TOWARDS A METHODOLOGY FOR HUMAN BEHAVIOUR ELICITATION: PRELIMINARY RESULTS

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ABSTRACT
Human behaviour knowledge is an important requirement for implementing realistic evacuation models. Although much work has been done in this field of research there are no universally accepted quantitative methods. In this paper we present a novel methodology for human behaviour elicitation that was coined SPEED (Simulation of Pedestrian and Elicitation of their Emergent Dynamics). An experimental setup to test the concept was envisaged and validated by a group of experts using the Delphi method. A test bed was designed using the Serious Games concept and 22 subjects were selected for a pilot test. Preliminary results are promising, showing that this methodology might be used for the elicitation of human behaviour of subjects when facing an emergency. Moreover, the data acquired is of great importance for the fire safety experts designing new buildings or planning strategies to improve emergency paths. Another possible outcome is to create an artificial population based on human behaviour to populate emergency evacuation simulators.

Keywords: fire safety, human behaviour, behaviour elicitation, decision-making.

1. INTRODUCTION

One of the topics within the modelling and simulation field that has an increasing importance among researchers is the study of building evacuation, especially regarding human factors. It was noted by one of the prominent researchers in this area, Prof. Galea, that the development of fully adaptive behaviour models, in which "agents react to the evolving situation rather than simply responding in a pre-programmed manner to a specified scenario," is one of the grand challenges for the 21st century (Galea, 2012).

Evacuation models are used by many architects and engineers when developing new complex buildings, and by emergency managers for improving the safety of existing ones. The behaviour of subjects when facing the need of a rapid exit of a building, due to an emergency situation, whether it is a fire or some other kind of hazards, is one specific field of research that has been gaining much attention and for which no definitive theory is available (Kuligowski, 2011).

Studies refer that many building occupants still lack the proper education and are unaware of the best exit choice strategies when facing a fire or some other emergency. The egress of buildings is a chaotic process depending on many variables, both quantitative and qualitative, that are unknown and hard to determine (Pauls, 1995; SFPE, 2002; Timmermans et al., 2009).

Building safety designers usually define egress paths based on the shortest way to the outside and other safety issues. However, the possibility of a predefined route being blocked due to some unpredictable situation, such as fire, smoke or even partial collapse resulting from earthquake, for instance, is a situation often ignored.

Events such as the fire in the Brazilian discotheque "Kiss", January 27, 2013, where 242 died, or the 2012's Halloween party, in Madrid, where an overcrowded concert led to the death of five young women crushed in one of the exit tunnels, are unfortunately more frequent than they should. Such occurrences rely greatly on the lack of information and training of occupants. It should be also noted the need of more information about occupants' behaviours when facing an emergency and the need to quickly find the best and safest way out of the building (Galea, 2012; Silva et al., 2013a).

Devising sophisticated and advanced evacuation models, using agents resembling human behaviour is a challenge that many researchers are currently pursuing. Carattin and Branningan (2013) state that historical and cultural issues play a great deal of importance in human factors, and for that reason "*behavioural uncertainties are extremely large and include types of uncertainties unknown to physical science models.*" To conduct human behaviour research there are no universally accepted quantitative methods (Ronchi et al., 2013).

Some researchers proposed using computer games to train and also acquire human behaviour (Chitaro and Ranon, 2009; Smith and Trenholme, 2009; Kobes, 2009; Cordeiro et al., 2011a, Almeida et al., 2013). Computer games have a set of features that address these problems. In fact they provide engagement to their players, keeping them focused; additionally they allow players to become experts in the resolution of challenges, and improve their skills. Some work has been done in this domain, using Serious Games (SG).

The availability of game engines such as Unity3D provides a rapid way for prototyping 3D scenarios and of performing experiments to elicit human behaviour in such emergency situations (Rossetti et al., 2013). By using the SG concept, it is possible to record some metrics associated with players' decisions (Almeida et al., 2013).

In this paper we present a novel methodology for the elicitation of the behaviour of pedestrians when exiting a building in case of emergency, designed on the grounds of recent developments in serious games, multi-agent systems, social simulation, and peer-designed agents (PDA). The methodology includes the specification and prototyping of different scenarios simulating various possible situations a building occupant may find in reality. Selecting and implementing scenarios alone represent a very laborious and time-consuming phase of our methodology; for the sake of illustration, in this paper we present only one of such scenarios though.

