An approach to validate Crowd Simulation Software: a case study on *CrowdSim*

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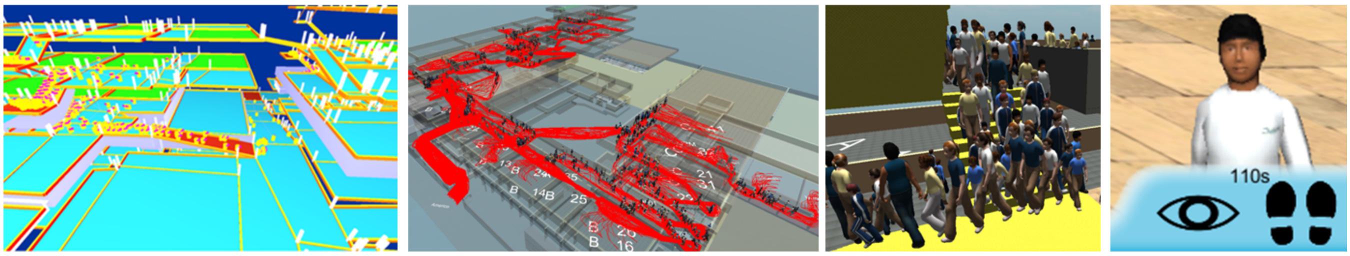

Figure 1: *A computational simulation visualized into a virtual environment. A game based approach offers to the user a better way to interact and qualitatively analyze simulation results.*

Abstract

Validation is an important topic on the life-cycle of software development, especially when we are working with crowd simulation. This is because when applied in safety fields, such simulation software must reproduce behaviors close to real life in order to obtain useful data. The International Maritime Organization of London (IMO) developed guidelines for validate evacuation systems. In this paper, these guidelines have been applied when using *CrowdSim* as a crowd simulation tool. It is important to mention that a set of validations must be reached by *CrowdSim* to consider it as an accurate crowd simulation software. In addition, we present the capabilities of *CrowdSim* when applied to provide crowd simulation on a middle school. The computed simulations are employed into an interactive game-based approach aiming to educate students and also develop a culture of safety.

Keywords: Evacuation Process, Simulation, Software Validation, Safety Culture

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1 Introduction

One reason for the growing interest in games is the engagement that they arouse in the players. In an opposite trend than entertainment, games can also be used to direct this engagement for improving users' learning and training. In that sense, serious games can be thought as an efficient tool to educate and train people aiming to develop, for example, an intrinsic thinking of safety.

One point addressed in this paper focuses on the importance to engage kids in the training of evacuation processes. Usually, buildings may have hundreds or thousands of occupants and, sometimes, many of them are not aware of the architect layout in order to know the safest exit from their location [Gwynne et al. 1999].

On the other hand, crowd modeling and simulation can be considered as an important research field on computer games industry as well as emergency and safety simulations [Thalmann and Musse 2013]. People (specially kids) can perform unusual behaviors [LeBon 1895] when they are part of a group. The possible injuries people are exposed when evacuating a building can be considered as a safety concern. Therefore, it is important to develop the thinking of safety in situations that possibly could affect their routine. In order to help to establish this culture of safety in children and teenagers, we present an approach to simulate people behavior in egress process applied to a school environment.

The approach presented in this work is composed by the software validation process of *CrowdSim* [Cassol et al. 2012]. The main goal of *CrowdSim* is to simulate people behavior when in groups or crowds. In this way, the software validation can be considered as an important issue when we are aiming the accuracy of the simulations results. *CrowdSim* was validated according to international guidelines [IMO 2007] in order to verify the confidence of produced results. In addition, we developed a prototype of a game which allows the player to interact with the results from simulations. A pilot project have been ran in a middle school and tested by a group of students.

The outline of our work is illustrated in Figure 1 which summarizes the main contributions of this work:

1. we employed *CrowdSim* with main goal to provide crowd simulation. In order to check the accuracy of simulation results, an entire **validation process** was performed according to international guidelines;
2. we ran a project of crowd simulation for a scholar environment. It was possible to identify the best routes to be followed by students to leave the school in a safe way;
3. a prototype of a game was developed, allowing to the students interact with simulation's results and navigating in their 3D school: trough this game, the student can analyze the entire simulation, in a 3D environment, and also chose specific places (e.g. a specific classroom) and agents to interact with. Called *Game4Safety*, the game was tested by a group of students.

The paper is organized as follows: The next section presents several methodologies for crowd simulation validation and its application in games. The Section 3 details our crowd simulation tool that is validated in Section 4. In Section 5 we present the case study applied to a scholar environment as well as the developed game. Discussion about the work are presented in Section 6.

2 Related Work

Validation is an important aspect to be considered during the life-cycle of software development. When we work with crowd simulation software, such process becomes even more important. In recent years, evacuation models have been increasingly applied in an attempt to understand the outcome of emergency egress scenarios. In this way, when predicting the behavior of a crowd, a simulation model must provide data coherently with real life. In order to attend such requirement, it is important to be sure that the used crowd simulation tool is able to produce accurate results.

The validation of crowd simulators have been addressed in different scientific approaches.The work of [Kuligowski and Gwynne 2005] presents a set of guidelines to be observed as general requirements of crowd modelling on simulation software. The authors attempted to aid users in the selection of an appropriate evacuation model by identifying key factors and explanations regarding project requirements, the background of the model, the current capabilities and characteristics of the model for comparison with other models, and the future progress of a model for a specific application. Furthermore, the authors observe that besides knowing the software, it is necessary to have knowledge in crowd behavior.

An approach to validate evacuation models is proposed by [Galea 1998] who describes the validation as an on-going activity that must take into account four different aspects: component testing, functional validation, qualitative validation and quantitative validation. This approach was applied in our work in order to evaluate the CrowdSim simulator, as explained in Section 4.

