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Cybernetics Approach Using Agent-Based Modeling in the Process of Evacuating Educational Institutions in Case of Disasters

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Abstract: In the context of an emergency, evacuating people from a location in the shortest possible time is essential, as is the high degree of safety that people should expect when evacuating. Lately, in Romania there have been more and more fire events generated by different causes. This article will use agent-based modeling to simulate an emergency evacuation model in NetLogo. The model has been used to perform and analyze various scenarios. With the help of NetLogo, we managed to perform 400 simulations with the evacuation of 180 people (students, teachers, and non-teaching staff) based on which we developed several recommendations to streamline the evacuation process in order to reduce the possibility of death. The present research will help to identify the evacuation times from a school, but it will also highlight certain aspects that may occur during the evacuation. The model that was used in this research took into account the individual particularities of the people taking part in the evacuation, emphasizing the effects that form in a crowd of people when evacuating; effects such as the funnel effect, which is caused by the formation of bottlenecks around narrow areas. All these things are part of the analysis of the measurement of entropy of the exhaust system, a problem that has captured all of the specialists' attention. Finally, solutions have been proposed to improve evacuation time in case of disasters.

Keywords: cybernetics approach; agent-based modeling; NetLogo; evacuation process; human behavior simulation



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1. Introduction

Over time, the problems generated by evacuation in cases of emergencies or disasters have attracted a large audience because such events are uncertain, and can occur anywhere and at any time, causing multiple damage, both human and material. In the last century, 13 major earthquakes were registered in Romania, which affected more than 400,000 people and resulted in over 2000 deaths [1]. Romania has been facing increasingly frequent extreme weather events in recent years—especially as Bucharest ranks third in terms of the fastest growing temperatures among the 58 largest cities in the European Union. According to information published by the World Bank, these disasters disproportionately affect over 23% of Romania's population living in poverty, both in terms of relative financial impact and longer recovery time. In the face of growing risks of disasters and climate change, Romania is focusing on developing sustainable projects and capitalizing on innovative technology to improve the way risk information is collected, analyzed, and communicated to build a strong basis for disaster risk management. This is an important point of view in terms of probability–impact and the severity of disasters, whether natural or human-caused. The World Bank and the Global Facility for Disaster Reduction and Recovery (GFDRR) collaborate with the Government of Romania to facilitate solutions for risk information, such as these, as well as other innovations aimed at reducing risks and improving emergency services. For example, the creation of a new risk assessment tool for multiple types of natural hazards at the national level (Ro-Risk) will provide all ministries with information needed to invest in risk reduction and help decision-makers

understand the economic impact and financial disaster. The World Bank also supports the modernization of emergency infrastructure across the country, ensuring that more than 3000 first responders can rely on safer and more resilient response facilities [1].

The VISION 2020 project will improve Romania's disaster management capacity through the purchase of new equipment and staff training, aiming to better protect its population in emergency situations and to fulfill its relevant international obligations. The funding will be used to purchase emergency equipment and search and rescue operations, including fire trucks and other special vehicles, helicopters, multi-purpose vessels, and river boats. The project also includes the acquisition and equipment of a dedicated control center. VISION 2020 is in line with Directive 2007/60/EC on the assessment and management of flood risks, to reduce their impact on people and the environment. The total investment for the VISION 2020 project is EUR 681 904 797, with the EU contribution from the Cohesion Fund being EUR 578 415 116 under the High Infrastructure Operational Program for the 2014–2020 programming period. The investment is part of the priority "Promoting adaptation to climate change, prevention and risk management" [2].

In a world where the imprint of conflict and disaster is constantly expanding, helping humanitarian action is a key pillar of EU external action and an important part of its capacity to project its values globally. However, humanitarian aid is currently facing an unprecedented set of challenges, amplified by the COVID-19 pandemic. Humanitarian needs have reached a record high, largely due to the resurgence of state conflicts, combined with the impact of climate change, environmental degradation, global population growth, and poor governance. Moreover, the gap between humanitarian needs and available resources worldwide is widening. The basic rules and principles are challenged as have rarely been the case so far, making the necessary assistance more difficult and dangerous. More generally, the EU will continue to promote the development and adoption of innovative solutions that ensure more efficient, cost-effective, greener, and more climate-friendly aid [3,4].

Chen et al., in their research on assessing emergency shelter demand using POI data and evacuation simulation, state that in the field of disaster relief, determining the exact spatial distribution of the population is a challenge [5].

The risks and vulnerabilities generated by natural hazards are gaining the attention of specialists more and more. For example, Dewan developed a conceptual framework based on the risk literature on Cutter's place hazard theory with entries from recent literature. In this context, the danger is seen as a threat that has the potential to overwhelm people, property, and the environment. It is a pre-existing condition that can turn into a catastrophe depending on the influence of exogenous and endogenous factors [6]. On the other hand, Lee et al. consider that pre-planning of shelters and escape routes is the basis for efficient and safe post-flood management. They have developed a hierarchical model for selecting the location of emergency shelters in preparation for immediate, short-term, and long-term floods [7].

In the context of an emergency, evacuating people from a location in the shortest possible time is essential, as it is the most important safety measure that people should benefit from when evacuating. The probability of having or not having human lives involved in this process, that of evacuation, leads to the realization of the most accurate predictions of the evacuation plans of buildings or open spaces [8].

The new rules imposed by the COVID-19 pandemic also brought important changes in terms of building sustainability certifications. The mandatory practices and requirements for the sustainable certification of a project will be quickly adapted to the new context. For example, a criterion has been introduced in the US LEED (Leadership in Energy and Environmental Design) [9] certification scheme that provides for measures to increase safety in terms of air quality, while in BREEAM Projects [10], a credit of a potential of 100 is granted for residential project areas that have spaces for work from home. However, in recent years, in Romania there have been many disasters caused by fires in buildings, public institutions such as hospitals, which has led to both human casualties and financial losses.

Recently, Romania has felt a large influx of events within its borders, which has led to an increase in the density of people in a certain area at a certain time [11,12]. In these circumstances, a well-designed escape plan, with the best possible values for the characteristics mentioned in the previous paragraph, crucially has to reduce the number of potential victims as much as possible. We can see the devastating effects of an inefficient evacuation by taking as an example the tragedy that took place on 30 October 2015 in Club Colectiv, located in Bucharest, where, following a fire, 64 people lost their lives and another 185 people were injured, 146 of them being hospitalized. This case will remain for a long time a significant moment in Romania's history, being the worst accident that our state has had in recent years [13]. Thus, in order to avoid this type of accident, a well-developed emergency evacuation plan is imperative.

In fact, the problem of emergency evacuation is basically a problem of detecting the optimal or shortest route. The researchers used a wide range of algorithms to solve this situation, algorithms such as Dijkstra's or optimizing an ant colony [14]. Moreover, the influence of cybernetics is present even in this example. The current object of study of cybernetics is the complex adaptive system and these systems are found everywhere in the environment. It is important to understand these systems because their analysis proposes other perspectives. A complex adaptive system (CAS) is a complex macroscopic collection of relatively similar and partially connected micro-structures, formed to adapt to the changing environment and to increase its ability to survive as a macrostructure [15].

Mauboussin et al. [16], in their Harvard Business Review article, use the ant colony as an example of a CAS in nature. They aim to build a mound. Thus, it could take thousands, maybe millions of ants to build a large mound. Interestingly, ants do not start with a well-developed plan about what the mound will look like, but simply evolve and adapt along the way. Somehow, these thousands or millions of ants work together as a team that organizes itself, without too many indications. When the mound is finished, it may not be a perfect-looking structure, but it fulfills the purpose for which it was created and will evolve as needed to adapt to the general environment of which it is a part. What is important is that complex adaptive systems have been found in many natural environments since the beginning of time. What has evolved is not the systems themselves, but our understanding of them. We need to take a similar approach to project management, whether we are talking about managing a company or a disaster evacuation plan, instead of thinking of projects as a linear process in which simple rules of action apply cause and effect, we need to think of them as a much more dynamic organism [15,16].

The sustainable development of Romania must also take into account the development of the educational system. Moreover, cybernetics as a science studies the control and communication between systems, and the national economy seen as a cybernetic system or complex adaptive system is also formed by the educational system. The environment is constantly changing and people's behavior in uncertain situations is changing and is influenced by many aspects. It is difficult to predict how people will react in conditions of stress and uncertainty. This article is also based on human behavior in the conditions of a disaster such as fires or earthquakes, Romania being a country where such events occur more and more often. Disaster laws or regulations alone are not enough to protect us from these phenomena. The limited nature of human resources in educational, medical, and other institutions is well known in Romania and a management of these resources is very important.

However, it is impossible for these processes to take into account the human factor. The psychological, emotional factor or inter-human relationships are just some of the examples that can lead to a chosen route different from the one predicted by the model. Thus, these factors are essential for an evacuation time as short as possible, with the evacuation problem being a more complicated process than it seems.

Nowadays, in order for the simulation of an emergency evacuation to be as efficient as possible, the simulation's model must impersonate reality as well as possible. Obtaining the most authentic data is a challenge as they can be extremely diverse when it comes to

human behavior, which leads to an increased difficulty in developing the model [17,18]. At the same time, these simulations are an efficient procedure for estimating evacuation times depending on various factors, variable or not. Thus, in the field of evacuations, researchers often use virtual models to come up with a conclusive and plausible answer.

The dynamics and predictability of space in evacuation situations is an approach to the simulation that Lu et al. [19] focused on in their article, noting that space can be altered in the event of a crisis. Another model that highlights the variability of factors and their importance for simulations is designed by Wang et al. [20,21], who used microscopic modeling to perform simulations that had as a reference the individual behavior and characteristics of each agent.

Observing and taking into account the current limitations of the aforementioned simulations, this paper aims to analyze the emergency evacuation of a middle school in different situations, taking into account the particularities of individuals who are evacuated. The study is based on the “Regina Maria” Gymnasium School, located in Sector 6 of Bucharest. In order to illustrate as accurately as possible the importance of a cybernetics approach and the proposal of the case study, we considered relevant the use of data as close as possible to reality, so we obtained the information needed for the case study from the above school. Empirical data suggest that one of the main causes of death is the irrational behavior of the mass of people when they panic, given the situation they are in [22]. Therefore, the purpose of this work is to create a model that is as close as possible to reality, appreciating the dynamics of space and without neglecting human features, which often make their presence felt during the total evacuation time of a location.

The paper is organized as follows: Section 2 provides some information about other research in the area of interest of this article, Section 3 describes the context of emergency evacuation, Section 4 presents the basic notions necessary to understand agent-based modeling, Section 5 is based on the design of the case study and the presentation of the main objective of the paper, Section 6 presents the simulation results performed in the case study, Section 7 s presents solutions that can improve the evacuation time, and in the last section were issued the conclusions and some discussions regarding the results obtained and the constraints of the case study.

