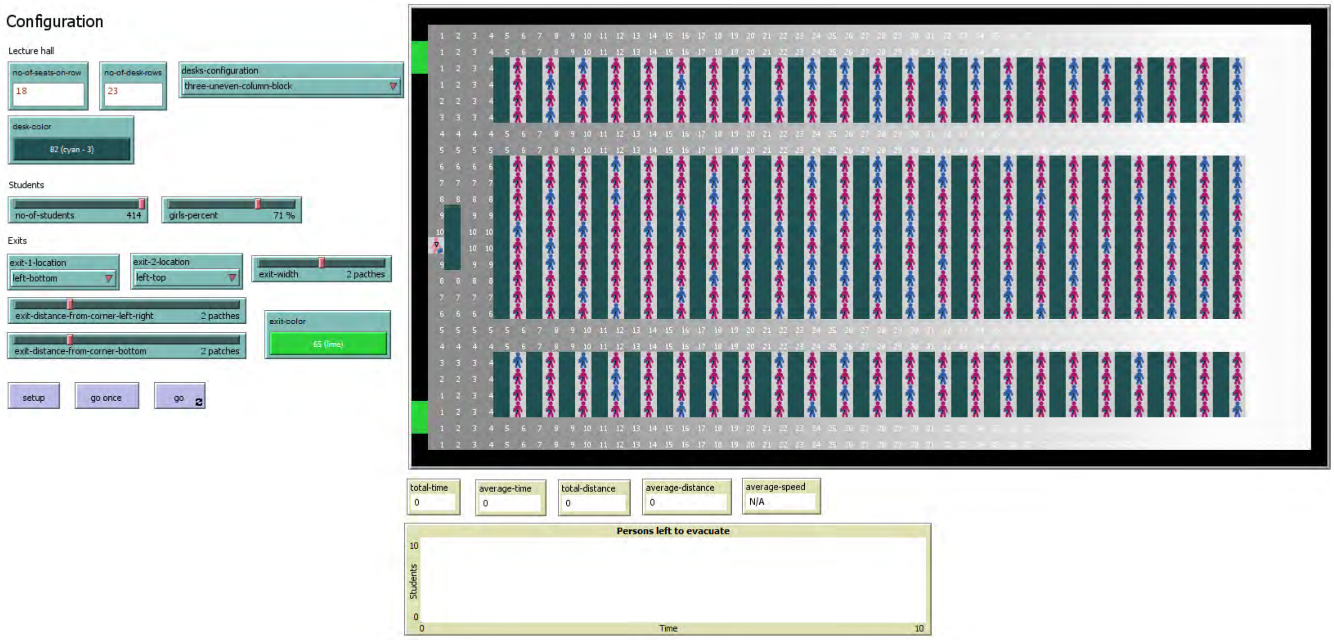


FIGURE 17. **The agent-based model's GUI.**

situations in the model in a future work. Last, the persons with disabilities are excluded from the current study and we aim to introduce them in a future work. Determining the best seat placement for these persons can insure their proper and safe evacuation.

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