The work of [Ronchi and Kinsey 2011] stated that evacuation models are increasing in complexity as the understanding of human behaviour in fire progresses, but there is a lack of understanding regarding evacuation model user experiences and needs. In order to find out the desired needs of the evacuation modelling community, an online survey was developed with participants from 36 different countries. Results have shown that model users consider validation/verification to be the most important factor when selecting/using a model.

Haron *et al.* described the evaluation process carried out to determine the most suitable software for the purpose of studying the evacuation process of Al-Masjid An-Nabawi in [Haron et al. 2012]. The authors compare the cost-benefit relationship of three off-the-shelf software systems.

Ronchi et al. analyze the impact of different strategies regarding the use of default model settings and embedded data-sets in [Ronchi et al. 2011]. The case-study employed by the authors refers to the correlation between smoke densities and occupant walking speeds. To test the impact of this representation within evacuation tools, the authors have analyzed three evacuation models. The authors reported that results appear to be consistent among models if they use the same data-sets; the same model can provide different results if applying different data-sets for configuring the inputs and models using embedded data-sets need user expertise and experience to configure the model and then to evaluate the results produced.

Besides the construction and evaluation of simulation models, an important contribution of the researchers in recent years is the development of tools that allow users to interact with the scenario in order to get trained for emergency situations. These tools frequently use game engines and/or gamification techniques to make the training interactive and more engaging. Our work also aims to contribute in this area. The next paragraphs exemplify other work related to interactive training tools to evacuation in emergency situations.

Emergency Evacuation Simulator[1] used a game engines to develop a tool for training for emergency. The main purpose of this application is to perform evacuation training among employees who work in large buildings with complex floor plan and evacuation routes. The software was already employed for a 5-storey office building in construction

Shatz et al. proposes a Building Information Modeling based serious game for fire safety evacuation simulations in [Schatz et al. 2014]. The research hypothesis examined by these authors is: can human evacuation behavior be explored using a computer game? The aim of the presented research is thus to achieve a better understanding of what actually happens during an extreme situation and how people come to decisions. While playing such a game, data could be collected about the viewing direction, at which virtual objects the player looks, and in which directions he or she decides to move. It is also possible to record biometrical data on the player like heart rate or brain activity at the same time.

[1] http://www.program-ace.com/portfolio/case-studies/emergency-evacuation-simulator

The work of [García-García et al. 2012] proposed a serious game for massive evacuation training and awareness. The authors employed several distributed programming techniques to simulate crowds of thousands of people. The agents are embodied with artificial brain and individual behaviour that are replicated into crowds. According to the authors, 3D models of the real venues and realistic humanoid models enhance immersion.

Xi et al. [Xi and Smith 2015] proposes a work to extend a virtual environment development pipeline for building virtual fire evacuation training systems. They integrate 3D building models and fire egress behaviour from fire evacuation simulations into a game engine. Evacuation time tests, with and without fire hazards, have shown that the overall evacuation time in with and without using a game engine are consistent. The time difference between the tested tools is caused by different collision detection and path planning functions.

The next sections present how we propose to validate a crowd simulation tool (*CrowdSim*) and our attempt to increase the user immersion by using game developing based techniques, in order to increase the engagement of children and teenagers for evacuation training. First of all, the *CrowdSim* simulator's main features will be highlighted.

3 *CrowdSim*: A Crowd Simulation Tool

CrowdSim is a rules based crowd simulation software developed in order to simulate coherent behaviors in an evacuation process [Cassol et al. 2012], [Cassol et al. 2015]. Its main goal is to computationally reproduce crowd motion and behaviors during the process of occupation as well as evacuation and also to present some data that are used to estimate people's comfort and safety in a specific environment.

Two key components are considered in *CrowdSim*, which are organized in distinct modules: *Configuration* and *Simulation*. Figure 2 illustrates the software architecture including inputs from the user and produced outputs. In the following sections we are going to describe such modules of *CrowdSim* and detail their inputs, dependencies and work flow.

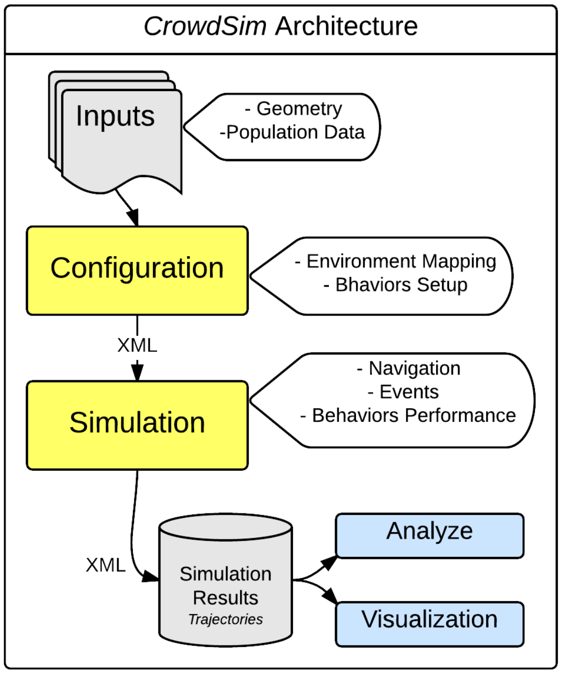


Figure 2: *General architecture of CrowdSim.*

3.1 Configuration Module

The configuration module requests, as a first input, the 3D representation of the environment in which a virtual crowd will be simulated. Such 3D model will be considered in order to allow the user to specify the walkable regions according to the building structure as well as physical restrictions and obstacles. Such walkable areas are called *contexts* and they are also able to store information regarding population data. Currently, we can work with three different types of contexts: *birth*, *motion* and *goal* contexts.

Birth Contexts are used to represent areas of the building where agents should be created during the simulation. The user is requested to inform the number of agents that should be created in such contexts. Also the user defines the following information based on the total number of agents to be created:

- *Groups Size*: The agents can be created in different groups until the total number of agents in the context is reached.
- *Creation Time*: Time when the groups of agents start to be created after the beginning of the simulation.
- *Time among groups*: Time interval to be taken into account when creating different groups.
- *Goal:* The context (or set of possible contexts) to be considered as goal to be reached by an agent.