2. Literature Review

Analyzing the existing literature, several elements were observed that influence the individual behavior of agents. For example, Guan and Wang [23] highlight the cooperative phenomenon. They believe that knowing the evolution of cooperation has an essential role in the evacuation process. Another important factor in the evacuation process, found in the literature, is competition. Wu et al. [24] performed an experiment on the evacuation of mice from a container in conditions of high competition. Their article is based on a case study of non-human creatures, mice. They are evacuated according to different scenarios built on several variables such as the location of the exit and the distance between them or the congestion of the area.

Evacuation is characterized by the immediate and rapid movement of people from the location of a threat or disaster to a safer destination. Disasters happen every day all over the world, and these dangerous, life-threatening events force people to move immediately from a dangerous area. Disasters can be classified as natural disasters or human-caused disasters.

In 2005, Wolshon et al. [25] presented a number of hazards that require evacuation and emphasized that some evacuations, especially in the case of natural disasters, can only be carried out after disasters have occurred. They classified disasters into natural events such as earthquake, volcanic eruption, tsunami, tornado, wildfire, flood, and hurricane, and human-caused events such as terrorist attack, chemical release, dam failure, and nuclear power plant accident. In the article written by Wolshon et al. [25] they deals with ways of evacuation and transport that are found in the conditions of the occurrence of events, such as disasters. They propose several methods to achieve the goals of their research.

An important aspect for our article is that they consider in their article that law enforcement agencies have a very significant role in the evacuation of educational institutions.

Other important factors that are taken into account in the evacuation process, but not limited to them are: social background [26], age [27], the degree of selfishness [28], the presence or absence of guidance or authority figures [29], the occurrence of herd behavior [30], and emotions [31]. All these factors are very relevant to emphasize that an accurate prediction of the evacuation process of an institution is quite difficult to obtain because human behavior cannot be fully predicted. On the other hand, there is still no way to classify these factors in terms of the importance or degree of appearance in people's decision-making choices. However, we could control certain factors, such as the laws and rules given by the authorities and respected by the institution.

The movement of masses of people to or from a certain location is an action that will often lead to the so-called "strait" (or bottleneck), a term that can be better described by a narrowing area (temporary or not) of the route to a certain location, resulting in an increase in the density of people around that area, leading to a situation in which the movement of individuals will be much slower, sometimes even stopped. At the same time, the appearance of these bottleneck effects has a major impact on both the safety of a mass of people during an emergency evacuation, as it creates a crowded space with many panicked people, who can act in an irrational way, and total evacuation time.

In 2005, Vermuyten et al. [32] analyzed the problem of optimizing a road facing a bottleneck, the optimization being in fact given by the largest number of people who can cross that strait per second, and in the case of evacuation problems, the optimization is given by the release time. The authors believe that in order to ensure the safety and comfort of people, it is necessary to design pedestrian facilities and good crowd management. At the same time, the analysis of pedestrian and dynamic evacuation is very complicated because the large number of people and the complex interactions between them are nonlinear, and psychological behavior and external factors are of great importance.

Thus, taking into account the above study, Duives et al. [33], through their paper, treat the movement of masses of people (according to Figure 1) and its effects as the main features of their model, using several possible displacements of the crowd, described in a tree, which have effects which lead to what is called "self-organization of the crowd", which is modeled on the following forms: string formation; stop and go waves; turbulence; herd; zipper effect; the faster, the slower. Numerous studies whose model started from "string formation" as a method of self-organization of the crowd have shown that it is among the most effective, due to congestion of the group, with the opposite pole being the "stop and go waves" due to the fact that individuals need some time to adjust to speed.

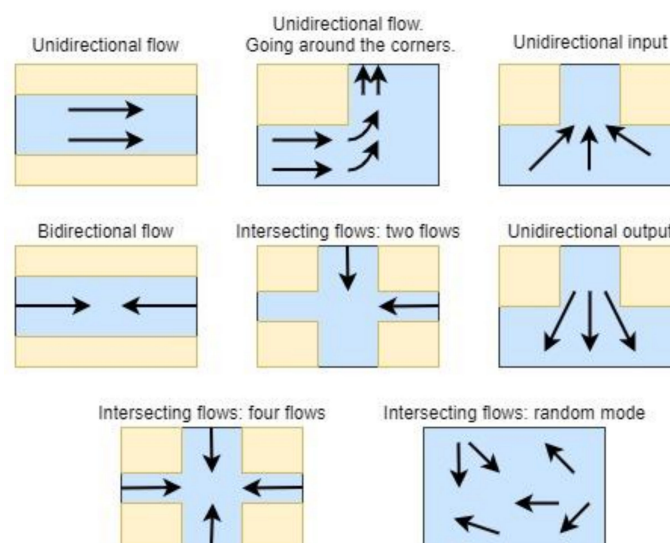


Figure 1. Cases of movement of the crowd of agents [33].

Regarding the variability of the human factor in the situation of an emergency evacuation, it is presented in a very complex way. The variability of the human factor is outlined by the possibility that some of the individuals have a disability, which would lead to a much slower evacuation of the person, but also by the psyche of each person, which will shape their behavior in such situations. For example, a study by Wood [34] showed that when people faced a fire in an enclosed space, 15% of them first wanted to put out the fire, 13% started the fire alarm, and only 9.5% started evacuating the next moment. Another researcher, Sime [35], mentioned that people tend not to be aware of the danger immediately, wanting to validate it for the first time, instead of evacuating immediately. However, regardless of the cause of the emergency evacuation, people tend to become irrational, illogical in their actions, and disorganized, which leads to an exponential increase in panic. A representative perspective, which expresses the factors that can induce panic in individuals in the event of an emergency evacuation (according to Table 1), is suggested by Proulx [36]. Proulx classifies these factors according to occupant characteristics, building characteristics, and fire characteristics. Dr. Guylene Proulx, in her article, argues that although most buildings are equipped with adequate fire safety systems, problems often arise because these systems are not made to react to the way human agents behave in those buildings. People tend to ignore fire alarms in shopping malls, museums, or airports, or they have installed stops to keep the doors open during the day, so all these factors have a negative impact on an effective evacuation without loss of life. The author of the article argues that human behavior varies depending on three major characteristics: the occupant characteristics; the building characteristics, and the fire characteristics. Dr. Proulx argues that one solution to these is to consider the interaction of all these factors in order to better understand human behavior [36]. Here comes, again, the cybernetics analysis that takes into account both the internal environment analyzed, but also external factors.

Table 1. Factors influencing human behavior in the event of an emergency evacuation [36].

	Occupant Characteristics		Building Characteristics		Fire Characteristics
Profile:	Gender Age Ability Limitation	Occupancy:	Residential Office Hospital College and University	Visual cues:	Flame Smoke (color, thickness) Deflection of wall, ceiling, floor
Knowledge and Experience:	Familiarity with the building Past fire experience Fire safety training Another emergency training	Architecture:	Number of floors Location of exists Complexity of space Visual access	Olfactory cues:	Smell Burning Acrid smell
Condition at the Time of Event:	Alone vs. with others Active vs. passive Alert Under Drug-Alcohol-Medication	Activities in the Building:	Studies Working Watching a show Sleeping	Audible cues:	Cracking Broken glass Object falling
Personality:	Influenced by others Leadership Negative toward authority Anxious	Fire Safety Features:	Fire alarm signal Voice communication system Trained staff Fire safety plan	Other cues:	Heat
Role:	Visitor Employee Owner Student				

In addition, the decision taken by individuals in such a context, that of evacuation, differs from day to day. Usually, under pressure, people tend to think that the decision needs to be made as soon as possible, even if the information on which the choice should be made is limited or too numerous. Therefore, behavior such as moving away and running away from the incident may seem, from the outside, a disorganized decision, but for those who evacuate, it is possibly the most rational response if their integrity is endangered.

In fact, many studies treat the idea of panic as a defining factor in the designed models, trying to simulate as well as possible the situations described by them, but due to the behavioral and mental peculiarities of each individual, creating a model that accurately describes real life based on the existence of panic is almost impossible.

As mentioned, this paper aims to address the evacuation of students from a school in an emergency situation, with a scientific basis on concepts such as the movement of masses of people in crowded situations or human behavior when faced with a situation of crisis. Thus, by carrying out the proposed research, the result of the analysis will be followed, which will take place as a result of the interweaving of the previously mentioned terms in order to elaborate several pertinent conclusions.

3. Presentation of the Evacuation Context

3.1. Location of Exits

An efficient evacuation plan is tailored so that there is a strategic location of the exits from the respective facility, so that each individual obtains an optimal evacuation time. However, even if an evacuation plan often revolves around human behavior, as it should, it does not address situations where obstacles arise within the evacuation site [37]. In this way, an imbalance is created in exit placement, as not all of them will be able to be used, which implies a less optimal evacuation time or even the injury of the people who are released.

A study attesting to the influence of the location of the exits inside an enclosure was carried out by Heba et al. [37], whose simulations could be better visualized using a system based on cellular automata and multi-agent technology. Four components made up this system: the plan generator, the choice of technique (depth-first-search/DFS), monitoring operations, and visualizing performance, and simulations were performed based on four equal rooms, each with four outputs that were located differently.

After performing the simulations, taking into account the human behavior, it was concluded that the evacuation of people could not be evenly distributed in any of the four possible circumstances, even if there was a greater balance between exits and different areas of the room in the case of exits placed diametrically opposite and the outlets placed on a single wall [37]. In order to establish a better dispersion of people between the exits, for the situation in which the second room was used, that of the adjacent exits, it has been shown that a new exit near Exit 1, or one positioned in a diametrically opposite way to Exit 1 has a lower density of people around the exits, the percentages being 27% and 33%, respectively, of the total population in the room [37]. However, many limitations are identified when it comes to studying the effect that position of the exits from a particular location has, due to the fact that few articles in the literature refer to this topic.

3.2. Emergency Exits

It is well known that emergency exits are important because they provide a safe and clear way to evacuate a location in situations that endanger the lives of those inside it. Local authorities responsible for mitigating the situation, such as the police or fire brigade, can use those emergency exits to enter the building and help any people who have not yet managed to reach a safe place. Thus, an emergency exit is defined as a continuous, unobstructed route leading to a safe area, as noted by the US Occupational Health and Safety Administration [38]. This department defines emergency exit as a concept that encompasses the following three characteristics:

- Access route—leads to the emergency exit and must be at least 70 cm wide at any point;
- Exit—is usually separated from other areas, to provide a safe way to reach the exit of the building;
- Exit the building—leads directly to a safe space.

It should be noted that these access routes and emergency exits must not be blocked, in order to reduce the evacuation time as much as possible, but due to unpredictable events, obstacles may appear around them, which may even block the emergency exits, a scenario in which panic will break out among the masses.

