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A Simulation tool for fire evacuation

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Dedication

First and foremost, all praise and thanks be to Almighty Allah for granting me the ability and assistance to complete this thesis.

Next, I would like to express my gratitude to my thesis supervisor, Dr. Fares kahlessenane , for his guidance and support throughout this thesis.

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To every student who has helped us succeed in our humble academic journey, even with a single word of encouragement.

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We extend our heartfelt thanks and appreciation to all of you, and may Allah reward you with the best in this life and the hereafter.

ABSTRACT

Influence of human behavior as well as the demographics or organization of the evacuation site. Therefore, it is essential to consider how to arrange the evacuation upstream since an emergency scenario might result in disorder due to the fear that grips evacuees on the one hand and the high number of evacuees in hazardous conditions on the other. Several fire evacuation strategies have been developed in recent years. Unfortunately, the majority of these tools do not explicitly state which variables should be taken into account when evaluating them. More generally, these models use the number of survivors as a primary criterion for evaluation. This thesis goal is to provide an intelligent agent-based model that would allow for modeling and simulation of the evacuation of individuals from a burning building.Our suggested technique is based on three criteria that allow her to be evaluated practically. In a structure with a general 3D virtual environment setup, a case study of simulation is conducted. This method may be used without significant alterations on a variety of commercial building types since it is sufficiently broad.

KEYWORDS: Simulation, Fire propagation , Evacuation , Intelligent Agents , crowd simulation, psychological models, dynamic behaviors.

الملخص

يتأثير السلوك البشري وكذلك التركيبة السكانية أو تنظيم موقع الإخلاء بعدة عوامل , لذلك من الضروري النظر في كيفية ترتيب الإخلاء في اتجاه المخرج لأن سيناريو الطوارئ قد يؤدي إلى اضطراب بسبب الخوف الذي يسيطر على الأشخاص الذين يتم إجلاؤهم من ناحية والعدد الكبير من الأشخاص الذين يتم إجلاؤهم في الظروف الخطرة من ناحية أخرى. تم تطوير العديد من استراتيجيات الإخلاء من الحرائق في السنوات الأخيرة. وللأسف، فإن غالبية هذه الأدوات لا تحدد صراحة المتغيرات التي ينبغي أخذها بعين الاعتبار عند تقييمها. وبشكل أعم، تستخدم هذه الادوات عدد الناجين كمعيار أساسي للتقييم. الهدف من هذه الأطروحة هو توفير نموذج ذكي قائم على الأشخاص و التغيير في السلوك حسب الحالة التي هم عليها يسمح للمستخدم بنمذجة ومحاكاة إجلاء الأفراد من مبنى محترق. يستند أسلوبنا المقترح إلى ثلاثة معايير تسمح بتقييم عملية الاخلاء عمليًا. في هيكل به يمكن إعداد بيئة افتراضية ثلاثية الأبعاد، يتم إجراء دراسة حالة المحاكاة. يمكن استخدام هذه الطريقة دون تعديلات كبيرة على مجموعة متنوعة من أنواع المباني التجارية لأنها واسعة بما فيه الكفاية.

الكلمات المفتاحية : المحاكاة، انتشار الحريق، الإخلاء؛ الوكيل الذكي ، محاكاة الحشود، النماذج النفسية، السلوك الديناميكي

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General introduction

Since the Industrial Revolution, the world population has been growing at an unprecedented rate. In **Fig 1**[4], we can see that the population has surpassed six billion in the last two hundred years. This population growth has led to a rapid increase in the number of cities and their populations. Mega-cities, defined as cities with more than 10 million people, have become more common due to the expansion of the populace and emigration from villages. There are currently 35 megacities around the world, and they pose potentially dangerous situations that have become part of our reality.

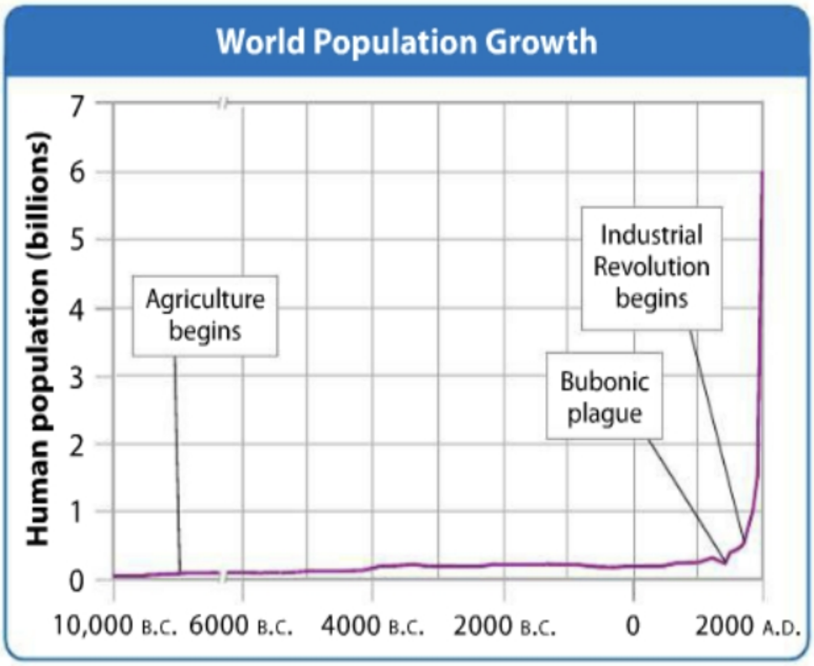


Fig 1 : world population growth throughout Human history

As such, there is a need for crowd safety measures to reduce possible injuries. Unfortunately, disasters in evacuation situations have occurred, such as the

Hillsborough Stadium Disaster (Sheffield, England in 1989) and the Love Parade

Disaster (Duisburg, Germany, in 2010), resulting in 69 and 21 deaths, respectively. Proper planning can help ensure that buildings are designed with safety in mind, such as by designing buildings that can withstand natural disasters and having fire safety measures in place to protect occupants. One effective way to improve the safety of building occupants during a fire emergency is through the use of fire evacuation simulation. This simulation provides a cost-effective and safe way to study and test various evacuation scenarios without putting real people at risk. By exploring different evacuation strategies and identifying potential weaknesses in evacuation plans, researchers and building designers can improve evacuation plans and procedures, as well as develop effective communication strategies and training programs for building occupants and emergency responders. Evacuation simulations can also help assess the impact of different factors on evacuation times and effectiveness, such as building layout, occupant demographics, fire spread, and smoke movement. Overall, the use of fire evacuation simulation can greatly enhance the safety of building occupants during a fire emergency by providing a better understanding of human behavior identifying potential weaknesses, and optimizing evacuation strategies and fire safety measures

However, there are some potential problems associated with the use of fire evacuation simulation tools. The accuracy of the simulation results is highly dependent on the quality and accuracy of the input data used in the simulation. Simulation tools may also not always accurately simulate the behavior of individuals during an emergency situation due to unpredictable factors like panic and confusion. The cost and time associated with the use of simulation tools can also limit their accessibility to small organizations or building owners who may not have the specialized knowledge and training to operate them effectively. Over Reliance on simulation tools can also lead to complacency in real-world emergency situations

Overall, while fire evacuation simulation tools can improve safety, their limitations and potential problems should be carefully considered and addressed. These tools should be used in conjunction with real-world testing and evaluation to ensure their effectiveness.

The present thesis focuses on creating a user-friendly evacuation simulation tool. This tool will represent fire propagation and crowd simulation tools to provide a robust and efficient solution for accurately modeling fire behavior and crowd movement in fire evacuation simulations. This tool aims to assist researchers, architects, emergency response teams, and safety professionals in analyzing and improving the effectiveness of fire evacuation plans and strategies.

Key goals of the tool include:

1. Accurate Fire Propagation Simulation: The tool aims to accurately model the spread of fire, considering various factors such as fire range and fire speed movement. It will provide a realistic representation of fire behavior, enabling users to evaluate potential fire growth patterns and assess the impact on evacuation routes and safety.
2. Realistic Crowd Modeling: The tool will incorporate advanced crowd simulation algorithms to simulate the behavior and movement of individuals during fire evacuation scenarios. It will consider factors such as human psychology, panic behavior, obstacle avoidance, and spatial awareness to generate realistic crowd movement patterns.
3. Scenario Analysis and Optimization: The tool will allow users to create and analyze different fire scenarios, considering various parameters such as building layouts, occupancy levels, exit locations, and evacuation strategies. Users can assess the effectiveness of different evacuation plans, identify potential bottlenecks or safety hazards, and optimize evacuation procedures to enhance overall safety and efficiency.
4. Visualization and Reporting: The tool will provide intuitive visualization capabilities, allowing users to observe fire propagation, crowd movement, and evacuation dynamics in real-time or through playback features. It will also generate comprehensive reports and analytics, including evacuation

timeframes, congestion areas, and potential safety risks, enabling users to make data-driven decisions and improvements.

5. User-Friendly Interface and Integration: The tool will feature a user-friendly interface, making it accessible to a wide range of users with varying levels of technical expertise. It will support integration with existing fire safety and evacuation software platforms, enhancing interoperability and allowing for seamless data exchange.

Overall, the fire propagation and crowd simulation tool aims to enhance fire safety analysis by providing accurate and realistic simulations, enabling users to improve evacuation plans, optimize emergency response strategies, and mitigate potential risks during fire incidents.

The work presented in this thesis is divided into the following chapters

Chapter 1 : will introduces simulation theory , high performance computing architectures and programing models and the application of parallelism to simulation

Chapter 2: will shows the existing models at the state of the art and explains them. Some basic concepts needed to understand the present thesis are explained. The differences and similarities with the present work are described.

Chapter 3: will introduce the simulation models that used in the tool , shows the algorithmic description

for how the agent reacts realistically to the changes in the environment.

Chapter 4:will We discuss the tool's internal features. We talk about the algorithms that determine how it behaves. Along with the internal factors.

Chapter 5: will In addition to the simulations described in various situations, we used the special tool and retrieved a set of results.

Conclusion : will We have a variety of conclusions about the material presented, highlighting the thesis' contributions and referencing the research papers produced. Finally, it presents fresh research directions that consider the possibilities of this piece.