Goal Contexts are regions of interest to be considered during agents' motion (goals). The user is requested to define the percentage of agents that should be removed of the simulation when achieve the goal context, the percentage of agents that should stay moving into such context and the percentage of agents that should find another goal and move in its direction.

The last type of context, i.e., the *Motion Contexts*, are considered by the simulation algorithm as connection regions between birth and goal contexts. They are important when calculating the agents' motion routes, which are detailed in Section 3.2

When the environment is coherently mapped as well as the user have defined all the information regarding to *population data*, it is possible to specify how agents should behave when moving. The behaviors able to be performed are:

- *Goal Seeking*: The agents should seek their goals immediately or vague, performing random motion;
- *Keep waiting*: The agents can spend some time on specific regions of the environment before seeking for another goal;
- *Perform random motion*: The agents can chose random destinations during a specific time, before trying to identify the best path to achieve the main goal.

It is important to mention that the correct configuration of the simulator is a crucial point because the combination and analysis of such information is responsible to lead to acceptable results. Thus, when the environment is totally configured with all walkable regions defined, all the parameters are set as well as desired behaviors are specified, the user is able to run the second module of *CrowdSim*: Simulation. The data transition between configuration and simulations modules is currently performed by an scenario file (XML), able to store all the configurations to be observed when computing a new simulation.

3.2 Simulation Module

The simulation module of *CrowdSim* is responsible to compute the **navigation** of virtual agents in a specific environment. The navigation must be computed coherently, taking into account several aspects such as agents' motion, collision control and other pedestrians' **behaviors**. Also, the simulation module is responsible to detect and start specific **events** during agents' motion. Such events can be the start of an evacuation process, speed variation by some agents located in a specific region of the simulated environment or even other behaviors.

A simulation setup is requested as input in order to define the simulation parameters and must be previously set in the configuration module. Considering such setup information, this module is able to compute the routes for each agent to achieve a specific goal. Routes can be computed based on user specification (i.e. a graph determined by the information defined in the contexts) or the best paths are determined considering only the distance criteria. In addition, during the motion simulation, *CrowdSim* is able to provide collision avoidance among agents and/or obstacles, using a simple local geometry method. Indeed, *CrowdSim* uses A* [Hart et al. 1972] in order to compute shorter paths.

The output of each simulation contains the following information:

- agents trajectories during the simulation;
- speed variation for each agent;
- agents' simulation time;
- local density along the time, we computed the local density by counting the number of agents per square meter;

The output data is stored and can be used to produce different statistical analyzes. On the other hand, the agents' trajectories can be easily visualized with 3D humans in a virtual environment in order to provide a qualitative validation of the simulation performed by visual inspection.

4 Software Validation

Validation & Verification are some of the most important software development activities [Beizer 1984], [Adrion et al. 1982]. The purpose is to guarantee that the software was correctly built. In this section we present how the validation process was performed in *CrowdSim*. We assume as *validation*, for this work, the systematic comparison of *CrowdSim* predictions with reliable information (usually from real data analyzes) The work of Galea [Galea 1998] presents a set of different validations to be performed. According to the author, there are different forms of validation/testing that evacuation models should undergo. We focus in three of them: *Component Testing*, *Qualitative and Quantitative Validation*. Such tests are already recognized and considered on the field of safety engineering in order to validate evacuation systems[2]. In London, the International Maritime Organization (IMO) developed *guidelines for evacuation analysis for new and existing passengers ships* IMO [IMO 2007] based on Galea's work. Such guide aims to develop a methodology for conducting an advanced evacuation analysis in order to built systems coherently able to:

- identify and eliminate congestion regions which may arise during an abandonment, due to normal movement of passengers and crew along escape routes, taking into account the possibility that crew may need to move along these routes in a direction opposite to the movement of passengers;
- demonstrate that escape arrangements are sufficiently flexible to provide the possibility that certain escape routes, assembly stations, embarkation stations or survival craft may be unavailable as a result of a casualty.

In this section we relate a set of case tests suggested by IMO in order to validate *CrowdSim* in each category. In addition we detail how we particularly validate the software in a qualitative way.

4.1 Component Testing

Component testing is part of the normal development cycle and involves checking if the various components of the software perform as intended. This involves running the software through a battery of elementary test scenarios. Following, we present a list of adopted component tests extracted from [IMO 2007] and applied on *CrowdSim*.

[2]This procedure has been highlighted in ISO document ISO/TR 13387-8:1999.

4.1.1 Maintaining set walking speed

Validates the speed of a single agent when moving in a specific known environment. We built a 2m wide and 10 m long corridor (illustrated in Figure 3) and simulated one agent walking from left to right with speed of 1 m/s. The success criteria of this test assumes that the agent should walk 10 meters in 10 seconds.

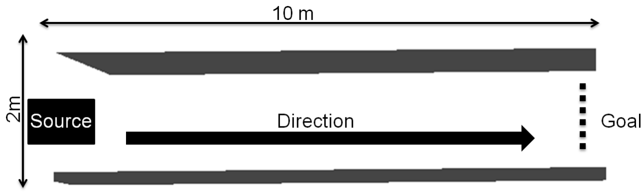
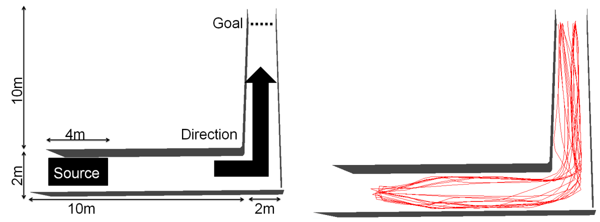


Figure 3: *Environment of walking speed test*

After ten individual simulations we compute acceptable average values. The obtained average individual velocity was $1.08m/s$ with standard deviation of 0.09m/s. The average walked distance was $10.232m$ (standard deviation of = 0.097m) and time of $9.506s$ (standard deviation = 0.769s). According to IMO's specifications we observe that *CrowdSim* is validated in this criteria.