3.3. Chain of Command in Case of Evacuation

A chain of command is an essential aspect of the organizational structure that aims to delimit and distribute a responsibility to each person, depending on the degree occupied in a certain location (e.g., visitor, director, etc.). During an emergency evacuation, it is mandatory that order has to be maintained. If it is not kept as efficient as possible, people evacuating or coordinating them may be harmed or, often times, may lose themselves organizing people [39]. The person who usually handles the emergency in the event of an evacuation is usually a qualified person in this matter, who is obliged to inform the other individuals about the steps to be followed. In the case of a school, the responsibility for managing a crisis situation often falls on the shoulders of the person with the highest authority at that time, i.e., the school principal, or the teachers (in special circumstances, if the school's auditory information system does not work). This approved entity must follow well-defined protocols and provide precise guidance, being responsible for how the discharge will be carried out. Given the fact that in the case of evacuation of a school, children can panic very quickly, thus becoming disorganized, and the following lines include some of the responsibilities of such an authoritarian person:

- Checking the rooms (preferably the nearest one, if there is a major incident) to identify people who are stuck or unable to evacuate;
- Know who may need support during the evacuation and how these people can be helped;
- Coordination of emergency activity;
- To know the architecture of the school, and the evacuation routes most suitable for the context;
- Check that students are distributed to safe areas after evacuation.

3.4. The Role of Evacuation Simulations

Existence of evacuation simulations in case of fire/earthquake, etc., proved to be of major importance in the reaction time of the people involved. Thus, through these simulations, certain situations can be predicted that, in real cases, even when life is endangered, people learn how to respond to unforeseen events.

As early as the middle of the last century, most school systems began to implement, frequently, fire simulations, in which all those present in the school practiced evacuation from school, reaching a safe area [40]. In areas vulnerable and susceptible to natural disasters, many schools perform evacuation simulations for contexts such as earthquakes, tsunamis, tornadoes, wildfires, and terrorism [41].

It turned out that due to fire simulations, there was a decrease in injuries or deaths that occurred during such an incident, which was common in the 19th century and the first half of the 20th century [42].

However, even if schools are prepared to face such unpleasant situations, there is a factor that intervenes when everything is real, and that factor is emotion. During a seminar given by Lt. Col. Dave Grossman [43], he talked about the fact that a human's most important survival mechanism is their brain, but only when they are prepared as such. Undoubtedly, the incredible pressure that a crisis situation can bring can have extreme effects on the human body. Unfortunately, when they are put in a circumstance that

could lead to their injury, people become confused, panic, and fail to complete activities that present a small degree of difficulty. Thus, in order to improve the simulations, those responsible for the response to an emergency evacuation from each school must explore ways to include cognitive thinking [43]. These improvements should encourage teachers, students, and school staff to think quickly when emotions are high, and some strategies that propose these improvements are:

➤ Encouraging role change:

Simulations can be organized to include role change. Thus, for example, the participants in the simulation will be given the opportunity to decide whether to evacuate, to be the ones to trigger the alarm, to barricade the classroom doors, to charge an armed individual, and so on.

➤ Incorporation of real scenarios:

Simulations can be organized in such a way that surprise elements are added, such as blocking some exits in the last moment of the evacuation to test the reaction skills of the participants, etc.

➤ Interweaving the simulations with the theoretical exercises discussed:

Unusual simulations can be organized in which to discuss various theoretical but real situations, which participants can face. Compared to the method used in the previous sub-item, it includes several situations, being more discussed, such as not necessarily having a well-established escape route in case of their occurrence.

4. Conceptual Dimensions of Agent-Based Modeling

In the literature, there are many definitions formed by various researchers regarding agent-based modeling, which are more or less similar, but their meaning is to some extent the same. Thus, the significance of an agent-based model is given by a computer-programmed model, using various mathematical or statistical formulas, which aims to capture the evolution and behavior of one or more individuals, but within a certain environment, with conditions well established, depending on what we want to simulate or study [44].

The advantage that agent-based modeling offers is represented by the visualization of the results and the process by which they were reached using an interactive form, not an abstract one, even if the starting point in solving the problem is an abstract, theoretical structure, such as a formula or an indicator. For example, one can also observe how a certain agent changes during a simulation, which is often associated with real-life entities; video games such as “The Sims” or “SimCity” state what has been said before, because a person can transpose in the virtual environment, interacting with other people or with the game environment [45].

Currently, there are many main types of agents that can be an agent-based application. Their classification, nowadays, is quite detailed and segmented, using various criteria according to which the hierarchy is made, such as: the functions that are performed by agents, their properties, their type, their behavior, etc.

As Bradshaw et al. [46] mentioned in their article, several types of agents are highlighted when they are related to their properties, namely:

Cooperative agents: agents who synchronize their actions and, in order to achieve common goals, they negotiate;

Autonomous agents: tend towards a certain goal, acting in such a way as to achieve it, without the need for intervention or confirmation from the user. They are also called proactive agents;

Adaptive agents: flexible agents that adjust in a dynamic way, learning from and about their environment. They can adapt to the unforeseen, but also to changes;

Reactive agents: agents that are triggered by the occurrence of events, being sensitive to the context of the environment. They are able to act and feel;

Mobile agents: agents who follow a certain route, moving. This movement can be performed in both the real and the physical environment;

Interactive agents: their responsibility is to interact with legal systems, people, information sources, or even other agents;

Social agents: agents who are cooperating with agencies or people who have common goals;

Agents with personality: they have particularities that are found among people, such as emotions, values, cultural affiliation, etc.;

Intelligent agents: agents that mimic the defining characteristics of human intelligence, such as introspection, meditation, etc.

When agents relate to the functions they perform, the classification is as follows [46]:

Information agents: by collecting information from several sources, they forward the information to many other sources;

User interface agents: agents that are in a correspondence relationship with people, the communication being undertaken through several types of interfaces;

Reactive agents (or actors): agents who perform certain operations in an independent way, but are nevertheless influenced by the events and messages in the environment that were triggered before the operation;

Mediating agents: agents responsible for the distribution of any resource between people and/or various types of agents.

When discussing the behavior of agents, it is taken into account that they must best represent human behavior. Therefore, for the integration of human and social behavior in the results offered following the simulations that are performed, three types of behaviors of agents are outlined, ranked according to their complexity [47].

(a) Behavior during movement:

This type of behavior corresponds to the simplest action that an agent can take, namely moving. Thus, an agent can walk or run forward, stop, turn, or follow a previously traveled route, and travel at a certain point in time depends on a well-defined decision or rule [44].

(b) Behavior during change of direction:

Used very often in artificial and robotic intelligence, this type of behavior is essential in the path followed by an autonomous agent in its virtual environment, because the journey must be undertaken in a more realistic way [47]. Thus, more complex simulations can be performed, which present more interesting results than those that are based only on behavior during movement. Next, some particularities that underlie this type of behavior will be described, and starting from them, much more complex situations can be created [47]:

- Random movement;
- Exploration—has the role of guiding an agent to a desired point. When such a point is detected, the agent adapts their speed and orientation to that location;
- Negotiation—due to this feature, agents can exchange information with each other, and can even reach certain agreements;
- Collision avoidance—gives agents the ability to choose unobstructed routes/other agents;
- Target tracking—gives the agent the ability to track a moving agent.

(c) Behavior in social situations:

Described by its complexity, behavior in social situations is based on the premise that there are multiple interactions between autonomous agents, for which, if they were isolated, the simulations would have felt small deviations between them, but being in a group of such agents, their results helped specialists to observe patterns of social behavior [48]. These include the herd effect or competitive social behavior, in which case individuals compete for the chance to leave a particular location.

Agents of agent-based modeling are able to provide unbalanced solutions, but also to describe complex phenomena. Often, one of the characteristics of the results achieved

by an agent-based model is the emergence of self-organization. Self-organization is based on the existence of a certain model, a pattern to be followed, or on its creation from the bottom up, and the emergence can be applied to structured phenomena that include higher order functionalities [48].

Agent-based models in trading and negotiation often produce different results, with Kirman and Vriend's studies [49,50] being conducted in this matter. In their research, the financial market was abstracted, offering buyers and sellers the opportunity to form relationships with each other, a situation in which individuals had different customer behaviors. For example, customers who offered more for goods are generally less loyal to sellers than customers who offer less money. Thus, the agent's reputation and networking ("social network") are present in a very complex way, being determined and directly influenced by the interactions between them.

Agent-based models are also used to study the distribution of event dimensions [48]. When the aggregate variables are equaled by the sum of the individual variables, it means that, in more relaxed conditions, these parameters will be normally distributed. However, when there is positive feedback or when the values of particular attributes are independent, it means that the aggregate variables are able to support more extreme distributions.

A graphical representation of the event size distribution is the most used method in analyzing the aggregate results [48]. For example, according to the study conducted by LeBaron [51], when an agent-based model is built and formed on the stock market, it is possible to graph the daily fluctuations of stock prices on the stock exchange, where it is possible to observe indices of bubbles and the fall in stock prices for certain companies. In other situations, such as patterns of traffic flows, the entities that make up the model can self-organize in critical states, where even seemingly insignificant events can have a large impact on the outcome.

Agent-based modeling is represented by computer systems in which, based on well-established rules, agents interact with each other, taking place in an environment [52]. On the other hand, the set of rules and conditionings defined by scientists can outline predictable behavior at the micro level, with interactions between agents and their environment leading to unexpected results from experiments [53].

5. Case Study: Emergency Evacuation of a School

The problem proposed in this paper is the evacuation of the ground floor of the school "Regina Maria", located in the Bucharest's 6th district, which targets the studying of the impact of various parameters in the context of an evacuation, such as obstacles or possible disabilities that children may have. With a first-floor capacity of exactly 202 people, taking into account not only the children, but also the teachers (18 people), the principal or the secretaries (4 people), and with three access ways (all for entering/leaving the school, unfortunately without any emergency exits), will be one of the parameters that the model used to perform simulations, and that intends to highlight, as well as possible, the effects of specific values for the parameters considered. The 22 people (principal, secretaries, and teachers) are considered fixed agents in the model, so they will always be present. The number that varies is that of students, i.e., 180 people.

5.1. School Architecture

Being built in 1970, "Regina Maria" school is a "U" shaped one, on three floors, with classrooms on both sides, the two "wings" being separated by a hall. Thus, in order to describe the architecture of the model, we chose to present the dimensions of the rooms only for the first floor, as only these are relevant for the study. Therefore, the dimensions of the rooms located on the ground floor of the educational institution are specified below.

Presentation of room dimensions:

- The size of a classroom is $(6.5 \times 9.5) \text{ m}^2$, with a maximum capacity of 30 children plus a tutor (marked with the letter A in Figure 2);
- The size of the main hall is $(3 \times 35.5) \text{ m}^2$ (denoted by the letter B in Figure 2);

- The size of the side hallways is $(3 \times 29) \text{ m}^2$ (denoted by the letter C in Figure 2);
- The size of the teachers' office is $(4 \times 6) \text{ m}^2$, the principal's office is $(3.5 \times 5) \text{ m}^2$, and the office of the secretaries is $(3 \times 5) \text{ m}^2$ (marked with the letter D, E, and F, respectively, in Figure 2).