Chapter one : simulation

1. Introduction

Today, simulation is one of the most widely used methods around the world and is one of the best ways to conduct science experiments and other activities. Since its inception in the 19th century, civil engineers have used simulation in the design of bridges and buildings. In the 20th century, simulation entered the fields of natural sciences, physics, and mathematics and eventually became a core technology in engineering and technology in the 1960s and 1970s. It has been used in automobiles, aircraft, and medical equipment. At the moment, simulations are of great interest, especially with the development of artificial intelligence. Through simulation, we can understand how complex systems work and analyze their behavior in different conditions, which helps us make the right decisions regarding system design and optimization. In this chapter, we will talk about mimicry, mention its types and importance, and discuss some of its uses.

2. definitions

first definition : The process of creating a mathematical model for a real system and using this model to analyze and understand the behavior of the system, test different hypotheses about this system, and determine the best policies and procedures to deal with this system Simulation also includes creating a simulated environment that represents the real system to run the mathematical model, collecting and analyzing data to evaluate the behavior of the system in different conditions[1]

Second definition : The actual system uses a computer-generated model that simulates the behavior of the real system over time. Simulations are used to analyze system performance, test new hypotheses about the system, and develop and improve the existing system design. Simulations are used in a wide variety of applications, including industry, services, the military, medicine, the social There is no specific or fixed definition of simulation, but all definitions are formulated in one way: "the imitation of real-world processes or systems over time" using mathematical and computer models.[2]

3. The importance of simulation

In the real world, there are some experiments that cannot be performed. There are usually two reasons for this: either the cost is too high or the process is impossible to perform realistically. Simulation plays a critical role in these cases, as it provides a way to test and study these scenarios in a safe and controlled virtual environment.[5]

3.1 Risk Reduction

Simulation can help analyze potential risks in a particular process. When a simulation model is created, it can be used to analyze different scenarios and evaluate the potential risks in each of them. This can help avoid significant risks and reduce potential associated costs, which is the objective of this memo. [5]

3.2 Improving decision-making

Simulation can help improve decision-making by producing realistic results for a particular experiment. When a model is created to analyze a specific process, it can be used to analyze different scenarios and test the potential impacts of different decisions. This allows decision-makers to better understand the potential outcomes of different choices, which can ultimately lead to more informed and effective decision-making. [5]

3.3 Saving time and cost

Creating a simulation model requires a significant amount of time, effort, and cost, but in the long run, it can help save time and money. When the simulation model is used to analyze the current system or potential modifications, it is possible to avoid the actual testing costs of making modifications to a live system before ensuring its effectiveness. [5]

3.4 Development of Products and Services

Simulation can help in the development of products and services by analyzing their potential performance in different scenarios. The simulation model can be used to analyze the performance of a potential product in various conditions, identify potential problems, and make necessary modifications. [5]

4 computer simulation

Simulation modeling involves creating a computerized model based on a theoretical model. This involves translating the model into a format that can be processed by a computer, which involves arithmetic-logical operations, input-output interactions, and conditional and unconditional jumps. The use of simulation has increased in recent years due to scientific research. While it has a history rooted in military research , For instance, in the Manhattan project (1942-46) a simula- tor was built in order to simulate a model of a nuclear detonation and understand what could happen [3] It has now found applications in various fields. Simulations allow for the understanding of complex interactions within a system and enable the analysis of behavior over time, as well as the exploration of new concepts and hypothetical scenarios. They provide the ability to simulate highly complex systems that would otherwise be difficult to understand and can be used to predict the future or emulate existing systems. Simulators can also be used for training users in complex systems, such as flight simulators. However, it is important to note that the quality of the simulation is dependent on the accuracy of the model and its configuration. Simulations are not a universal solution to complex problems and require realistic models, proper coding, and accurate data to be effective

4.1 Simulation classification

There is no single way to implement a simulator, as its structure depends on various factors, such as the problem being addressed, the chosen approach, design decisions, and performance requirements. Simulations can be classified based on several attributes. **Fig 2[4]** shows a taxonomy of categorization based on properties such as determinism or stochasticity, static or dynamic behavior, and continuous or discrete variables. [4]

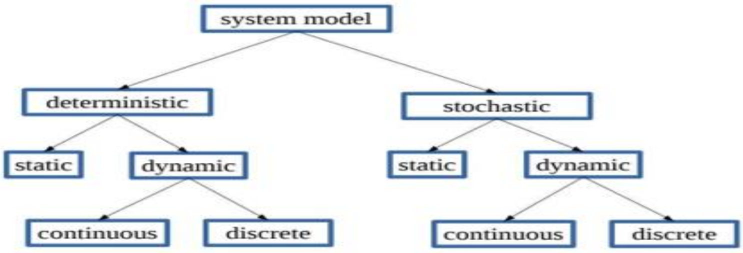


Fig 2 : Simulation model taxonomy.

4.1.1 DETERMINISTIC AND STOCHASTIC

Stochastic systems are characterized by random patterns that are determined by probabilistic components in the model. Small variations in the system can cause large variations over time. For example, stock markets are modeled as stochastic systems with random patterns modifying their behavior, as are the movements of cars in traffic or the probability of cancer cells reproducing. Therefore, even when the range of possibilities is known, the output of the simulation is unpredictable because it will vary. In this context, we can use Monte Carlo simulation, which is based on an iterative simulation with random behavior. On the other hand, deterministic systems do not have random patterns and do not behave randomly. Due to this, the output of the system will always be the same for a given input. Therefore, the output is more predictable compared to stochastic systems. [4]

4.1.2 STATIC AND DYNAMIC

Static systems do not change over time, which may be a result of a simulation that is done in a steady state for only one simulation step or because time is not a factor in some systems. On the other hand, dynamic systems change over time, and the state of the simulation will vary and evolve between simulation time steps. [4]

4.1.3 CONTINUOUS AND DISCRETE

Continuous simulation is one that is expressed in terms of continuous time, and the state is constantly changing. In contrast, discrete simulation advances over discrete time periods, and the change only occurs at these discrete steps. [4]

4.2 SCIENTIFIC SIMULATION CATEGORIES

In this section, we will discuss various methods of simulating physical systems. The methods used may vary depending on the problem being modeled. These categories are especially important in the field of evacuation and simulation. [4]

4.2.1 CONTINUOUS DYNAMIC SIMULATION

Continuous dynamic simulation is one of the most significant categories within scientific simulation. This approach is typically based on differential and algebraic equations. A wide range of physical systems can be modeled as a set of differential equations that evolve over time. These models are implemented using methods such as finite volumes, finite elements, or finite differences. The equations will define state variables, boundary conditions, and how the system changes between time steps. Even though continuous simulation represents a continuous system, the solution will always be an approximation. Continuous simulation is typically complex and requires high computer performance. For example, when modeling fluids, which can be compared to the movement of a crowd [04], we use differential equations to deduce the macroscopic behavior of the crowd. All the equations in the set must be solved for every time step and for every point in a given space defined by a set of points.

4.2.2 DISCRETE EVENT SIMULATION (DES)

Discrete Event Simulation (DES) involves using a sequence of discrete events to model a system, where transitions between states are determined by events with no updates occurring in between. The system consists of a set of variables that are updated with each event. DES is a widely used category in scientific simulation due to its adaptability to computing systems and the formalism that exists in this field. DES can be used to model finite state machines, Petri diagrams, queues, networks, and more. For instance, in the case of Petri diagrams, tokens, transitions, places, and arcs are used. Tokens represent items moving between places based on the event list rather than on a simulation time that would determine the system's evolution. Instead, events trigger transitions between simulation states. [4]

4.2.3 ABM, IOM

ABM, which stands for agent-based modeling, is a simulation approach used to model systems that consist of individual, autonomous, and interacting agents. These agents are defined by their behavioral rules and attributes, and their interactions can be observed on a macro level. The behavioral rules of each agent dictate how they act at each time step, and their behavior is influenced by both their environment and their attributes. Attributes are unique state variables of each agent that are independent from others and updated by behavioral rules. For example, in the case of crowd evacuations, attributes may include size, age, exit, and maximum speed. The environment in which agents operate consists of the elements that interact with them, such as walls, obstacles, and signals. ABM allows us to study how individuals interact with each other and their environment at discrete times and how the system evolves from their rules of interaction. This approach is considered more realistic than using a system of equations, as it offers more flexibility in terms of setting different behaviors depending on the environment and allowing for heterogeneous agents and environments. ABM also allows us to evaluate the internal evolution of the system by updating each agent's state variable at every time step. In the field of ecology, these models are known as individual-oriented models (IOMs) and are used to study natural systems such as herding and flocking. [4]

4.3 SIMULATION TIME

Simulation time is an artificial time used by computers to measure the passage of time in a simulated system. It is distinct from wall time, which refers to the total execution time of the simulation. Simulation time advances in discrete time steps, which directly affects the total execution time of the simulation. Choosing an appropriate time step is crucial, as a smaller time step provides more information but also leads to longer simulation times, while a larger time step may cause the loss of important details. For problems with significant fluctuations within a short time frame, such as combustion simulation, a short time step is necessary. In contrast, in the case of N-body collisions where collision times can be calculated, dynamic simulation time can be used to optimize the total execution time. [4]

5. SIMULATORS AND COMMERCIAL SOFTWARE IN EVACUATIONS

In the case of evacuations, crowds, and pedestrians, there are several academic and commercial simulators published. They differ on their approach to implementing and solving the crowding and evacuation problems. We analyze the models and also make use of a review made by NIST [06] to categorize and describe them.

Simulex [07]: allows you to simulate crowds in complex 3D structures. It is a partial behavioral model, considering distance between persons to set agents speeds. The goal of the simulator is to allow to set up occupants inside a building and simulate the movement during an emergency

Steps [08]: This is an agent-based modeling (ABM) tool that offers microscopic modeling of individual movement in complex 3D spaces, suitable for both evacuation and normal situations. It also supports group modeling and more complex elements, such as elevators.

Oasys MassMotion [09]: This 3D tool is compatible with software like 3D Studio Max and can build complex scenarios and simulate pedestrian navigation.

JuPedSim [10]: A public simulator developed by Jülich Research Center, it allows for 2D scenarios and agent movement based on Voronoi distance and a defined path. It includes several packages for simulation analysis.