4.1.2 Rounding Corners

This test evaluates the agents' capacity to walk around a corner without colliding with walls and other agents. We simulated twenty people approaching a left-hand corner according specifications illustrated in Figure 4(a).



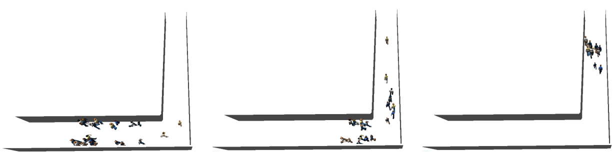
(a) (b)

Figure 4: *Setup of the experiment environment (a) and obtained trajectories of rounding corner simulation (b).*

According to IMO's guidelines, this test aims to verify two specific points:

1. *The agents should successfully navigate around the corner without penetrating the boundaries*. Figure 4(b) illustrates all the twenty agents simulated trajectories. It is possible to visually check that agents do not collide with the walls.

2. *The agents should successfully navigate without overlap at any time.* Figure 5 illustrates three views for a typical simulation in different moments. It is possible to check that there are no overlaps among agents.



(a) time = 10 seconds (b) time = 15 seconds (c) time = 25 seconds

Figure 5: *Simulation for rounding corner test.*

4.2 Qualitative and Quantitative Validation

Qualitative Validation concerns the nature of predicted human behavior with informed expectations from observed situations. While this is only a qualitative form of verification, it is nevertheless important, as it demonstrates that the capabilities built into the model are able to produce realistic behaviors. The qualitative tests performed in order to validate *CrowdSim* simulator are the impact of counter flow in time for evacuation, crowd dissipation from a large public room and exit route allocation. These tests are described in the next paragraphs.

4.2.1 *Counter flow* - impact in evacuation time in two rooms connected via a corridor

This test was performed according to the environment illustrated in Figure 6 populated by 100 individuals. The test was implemented in two steps described as follows:

1. Agents move from room 1 to room 2, where the initial distribution is such that the space of room 1 is filled from the left with maximum density. Initially, no agent was placed in room 2. The time elapsed for last person enters room 2 was recorded.

2. Step one was repeated with an additional ten, fifty, and one hundred people in room 2. Agents from both rooms move off simultaneously and the time for the last persons in room 1 to enter room 2 is recorded. The expected result is that the recorded time increases with the number of persons in counter flow increases.

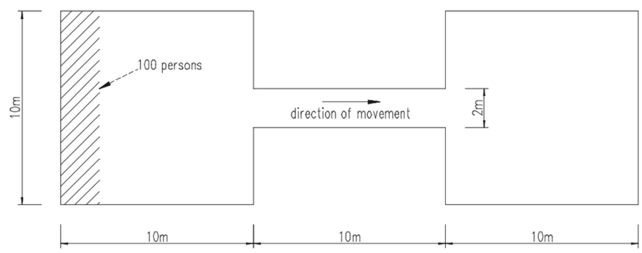


Figure 6: *Counterflow scenario configuration according to IMO's specifications*

We repeated each one of the scenarios described in steps 1 and 2 ten times, considering different seeds for the random number generator, which lead us to a test bank of 40 simulations. The expectation of increasing the time for evacuation of room 1 with the increasing of agents in counter flow was meet, as shown in Figure 7. The graph of this figure illustrates the average time variation with the number of agents in counter flow. The black markers near to each point represent the standard deviation for the ten performed simulation in each case.

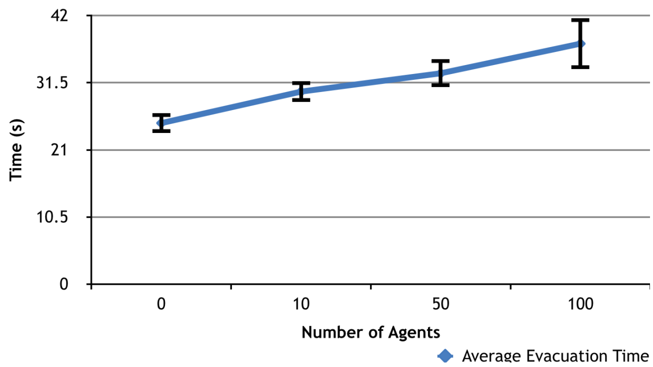


Figure 7: *Average and standard deviation of time for evacuation from room 1 as a function of the number of agents in counter flow.*

4.2.2 *Exit Flow* - crowd dissipation from a large public room

This test was performed in a public room populated by 1000 agents where 4 exits are available to be considered during evacuation as illustrated in Figure 8. According to IMO's instructions, the test should run according to two steps: first, simulate and record the time for last person leave the room when 4 exits are available and second, the same situation but considering doors 1 and 2 as closed.

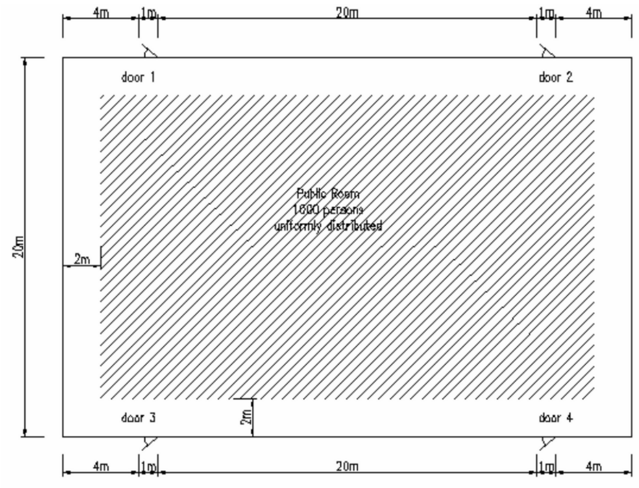


Figure 8: *Exit flow scenario configuration according to IMO's specifications*

The success criteria for this test is related to the amount of time for evacuation on the two cases. According to IMO, the elapsed time of second case should be around 50 percent greater than in case 1. When such experiment was performed by *CrowdSim*, we computed the time of 83.79s on the first case and 181.62s on the second test. These values meet the requirement and, as a consequence, we can consider that *CrowdSim* is validated according to this criteria.