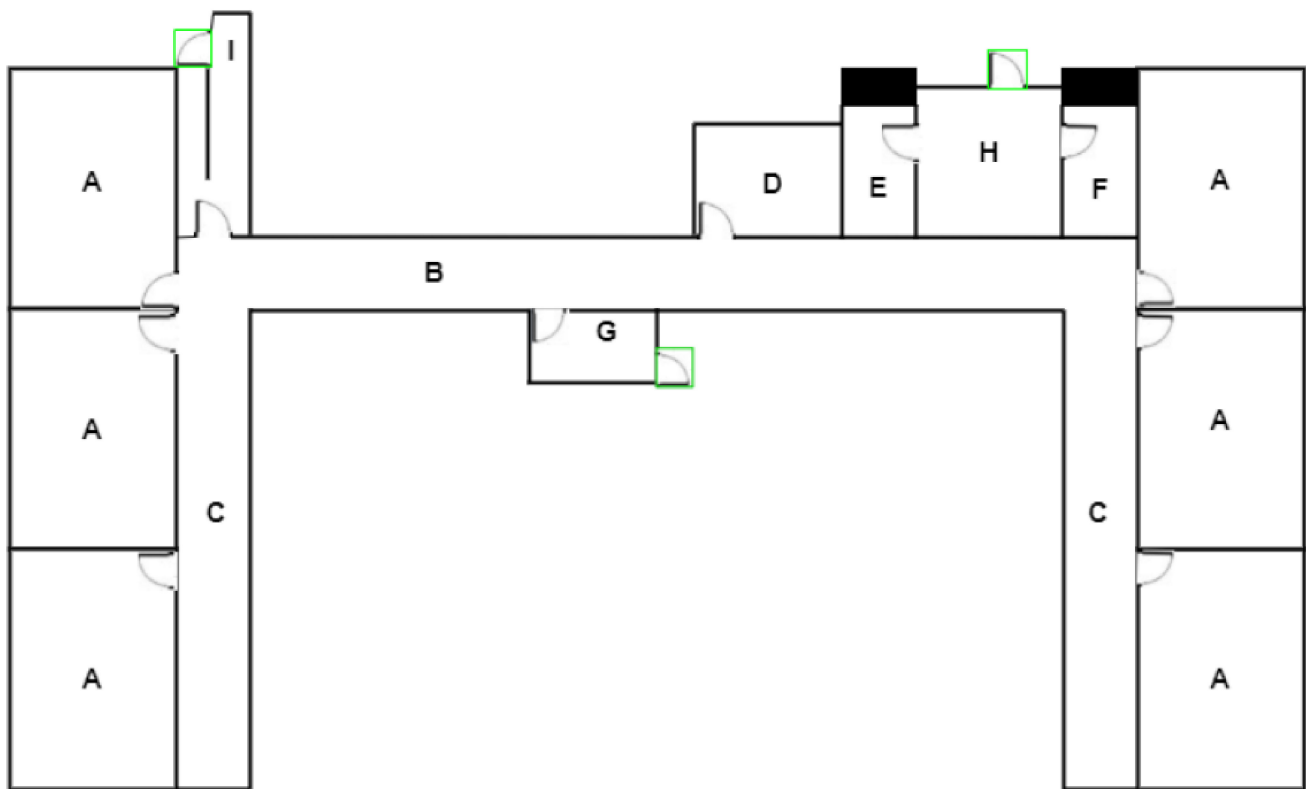


Figure 2. Architectural sketch of the school (made by the authors in draw.io).

Output size of the rooms:

- The main exit has the area of $(3 \times 5) \text{ m}^2$ (denoted by the letter G in Figure 2);
- The teachers' exit has the area of $(7 \times 5.5) \text{ m}^2$ (marked with the letter H in Figure 2);
- The rear exit has the area of $(2 \times 3) \text{ m}^2$ (denoted by the letter I in Figure 2).

In Figure 2, we can better see the architecture of the school, which also provides a visual representation of the rooms inside it. The entrances of the school are marked with a shade of green, to differentiate themselves from the rest of the doors, which can be "intermediate" doors, which only lead to one of the three exits.

5.2. Building the Model in NetLogo

Created in NetLogo, the model aims to best imitate reality in the case of an emergency evacuation. Thus, there are several factors that directly impact the evacuation time from the building and the results of the simulations; factors such as the number of people present or the physical characteristics that each of the children may have. According to the National Institute of Statistics [54], in Romania there are approximately 70,000 children with disabilities of any type (visual, olfactory, locomotory, etc.), which constitutes a percentage of 0.1% of the total number of children enrolled in a pre-university education cycle.

The process of an emergency evacuation involves a fast reaction time, with the main method of evacuation being walking. Being subjected to an evacuation, the behavioral peculiarities of individuals, such as panic, directly impacts the release process inside each individual who evacuates, triggering the mode of survival. Therefore, three behavioral characteristics were considered for the accuracy of the simulations:

- (1) Choice of exit: The evacuating agents will be aware of the three access routes of the school, and they will choose a single exit for evacuation, based on the distance criterion. Thus, an agent will choose to evacuate using the nearest of the three available exits, around which the “funnel effect” is formed.
- (2) Relative position in space: Characterized by the location of the agent in the model, this factor greatly influences the evacuation times, because a shorter distance between the exit and the agent will lead to a relatively short evacuation time. At the same time, obstacles will appear inside the school, which can be skipped or bypassed, which will influence the time of evacuation.
- (3) Travel speed: According to a study by Thiele et al. [55], an individual’s ability to evacuate takes into account factors such as tone or physical features. Thus, in the model, these factors will be reflected in the speeds of the agents.

In this research, a factor that influences the speed of children who are evacuated is represented by the evacuation instructions held in schools, given the number of children who participated in these courses, as they have a higher travel speed because they know certain procedures that will help them evacuate faster, and they will be less panicked, treating the situation with greater calm. There are few studies that specify how much the speed of travel changes as a result of evacuation instructions or fire simulations, but according to a few studies conducted by Peacock et al. [56,57], it was shown that the movement speed of those who participated in such trainings increased by up to 10%, which was noticed due to the shorter evacuation times. At the same time, another factor that influences the speed of children in this work is the help and instructions provided by the tutor to the children for whom they are responsible. Based on an article by Kawasaki et al. [58], we were able to estimate an increase in children’s movement speed of up to 8% around teachers, as teachers have been shown to take the initiative to evacuate due to the confusion created among children, guiding and helping them, especially those with disabilities.

Therefore, following a study by Chu et al. [59] on the emergency evacuation of people from residential areas, we assessed the average travel speeds as those in the Table 2, also taking into account the influence of the factors presented above. Furthermore, in the Table 2 is included the maximum number of people in each category that will be present in the simulation, and in the case of students with disabilities, we estimated an upper limit of 10%, taking into account the fact that the number of children enrolled in the secondary education cycle fluctuates every year, with the students with disabilities constituting a percentage of 0.1% of the total children.

Table 2. Average travel speeds of people participating in the simulation.

Category	Average Travel Speed (m/s)	The Presence of Teachers Around	Maximum Number of People (Absolute or Relative)
Student	1.02	(1+0→8%) * 1.02	180
Student who participated in evacuation training	(1+0→10%) * 1.02	(1+0→10% + 0→8%) * 1.02	(0→100%) * Total Students
Professor	1.2	N/A	22
Student with disabilities	0.42	(1+0→8%) * 0.42	(0→10%) * Total students

These types of agents can be distinguished in the model made using the color they have in the simulation:

- Student—marked in yellow;
- Student who participated in evacuation training—marked in green;
- Professor—marked in white;
- Student with disabilities—marked in red.

An architectural sketch of the school was also made in the NetLogo interface, which, this time, also includes the agents involved in the analysis. Thus, Figure 3 shows the model to be used, thus providing a better overview.

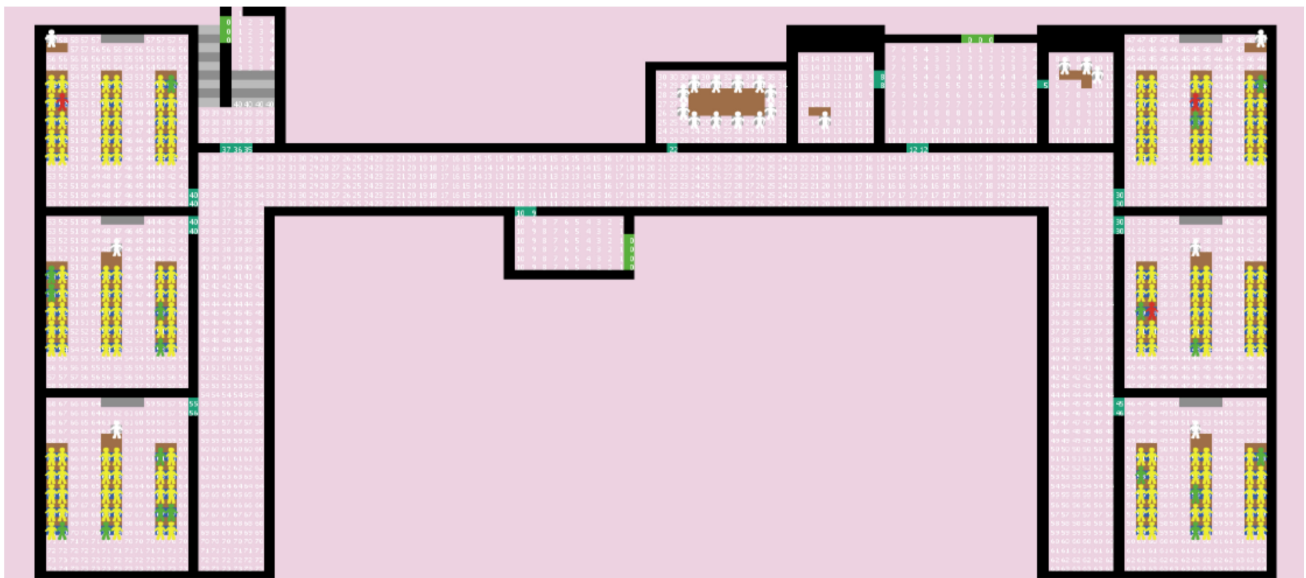


Figure 3. Architectural sketch and location of agents within the model (designed by the authors in NetLogo).

The above-mentioned parameters, which can impact the evacuation times of the simulations, will be presented, together with the other parameters that can have an effect on the evacuation times, using the NetLogo interface in the Figure 4.



Figure 4. Parameters used in the analysis of emergency evacuation of the school (designed by the authors in NetLogo).

Below, we will describe the parameters in the Figure 4, providing more details for the parameters that have not yet been presented in the previous rows:

- Number-of-children: the total number of students of the simulation, which will be randomly distributed between classes;
- %-Children-evacuation-courses: represents a certain percentage of the total number of students present;
- %-Children-with-disabilities: represents a certain percentage of the total number of students present;
- %-Probability-of-obstacles: randomly placed, represents the density of obstacles in the total area of the first floor of the school;
- Main-exit: one of the three access roads;
- Backdoor-exit;

➤ Office-exit.

The three access roads to the educational institution can be open, semi-open, or closed.

5.3. Obstacles as a Major Effect during Evacuation

Obstacles are a major impediment for people who want to evacuate in emergencies, as they not only reduce the space in which people can act, but also force individuals to choose other alternative routes, which are safer in terms of their integrity but lead to a longer evacuation time. The precious seconds that are lost when the route deviates from the normal one is unfortunately one of the most important factors that decide whether the evacuee will manage to get injured or not in a safe place, and safe from danger after release.