PathFinder [11]: This simulator offers egress analysis in complex 3D structures, tracking agent positions and following certain constraints for movement towards exits. It is also compatible with fire simulators.

Myriad II [12]: This software handles complex 3D buildings and calculates congestion severity, movement overview, and occupant interactions. Its purpose is to assess security, calculate times, and determine exit capacity.

Exodus [13]: This behavioral model is used for evacuation analysis and pedestrian dynamics, considering people-people, people-structure, and people-fire interactions. It models toxic gases, smoke, and temperature using submodels for occupant, movement, behavior, toxicity, hazard, and geometry.

Legion Evac [14]: This behavioral model can handle CAD structures and optimize crowd behavior and interaction between individuals to study evacuations. It calculates counterflow and evacuation times and is compatible with Fire Dynamics Simulation software for simulating evacuation under fire conditions. It is primarily used as a consultancy tool

8. CONCLUSION

We have studied how computer simulations play a critical role in advancing our understanding of real-world systems and helping make decisions to improve our knowledge. Simulation finds its applications in different domains, and some areas have specific computational requirements that require the overall execution time of the simulator to be reduced to achieve a feasible computing time. However, in the context of evictions and crowds, current approaches have focused more on the simulation itself than on optimizing the computer graphics.

The next chapter introduces important concepts for understanding eviction and mobilization models, as well as ways to represent them. Models relevant to modeling these are presented and described along with methods for representing them, and specific crowd situations, crowd disasters, and crowd disturbance are explained.

Chapter two: modeling crowds and evacuation

1. INTRODUCTION

Over the past few years, there has been a growing effort to solve the issue of evacuation safety. Various fields such as engineering, computer science, psychology, architecture, and sociology have shown interest in this problem, with each tackling different aspects of it. Within the evacuation problem, there are several sub-problems, including the person model, psychological components, free navigation through space, path planning to reach the exit, simulation techniques, and performance issues of the simulator. The ultimate aim of all these areas and components is to gain a better understanding of the model and improve the implementation of simulators. Therefore, most research in this field shares the same starting premise: evacuating a certain number of agents from a specific space. This chapter will introduce several models and approaches to the evacuation and crowd modeling problems, including complex systems, computer graphics, and mathematical modeling. We will first distinguish between various approaches to modeling crowds and evacuations and then extend the discussion to parallel problems that need to be solved, such as path planning, collision avoidance, and numerical methods.

2. CLASSIFICATION OF EVACUATION AND DYNAMICS MODELS

The representation of reality through modeling can be approached from various perspectives, each with its own advantages and disadvantages based on factors such as complexity, performance, simplifications, and aims. In this regard, it is important to first examine the different general classifications of models and their respective characteristics.

2.1 MACROSCOPIC AND MICROSCOPIC

Macroscopic models rely on data such as flow rate, population, and the width of the scenario. They use a set of mathematical formulas to calculate the overall results of the scenario. The agents' movement is seen as a continuous flow and assumes that the behavior of the flow is homogeneous, with no significant variations in the decision-making process of individuals. While macroscopic models may not provide a detailed analysis of the causes of crowd phenomena, they can be computationally efficient since they simplify the small scale into a larger one. In contrast, microscopic models consider the individual interactions of pedestrians with the environment and other agents while moving towards their desired goal. These models use individual agents with their own set of ruls, capable of interacting and making decisions in both space and time. Microscopic models offer a more realistic approach in terms of navigation, movement, and decision-making compared to macroscopic models. However, this increased realism comes at the expense of computational performance, as the detailed configuration of the system can become complex. [4]

2.2 CONTINUOUS AND DISCRETE

Microscopic evacuation models can be classified into two types: discrete and continuous. Discrete systems have state variables that change at specific, countable time intervals. Continuous systems, on the other hand, experience continuous changes over time. Cellular automata (CA), first proposed by Von Neumann, are a prominent example of a discrete-time approach. CA models evolve in discrete time phases and are characterized by a set of states. The space is typically divided into a grid, and each automaton interacts with its neighbors in the grid. Transitions between time steps are done simultaneously by all the automata, taking into account the local state and the neighboring automata surrounding the target automaton. Homogeneous and heterogeneous models can be used in CA, depending on the definition of agents. This model has been widely used in evacuation simulations. Continuous models, on the other hand, describe systems with variables that exist on a continuum. While discrete models can only represent a limited number of positions in space, continuous models can describe the positions of their components in any . Therefore, the simulation time and time step can be modified, whereas in discrete models, they are fixed due to the discrete evolution of the simulation. Continuous models offer greater realism than discrete models but require additional computation. [4]

2.3 BEHAVIORAL

In certain applications, the purpose of the model is not to replicate real-world evacuations for validation but rather to simulate crowd behavior that appears realistic. These models are known as behavioral models, which aim to accurately simulate the behavior of individual agents, also referred to as "boids" in this context. They have been extensively utilized in animation graphics for simulating the behavior of boids. For instance, Reynolds' flocking model [15] realistically models the behavior of birds. Although these models were not originally designed as tools for the evacuation domain, they have made significant contributions to the field.

3. SOCIAL FORCE

The social force model, introduced by Helbing, holds significant influence in the field of evacuation research. It is a microscopic continuous model that aims to explain the behavior of pedestrians in the presence of others and physical barriers. The model was developed based on the analysis of videos, which led to the identification of several key characteristics observed during evacuation situations. These characteristics, as described by Helbing, include :

- Increased speed or attempts to move faster than usual.
- Physical interactions and pushing among individuals
- Uncoordinated movement and congestion at bottlenecks.
- Arching and clogging at exits.
- Formation of jams or blockages.
- Dangerous pressures resulting from physical interactions.
- Tendency towards mass behavior.
- overlooking alternative exits.

This list of characteristics has played a crucial role in summarizing the essential aspects that evacuation models involving crowds need to consider, including both physical and psychological forces that impact the behavior of evacuees. Building upon these observations, the Social Force model was developed to describe the forces acting on an agent with mass m who desires to move towards the exit e at a desired speed v. The interaction forces fi and fiw account for the influence of other agents and walls on the agent's movement and trajectory.

$$m_i \frac{d\mathbf{v}_i}{dt} = m_i \frac{v_i^{o}(t)\mathbf{e}_i^{o}(t) - \mathbf{v}_i(t)}{\tau_i} + \sum_{j(\neq i)} \mathbf{f}_{ij} + \sum_{W} \mathbf{f}_{iW} \tag{1}$$

The interaction among agents is defined by the force fi. This force is characterized by two distinct components incorporated in the formula. The first component represents the interaction between agents, considering the distance between them and the contribution of various constants (A, B, and k) to the body force component. It accounts for the force exerted by one agent on another based on their proximity.

The second component of the formula restricts tangential movement between agents. If agents are not in physical contact, the tangential force component becomes zero, effectively prohibiting any sideways movement between them. This ensures that agents can only exert force on each other when they come into direct contact.

$$\mathbf{f}_{ij} = \left\{ A_i exp\left[\frac{r_{ij} - d_{ij}}{B_i}\right] kg(r_{ij} - d_{ij}) \right\} \mathbf{n}_{ij} + \kappa g(r_{ij} - d_{ij}) \Delta v_{ij}^{t} \mathbf{t}_{ij} \tag{2}$$

The force is utilized to model the interaction between agents and walls. It follows a similar notation to the force employed in agent-agent interactions, but with walls acting as the interacting entities. This force also incorporates an exponential repulsion factor that considers the distance between the agent and the wall, ensuring that they do not overlap or collide.

$$f_{iw} = \left\{ A_i \exp\left[\frac{r_{iw} - d_{iw}}{B}\right] kg\left(r_i - d_{iw}\right) \right\} n_{iw} + kg(r_i - d_{iw})(d_i.\, t_{iw}) t_{iw}$$

(3)

This model, the Social Force model, effectively explains self-organized phenomena such as group formation and bottlenecks while encompassing the previously mentioned characteristics in a coherent manner. It has gained widespread acceptance and validation within the evacuation research community, serving as a fundamental tool in this field.

Following the publication of the Social Force model, researchers have made further contributions building upon this work. For instance, Quinn parallelized the Social Force model for real-time simulations involving 10,000 agents, utilizing space partitioning and distributing the computational load with MPI on a parallel architecture [16]. Additionally, the social force model has undergone continuous review and refinement by various researchers.

One notable revision of the Social Force model is the work conducted by Pelechano on HiDAC and MACES [17][18]. Her research focuses on virtual crowds, particularly in the realm of computer graphics, while also contributing to the advancement of evacuation modeling. Her proposed model addresses aspects such as obstacle avoidance, path planning, and high-density scenarios, offering rich and realistic behavior suitable for 3D simulations.

4. CROWDS

The analysis of crowds has been crucial in various areas such as building construction, public transportation, airports, shopping malls, theaters, and more [19]. With disasters occurring throughout history, crowd analysis has gained importance in the last century. **Fig. 3** [53] [52] [55] [54] illustrates some of these disasters that have occurred in different settings. These images give an understanding of the size and complexity of crowds and how they affect different parts of the world. Crowd evacuations are a unique case within pedestrian evacuations. Apart from the number of agents involved in the simulation, there are other important factors that impact the model, including special crowd phenomena. When there are hundreds or thousands of people in a dense mass, the events that occur are different from those in a low-density evacuation. These phenomena can vary from stop-an to-go waves, laminar behavior, crowd turbulence, stampedes, and more.

Fig 3: Crowd events and places where people resulted death and in- jured: (a) Mahamaham Festival, Kumbakonam. (b) Hillsborough disaster in the newspapers. (c) Love Parade in 2010. (d) The way to Jamarat bridge .

4.1 CROWD DISASTERS

Crowd disasters, caused by stampedes, high-density situations, and poor planning, have been a historical problem in crowd situations. They have resulted in injuries and deaths, with some cases resulting in hundreds or even thousands of fatalities. (Table 1) lists historical crowd disasters and those that have occurred in the last decade [20][21]. This highlights how crowd disasters have continued to occur, with a high number of deaths in some cases, despite the advances in crowd management techniques. For example, the situation in Mina, Saudi Arabia, where millions of pilgrims travel, has resulted in several disasters over the years due to the complexity of the situation and the large number of people attending. In the 21st century, disasters have continued to occur around the world, with varying numbers of deaths ranging from a few to thousands. Additionally, there is often a large number of injured people in these situations, and the table demonstrates that these incidents are not restricted to a particular pattern or region.