4.2.3 Exit route allocation

The IMO specification for this test have guided us to built a cabin corridor section populated as indicated in Figure 9(a). The success criteria for the test assumes that:

1. The main exit was allocated as goal to the people from cabins 1, 2, 3, 4, 7, 8, 9, and 10.
2. The secondary exit was allocated as goal to all the remaining passengers.

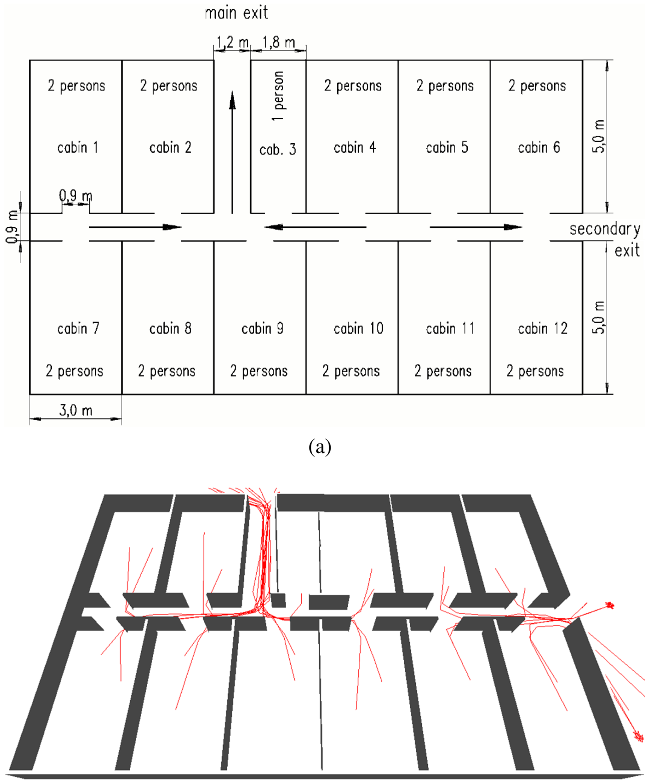
We performed such test in *CrowdSim* and the agents have moved to the appropriate exits. Figure 9(b) presents the agents trajectories in the 3D environments illustrating the success on the test.

Quantitative verification involves comparing model predictions with reliable data generated from evacuation demonstrations. Galea's work highlights[Galea 1998] two kinds of quantitative validation: *historic* and *prediction* based validation. In the first case, the user knows the results from previous simulations and real exercises. On the other hand, the second case refers to the usage of the model to perform predictive simulations prior to having sight of experimental results.

To the best of our knowledge, current IMO's guidelines do not have evaluated any experimental data in order to allow a thorough quantitative verification of egress models. Therefore, in this work, we propose method to quantitatively validate *CrowdSim*.

It is important to mention that the quantitative validation should take into account other information besides the total evacuation time. Such information is based on the simulation model outputs and should include data as exit selection, behavior in different conditions, bottlenecks regions, exit and finish times, among others. Thus, the level and quality of quantitative validation is dependent on the completeness and quality of the simulators reported data.

Wherever possible, the simulations performed by *CrowdSim* have been quantitatively evaluated. Several analysis have been undertaken in order to validate simulation results. For the purposes of the *CrowdSim* validation, we present the following results of performed comparisons:



(a)

(b)

Figure 9: *Exit Rout Allocation: (a) IMO's specification for the test and (b) agents performed trajectories.*

- *CrowdSim* was used to simulate the evacuation of a night club. The results were compared against data collected from a real egress exercise [Cassol et al. 2015]. In this project, we were able to record data from real life in order to contrast with *CrowdSim* predictions. Such recorded data includes local and global times, local and global densities and velocities. The analysis of simulated data allowed us to verify some attention points validated during the real egress exercise: *i)* region of highest density (stairs); *ii)* we have estimated a greater density of 5.4 people by sqm while, in the real exercise, the max value was 4.5 people by sqm. *iii)*the greater density was observed at second 40 of simulation, whilst that occurred in second 50 during egress exercise; *iv)* the observed times of simulation and real life were coherent.

- we also applied *CrowdSim* to reproduce crowd behavior when evacuating a college building. An analyzes of the extracted data from real and simulation scenarios allows us to observe that: *i)* times observed in simulated and real scenarios, besides different, are coherent (rel life evacuation takes 15% more time than simulation). We believe that the difference between simulated and real life time occurs because all the simulation agents were created and started to move in the exact same time, while in the real life people had different response time to events. Also real people do not feel panic voluntarily, since they know that an egress exercise is not a real fact of panic. The simulation assumes that all agents are supposed to go immediately towards the exists. *ii* The analyzes of the simulation results allows us to compute the density of the place during the simulated evacuation process and address attention points.

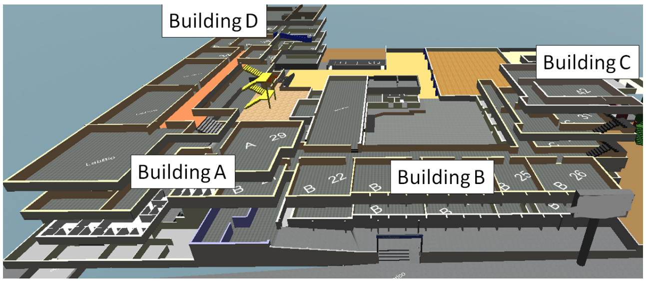
We are aware that this process for quantitative validation is yet simple due to the lack of rich information captured during an egress event (real life or simulation). However the qualitative validation were used by the managers of the night club and college building in order to improve their evacuation process.