A preliminary experiment implementing a scenario known as the "exit choice problem" was then set up, with the objective of gaining some insight into how humans behave when trying to leave a room. Two possibilities were considered, namely choosing the left or choosing the right side of a corridor, in different circumstances.

This experimental setup was validated by a panel of international fire safety experts, including researchers, practitioners and fire fighters, using a mix of questionnaire and live interviews based on the Delphi method (Dalkey and Helmer, 1963).

A sample of subjects was selected to play the game that was developed using the Unity 3D game engine. Results were recorded and analysed. During the experience, players' comments were also collected, which will be used to enhance futures scenarios and the game features as this research evolves. Part of the data recorded is expected to be used further to drive the artificial agents trying to recreate player decisions, based on their previous selections and the selected category of behaviour, a process known as peer-designed agents.

The remaining part of this paper is organised as follows. We start by briefly presenting some related concepts that underline and motivate this project. We then put forward the pilot study, describe the setup scenario and characterise the population sample. Results are presented and discussed afterwards. We finally draw conclusions and list some further steps in this research.

2. BACKGROUND AND RELATED WORK

2.1. Agent-based Modelling and Simulation

Agent-Based Modelling (ABM) and Agent-Based Simulation (ABS) are particularly adequate for representing social relations by using behavioural models exploiting emergent behaviour (Almeida et al., 2011), for which the main modelling metaphor is the so-called agent. An agent is basically an autonomous entity, capable of perceiving the surrounding environment through a set of specific sensors and of acting upon the same environment, maybe directly affecting its current state, through specific effectors. They feature reasoning mechanisms underlying their decision-making abilities and may exhibit communication channels allowing them to interact between each other (Russell and Norvig, 2009). When multiple agents are put together, they can perform rather socially, building upon a multi-agent system (MAS) which makes ABMS ideal to represent many scenarios of our daily lives, including pedestrians. These concepts briefly introduced are a subset of the Artificial Intelligence (AI) techniques that are used in social simulation (Wooldrigde, 2002).

For these reasons, ABMS has been widely used to simulate pedestrian interactions and crowds in a vast range of different scenarios, naturally including evacuations and risk situations (Almeida et al., 2012).

2.2. Pedestrian modelling and simulation

Although some attempts of modelling and simulating pedestrian movement have been around for decades, this field of research has recently received a clear boost in attention in a variety of disciplines, not only in the ones traditionally concerned with pedestrians, such as transportation, urban planning and design, but also in applied physics, computer science and artificial intelligence. In the latter case, pedestrian movement is often viewed as an interesting case to show properties of complexity theory and multi-agent models such as aggregate patterns emerging from simple principles applied to microscopic agents (Timmermans, 2009).

The more common representation models use one of the three following formats (Castle 2007):

- Coarse Network (or physics-based models of particle flow) typical of macroscopic models;
- Lattice or Cellular Automata;
- Continuous space.

Pedestrian simulators model real-life situations using collection of various mathematical methods, such as human behaviour models, hazard propagation models and the geometric data of the environment (scenario) in 2D or 3D. Due to heavy computational requirements and long run times, these simulations are performed mostly during the planning stage, helping architects to design safer buildings where human casualties in case of possible hazards are minimized (Jafari et al., 2003).

Pedestrian simulation methods vary with the application domain. The environment is a key aspect to consider when modelling pedestrians. Their behaviour is different indoors and outdoors. Applications of pedestrian simulation range from entertainment to more serious use. Entertainment includes video games where artificial societies are reproduced with diverse purposes, such as the cinema and TV industry so as to create synthetic population in films. In the serious uses, training and education are the most common applications. Other domains include transportation and urban planning, namely in transportation systems where pedestrian simulation is an important aspect.

Safety is one of the areas where pedestrian simulators have gained and increased development and focus. Aim is obvious and quite straightforward. Architects and engineers will benefit in the designing phase to evaluate the safety conditions of a building in an emergency situation. New advanced and complex buildings, like skyscrapers, with large occupancy and multi-floors, stadiums or other public facilities need tools to validate if they are compliant with fire safety regulations. Evacuation simulators are increasingly used for this purpose (Kuligowski et al., 2010). Some public transportation vehicles such as trains, planes and ships, are nowadays designed bearing in mind the safety issues, using specific developed simulators (Santos and Aguirre, 2004).

2.3. The decision-making process in building evacuation

When pedestrians have to leave a building, especially if some sort of emergency requires this action, decisions on which direction to follow must be made. This decision process gets an additional importance when due to safety issues the time to exit is vital. Indeed, if a wrong decision is made, which leads the occupants to a blocked exit or causing them to get stuck with smoke and fire, it may have disastrous consequences.