4.2 CONTINUOUS CROWDS

The term "continuous crowds" is commonly used to describe the constant movement of pedestrians. Several models have been developed to simulate the navigation of large crowds through space. Treuille [22] introduced a real-time crowd model with collision avoidance under dynamic conditions based on limited knowledge of pedestrians and dynamic paths using potential fields. This approach led to an efficient algorithm for simulating continuous crowds. While pedestrian models are primarily focused on the real-time simulation of pedestrians, they have also been used to model real-life phenomena such as line formation and have been informed by contributions from evacuation models. These models are primarily geared towards graphics and rendering, and are optimized to reduce computational complexity. They are capable of simulating thousands of pedestrians moving in a space, making them useful in video games for simulating cities, armies, and other scenarios involving large populations.

4.3 CROWD TURBULENCE

Crowd turbulence has been a critical phenomenon that has transformed various events into disastrous situations, such as the Love Parade incident in 2010 or the Hajj disaster in 2006. In his empirical study of the Hajj disaster, Helbing extensively analyzed videos of the Jamarat bridge, where over 3 million people gathered and tragically resulted in the deaths of 345 individuals each day. Through the video analysis, Helbing gained insights into the occurrence of turbulence and proposed a "pressure" formula to characterize the behavior of the crowd mass. Subsequent research endeavors focused on developing a model to replicate crowd turbulence and utilized the "pressure" formula for validation. The details of the "pressure" formula will be outlined in Section 4.1, where it will be employed to elucidate the manifestation of crowd turbulence within our model.

Year	Place	Venue	Deaths	Comment
2012	Madrid, Spain	Stadium	5	Egress
2013	Abidjan, Ivory Coast	Stadium	60	Egress
2013	Santa Maria, Brazil	Nightclub	242	Egress
2013	Uttar Pradesh, India	Railway station	36	Egress
2014	Shanghai, China	Outdoor event	36	During event
2015	Cairo, Egipt	Stadium	28	During event
2015	Mina, Saudi Arabia	Holy site	2262	During ceremony

Table 1 : Major crowd catastrophes

To enhance the Social Force model and account for turbulent flows, Yu and Johansson extended its capabilities in their work [23]. Their approach involves augmenting the repulsive force exerted by agents by introducing additional terms to the original social force model. These supplementary terms consider the distances between agents and the angles of their interactions, resulting in a more intricate framework for resolving agent overlapping and integrating the concept of "social force." Notably, the updated model incorporates new constants that are derived from the aforementioned agent distances and interaction angles.

$$\vec{f_{ij}} = F\Theta(\varphi_{ij})exp[-d_{ij}/D_0 + (D_1/d_{ij})^k]\vec{e_{ij}} \qquad (4)$$

$$\Theta(\varphi) = (\lambda + (1-\lambda)\frac{1+cos(\varphi)}{2})$$

Additional investigations, including Helbing's analysis of the Love Parade incident [24], have identified instances of crowd turbulence that led to excessive pressure, resulting in severe chest injuries for numerous attendees. In a separate study, Golas [25] presented an alternative model known as Fluid Implicit Particle, utilizing a PIC (Particle-in-Cell) code. This model aims to depict the crowd as a continuous medium while incorporating collision avoidance mechanisms and calculating friction stress. By adopting this approach, the model seeks to capture the complex dynamics of crowd behavior, particularly in scenarios where turbulence and inter-agent interactions play a significant role.

5. NAVIGATION AND COLLISION AVOIDANCE

As pedestrians navigate through the streets, they encounter various challenges, such as changing directions, crossing paths with others, stopping in response to obstacles like bins or posts, and avoiding collisions. Consequently, intelligent agents need to possess the ability to navigate around other agents and obstacles while following their intended paths. Navigation and collision avoidance algorithms play a crucial role in addressing these issues, particularly in the field of pedestrian dynamics, where they find applications in computer graphics and robotics.

One prominent algorithm in this domain is Velocity Obstacles (VO) [26]. VO is a behavioral model that anticipates the future positions of agents and adjusts their trajectories when multiple agents share the same path. It has been widely used [27] and has undergone reviews and extensions, resulting in algorithms such as reciprocal Velocity Obstacles [28] and Hybrid Reciprocal Velocity Obstacles [29]. VO is expressed using Minkowski notation, which denotes the intersection areas of the navigation regions associated with the agents. The fundamental concept is that each agent has a cone that defines potential future positions. Agents strive to move towards areas where their projected positions do not conflict with those of other agents, always seeking free areas to move into or coming to a halt if necessary.

$$VO_B^A(v_B) = \{v_A | \lambda(p_A, v_A - v_B) \cap B \oplus -A \neq \emptyset\} \tag{5}$$

To provide further elaboration, let's consider two agents, A and B. In our approach, we employ Minkowski notation to express the cones that define the potential areas of movement for each agent. The notation $B \oplus -A \neq \emptyset$ is used to indicate that there is no intersection between the areas occupied by A and B.

Our algorithm focuses on ensuring collision-free navigation between the two agents. It achieves this by checking whether a collision is anticipated in future time steps. By analyzing the trajectories, velocities, and positions of A and B, the algorithm determines if their paths will intersect at any point.

If a collision is predicted, the algorithm takes corrective action to adjust the navigation plans for the next step. This adjustment ensures that both agents can navigate without colliding with each other, thus providing a mechanism for free collision navigation.

By considering potential collisions in advance and making necessary navigational corrections, our algorithm effectively facilitates safe and collision-free movement between agents A and B.

6. MODELING HUMAN PSYCHOLOGY

Although some macroscopic models of crowd behavior have ignored the influence of sociological factors and individual characteristics, these can significantly affect the outcomes of emergency situations. Therefore, it is important to consider psychological and sociological aspects in risk scenarios and analyze how people behave in such situations.

6.1 SOCIOLOGICAL COMPONENTS

Contrary to popular belief, current literature has shown that aid and non-selfish behavior are more prevalent in potentially dangerous situations than mass panic and self-preservation. Additionally, social factors such as emotional attachment to family or close individuals can lead to gregarious behavior and calmness in stressful situations. Conversely, distance from emotionally attached individuals can be a greater stress factor than any physical danger. The reactions of different countries and societies to panic situations can also have a direct impact on the outcome of a potential risk situation. For instance, the "War of the Worlds" broadcast by Orson Welles and a Swedish broadcast of a radioactive leak elicited different reactions from different societies. Furthermore, studies such as Helbing's analysis of the Love Parade [24] have detected crowd turbulence resulting in high pressures that caused chest compression in several attendees. Golas also proposed a model based on Fluid Implicit Particle, a PIC code that represents the crowd as a continuum with collision avoidance and computes friction stress.

6.2 PSYCHOLOGY AND PANIC

Even in events that are often portrayed in the media as causing panic and stampedes, such as the Who concert stampede that resulted in 11 deaths, research shows that people often try to help each other, and these situations are not actually stampedes [30]. The term "panic" is defined by Mawson as inappropriate or excessive fear and flight, and instances of panic are difficult to identify in practice. Retrospective judgment is usually necessary, especially if there is a significant loss of life. Current research rejects the concept of mass panic, which historically assumes that crowds act irrationally and selfishly. These ideas are now considered irrational theories that do not account for individual personalities. Even in disasters such as the Hillsborough disaster, where 96 people lost their lives, there were testimonies of cooperation and orderly behavior, even when the threat of death was present[31]. Therefore, humans do not always act selfishly or irrationally, and it is rare for panic and stampedes to occur. Factors such as social identity and psychological membership in a community can mitigate the effect of crowd risk, promoting prosocial behavior during evacuations[32][33]. Although panic situations are often used as an explanation for selfish behavior, the evidence shows that this is seldom the case.

7. MASS FORCES

During the Hillsborough disaster, the barriers collapsed under the pressure of the crowd. Subsequent analysis revealed that the barrier could withstand up to 6 kN/m [34][35], but the force exerted by the crowd was directed in one direction, which posed a potentially dangerous situation. This type of force has been extensively studied, and Henein [36] proposed four general principles to describe and model it:

> Force is directed, meaning it is applied by one agent to another in a specific direction. Forces in models should be represented as vectors, not scalars.
>
> Force carries consequences, which means that it has measurable effects outside of an individual's control rather than being an invisible field guiding cognitive decision-making.
>
> Force is propagated through the crowd in the direction of the force and is additive when encountering other forces.
>
> Force is generated purposefully and is not just an emergent property of the crowd. People exert force in certain circumstances but not in others.

7.1 HIGH DENSITY

High-density crowds differ from other crowds due to the increased pressure and potential for different consequences. Agents in these crowds experience higher pressure, and the risk of crush is elevated. Helbing's analysis of crowd turbulence found that more than 10 people per m2 were observed, while the average should be 4 [37]. The analysis also revealed that exceeding the local density of people/m2 resulted in a local flow decrease of at least three times. These pressures can be hazardous and can propagate forces throughout the crowd, endangering those present. For instance, during the Madrid Arena disaster, survivors recounted being unable to walk and being dragged by the mass's force, causing bodies to fall and crush others at the bottom of the pile. In such cases, the will and forces of individuals may be insignificant, but the sum of all forces can become critical. Pressure analysis and modeling [38] have shown how pressure can impact people's survival. The Ibrox Park soccer stadium incident resulted in asphyxia, with a 3-meter pile of bodies supporting N. The addition of forces generates enough pressure to compress the chest and cause asphyxia, or in severe cases, "chest crush." These forces are dynamic as all affected people gain breathing space. Analysis from videos of disasters, such as the Love Parade disaster, demonstrates that people tend to seek free space, as previously concluded in Helbing's first Social Force paper [39].