5 Simulating a Scholar Environment

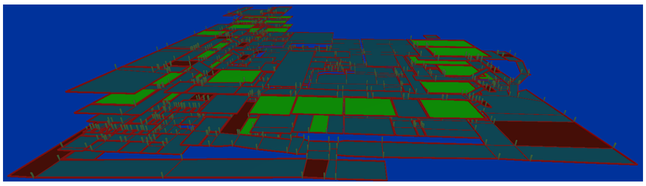
Once we have validated the *CrowdSim* simulator, we decided to apply it in other scenarios in order to verify its scalability, generality and adaptability, while predicting attention points in a real environment, if an emergency situation occurs. To this end, *CrowdSim* was configured to simulate a scholar environment. This section details this case study.

Firstly we reproduce the school in a 3D environment as requested input. Subsequently, we defined the environment constraints and the desired behaviors according to the steps enumerated as follows (see Figure 2):

1. we specified the regions where motion is allowed (e.g corridors and stairs) in the 3D environment. Moreover we defined the regions where the agents should be created (i.e. class rooms) and the regions to be considered as goals (i.e. exit doors). Such information is taken into account by *CrowdSim* when running path planing in order to compute agents routes. Figure 10 illustrates a comparative between the 3D model of the school (a) and the environment mapped on *CrowdSim (b)*.
2. The population data was defined according to environment specifications on *CrowdSim*. We were able to define (according to different kinds of contexts) the number of agents to be simulated as well as their goals during simulation. In order to specify such information, we have considered the values according to the real occupation of the school for each classroom. Also, we observed the best school exit to be considered in an egress process according the school structure. The school has two exits that are considered by the students when leaving the building in normal days. In addition, we observed the existence of extra doors (not used by the students) that are able to be considered by additional routes when thinking about egress process. The school structure allow us to validate different routes for possible egress situation that are further described.



(a)



(b)

Figure 10: *A comparison of the school environment modeled in 3D (a) and the environment specification in CrowdSim (b).*

After the environment and population constraints specifications, we performed simulations according to four different scenarios. Such scenarios were defined considering the school population in the morning (1067 students) and afternoon (729 people) as well as available exists (Figure 11 illustrates the available exits considered in the experiments).

The four simulated scenarios are:

1. morning population with only the main exits available;
2. afternoon population with only the main exits available;
3. morning population with all exits available;

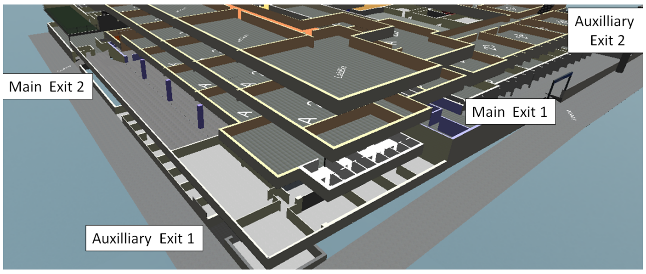
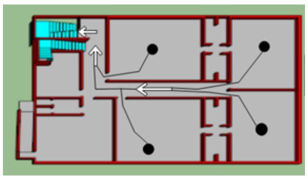


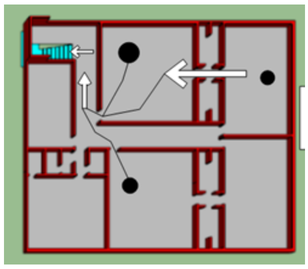
Figure 11: *Available exits from the school.*

4. afternoon population with all exits available.

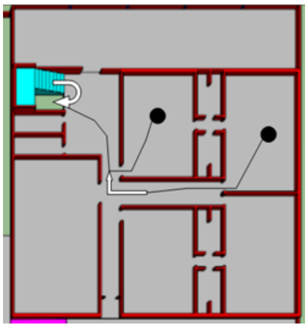
In order to attend the four scenarios that should be simulated it was necessary to define routs able to guide the agents until the nearest exit, according to the classrooms' locations. The routs represent, at this point, an evacuation plan to be performed. In this work, four evacuation plans have been developed according to the specification of each evacuation scenario. Figure 12 illustrates part of a rout to be followed by the agents that should leave the Building D of the school. The lines indicate the path to be followed while the white arrows represent the direction of the motion. As previously illustrated in Figure 10(a) the school is composed by four buildings of classrooms.



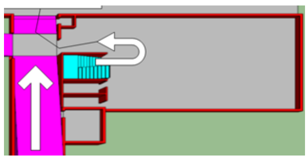
(a) 4th Floor



(b) 3rd Floor



(c) 2nd Floor



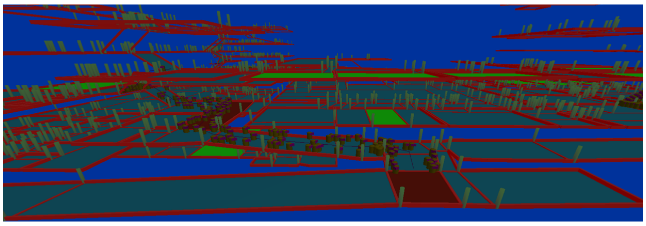
(d) 1th Floor

Figure 12: *Route representing the evacuation plan of Building D.*

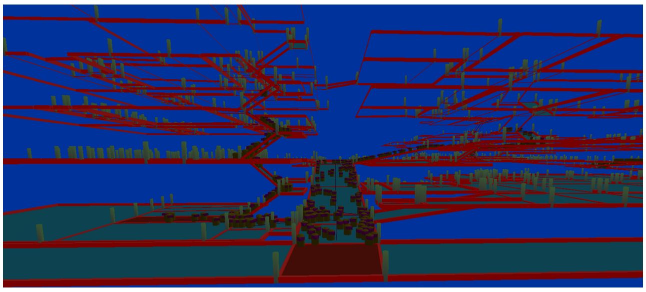
Besides setting the evacuation plans (environment and people data, behaviors and routs) it is important to emphasize some points to be observed during the simulation of all scenarios:

- The people distribution per classroom was computed according to data provided from school staff.
- We consider a reaction time for all scenarios. This time represents the response time of each agent until it starts to move after received an orientation to egress. We considered the response time as $5s$ for all the experiments.
- The agents are not created in the exact same time. In the experiments, we created groups from 1 to 10 agents (in each classroom) observing an interval of 10 seconds. This procedure was adopted to avoid that all agents start to move at the same time.
- All agents aim to move at speed of 0.8 m/s.