In complex buildings this problem gains even bigger importance, such as shopping malls, schools, hospitals and hotels (Kobes et al, 2007); this scenario gets worse in case of an emergency such as fire (Xie, 2011).

The behavioural process of way-finding in such emergency situations has been studied by many researchers for the past decades (Pauls, 1995; SFPE, 2002; Kuligowski, 2011). When modelling pedestrians both the collective and the individual issues should be addressed (Hoogendoorn et al., 2004). Timmermans et al. (2009) state that the pedestrians' decision-making process, as well as their movement are of critical importance in the development of pedestrian models that aim to reproduce the reality. Kuligowski (2008, 2011) has brought some insights into the matter regarding human behavioural process during building evacuation. Also, the validation and verification of pedestrian models often relies on data collected by means of direct observations, photographs, videos (Qingge et al., 2007), various sensors (Vasconcelos et al., 2012) as well as stated preference questionnaires (Cordeiro et al., 2011b).

2.4. Serious Games and Gamification

The Serious Games (SG) concept emerges with the use of video game frameworks for rapid prototyping applications with purposes other than mere entertainment. Taking advantage of state-of-the-art software technology that includes appealing high-definition graphics and animations, it is possible the creation of virtual-reality worlds without the need of a battalion of software developers. SGs are nowadays used in a variety of applications including education, training, health, advertising as well as social simulation (Hays, 2005; Frey et al., 2007; Ribeiro et al., 2012a).

The benefits of SGs combined with other training activities include: learners' motivation is higher; completion rates are higher; possibility of accepting new learners; possibility of creating collaborative activities; learn through doing and acquiring experience (Freitas, 2006).

The gamification concept is another new buzzword deriving from the use of game thinking of a game mechanics in a non-game context to engage subjects and make them loyal. Huotari and Hamari (2012) define it as "*a process of enhancing a service with affordances for gameful experiences in order to support user's overall value creation*". Rossetti et al. (2013) suggest that "*gamification is an important instrument towards behaviour persuasion,*" in the perspective it has the potential to influence behaviour in longer term.

These aspects briefly referred above are a subset of the reasons that are underlined in SG-based applications that make them so common nowadays for many uses, including human behavioural data acquisition.

3. TOWARDS SPEED: A METHODOLOGY FOR HUMAN BEHAVIOUR ELICITATION

Due to the high complexity and uncertainty of all environmental and intrinsic variables that affect human behaviour, existing evacuation simulators fail to capture in detail all the dynamics that characterize them. Besides cultural and historical aspects, pedestrians can choose the direction to take; can change at any moment their planned itinerary; and their choices might be affected by any social, economic, or environmental phenomena.

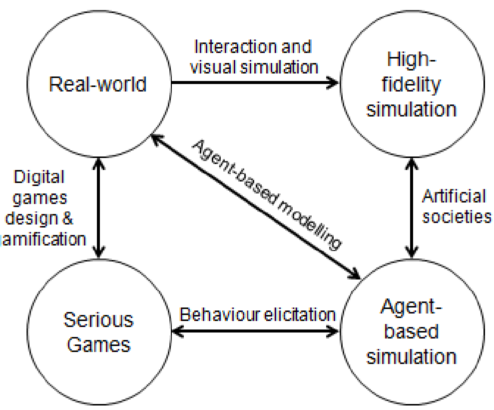

Figure 1 – Methodological perspective combining SG, ABM, ABS, behaviour Elicitation (adapted from Rossetti et al., 2013).

This consists on the basis for the need of a framework to allow consistently acquisition of human behaviour in such hazardous situations that can hardly be recreated due to the inherent risk for the subjects. As stated in previous section, SG and the gamification concepts seem to be an obvious candidate for the process of behaviour elicitation.

A methodological approach for capturing the complex and uncertain activities of pedestrians in the real-world was devised as a first-class abstraction for behaviour elicitation, using agent-based simulators, virtual-reality simulators and the real world (fig. 1).

The real-world ecosystem is where pedestrians live and interact with themselves and the environment. For practitioners and domain experts simulating extreme situations, testing theories and what-if scenarios, the agent-based modelling and simulation (ABMS) is of paramount importance. The agent-based simulation ecosystem is actually where artificial societies (as a means to represent human behaviours and social interactions) grow and breed. To create such virtual worlds the modelling of agents by means of ABMS needs behaviour knowledge for which the behaviour elicitation is required.