However, according to a study by Wei et al. [60], in which the simulations were performed on the basis of a room of (1.6×3.2) m², it was shown that the evacuation times were similar, regardless of whether the obstacles were large or small, but only if they were at least 1.5 m in size.

It has also been shown that, in very few cases, the appearance of obstacles in strategic places leads to a slightly shorter evacuation time than if there were no obstacles, as the bottleneck effect is more difficult, but once formed, it is much more expensive from the escape-time point of view, compared to the obstacles themselves. However, in most situations, obstacles do not have a positive impact on those who evacuate, primarily because of the uncertain route that individuals must follow, which almost always deviates from the one that would have been followed under normal conditions, and secondly because of their possibility to block some escaping routes, in which case we can even talk about loss of human lives.

Based on studies conducted by Wei et al. [60], we were able to estimate the density of obstacles in the model proposed in this research, with the obstacles being placed between 0–25% over the surface of the first floor of the school, but also the minimum distance between an access path and an obstacle, which must be at least two meters. In Figure 5, we can see more clearly the density of obstacles in the proposed model, with a value of 25% of the area, and being a shade of purple.

5.4. Proposed Scenarios Based on the Model

Creating scenarios that are reflected in the simulation results is an essential step in the veracity of the model, because there cannot be more emergency evacuation simulations performed within the same school that will lead to identical results, but rather similar ones. In reality, it is almost impossible for evacuation times to be identical under similar conditions, as the uncertainty factor must be taken into account, such as a child stumbling, or a different distribution in classrooms at the beginning of the evacuation simulation, which leads to already another scenario.

5.4.1. The Baseline Scenario

The model proposed in this paper will start from a Baseline Scenario, which is exemplified in Figure 6 and for which the following values are known for the parameters used:

- During the simulation, the maximum attendance at classes is considered;
- All three access roads will be fully open and can be used by evacuees;
- A value of 30% of all students for children who have given evacuation instructions, due to the fact that they are often ignored, or the presence of children at school was low when they were held;
- Children with disabilities will be in proportion of 1% of the total students;
- There will be no obstacles.

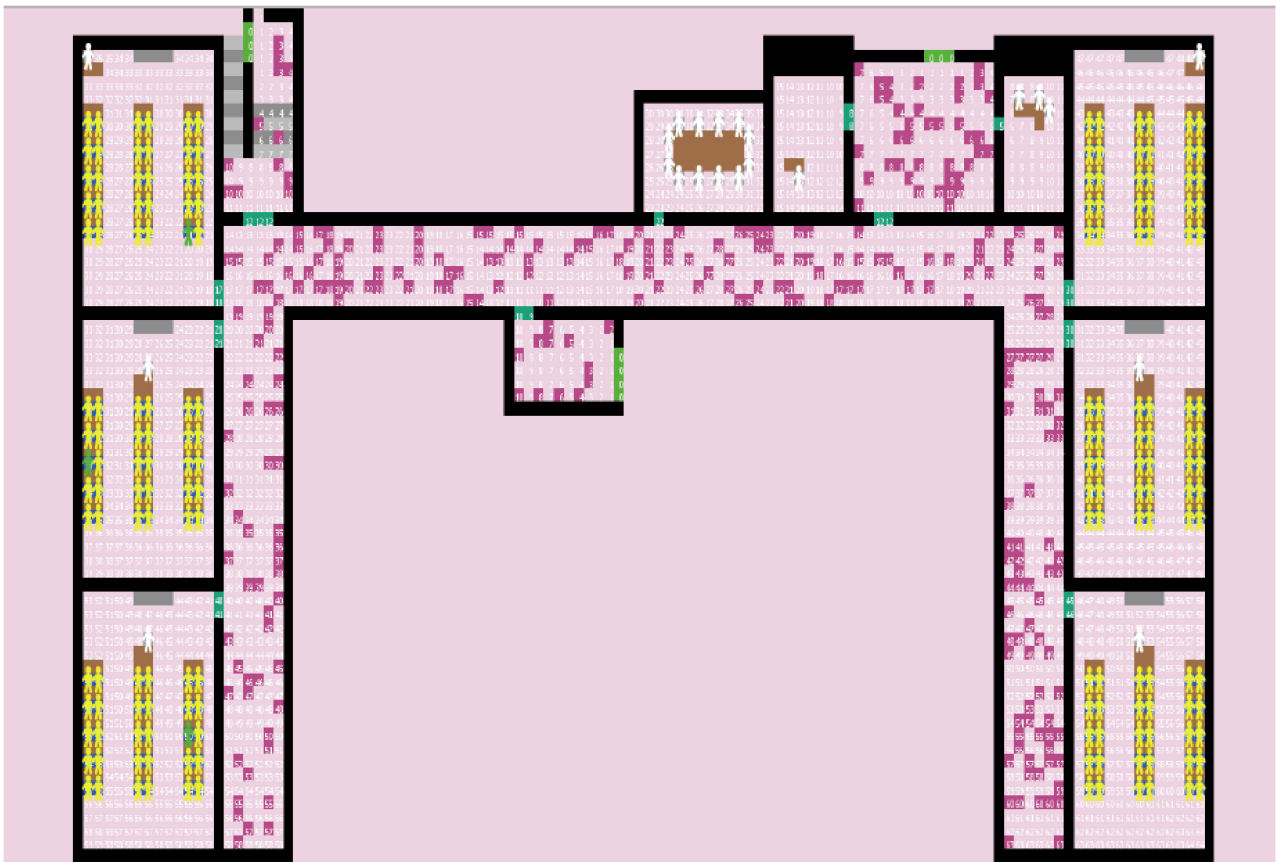


Figure 5. Random obstacle distribution (designed by the authors in NetLogo).

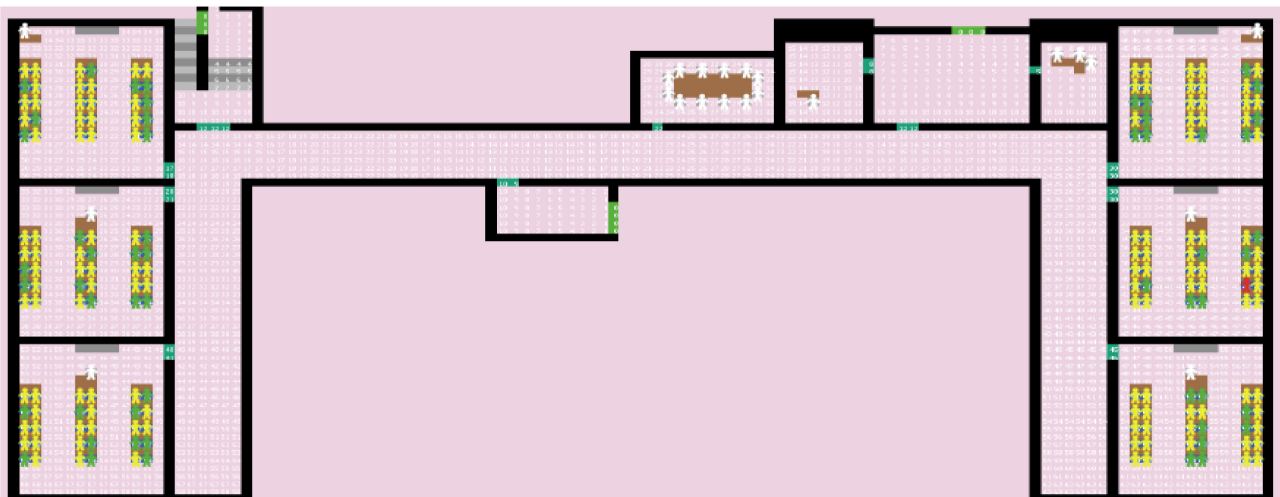


Figure 6. Placing agents in the baseline scenario (designed by the authors in NetLogo).

For each scenario, 400 simulations will be performed in such a way that the results are as accurate and relevant as possible. According to Safelenics [61], it has been shown that, in the case of a school, an optimal evacuation time would be two and a half minutes; this being measured from the place where individuals start to evacuate, until they reach a “green” point, safe from danger.

5.4.2. Scenario I—Variability of Access Paths

The simulations based on Scenario I will rely on the openness of the access ways, because often times they were not completely open, and sometimes they were even closed, as happens in reality. To study this scenario, the parameters that will change are the main entrance and the teachers' entrance openness, with the rest of the properties remaining constant, similar to those in the Baseline Scenario. Therefore, the situations that may arise as a result of this scenario are the following:

A. The teachers' exit will be semi-open:

The deviation from the Baseline Scenario can be seen in the Figure 7, where the access road that is delimited by the two administrative offices is partially open, by only two thirds of the width.

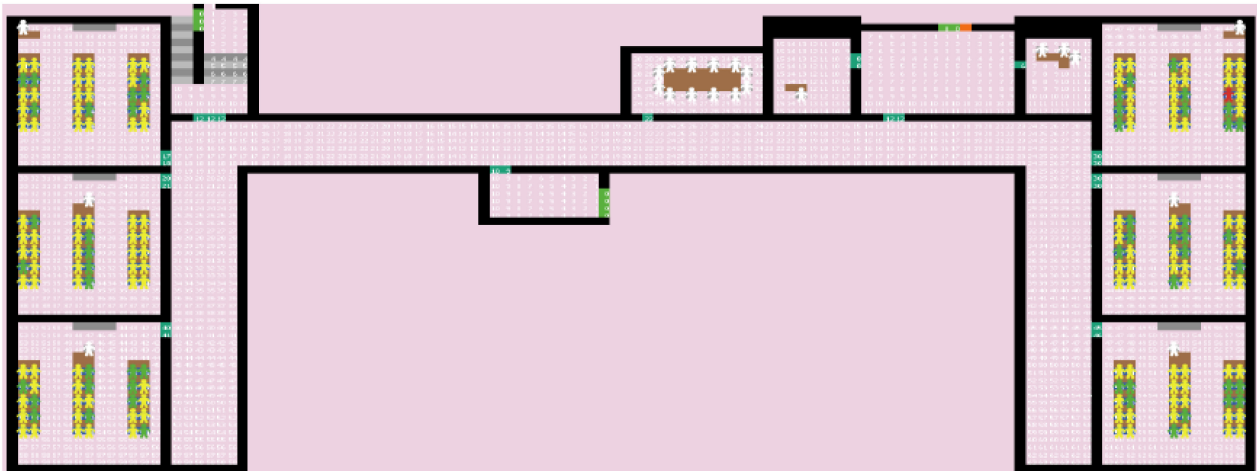


Figure 7. The teachers' exit: semi-open (designed by the authors in NetLogo).

B. The rear exit will be semi-open:

In the model based on the "Regina Maria" school, the rear exit will be considered as semi-open, and thus the bottleneck effect takes a more accentuated shape. Figure 8 highlights the modification of the rear access path and the deviation from the Baseline Scenario for the case from this subpoint.