Table 1 summarizes the obtained results from performed simulations. Also, Figure 13 shows two frames from distinct simulations, which aim to illustrate the two main exits from school taken into account during the simulation of egress.



(a) Main Exit 1



(b) Main Exit 2

Figure 13: *Tow frames of distinct simulations illustrating the position of the two main exits of the school*

The analyzes of crowd simulation results have allowed us to observe different points of attention about the egress process. One important point is concerned to the variation of density in the buildings of school during the evacuation. The statistical data have shown the time of simulation when the higher density was detected. The estimation of the time for higher density allowed us to analyze the simulation and environment in order to identify the place of high density as an attention region. In the four simulated scenarios, the higher density have occurred in the stair of buildings C (scenarios 1 and 3) and D (scenarios 2 and 4). Figure 14 presents a frame of simulation when the highest density was detected on Building C (left) and Building D (right).

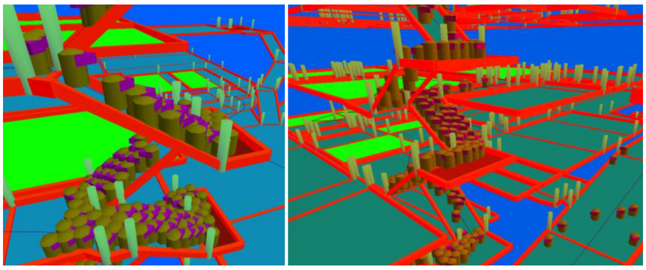


Figure 14: *Available exits at school.*

At this point, all simulated agents follow the same behavior when in egress. However, one of the concerns from the school manager was related to one special building of the school: Building D, where the kinder garden classrooms is located. We know that small kids usually present different behavior of teenagers or adults, specially when they are part of an evacuation process. In order to deal with this situation, we implemented a new rule in *CrowdSim*. We propose to implement an individual attribute in the agents called "goals persistence", which is related to a factor that represents how much time the agents seek goals during the simulation. This factor makes the agents ignore the goal seeking behavior and remain wandering during some specific time. We didn't found any specific literature about children behavior in order to validate our approach. In this way, we empirically applied the factor in order to represent the following case: The children of Building D should perform goal seeking behavior during 4 seconds and keep wandering during other 8 seconds. Experimental simulations have shown that the Building D is evacuated in 260 seconds, without goals persistence factor, while the time increases to 325 seconds when the factor is applied.

After these simulations, we could observe that *CrowdSim* is scalable, since the amount of agents was varied without significant loss of performance. Also, it could be noticed that it is general enough to simulate different environments and population characteristics. Finally, we observed that the software is easily adaptable, since we could simulate a population of kinder garden children with just minor modifications in the model. However, we noticed that the numerical output of the software, besides its utility for evaluation of the school safety, is not good enough for training the children and teenagers of the school. In order to improve this feature, we developed a game like interactive tool that allows students to embody the simulation results in a more attractive and engaging way. The next section details this improvement.

5.1 The Game

When we are working with crowd simulation on safety applications it is very common to analyze the produced data according some statistical criteria. This kind of analyzes provides important information to be considered by the buildings managers as previously detailed (Sec. 5). Once this project was performed at a school environment, however, the customer isn't only the school managers team. We are very interested in developing a culture of safety on the students and their families. We believe that games can be a powerful tool in order to achieve this goal.

With this aim, we created a game-based interactive visualization tool, in order to engage the students and make they able to think about safety and really know and virtually practice about a possible egress process from their own school. This tool was called *Game4Safety* and was developed according to the following requirements:

1. *Recreate the realistic training environment (precise 3D model of the school).* We reproduce the interior of the school according to its physical structure. At first, we do not consider furniture due to the time consuming work necessary to reproduce the details on each classroom. It is important to mention that the approach presented here is able to consider furniture as obstacles if their 3D models was available.

2. *The student should be able to explore the school space in its normal state.* As in *FPS* game, the player is able to navigate in the environment as one of the characters present on it. Also, the player is also able to navigate as in a RTS game.

3. *It should be possible to the users to observe the way out and the shortest routes to it from different locations on the environment*. The player must be able to choose a specific classroom of the school. With this feature, the camera is positioned on such point of the environment and the user is able to observe the best route to leave the school from that point. Also, the player can adopt a FPS camera view and move around the environment according the presented rout.

4. *Time monitoring.* We allow the player to select one specific virtual human to monitor his/her behavior when evacuating.

5. *Emulate different population scenarios*. When running the game, the player is able to choose among different scenarios to explore. Such set of scenarios represent 4 different simulations performed according to populations on the school during different periods of the day (morning and afternoon) and also the variation of available exits. We considered the normal exits used by students in normal days and also presented scenarios taking into account emergency exits simulating a possible emergency egress process. A total of 4 scenarios is available to be explored by the students as detailed in Section 5.

In order to meet such features and requirements, a prototype based on Unity 3D game engine[3] was developed. Figure 15 illustrates a comparative of a simple simulation visualization on *CrowdSim* and the same point visualized on *Game4Safety*.