Instead of using high-fidelity simulation that recreates with a high degree of detail the real domain, for which complex and expensive simulators are necessary, such as CAVEs and other sophisticated virtual-reality technology (M.Kobes et al., 2009) we propose the use of simpler SG for behaviour elicitation. Of course we do not mean to replace previous efforts and technologies, but rather complement them with SG techniques to enhance behaviour modelling and analysis (Almeida et al., 2013).

This extended account of the concept of SG is in accordance with the integrative perspective of behaviour elicitation to reveal the decision processes behind the course of action people perform to achieve certain goals and respond to stimuli, or during deliberation. This process is not just a matter of collecting data through logs of different and successive interactions of the player during the game for post processing. Rather, we make use of the intrinsic nature of SG to impel the player to add semantics to every decision and action performed during the game that might better clarify the sequence of cognitive states that resulted in or triggered certain actions. In other words, we ask the player to model his/her own agent, in a process that is known by peer-designed agents (PDA).
In brief, we thus integrate serious games into the conceptual framework SPEED (Simulation of Pedestrians and Elicitation of their Emergent Dynamics) by combining behaviour elicitation with the PDAs, allowing players to feature their peer agents with their own idiosyncrasy (Rossetti et al., 2013).

The SPEED framework is thus one instantiation of the aforementioned methodology devised by Rossetti et al. (2013), which aims at the study, simulation and elicitation of the pedestrian interactions and processes namely the reasoning and decision-making aspects related to movement, both indoors and outdoors.

An experimental setup to test the concept was envisaged and validated by a group of experts based on the Delphi method (Dalkey and Helmer, 1963). A test bed was designed and a pilot test devised to implement the Serious Games concept test bed in which various scenarios for behaviour elicitation are shown to players.

The overall idea is to create a set of scenarios, using the well known concept of "game level", in which the player is moving from one scenario to another, in a succession that can lead to increasing stages of difficulty. This is one important mechanism explored in the gamification concept, which is currently a fashionable way of engaging subjects and enhance their commitment to the task at hand (Rossetti et al., 2013).

4. PILOT TEST

4.1. Prototype development

A preliminary simple scenario was devised for behaviour elicitation and as a proof of concept. Players start in a study room, which could be an office in a university building, with two desks, some computers and bookshelves. To implement the prototype we have selected the Unity3D game engine. For the scenario creation we use free-of-charge 3D models available at the Unity Asset Store, a place within the Unity company website (see www.unity3d.com) where developers share models. Some objects were collected from the Google Warehouse, developed in SketchUp, and afterwards converted in a Unity3D compatible format to be imported into the game framework.

4.2. Unity3D and First-Person-Shooter game genre

Unity3D is a powerful WYSIWYG (What You See Is What You Get) game engine that has some interesting features such as: i) free use; ii) powerful graphical interface; iii) capability to import models from other sources; iv) Programming support in JavaScript, C# or Boo.

The First-Person-Shooter (FPS) game genre is very common among video games. FPS is characterised by placing players in a 3D virtual world which is seen through the eyes of an avatar (Silva et al., 2013b). The aim is to give the feeling of immersion in the virtual environment via this first-person view.

The controls for this game use the FPS common standard: a combination of keyboard and mouse to move the player around the environment. To improve usability and having in mind subjects who are not familiar with PC video games and this keyboard plus mouse technique, a joystick was also used as an alternative (Figure 2).

Figure 2 – Thrustmaster joystick T-Flight Stick X PC/PS3 used in our game framework.

The character movement control using the joystick is very straightforward and intuitive: moving back and forward or left and right has the same correspondence in the game. To rotate the avatar, the user has to twist the joystick.

The trigger button was configured as "accept_button" to confirm the game messages and the button number "2" to present the game main menu. Mouse right button was also another way of leaving game and returning to the main menu.

Main menu was a simple one with a set of buttons, each one giving access to different functionalities of the game: i) training; ii) game (all five levels continuously); iii) one button for each game level (five in total); iv) exit button (to end the game).

4.3. Game scenario

The game scenario consists of a typical office room, having two desks with computers, bookshelves, a scoreboard and some other furniture and details to give as much of a realistic look-and-feel immersion as possible. The exit door leads to a corridor with two possible ways; both are similar, having the equidistant way to double exit doors located at the end of the corridor after a turn. The plan is represented in Figure 3.