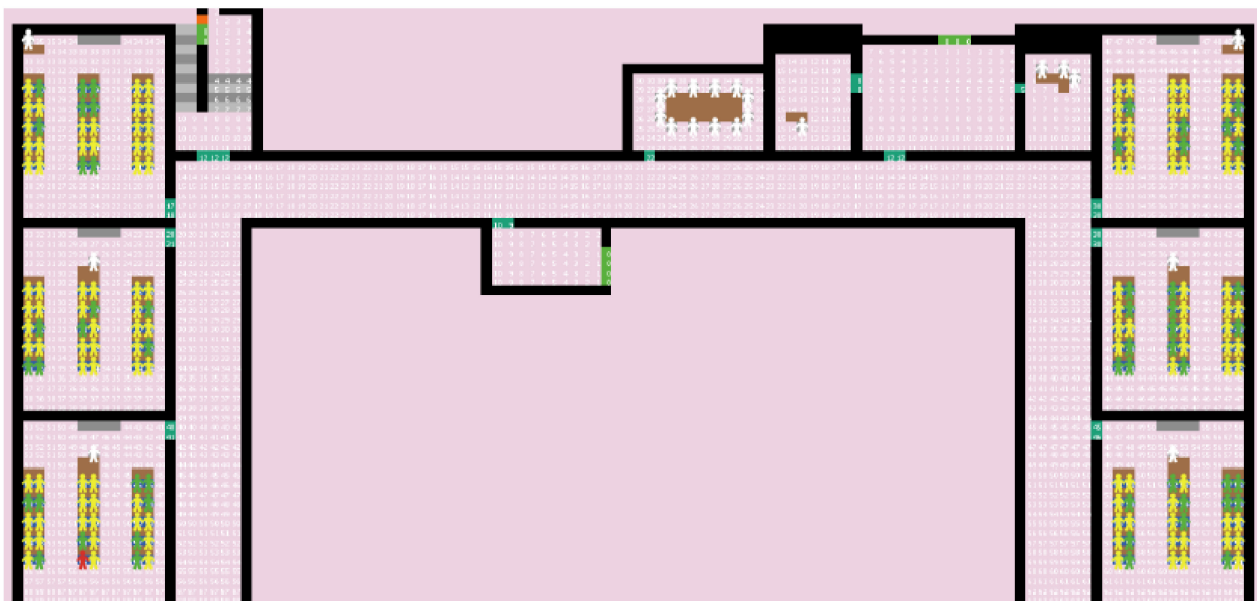


Figure 8. Rear entrance: semi-open (designed by the authors in NetLogo).

C. The rear exit will be completely closed:

As in the previous case, in the Figure 9 will show the change and deviation from the Baseline Scenario, with the rest of the variables remaining constant.

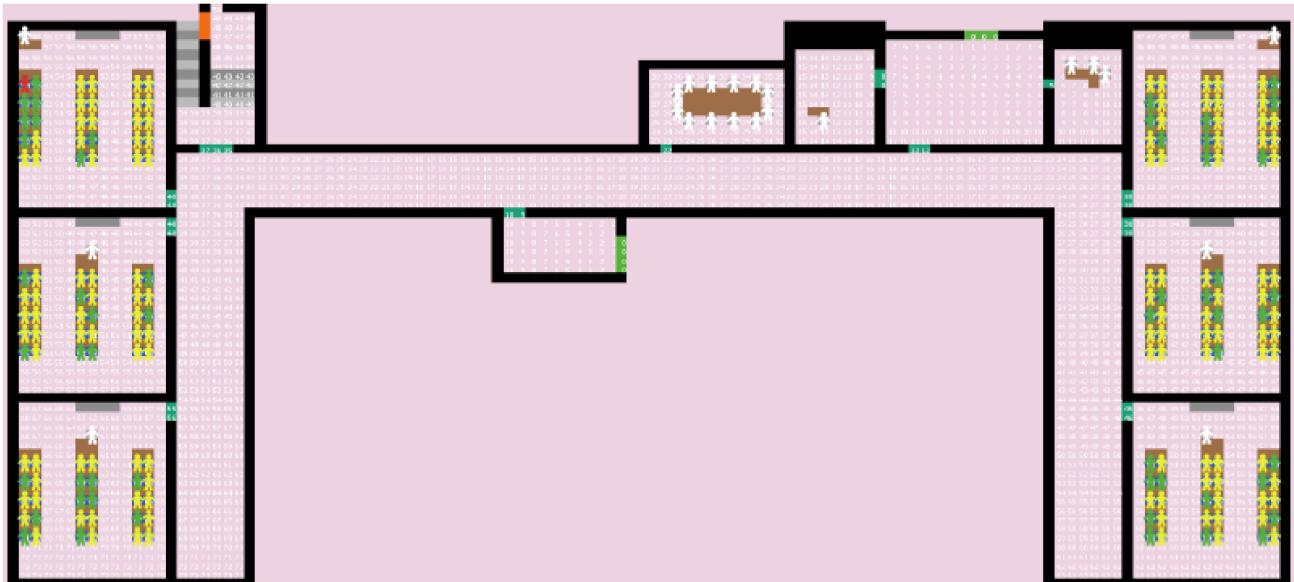


Figure 9. Rear entrance: closed (designed by the authors in NetLogo).

5.4.3. Scenario II—The Appearance of Obstacles as a Factor of Uncertainty

Performing simulations based on Scenario II will be based on the variability of obstacles, as they are an unforeseen element, which is theoretically taken into account in emergency evacuation training or courses, but it is quite difficult to implement an evacuation with obstacles, mainly because of their uncertainty of occurrence. Therefore, for the study of this scenario, the parameter that will change is the total number of the obstacles, with the rest of the properties remaining constant, similar to those in the Baseline Scenario.

Therefore, the situations that may arise as a result of this scenario are the following:

A. The appearance of obstacles on 10% of the surface of the first floor, randomly:

A percentage of 10% of the first-floor area to be considered as an obstacle during an emergency evacuation can be perceived as a unique value, but taking into account the interior structure of a school, with elements such as paintings, locker rooms, and closets, this is possible. Thus, Figure 10 highlights the surface with obstacles, while outlining the difference between this case and the Baseline Scenario.

B. The appearance of obstacles on 20% of the surface of the first floor, randomly:

As in the previous case, in the Figure 11 will show the change and deviation from the Baseline Scenario, with the rest of the variables remaining constant.

5.4.4. Scenario III—Variation of the Number of Present Children

The severity of a situation that causes an emergency evacuation has as an influencing factor the total number of people inside the building at the time of the evacuation, because a small number of people will theoretically lead to a shorter evacuation time.

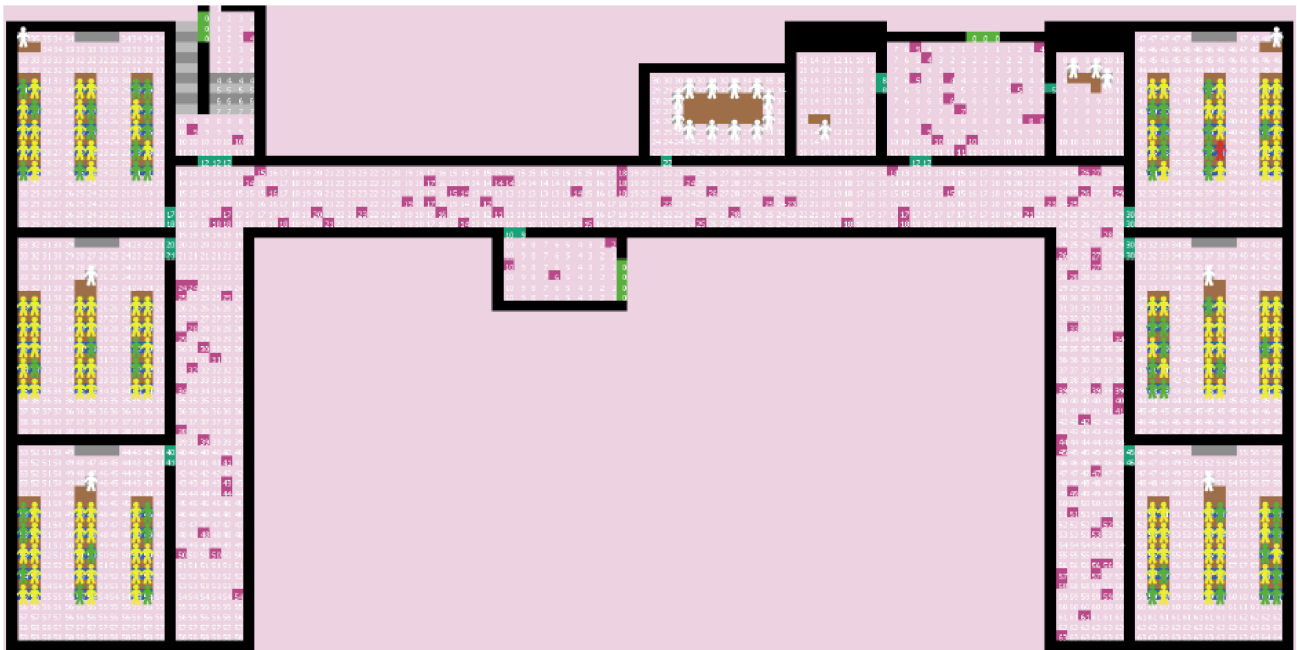


Figure 10. Obstacles in case of emergency evacuation (designed by the authors in NetLogo).



Figure 11. Obstacles in case of emergency evacuation - change and deviation (designed by the authors in NetLogo).

At the same time, in a school, it is often the case that students are unequally distributed between classes, because they may be absent or absent from classes, thus creating an inequality between the places occupied in each class. For example, in the context of the COVID-19 pandemic, some students may be absent for a certain period of time, if they are positively confirmed with the existing virus. Thus, considering the random seats in which students are placed within the classroom in the proposed model, to study this scenario, the parameter that will change is the total number of children, with the rest of the model properties remaining constant, such as those in the Baseline Scenario.

Therefore, the situations that may arise as a result of this scenario are the following:

A. Decreasing the presence by 15% of the initial value:

A lower attendance by 15% leads to a number of 27 individuals who are absent from the course, with the total number of children present being 153 in this case. This low attendance of 85% at classes, can be caused by various reasons, such as social, family, bad weather, student illness, etc. Figure 12 provides a larger overview of the differences between this case and the Baseline Scenario.