8. MODELING WITH DE

A model is a tool used to imitate the behavior of the real world, which is often expressed or can be expressed in differential equations (DE). DEs are important in scientific simulation, and they are frequently used to describe mathematical and physical models in science and engineering. Partial differential equations (PDEs) are DEs that have more than one independent variable and its derivatives, and they are widely used in scientific simulation to describe processes, especially in physical processes that set a model in space and describe how it evolves over time. In the context of evacuation, PDEs have been used to solve the movement of the population using gas-kinetic or fluid dynamics approaches, and crowd dynamics theory has established an analogy between the flow of the crowd and the Navier-Stokes equations. Navier-Stokes equations are a set of PDEs used to model computational fluid dynamics, and they have been used for 2D problems in the case of crowds.

Hughes made contributions to the modeling of the flow of pedestrians using PDE, focusing on the dynamics of the mass as a global behavior using a macroscopic approach. The Social Force model used the differential form of Newton's second law of motion as a starting point for its model. Ordinary differential equations (ODE) are DEs with one or more functions, one independent variable, and their derivatives. These equations are easier to solve since the number of independent variables used is lower than in PDE, and they are also widely used. ODE will be used in the present work to define the continuous crowd model. There are several numerical methods to represent ODE and PDE. In the finite differences method, the space is divided into neighboring points, and a differential formulation of the DE is used with an expansion of the Taylor series between two points. Other methods include the finite element method and the finite volume method, which allow PDE to be solved for unstructured grids.

9. CONCLUSION

This chapter explores different approaches to modeling mass evacuations and highlights the unique complexities and challenges associated with them. Various modeling techniques, including discrete, continuous, microscopic, and macroscopic, are discussed, each with its own advantages and disadvantages. The social force model, which considers the forces exerted by individuals and obstacles on each other, is a significant contribution to evacuation modeling. It is important to recognize that crowd psychology can significantly impact the outcome of an evacuation, and panic is not always the cause of crowd disasters. By gaining a better understanding of and modeling crowd behavior, we can develop more effective strategies and ultimately save lives.

The next chapter describes the simulation model employed in this thesis: the GAS (General Adaptation Syndrome) model. Alongside its internal behavior, we delve into the algorithms that govern its behavior. Additionally, we discuss the internal aspects

Chapter three: crowd modeling

1.INTRODUCTION

Models allow us to engage with and test systems without really utilizing them. We employed one of these crowd models in this thesis, utilizing the GAS (General Adaptation Syndrome) technique.

Using a stress model, this approach seeks to recreate the internal behavior of the population while also increasing realism under strained conditions. We sacrificed performance for realism. The models will be described and detailed in this section.

2.GAS (General Adaptation Syndrome) BASED MODEL

We used the Gas model, as shown in **Fig 4** [43] to simulate the internal behavior of the crowd. Based on the psychology of each agent, this model employs behaviors as a reaction to meet particular needs or cope with changes in a scenario or environment. These environmental elements are referred to as stressors, and the effect of these stressors on the agents is referred to as stress. The strategy is based on the psychological idea of General Adaptation Syndrome [41], which provides a well-established behavioral model of how humans respond to stressful events. As in the case of a fire evacuation, this allows us to create a more dynamic crowd response.

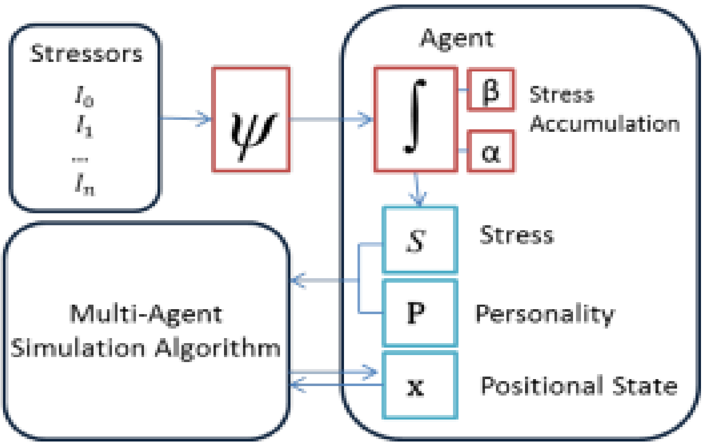


Fig 4: System Overview Different levels of stress behaviors are simulated by updating agent parameters

2.1-APPROXIMATION OF THE GAS MODEL

See Fig 5 [43]

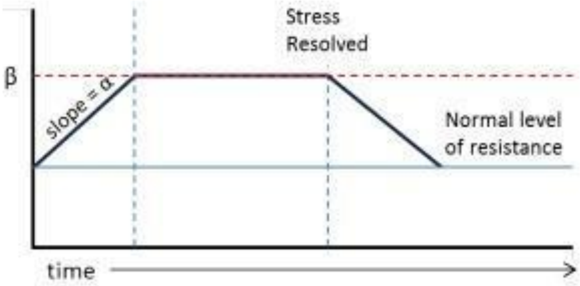


Fig 5 :Response generated by Gas model

We were provided with the model description in [42], which represents stress as quantitative values for measuring the intensity of responses to different stressors. The approach assumes that an agent is experiencing a perceived stress with a value denoted by ψ. The goal is to calculate a stress response, represented as S. To maintain the original shape of the General Adaptation Syndrome (GAS) response, [42] incorporates two essential characteristics with the model. Firstly, the rate of change in an agent's stress response is limited by a maximum rate, indicated as α. This limitation ensures that the stress response doesn't sharply spike when exposed to sudden stressors. Secondly, an agent's stress response is capped at a maximum level, denoted as β. This ensures that if the perceived stress keeps increasing without bounds, there will be a limit to the agent's response. By combining these attributes, the values of α and β allow us to map the perceived stress ψ to a corresponding stress response S, as described below that provided by [45]:

$$x = \begin{cases} \alpha & \psi > S \\ -\alpha \leq d\psi dt \leq \alpha & \psi = S \\ -\alpha & \psi < S \end{cases} \tag{6}$$

2.1 STRESSORS

[42] provides us with a number of equations to express the difference in stress during specific events. We used four prototype stressors that can be used to model various types of stress. There are four types of stresses: time pressure, positional pressures, environmental stressors, and interpersonal stressors.

2.2.1 TIME PRESSURE

The pressures associated with meeting a deadline include various situations, such as crossing the street when the traffic light is timed or catching a train before the doors close. Another example is evacuating a building during a fire emergency. To represent these types of stressors, agents are assigned a goal position and a time restriction denoted as tallowed. We model the intensity of time pressure, It, by considering the difference between the allotted time and the predicted arrival time. Formally, it can be expressed as follows:

$It = \max(testimated - tallowed, 0), \quad (7)$

where *testimated* is the estimated amount of time an agent will take to reach its goal,i.e.

testimated = distRemaing/avgSpeed.

2.1.2 AREA STRESSORS

These stressors arise from environmental conditions, encompassing factors like noise, heat, bright lights, and smoke. These stressors exert a relatively constant level of intensity across a specific area, which can be described as follows:

$$Ia = \left\{\frac{c\ if\ pa \in A}{0\ if\ pa \in{-}A}\right\} \qquad (8)$$

where A is the stressor's affect region and pa is the agent's current position

2.2.3 POSITIONAL STRESSORS

These are stressors linked to a specific source of stress. These, as opposed to area stressors, relate to stressors whose strength increases as an agent approaches them. Examples include both static stressors like fire and dynamically moving stressors like a fleeing automobile or an intruder. Formally, the intensity is defined as

$$Ip = ||pa - ps||, \qquad (9)$$

where pa and ps indicate the position of the agent and the stressor, respectively

Fire, for example, has a high intensity over a vast region.

We compute the intensity of these stressors using a Gaussian distribution with a standard deviation of:

$$Ip = N\,(pa - ps, \sigma) \qquad (10)$$

2.2.4 INTERPERSONAL STRESSORS

These stressors are linked to stress induced by other agents. An example frequently observed is crowding, where individuals experience stress due to the presence of excessive proximity with other people. Studies have identified that these interpersonal stressors follow a similar exponential pattern [45]. The severity of these stressors can be estimated, as described in [41], by considering the disparity between the preferred density of neighbors and the actual density through a specific function.

$$Ii = \max(ncur - npref\,, 0), \qquad (11)$$

where $ncur$ is the current number of neighbors in a unit space and $npref$ is the desired number of neighbors in the same region.

2.2.3 PERCEIVED STRESS

We use Stevens' psychophysical power law [42] to characterize the perceived level of stress experienced by an agent. This rule expresses the link between the perceived magnitude of a stress and the physical measurement of the stimulus intensity, such as the relationship between sound intensity and the felt magnitude of a stress.

Loudness, luminance, perceived brightness, density, and felt crowding are all factors to consider. According to Steven's Law, the connection between the perceived intensity of the stressor ψ , and the magnitude of the physical intensity of the stressor, I , has the following form.

$$\psi(I) = kIn\,, \tag{12}$$

depending on the type of stressor, with two parameters, a scale factor k and an exponent n. [50] gives approximations for exponent values for various stimuli. Furthermore, the computation of the intensity I is affected by the type of stressor.

Steven's Law was originally developed to deal with low-level stresses like noise and heat. Subsequent research, however, discovered that comparable power laws may be applied to a wide range of stressors [51]. In response to this discovery, we employ Eqn.2 as a general model of the influence of the stressors.

2.2.4 BEHAVIOR MAPPING

In this section, we outline our psychologically driven model of how an agent's degree of perceived stress, S, fluctuates in response to various stressors. We will now look at how an agent's behavior varies in reaction to these fluctuations in stress level. The major observable reaction to increasing levels of stress, as stated in Section 3.1, is an increase in aggressive and impulsive conduct. Our technique for modeling the dynamic changes in behavior caused by stress is based on a multi-agent system capable of replicating variations in the agents' degrees of aggressiveness and impulsiveness. The model employs multi-agent simulation techniques proposed in [43] , although our methods are easily adaptable to other systems with similar characteristics.

2.2.4.1 INCORPORATION OF BEHAVIOR CHANGES

[43] introduced a reparametrization method for the reciprocal-collision-avoidance based simulation approach described in [44]. The purpose was to achieve variations in agent behavior based on perceptual cues. They conducted

a user study where participants classified the apparent behavior of agents in terms of aggressiveness, impulsiveness, shyness, tenseness, activeness, and assertiveness. The study findings suggested a method for selecting simulation parameters that could yield desired agent behavior. These parameters included agent radius, preferred speed, planning horizon, number of neighbors, and agents' sight distance. Different parameter values resulted in distinct goal-directed behaviors and local interactions with neighboring agents, which were perceived as representing different personalities.