Figure 3 – Bird view of a building layout: room with corridors leading to two possible emergency exits

Looking at the image, player starts located at the desk that is positioned to the right side, when looking towards the door. Corridor has the same length for both sides. The player chooses either to go left or to go right. When exiting the room, there will have a 90º turn followed by a pathway leading to a double exit-door, with exit signs on the door and on top of it, as it would be in any real scenario. When moving towards the exit, an invisible collider was thoroughly put in place to end the game level and move on to the next scene or return to the main menu.

4.4. Experimental setup

The test-bed prototype was run under a Windows 7 commodity laptop with no special specifications. All subjects were tutored in the game controls usage, keyboard and mouse or joystick, and were given a small time to adapt in controlling the FPS character and how to move around the scenario by loading a tutorial scenario with no goals or restrictions.

During experiments, each player had only one run so as to capture his/her reactions to the gaming experience and controls. To avoid any source of biased data and noise in subjects' responses, other players were kept apart prior to simulation runs. This way no one possibly had any previous knowledge on the scenario and activities of other players. It is important to stress on this aspect as our expectation was to acquire genuine reactions and register as naturalistic choices as possible.

All subjects were instructed previously about the experiment and signed a written consent.

4.5. Game description

The game starts with the player inside the office room. After a small period of time (it was setup for 5 seconds), the fire alarm triggers and the player is urged to exit as quickly as possible, using the nearest exit. In the first level only an exit sign on the top of the office entrance is presented. No other cues are given on which direction to take. Players can equally choose between going left or right (see Fig.4).

Figure 4 – Level 1: no direction sign on the corridor

When the player chooses one direction, moving the character towards the exit, this level finishes as soon as he/she gets near the door (Fig. 5).

Figure 5 – Exit double door at the end of the corridor

The next level starts exactly at the same point, the fire alarm triggers and the player must repeat the process of steering his/her avatar towards the nearest and safest exit. This time, however, there is an emergency sign pointing to the left (Fig.6). The player is expected to follow the exit sign direction but there is no deterrent if he/she chooses the other way.

Figure 6 - Level 2: direction sign pointing left is visible on the corridor wall.

The third level starts similarly the previous one, showing the left turn sign depicted in Fig. 6, and players are expected to follow that direction. However, in this level, there is smoke coming from the end of the corridor (Fig.7). The goal of this level is to present the player a dilemma: should he/she go forward regardless of this obstacle or follow the other direction even though the exit sign is pointing left?

Figure 7 - Level 3: sign pointing left is visible on the corridor as well as smoke

Fourth level is again similar to the previous one. The only difference is that besides the smoke, there is also fire (Fig.8). To prevent players from trying to pass through the fire, this object is set with a collider and is insurmountable. So, all players on this level have no option other than escaping through the right corridor.

Figure 8 - Level 4: sign pointing left is visible on the corridor as well as the huge fire.

The fifth, and last level, presents a different challenge. This time there is neither fire nor smoke, but rather people are running from the left towards the right side of the corridor. The goal is to see the reaction of players when having to select between following the exit direction shown in the sign (left) or following the crowd moving in the opposite direction (see Fig. 9).

Figure 9 - Level 5: People running the opposite direction of the exit sign

4.6. Population Sample

A total of 22 subjects were selected as a sample to test the developed prototype. These testers can be classified according to the parameters presented in Table 1. This data was collected in a questionnaire presented to the players at the end of the game.

Table 1 - Population sample's age and gender

	Values
Male subjects	13
Female subjects	9
Min age	14
Max age	55
Mean age	35
Age SD	14,95
Number of subjects	22

Subjects, prior to playing the game, had to answer a small initial questionnaire. Results are presented in Table 2. The objective was to assess the computer and game expertise as well as fire safety training.

Table 2 – Population sample's skills on computers, gamming and fire safety

	Yes	No
Computer basic skills	20	2
Video game expertise	6	16
Fire safety training	5	17

4.7. Data Collected

For each scenario, the choice on whether to use the left or the right exit was recorded. Results are presented in Table 3.

Table 3 - Exits used by the players

	Left	Right
1 - no sign on corridor	8	14
2 - sign pointing left	21	1
3 - sign pointing left + smoke	12	10
4 - sign pointing left + fire	0	22
5 - sign pointing left + people running in opposite direction	6	16

5. PRELIMINARY RESULTS AND ANALYSIS

All subjects found the experiment very interesting and educational. Only five said to have some sort of fire safety training, so the situations presented at the game made them think on which option would be the best and possible consequences in real life. The realistic 3D scenario provided by the game was a positive aspect most players remarked. The possibility of choosing the keyboard plus mouse or the joystick was also noted.