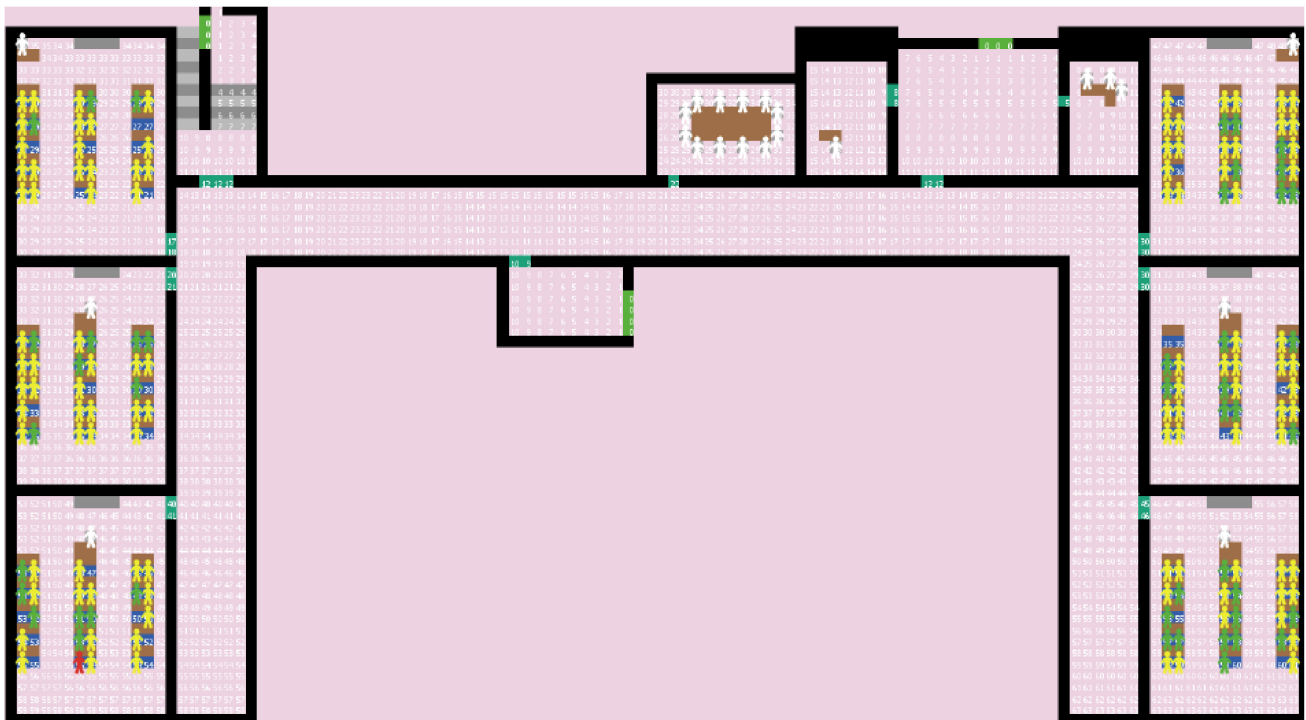


Figure 12. Example of placing children at a 15% lower attendance (designed by the authors in NetLogo).

B. Decreasing the presence by 35% of the initial value:

As in the previous case, the distribution of children will be observed when their presence is worth 65% of the total capacity of seats in banks, with only 117 of them being occupied. Thus, Figure 13 represents how the minimum number of students are divided in order to simulate, with the rest of the parameters remaining constant with values identical to those in the Baseline Scenario.

The values of the parameters for which the simulations were considered for this case can be better visualized in Figure 14.

In the Figure 15 shows the bottleneck effect that was formed in the model studied during the emergency evacuation, with this factor having the same effect in all the studied scenarios, with it being in fact the reason of the increase in time when it comes to the evacuation time, given the normal sizes of the doors in ordinary situations, but relatively low when considering such an evacuation situation. The phenomenon that occurs as a result of the bottleneck effect is described as the funnel effect, where the distribution of people evacuating when they encounter a narrower place takes the form of a funnel, as can be seen in Figure 15. In fact, at the beginning of each simulation, students with disabilities will always be helped and guided by the closest person.

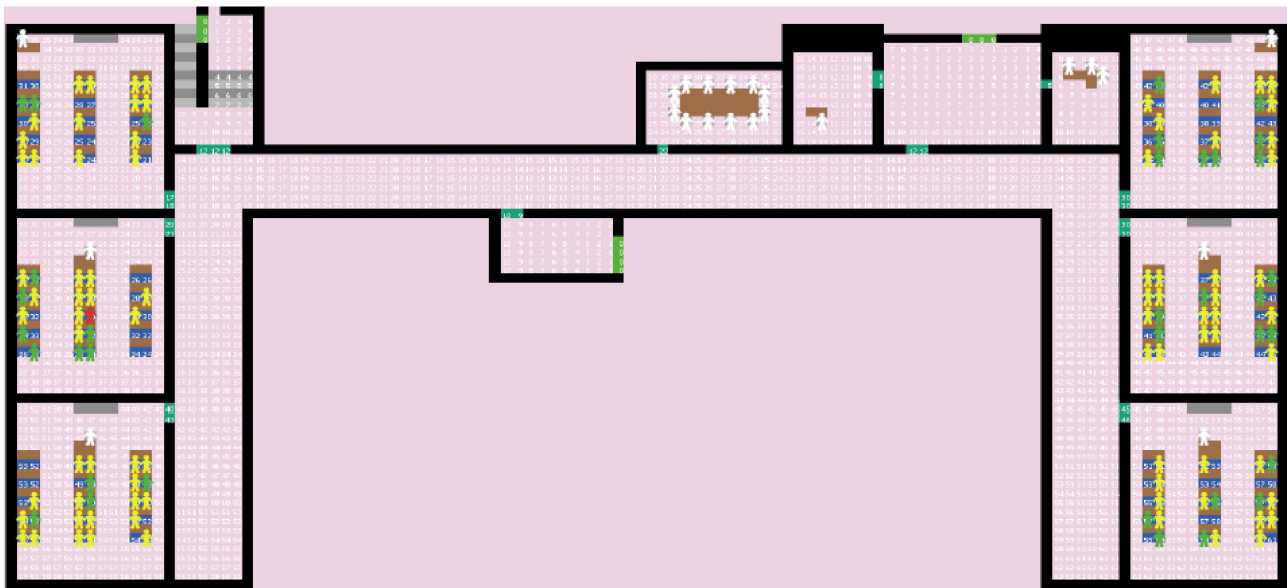


Figure 13. Attendance of 65% of children in classes (designed by the authors in NetLogo).

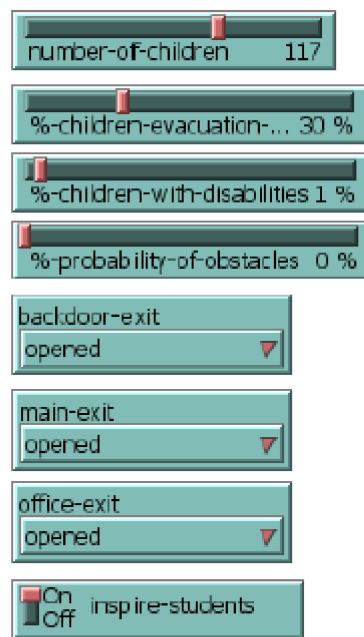


Figure 14. Parameter values in cases where the presence is minimal (designed by the authors in NetLogo).

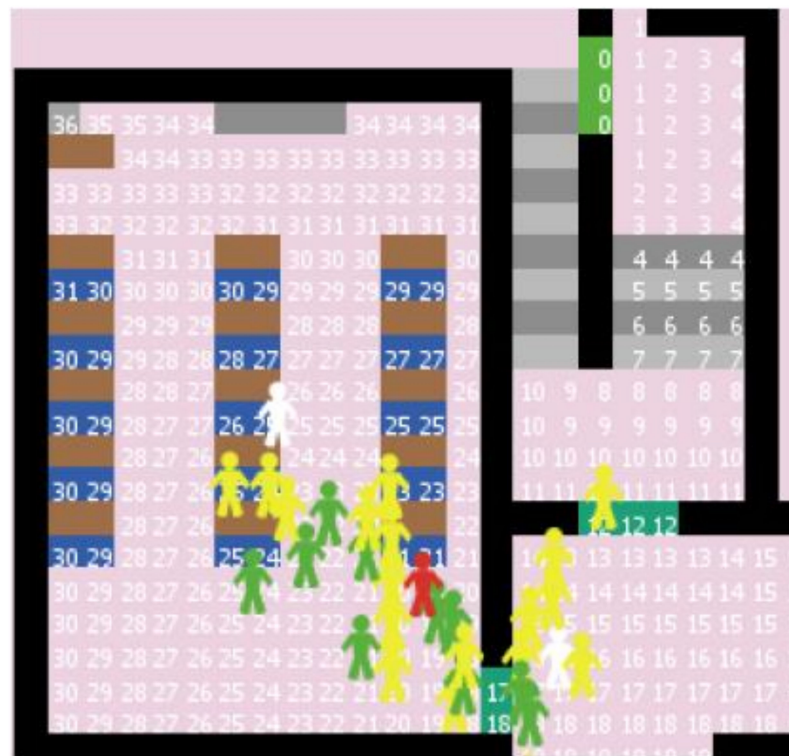


Figure 15. Formation of the bottleneck effect in the analyzed model (designed by the authors in NetLogo).

6. Results

In order to perform a more accurate and relevant analysis of the model, 400 simulations were performed for each case of the scenarios previously studied. The results include the most important aspects that appear in an emergency evacuation, such as the total evacuation time and the number of injured people, with these being the main criteria based on which the severity of such an unpleasant event was established. An average of the aspects mentioned above were performed, and they are represented in Table 3 for each situation.

Table 3. Simulation results for each situation.

Scenario	Situation	Total Evacuation Time (seconds)	Total Number of Injured People
Baseline scenario	-	153.363	0.023
Scenario I Variability of access paths	A	153.543	0.028
	B	157.823	0.038
	C	184.248	0.054
Scenario II The emergence of obstacles as a factor of uncertainty	A	169.323	0.063
	B	188.815	0.110
Scenario III Variation of children present	A	146.304	0.021
	B	137.012	0.010

Based on Table 3, we observe that the evacuation times fall within the interval (137.012; 188.815) seconds. Considering an optimal evacuation time of a school as two and a half minutes, a fact claimed by Safelenics [61], these values are approximately in the area of that time. However, there are quite large deviations in certain situations of the proposed scenarios, with these being given by Scenario II—A, B, and Scenario I—C. Therefore,

a detailed analysis was performed on the scenarios studied to identify the reasons that led to those times.

Scenario I—Variability of access paths: A. The teachers' exit will be semi-open:

The evacuation time of this scenario was very close to that of the Baseline Scenario, so an open exit of teachers is not reflected in an evacuation time that deviates to a large extent from the optimal situation—two and a half minutes. However, the number of injured people is 28 per 1000 people, with this being most likely caused by the panic that was created in the crowd, with people being disoriented or rushing to evacuate, without paying attention to those around them.

Scenario I—Variability of access paths: B. The rear exit will be semi-open:

When the back door was ajar, there was a small increase in evacuation time, compared to the Baseline Scenario, which has a value of 157,823 s, compared to 153,363 s. Even if the difference between the two times is apparently small—four seconds—which are essential in an evacuation, and it may be that they make the difference between life and death in certain situations. We can notice that the number of injured people is 38 per 1000 people, which is a slight increase compared to the previous situation because the rear entrance has a much narrower width than the teachers' entrance, thus forming a much denser crowd around the exit than the one formed in Scenario I—A. As the density of panicked people has increased, an increase, no matter how small, of the injured people is inevitable.

Scenario I—Variability of access paths: C. The rear exit will be completely closed:

There is a large discrepancy between the evacuation times between the current situation and the Baseline Scenario, as there was a longer distance to be covered by the students to the exit, as about half of them were not able to use the nearest exit (the back one), but the main one, which involves a longer route than the initial one. At the same time, the number of injured people is 54 per 1000 people, being also influenced and determined by the panic that broke out among the people who were evacuating.