The researchers in [43] proposed that there are two primary dimensions, $PC1$ and $PC2,$ that characterize crowd behavior at a high level. $PC1$ was associated with more extraverted or intense behavior, while $PC2$ reflected increasingly careful behavior. By utilizing this parameterization, they were able to automatically determine simulation parameters in order to produce behaviors that appeared progressively aggressive and impulsive. This change in parameters, referred to as the stress behavior vector $Bstress,$ when added to an agent's current simulation parameters, increased their perceived level of stress. The results presented in this paper are based on employing this approach

$$Bstress = (PC1\ PC2) * (0.95 - 0.3) \ (13)$$

since it results in mostly aggressive behavior (extreme "egocentricity") and impulsiveness (bad "carefulness").

2.2.4.2 COUPLING WITH PERSONALITY ATTRIBUTES

[43] also produced a matrix, Apc, that provides a linear mapping between PC1 and PC2 values and simulation parameters. The same study also proposed Aadj, a matrix that links a number of various personality characteristics to simulation parameters. The final actions of our agents are determined by a linear combination of these two parameter matrices: the first representing an agent's situational reaction and the second representing the agent's stable personality. The impact of a situational reaction is proportional to the quantity of perceived stress S that an agent is now feeling.

The resultant equation for calculating simulation parameters that portray the agent's behaviors as a function of intrinsic personality features and dynamically changing stress reactions is as follows:

$$SimParams = S\, Apc\, Bstress + Aadj\, P \qquad (14)$$

P is a vector that represents an agent's stable personality. When an agent is stressed and the value of S rises, the influence of Bstress grows, increasing the stressful behaviors demonstrated by the agent. S will drop when the stress is gone, and the agent's behavior will return to its stable personality P.

See fig [41].

Fig 6: **in the opposing group scenario, after pushing the alarm, the agents will try to push each other, resulting in clogged and congested behavior** ,

3. CONCLUSION

This methodology models the dynamic behavioral changes resulting from situational factors. The method involves deriving a linearized approximation of the widely recognized Generalized Adaptation Syndrome theory to capture stress responses. This approach successfully aligns with quantitative studies on human behavior, replicates significant phenomena like , and exhibits a range of emergent dynamic behaviors, all in real-time,and in the next CHAPTER we will describe the internal aspects of the tool We discuss the algorithms that define its behavior. In addition to the internal aspects.

Chapter four: Crowd Simulation

1. INTRODUCTION

In order to develop a comprehensive and effective software solution, it is essential to describe the applicability, implementation requirements, and necessary data structures for both the simulator and the application. The Fire Evacuation Tool, which incorporates the General Adaptation Syndrome (GAS) simulation model, addresses these needs by offering a robust architecture that integrates the GAS model and employs suitable data structures. This enables the tool to simulate the various stages of GAS, account for individual differences, crowd dynamics, and environmental factors. By carefully considering these implementation aspects, the Fire Evacuation Tool provides emergency management teams and building owners with the ability to analyze and optimize evacuation plans, thereby ensuring enhanced safety during fire emergencies.

2. MATERIAL

For this tool, we used the Unity game engine and a PC with a processor AMD Ryzen 5 3400G, a GPU Radeon Vega 3.70 GHz, 16.0 GB of RAM, and a 64-bit operating system with an x64-based processor.

3. VALIDATION

Models are representations of the real system, but we must demonstrate in some way that they accurately reflect reality. This is known as validation, which is concerned with the issue of accurately representing the real system. The model and simulator must be effective for their intended function in order to be used for probing. There are multiple validation categories with various approaches in the case of evacuation.

- validation and set fire drills or people movement. We can utilize actual data from experiments and compare the evaluated elements if the goal of our simulation is to replicate the simulation process as a full system intending to provide information on the entire evacuation duration.

- Validate Against validated simulators. If a simulator has been verified, we may utilize the simulation to cross-check the simulator by comparing our results with its.
- Validate for code requirements . If a simulator is designed to meet requirements for outcomes and succeeds in doing so, validation is utilized.
- Validate Against evacuation experiments. You can better comprehend the movement of individuals and their internal phenomena by planning and carrying out evacuation experiments. This is one of the techniques used to evaluate simulators like JuPedsim.

4. FIRE BEHAVIOR

In the application of this simulation tool, we need several elements, starting from setting the fire, to calculating the simulation results from the victims to the time it takes to get out. Each element is woven with a set of parameters that can be changed by the user , and can affecting the results simulation.

4.1 FIRE PROPAGATION

The simulation begins with starting a fire and constructing its behavior in the event of a fire inside the building. Here we will describe the method of its control and its impact on the agents

4.1.1 GENERATE FIRE NAVIGATION MAP

The fire needs fuel for its movement. The first thing we must do is generate this fuel inside the building; we'll call it points from now on. Here we will explain two methods that can be used in a tool

4.1.1.1 GENERATION IN SIMULATION ENVIRONMENT

Generating fuel in a random way inside the building is done by placing a certain number of fuel points in a grid list that has a height and width. After that, we give each point a random location that is inside this grid. This is done by following up on all the points that were generated and putting them in the list, then giving it a random position for each point from the list containing all fuel points.

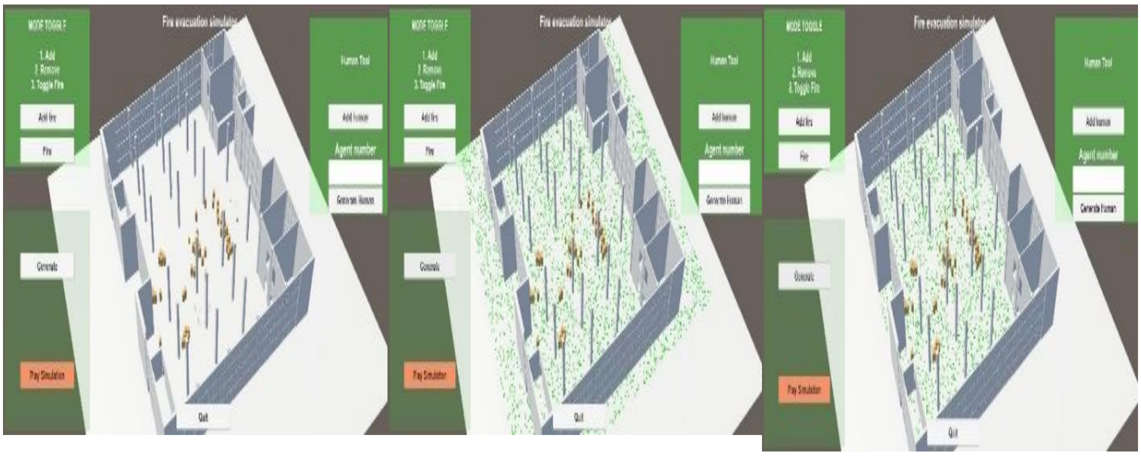


Fig 7 : the tool works to create a fire point map

Each fuel point has a set of rules. If one rule is not met, it will be removed from the list of points.

4.1.1.2 VALIDATED THE POSITION OF THE POINT

After generating all the points in a list, we apply a set of rules to each point in order to ensure that its position is correct in the simulated environment. These rules are Do not step into an obstacle like walls,Inside the building

- Do not overlap with obstacle

  We will use this feature when we receive data from a mesh that Unity creates to approximate the walkable regions and barriers in the virtual world for path finding and AI-controlled navigation, and every point not in the walkable area will be removed from the list of fuel points.

- point is inside building

Every point will project n rays in all directions. If a ray hits an object in the environment, it will return true; otherwise, it will return false. Next, we count the number of rays that return false. If this number is greater than n/2, the point position is deemed invalid and is removed from the list.

4.2 IGNITION POINT

The user has two options for starting the fire once the list has been filtered: either automatically, or by adding it themselves.

4.2.1-RANDOM POINT

Each point has three states: firstly, basic, then, if the point is in a state of fire, it is burning, and finally, burned. It takes a certain number that the user can choose from the random points in the list, and then we put its state in a burning state .

4.2.2 POINT SELECTION

When the user clicks the tool's chosen "ignition point," a ray will be projected from the location of the mouse, and a burning spot will appear in the mouse where the ray impacted the mesh, in this case the building floor.

4.3 FIRE NAVIGATION

Every point has an area within which it is influenced by all other points. The points inside that sphere radius will also enter a burning state if the object is in a burning condition.

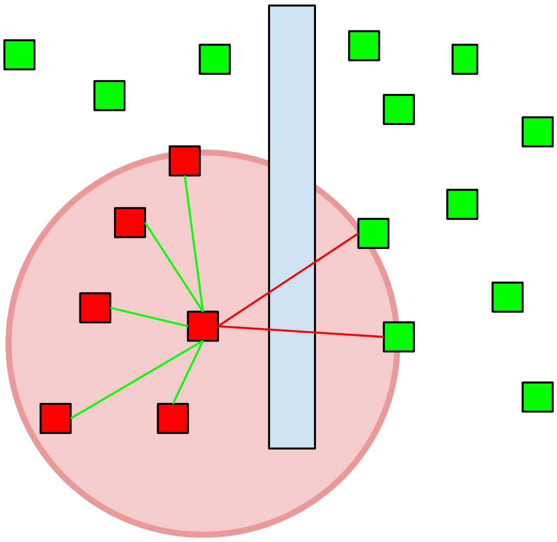


Fig 8 : picture shows how the point shows the niagbher points to continue the fire propagation

We added another criterion that is based on projecting a ray from the point that is in a burning state, where it must be a false in order to affect the target point since it will not touch them if there is an obstruction between the points.

Fig 9 : **a)** in the beginning of simulation, one point will begin burning and after some time will affect the neighboring points as shown in image (a), **b)**after some time point will brunette and painted with black and the fire range go bigger and bigger, **c)** the fire range go bigger and bigger over time and will avoid the obstacles .