On the negative side, the rotation speed of the joystick was considered to be too slow. This aspect was not changed, although noticed by most players, to avoid biasing the results. It will be improved and turning speed will be further calibrated in future versions of the game. Another aspect was that some players, noticeably the ones more used to playing this genre of games, did the path so quickly that missed the emergency sign pointing left. There was one player that only saw it in the last run. To overcome this issue in future experiments, the starting point of the player will be moved to the middle of the room in front of the door.

To level all players, time of execution was not recorded. In previous experiments (Ribeiro et al., 2012b; Silva et al., 2013c), authors have used the evacuation time as an important metric to evaluate the performance of a player, but we have just realized that gaming experience biases results, so in this setup focus was on understanding and eliciting user choices instead, as well as their reasoning and their underlying way-finding process.

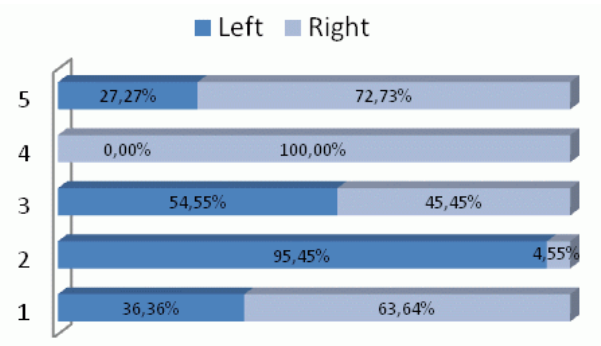

Figure 10 – Results in percentage for each level

The first level goal is to try and find a pattern, if any exists, of occupants when leaving a room turning right or left. Intuition led to the idea that most people prefer right instead of left; and over 72% in this test confirmed that assumption. We suspect the initial location led some players to go forward and left, but further tests are needed to confirm this hypothesis though.

The second level goal is to counteract that reaction (turn right) and force subjects to turn left. Even with the sign pointing that direction, there was one player that missed it and turned right.

The purpose of the third level is to pose a dilemma to the player: if the sign is pointing left but smoke is coming from that direction what should they do? Should they follow the emergency sign or avoid the smoke? Some players said that the game should have a command to lower the character and pass right through the smoke. More than half of players decided to face the smoke. This happens due to Unity3D limitations; smoke is dark but gets thinner when approaching thus allowing players to surpass it. The fourth level is similar, but this time fire is strong and all players decided to go back and turn to the right exit.

The last level presents another dilemma: people are running the opposite direction as pointed by the exit sign; what should the player do? Follow the runners or ignore them and go on through the left? Despite a great number of players that choose to follow the people running, more than 63%, some said they prefer to go the opposite direction to avoid crowd and respect the sign.

6. CONCLUSIONS AND FUTURE WORK

The aim of this experiment was to determine the validity of this methodological approach for human behaviour acquisition using SG in the specific domain of way finding in the evacuation of buildings.

Although the population sample is relatively small, results are promising and point out in the direction of considering that this tool for behavioural acquisition can be considered by social scientists and fire safety engineers. Furthermore when combined with other scenarios, results might be of great importance for researchers. The expert panel consulted using the Delphi method stated the importance of the experiments and the need of real data representative of the behaviours of building occupants when exiting the place.

The aim of the experiments described in this paper is to try and find whether there are patterns in behaviours when making the initial selection of which direction to take when exiting a room: left or right? For the practitioners, both architects and engineers, as well as emergency planners, this tool might be a valuable help in understanding what goes on through occupants' mind when escaping from a place. Will they consider the emergency signs? Will they follow others? Will they return upon smoke or only if they see insurmountable fire?

For fire scientists and researchers, the issue of the exit-selection is of great importance. Some experiments have been carried out, but only in a small scale. Future work will be the creation of a Web version of the game, playable by many people, to gather as much responses as possible, and try to establish a pattern. To this matter, the fact that many of the players confessed not to have followed the emergency signposting, pointing to the nearest and safest exit, must be emphasized.

The very next steps in this research are two-fold: to improve this experiment using players' comments collected during the experiments, and to implement other scenarios for a large sample of subjects to play. Expected results will be thoroughly analysed in order to try and establish some standard behaviour that might emerge from the data. There will be also a questionnaire presenting the same scenarios and asking the subjects for their decisions. Results of questionnaires and the SG tests will then be compared to see whether answers are similar or not.

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