[3] https://unity3d.com

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Evacuation Time	217s	207s	214s	172s
AVG Evacuation Time	98s	88s	88s	78s
Smallest Evacuation Time	31s	33s	16s	16s
Greater walked distance	132m	112m	130m	103m
AVG walked Distance	74m	68m	67m	59m
Smaller walked distance	30m	23m	21m	20m
Higher speed	1.5 m/s	1.59 m/s	1.5 m/s	1.5 m/s
AVG speed	0.81 m/s	0.82 m/s	0.82 m/s	0.81 m/s
Smallest speed	0.29 m/s	0.10 m/s	0.45 m/s	0.13 m/s
Higher observed density	6 people /sqm (at second 61)	4 people /s qm (at second 50)	5 people / sqm (at second 61)	4 people / sqm (second 60)
AVG of higher densities	2.2 people/sqm	2.2 people /sqm	1.79 people/sqm	1.49 people / sqm
Std deviation of higher densities	1.87	1.88	1.72	1.34

Table 1: *Summary of performed simulations.*

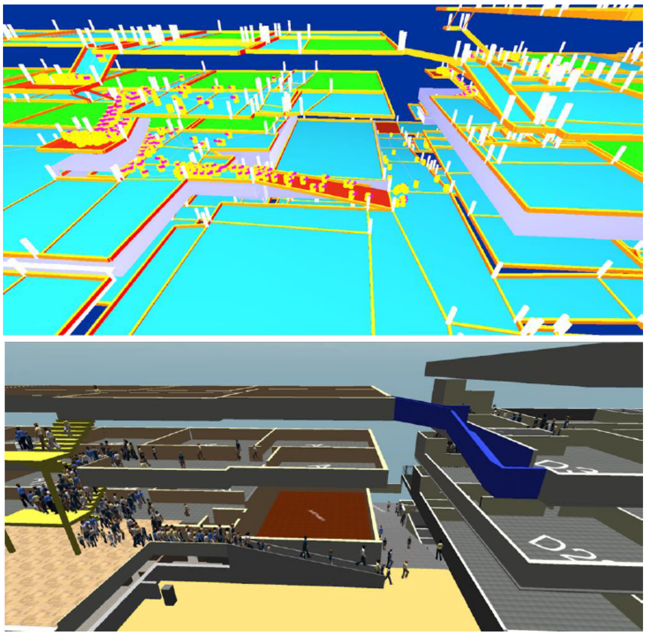


Figure 15: *Illustration of the some point of simulation visualized in the game at the same time.*

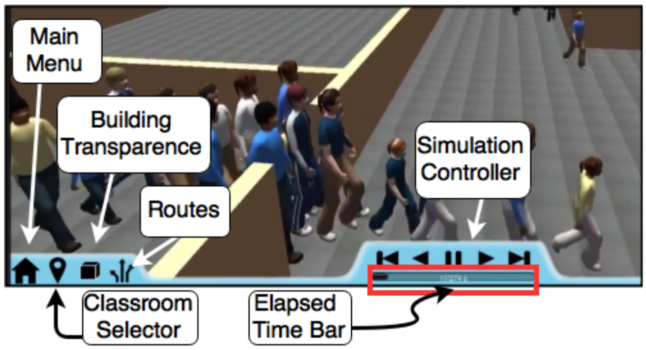


Figure 16: *Application Controller Interface.*

By starting *Game4Safety*, the player is able to select one of four available scenarios to be loaded. When the scenario is loaded, the user can interact with the environment and play a simulation. These options are available to the player on the developed interface:

- To choose the best camera to explore the environment (RTS or FPS). Controls are available on keyboard.
- To see the routes available to virtual humans. The user can also select one specific virtual human by click on it. When a virtual human is selected, specific information about he or she is displayed (e.g. total time to the virtual human leave the school and the followed route) - See Figure 1. The player can just follow the virtual human during the motion or also assume the character point of view.
- To apply transparency on the building in order to better visualize the 3D characters as well as the routes.
- To select a specific classroom and be transported to such location in the virtual environment.
- To increase the speed of visualization, back to initial point and also go to end point of simulation.
- Visualization of the elapsed time of simulation, in seconds.

An illustration of the interface controllers is available on Figure 16.

In order to verify the efficiency of Game4Safety, a supervised play test section was performed. A group composed by 10 students aged from 12 to 15 years and also 2 members of school staff have been part of the validation process of the game. During the play test section the testers were observed by the development team of Game4Safety.

After exploring *Game4Safety*, some testimonials from the group of testers have been collected. The overall impression of the group tester was positive and, according to them, very helpfull in order to learn how a possible evacuation process can be performed in the school. Some of them are presented next:

- *This is an important tool in order to develop a useful evacuation plan. It is a different approach to develop safety thinking in the students*. School's Principal.
- *The game is very cool and we can learn when playing. I went to my classroom and now I know how to leave the school when in emergency. It is very important to our safety.* Student, 13 years.
- *This game can help me and my colleagues to understand and think what is the safest way to leave the school in a possible emergency situation. The game also can help other schools.* Student, 14 years.

The analyzes of testimonials indicates the applicability of *Game4Safety*. The game is currently used in the school in order to train the students, and also their families about the importance of to develop a culture of safety.

6 Final Remarks

In this paper we detailed the validation process applied on *CrowdSim*. A set of tests were performed according IMO's [IMO 2007] guidelines in different categories [Galea 1998]. In addition we complemented the tests indicated by IMO by defining a process that allowed to validate *CrowdSim* in a qualitative way. This can be considered a differential of previous IMO's application on software validation. Results of this process show the accuracy of *CrowdSim* simulations.

Furthermore, considering *CrowdSim* as a validated software, we detailed its application on a Middle School project. Obtained data are useful to school managers in order to specify the best way to evacuate the school in a possible emergency situation. In addition, we develop *Game4Safety* in order to provide an interactive way for the students to analyze obtained data of performed simulations. We believe that training people is an important tool to prevent injuries and also to contribute to development of a culture of safe. Also, the use of game-based approach can engage people in the process, helping them to develop and share important information on the safety field.

The main contributions of our work are the development and validation of a crowd simulation tool able to coherently reproduce people motion behaviors. In addition, we showed that the use of the developed game can improve the students engagement in the training process concerning building exploration and evacuation. The possibility of the project application in an middle school made possible to validate the developed approach in a practical way. Obtained results as well as the the students feedback to the project have shown its applicability. As future work, we intend to improve the model in order to include different factors that could affect the trajectory (e.g, agents visibility along the time) and also increase the game-play in order provide an approach able to lead to an even more effective and engaging training system.

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