5. DECISION MAKING

All occupants of the building must evacuate when it is set on fire, but only if they directly witnessed the fire, witnessed another occupant fleeing, or heard a warning siren, in which case they will change their parameters and go to the closest exit until the agent is out of danger. [46]

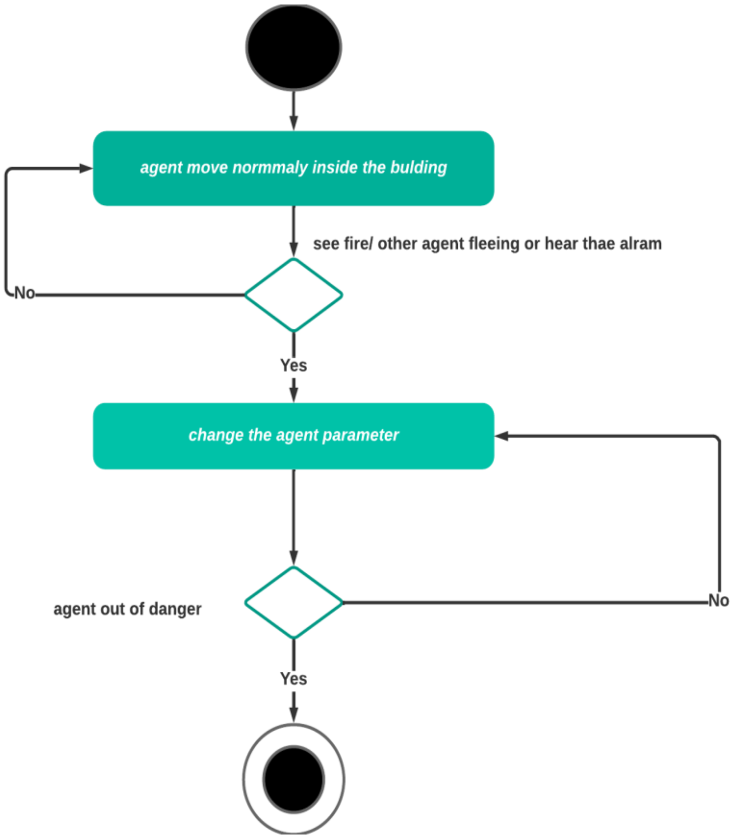


Fig 10 : activity diagram , shows how the agent interact with the environment.

Every agent keeps a list of possible exit doors, and new exits can be added or removed if they don't satisfy certain requirements, such as not being blocked by fire or other agents and being closer to the exit than the fire. [46]

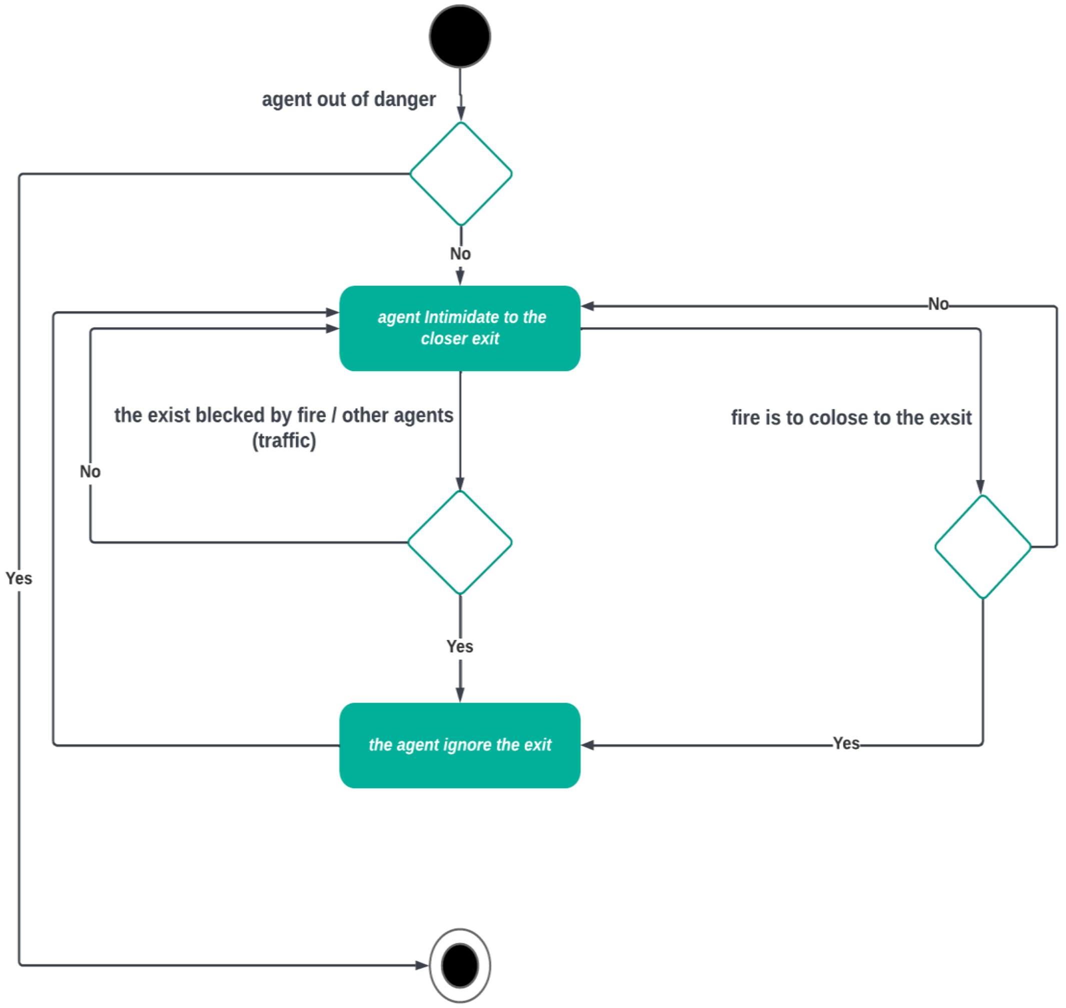


Fig 11 : activity diagram shows how the agents remove doors that not satisfy the requirement and adding new door if they.

6. Monitor the player's status

Depending on the condition of the person in it, the agent is controlled by a set of factors that determine how he acts. Potency, which measures the agent's skill at carrying out duties and his physical well-being, is one of these factors. The value of this parameter will drop if the agent enters the fire's influence field, because if it falls to zero, the agent is deemed to have perished in the fire. Utilize this parameter to modify the agent's status based on the machine's state.

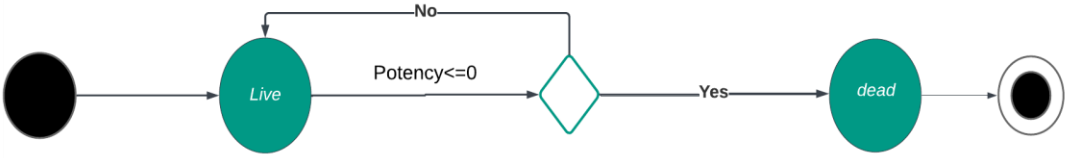


Fig 12 :state diagram Follows agent status, controlled by potency value

7. AGENT PARAMETERS

Each agent has a number of parameters that enable him to have a dynamic behavior and physical state depending on the circumstances to which it is subjected, and this parameters split to two categories , behavioral parameters

And environmental parameters.

7.1 BEHAVIORAL PARAMETERS

The stress simulation model effect agent radius , preferred speed, planning horizon, number of neighbors, and agents sight distance, but But it affects them according to the personality of the agent , thus the stress effect every agent

Differently According to his personality. These parameters include agent radius, preferred speed, planning horizon, number of neighbors, and agent sight distance. [43]

Trait	Radius (m)	Speed (m/s)	planning horizon (s)	number of neighbors (n/a)	agents sight distance (m/a)
Shy	1.1	1.25	30	7	15
Active	0.4	1.55	40	17	13
Tense	1.6	1.55	12	63	29
Impul	0.4	1.55	90	2	30

Table 2 : the different agent behaviour parmartmets for different Personality .

7.2 ENVIRONMENTAL PARAMETERS

parameters that have an impact on the agent physically or his response time when exposed to dangerous situations.

- olfactory distance

Each agent has a range of smells based on the strength of the senses. This is because when a fire is lit after some time, a smell will be released that will alert the agents, and since some people don't have senses of smell in the real world, this allows us to vary the agent's response and make it more realistic.

- vision distance

The agent also has vision, which he uses to perform evacuation procedures when a fire is present or when someone flees. However, just like in real life, not everyone has the same vision ability, so this will also help agents to diversify in addition to personality diversity.

- potency

It represents the agent's force or its energy (a value chosen at random between 50 and 100). Each evacuee agent is given this number at the start of the simulation. When an agent is exposed to fire, its potency is reduced by a random number between 0 and 1. The evacuated agent will perish if it is not yet safe once the individual power drops to zero or less.

- hearing distance

The gadget has an alert siren that sounds when it gets close enough to the fire. This parameter affects how quickly, or potentially, the agent will respond when they hear a siren.

8. PARAMETERS EVALUATION OF THE OBTAINED RESULTS

[46] provided us the (14),(15),(16) , After the simulation ends, when there are only survivors or victims left, the tool calculates three outcomes , The total of people alive donated as Tv , Total deaths donated as Tm; average time taken to exit donated as Mt.

The total number of people alive (TV) represents the number of people having a potency superior to 0 who have left the building.

$$TV = \sum av \qquad (14)$$

Total deaths (TM): represents the number of people with a potency less than or equal to 0.

$$Tm = \sum ag - \sum av \qquad (15)$$

Average time taken to exit (MT): means the average time taken by an evacuated agent to leave the building. It is calculated as follows

$$Mt = \frac{\sum_{i=1}^{av}(fs_i - ds_i)}{av} \qquad (16)$$

9.AGENT STAUT

FIG 13 : Cases representing the agent

10 . CONCLUSION

We have described the functionality of our tool, which is divided into two parts: a fire simulation component and a Moodle application that controls the workers' response based on their personality traits. Additionally, the application regulates the speed of their reaction to the fire, simulating various physical and psychological conditions for each worker. Furthermore, we have developed the tool to calculate three critical simulation outcomes: the total number of victims, the number of survivors, and the average evacuation time, which is of utmost importance. Finally, we have discussed the inclusion of user control over a wide range of parameters.