Scenario II—the appearance of obstacles as a factor of uncertainty: A. The appearance of obstacles on 10% of the surface of the first floor, randomly:

In an emergency evacuation, it is very likely that obstacles will intervene in the route chosen by those evacuating, which will leave their mark on evacuation times, but also on the individuals' integrity. Therefore, in the case of this scenario, the evacuation time increased by about 15 s compared to the Baseline Scenario, due to obstacles, which change the dynamics of students, with some choosing to jump over obstacles, and others choosing to avoid them, but regardless of the choice made, the evacuation time increases, precisely because of the deviation from the normal route, with the shortest not being able to be followed in most similar situations. At the same time, the number of injured people reaches the value of 63 per 1000 people, because in addition to the panic, the obstacles make it difficult for people to evacuate, with some of them even injuring themselves in this. An example of this can be given by the burns caused to individuals after touching hot objects, in their attempt to evacuate as quickly as possible.

Scenario II—the appearance of obstacles as a factor of uncertainty: B. The appearance of obstacles on 20% of the surface of the first floor, randomly:

An obstacle density of 20% on the surface of the first floor leads to an evacuation time of 188,815 s, being the largest of all times for the scenarios studied. It exceeds the optimal average evacuation time by 38 s, a very high value in this context, which can have disastrous effects on those evacuated, with the unhappiest scenario being the loss of human lives. Therefore, it is observed that there are 110 per 1000 injured people because, compared to the previous scenario, the space of action of those who evacuate has decreased considerably, and they have to think about the next move in a very short time, creating an imbalance between panic and integrity or possibility of self-harming them, an imbalance that dictates how each individual will evacuate.

Scenario III—variation of the number of children present A. Decreasing the presence by 15% of the initial value:

A 15% decrease in the number of people evacuating compared to the Baseline Scenario will lead to an evacuation time that is shorter by 7 s, which is also less than the optimal evacuation time of a school. However, it is observed that, although there are fewer people involved in the evacuation process and their density being lower, panic is still established among those who evacuate, bringing the number of injuries to the value of 21 per 1000 people. No matter how small the number of people evacuating, undoubtedly there will always be panic within when they know they are endangered and that they can be seriously injured.

Scenario III—variation of the number of children present B. Decreasing the presence by 35% of the initial value:

A 35% decrease in the number of people evacuating compared to the Baseline Scenario results in a total evacuation time of 137 s, much less than the optimal evacuation time of a school. However, even if the number of people involved in the evacuation process is one third lower than in the Baseline Scenario, there are still injured people; 10 per 1000 people.

According to the differences between the studied scenarios, it is easy to see what influence various factors can have on the evacuation time, but also the complexity that emergency evacuation shows in creating a model that includes all the elements that impact evacuation times. Obstacles, how wide the entrances are, the number of people present, or panic are just some of the properties that make their mark on both the evacuation time and the number of injured people.

7. Solutions That Can Improve Evacuation Time

As a first proposed solution to reduce evacuation times in emergency situations, the construction of two new access roads to the educational institution are considered, which can be used only in case of catastrophic events, such as fires or earthquakes, and these new access roads will be, in fact, emergency exits. Next, a situation is presented in which two emergency exits will be added in the middle of the side halls; a strategic location, which will provide a balance between the distances between the school rooms and these exits. To observe the new access roads, which can only be used in crisis situations, we can see the Figure 16.

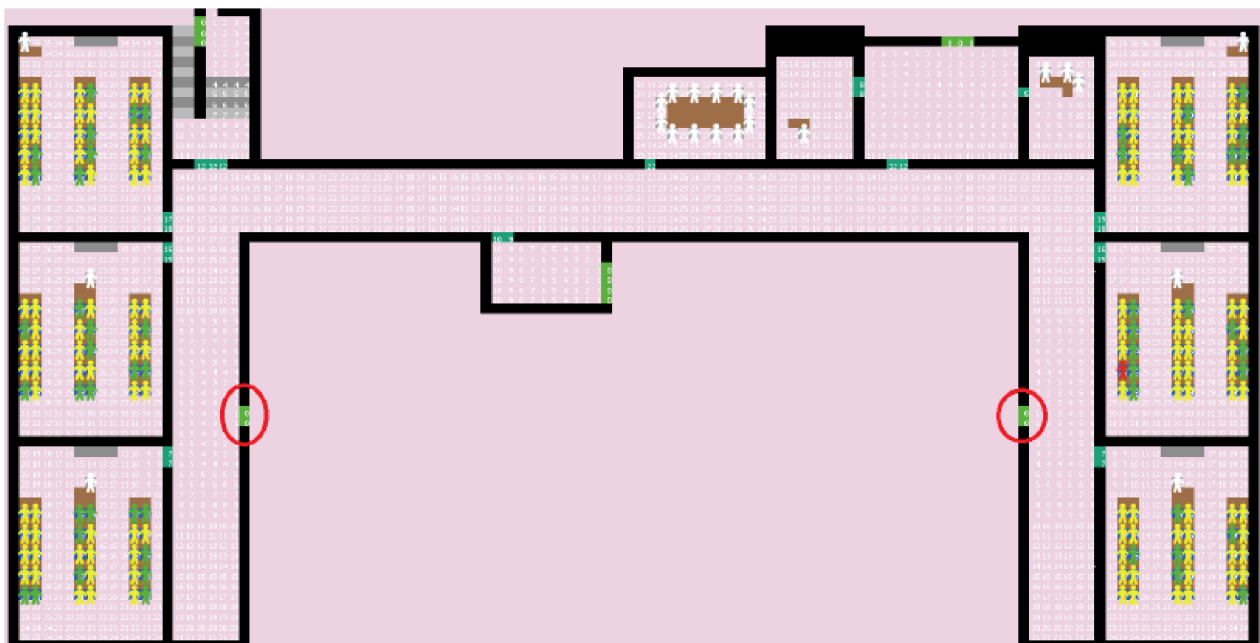


Figure 16. Emergency exits from the model (designed by the authors in NetLogo).

For the model with the two emergency exits considered, 400 simulations were performed again based on the same scenarios presented in the previous section, with the new results being highlighted in Table 4.

Table 4. Simulation results.

Scenario	Situation	Total Evacuation Time (seconds)	Total Number of Injured People	Impact on the Initial Type of Discharge
Baseline scenario	-	116.462	0.017	−24.06%
Scenario I Variability of access paths	A	111.990	0.020	−27.06%
	B	115.323	0.029	−26.9%
	C	120.985	0.037	−34.3%
Scenario II The emergence of obstacles as a factor of uncertainty	A	113.865	0.042	−32.76%
	B	136.193	0.079	−27.86%
Scenario III Variation of children present	A	101.713	0.015	−30.47%
	B	94.185	0.007	−31.25%

Analyzing Table 4, it is observed that the evacuation times decrease by at least 24% compared to the initial situation, in which there were no emergency exits built. Therefore, this solution is an extremely viable alternative for a faster and safer evacuation, and the costs for building exits and adjacent systems (signals, indicators) are RON 16,000 (EUR 3500), according to Prompt System [62]. Considering the possibility of serious injury to evacuees, the investment is very small considering that there is a risk that in the scenario of a disaster, the educational institution will pay compensation much higher than the cost of new emergency exits.

Another way to drastically reduce evacuation time is through school regulations to limit the capacity of a classroom to a maximum of 25 students, compared to 30 as before. Thus, this change will make it possible to reach an emergency evacuation time considerably shorter than that presented in the initial situation.

8. Conclusions and Discussion

The problem of emergency evacuation has been frequently studied, with the aim of wanting to optimize it as much as possible. Unfortunately, due to the variability and dynamics of human nature, an optimal model which takes into account all the influences reflected in the total evacuation time is almost impossible to determine because there is not only a small range of cases that can be studied, but there is an infinity of possible situations. An example of this can be the placement of obstacles, with some areas having a lower density of obstacles than others, or the fact that some obstacles can even help to improve evacuation time, although they are perceived generally as a bad thing. It is also impossible for all individual features to be included in the models, as all people are different from each other by at least one characteristic, a difference that proves to be one of the main factors in making emergency evacuation models, along with the eventuality of the unforeseen.

The purpose of this study was the analysis of evacuation simulations in emergency situations of a school. The model that was used took into account the individual particularities of the people who took part in the evacuation, emphasizing the effects that form in a crowd when evacuating; effects such as the funnel effect, which is caused by the formation of bottlenecks around narrow areas. At the same time, the importance of an evacuation being as fast as possible, carried out in the safest way possible by those taking part in the simulation was also taken into account. Interpreting the results of the simulation on different scenarios, we highlighted some issues related to emergency evacuation. In fact, the advantages of this model also stand out, these being:

- Manages to expose in a precise way the differences of the evacuation times depending on the opening of the access ways that are available during the simulations;

- Succeeds in taking into account the obstacles that appear during the simulations, outlining the differences that appear in the evacuation times;
- Agencies are categories of reality, they can be diversified in terms of individual characteristics (different speeds depending on the category, people with disabilities present).

It should be noted that, following the study carried out on the basis of the “Regina Maria” school, the shortest evacuation time in case of emergency, with a distribution of people according to real data, was present in the situation where only 65% of the places addressed to students were occupied. An evacuation time of about two and a quarter minutes is one that is below the optimal average of school evacuation times, but this time can be reduced by implementing measures such as the construction of at least two new access roads, which are to be used only in emergency situations.

To have a clearer view on the correlation between the factors that could impact the evacuation time and the actual duration of the evacuation, we decided to consider these factors one by one in our scenarios, as this would better explain their individual importance in the analysis, rather than having them all considered in other scenarios. In this paper, we took into account our thoughts about what may impact the evacuation time, and also after observing that there are not many studies conducted which included them, with these items being actually only some of the many elements behind one’s behavior, as the “emotional” part of humans will never be deterministic with regards to the outer factors. As a justification for the aspects covered in this article, a number of factors were considered which could be estimated in order to make our analysis possible, but, at the current rate of the technology improvement, especially with regards to the AI area, guaranteed is the fact that, in the near future, estimable factors could be taken from our thoughts and what we think and these could represent the factors that we would want considered in our further research regarding this paper’s topic.

The variety of elements that contribute to the modification of human behavior and their reactions implies the understanding and knowledge of complex adaptive systems. Between all these elements there is connectivity and interdependence, functioning far from equilibrium and emergence. These are just a few properties of complex adaptive systems, so understanding them can help influence people’s decisions in evacuating themselves in the context of disaster scenarios. Agent-based modeling, as a working tool from a cybernetic perspective, contributes to understanding how agents (in our case, students) react in different contexts. In order to observe how the model proposed by us in NetLogo works, we made a video available at <https://github.com/qfanee/Disaster-Evacuation-Process> (accessed on 10 September 2021). Furthermore, the written programming code is at the same online address.

The model we propose and the continuous improvement of life safety systems, together with the environmental settings, can be considered sustainable practices for the future. We aim to capture in future research other aspects that can improve the safety of human life.

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