In the upcoming chapter, we will conduct experiments using our proprietary tool and extract a set of results. We will also present simulations conducted under different scenarios.

Chapter five : Experimental Evaluation

1. INTRODUCTION

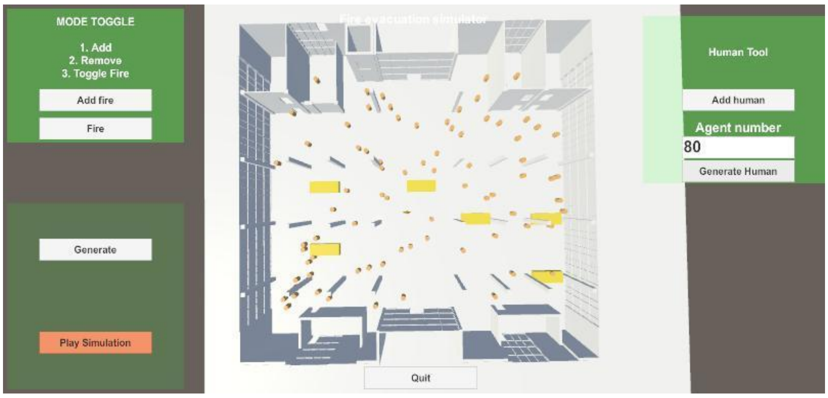
The results section of the fire evacuation tool created using the Unity game engine presents the average evacuation time and performance of participants. The average evacuation time provides insights into the efficiency of the tool and identifies areas for improvement. Performance analysis evaluates participants' adherence to evacuation protocols and decision-making abilities. The findings aim to enhance fire safety procedures and emergency preparedness.

2. OFFICE BUILDING

We created a virtual environment in the form of an office and applied a set of experiments on the office in order to extract the results

2.1 EXPERIMENT ENVIRONMENT

The test simulation environment utilized a 3D model of an office building within the Unity game engine. This realistic representation allowed participants



Agent number
80

Fig 14: 3d environment to test simulation on it

to navigate and interact with the virtual environment, simulating a fire evacuation scenario. The office 3D model accurately replicated the layout, obstacles, and environmental factors of a typical office building. Participants' movements and actions were recorded to analyze key metrics such as evacuation time and performance. The use of the office 3D model provided reliable results and insights into participant behavior during fire evacuation.

2.2 OBTAINED RESULTS SIMULATION RESULTS

There is no exemption for this tool; all tools must deliver outcomes. Here, the simulation's output includes three values: the number of casualties, the number of survivors, and the average time to exit the evacuation situation. The average time represents the tool's efficacy. Here, we used three examples with 200 agents, 100 agents, and 50 agents to apply the situation that was previously mentioned.

. Survivors and victims with a different number of clients

The first scenario, we applied a fire condition to 50, 100, and 200 different agents, as shown in the fig 14 , these results, which show the number of victims in orange and survivors in blue, and in the fig 15 show the average exit time

Between the different numbers of agents

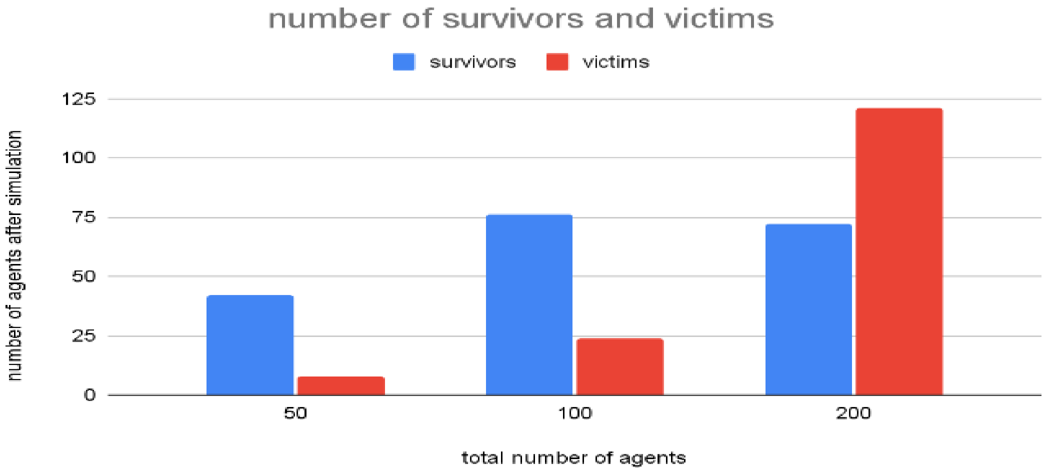


Fig 15 : the values of survivors , victims and average time for 10, 50 , 200 agent

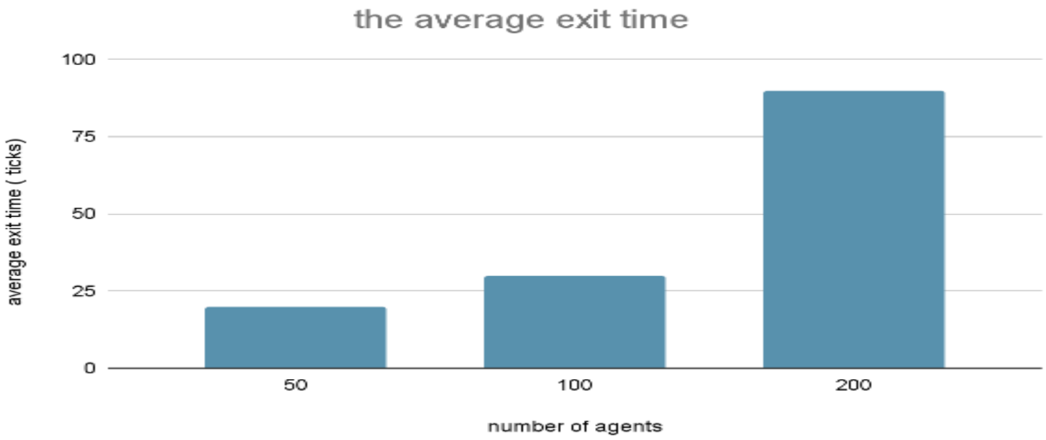


Fig 16 : the average time for different number of agents

.Survivors and victims with a different number of exits

The results of our experiment with the same number of agents but a different number of emergency exits are displayed in Fig16.

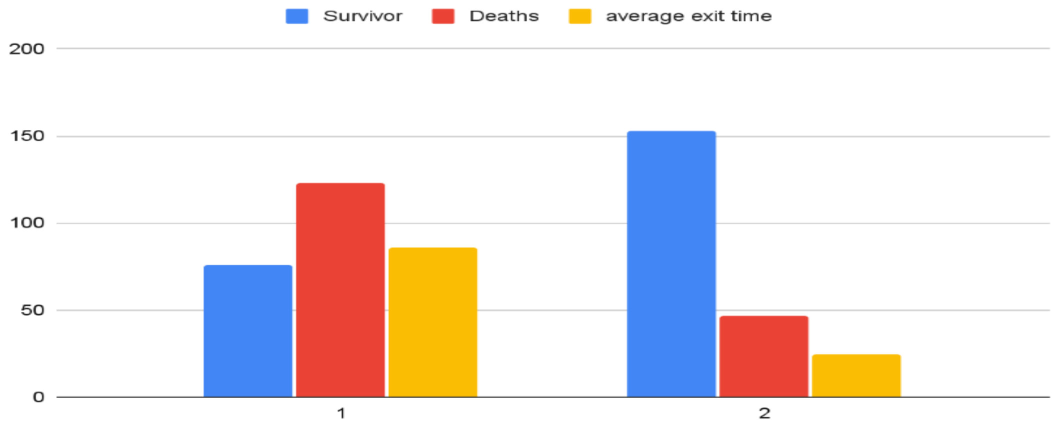


Fig 17 : the values of survivors and the death, average time for one and two doors

3. CONCLUSION

Based on the results obtained from the simulations carried out, we draw a set of conclusions.

- The greater the number of agents in the simulation, the higher the percentage of victims and the decrease in the percentage of survivors and the time spent, because the time spent and the survivors have a direct relationship, that is, the greater the number of survivors, the greater the average time spent exiting.
- The number of doors correlates directly with the overall number of survivors and inversely with the number of casualties since more exits increase the likelihood that agents will leave the area more quickly. In other words, the agent exits the hazardous area faster.
- Because the potency parameter is continually exposed to a source that we lack, we see that there is an inverse connection between the speed of fire propagation and potency, which explains why it is observed that the

quicker the fire spreads, the higher the number of victims it brings with it.

- When the covert range of the fire is high, the TV parameter is quite low. This condition can be explained by the fact that many agents are killed quickly by the fire. The covert range of the fire in the environment also has an impact on the TV parameter.

GENERAL CONCLUSION

1. CONCLUDING REMARKS

In this thesis we have created a simulation tool that help architects for design a better designs for safer building to avoid the human or the financial losses , this simulation combined the fire propagation and the dynamic behavior by using a stressor model, of the agent base on psychosocial and physical traits and the result was a simulation base of multiple parameters of multiple parameters , one from the environment factors and the others from the agent factors, and we obtain results calculating the number of total agents alive , dead and the average existing time and implementation are summarized as follows:

- We have implemented the GAS (General Adaptation Syndrome) model, for using to reproduce a complex behavior during stressful situations.
- Then we created the fire propagation system to simulate the fire navigation inside a closed environment.
- And we combined two simulation models to create the interaction between the agent and the environment.
- Finally, we obtained the results from the tool , and these results summed up in three values, total alive who were out from danger, total deaths who were killed by the fire , and the average time wich represents the average time for exiting the building .
- It has been found that the number of doors and agents can affect the average time, the speed and range of fire can affect the total number of deaths and alive agents.

There are, however, some limitations to our tool: the tool can't handle so many agents, and there is some organization on the UI side for controlling the parameters.

2. Future Work

- Update the tool code in order to make it running in multicore threading, to increase the performance.

- Adding more functionality to the tool to make the user have more control over simulation .

- Adding more Simulation models and options to the user .

- We are planning to add the ability to import 3d models to the tool from external 3d modeling softwares like blender … etc.

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