Serious games for the human behaviour analysis in emergency evacuation scenarios

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Abstract This paper describes an experiment designed to elicit human behaviour when facing the urgent need of exiting an unknown building. This work is part of a larger effort to devise the methodological approach underlying the implementation of simulation of pedestrians and elicitation of their emergent dynamics, an experimental framework coined SPEED. To validate our experimental setup, a group of 16 experts on fire safety, emergency planning and building evacuation were consulted. The experts were solicited to answer a questionnaire, rating their gaming experiences and validating the questions in the form to be presented to subjects. Their comments were valuable inputs used in the development of the experiment described in this paper. A sample of 62 subjects was then used to test our approach, which consists in having the subjects answering a questionnaire and later on playing a Serious Game resorting to the Unity3D game engine. Some specific scenarios were carefully designed and presented to subjects, both in the questionnaire and in the game environment to maintain consistency of answers. Preliminary results are promising, showing that the challenge made players think about the various situations that might happen when facing an emergency. They are also implied to reason on their stream of decisions, such as which direction to take considering the environment and some adverse situations, such as smoke, fire and people running on the opposite direction of the emergency signage.

Keywords Serious games · Way-finding · Emergency planning · Building evacuation · Human behaviour elicitation

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1 Introduction

1.1 Problem description

Understanding the egress of buildings when facing emergency situations is a major concern for both the academic community and practitioners, such as architects, engineers and building emergency managers. The behaviour of subjects when facing the need of rapidly exiting a building, due to an emergency situation, whether it is a fire or some other emergency, is a specific field of research that has been gaining much attention and for which no definitive theory is available [1–3].

Many buildings' 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, which are unknown and hard to determine [4,5].

Building safety designers define the egress paths based on the shortest way to the outside and other safety issues. But the possibility of a predefined route to be blocked due to some unpredictable situation, such as fire, smoke or even partial collapse due to earthquake is often ignored [6,7]. Another important issue resides on the need of more information about occupants' preferences and behaviours when facing an emergency and the need to rapidly find the best and safest way out of the building [8].

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 [9–11]. Besides cultural and historical aspects, pedestrians can choose any direction to take, change at any moment their planned itinerary, and their choices might be affected by any social, economic, or environmental phenomena [12].

1.2 Motivation

Events such as the fire in the Brazilian discotheque "Kiss, on 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 expected. Such occurrences rely greatly on the lack of information and training of occupants [13].

Devising sophisticated and advanced evacuation models, using agents resembling human behaviour is a challenge that many researchers are currently pursuing. 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 [14]. The field of Human Behaviour research has currently no universally accepted quantitative methods [11].

Some researchers proposed using computer games to train and also acquire human behaviour [15–18]. Computer games have a set of features that address these problems. In fact, they engage their players, keeping them focused; additionally they incentive players to become experts in the resolution of challenges, and improve their skills. Games that are developed with a main goal other than mere entertainment (such as raising awareness regarding certain problems, teaching, brand awareness, among other possible applications) are known as serious games (SG). The availability of game engines such as Unity3D provides a quick way for prototyping 3D scenarios and performing experiments to elicit human behaviour in such emergency situations. By using the SG concept, it is possible to record some metrics associated with players' decisions [19].

1.3 Paper structure

In this paper we present a preliminary experiment that was envisaged to elicit human behaviour patterns when leaving a room: each subject may turn left or right. Five variants of the same scenario were created. This test is part of a wider project under development, aiming at the creation of a framework coined simulation of pedestrians and elicitation of their emergent dynamics (SPEED) [19]. A methodological approach was outlined and is presented briefly, explaining the context behind the experiment described in this paper.

To validate this experimental setup, a group of 16 experts on fire safety, emergency planning and building evacuation, were consulted. These experts were solicited to answer a questionnaire, rating the gaming experiences and validating the questions in the form to be presented to subjects. Their comments were valuable inputs used in the development of the experiment described in this paper.

A population sample of 62 subjects played the game developed using Unity 3D and filled in a questionnaire having the same scenario possibilities. Results were saved and analysed. Players were also asked to comment on their experience, both relative to the game as well as to the questionnaire. These will be used to enhance some of the game features and to prepare other scenarios as future work. Part of the data recorded is expected to be used further to derive the artificial agents trying to recreate players' decisions, based on their previous selections and the selected category of behaviour.

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

2 Background and related work

2.1 Way-finding in building evacuation

When leaving a building pedestrians must make some decisions on which direction to follow. This decision process gets an additional importance when occupants are facing some sort of emergency and time to exit is crucial. Moreover, a wrong decision might be fatal if leading to a blocked exit or trapping the occupant with smoke and fire.

It is quite common to be circulating in complex and big buildings, sometimes without knowing the layout, posing problems to the occupants when trying to find a path to their destinations or final exit. Many times it happens when shopping in big malls or staying in hotels [20]. This scenario gets worse in case an emergency should arise, such as fire and smoke [18,21], blackout due to power failure [22], terrorist attack [23], gas or chemical leak [24], among other possibilities [25].

The behavioural process of occupants searching the best exit in such emergency situations has been studied by many researchers for the past decades [1,2,4,6–8]. Experiments in a variety of situations have been made, such as lecture theatres [26], movie theatres [27], pedestrians route choice [28], single room [29,30], hotels [31].

To correctly represent pedestrian flow, both the collective and the individual issues should be addressed such as route-choice [28,32,33], the emotional impact on travel speed [34], visual information [35], self-organization and pedestrian interactions [36].

Timmermans [6] states that the pedestrian decision-making process, as well as its movement, is of critical importance in the development of pedestrian models. Kuligowski has brought some insights into the matter regarding human behavioural process during building evacuation [8,37–39] proposing a method combining the perception of cues, interpretation of situation and risk, decision making and actions [37]. Some authors state the evidence of leaders emerging during the evacuation process [40–42]. Another phenomenon that sometimes arises is fear which stalls the evacuees leading them to fail to react accordingly [43]. A mathematical model based on Game Theory was proposed by [44], using a stochastic approach instead of observing or collecting data from real people. Xie has researched the influence of emergency signage in the way finding process during building egress [45].

In their common environment pedestrians tend to show some basic attributes. For example people always try to find the shortest and easiest way to reach their destination. If possible they avoid detours, even if the shortest way is crowded [1]. The basic principle is the least effort principle, which means everyone tries to reach their goal as fast as possible spending the least amount of energy and time [46].

Nevertheless, the behavioural aspects that govern the decision-making process of pedestrians, either in normal or emergency situations, still need more research to master the rules underlying all intelligent mechanisms [1,47]. This is considered to be one of the great challenges for future research in the pedestrian and evacuation dynamics (PED) field [48].

2.2 Evacuation simulators

Research on crowd behaviour in emergency situations is complicated since it is not possible to expose real people to dangerous environments [3]. Fire drills are a possible approach but hardly recreating the real panic conditions, people tend to take them not seriously [49]. Computer simulation is a valid alternative, bearing in mind that it takes into consideration the human and social behavioural aspects of a crowd to get results as realistic as possible.

There are three main reasons for developing computer evacuation simulators: first to test scientific theories and hypotheses; second, to test design strategies; third, to create phenomena about which to theorize [8].

Although many approaches exist to virtually simulate the behaviour of crowds with varying levels of realism and computational efficiency, the three models that seem to be the most used, are: (i) Cellular Automata-based, using the concept in which individuals are treated as separate objects in an area divided into the so-called cells [5,50,51]; (ii) forces-based such as the social forces model (SFM) [52] or the magnetic forces model (MFM) [53] using analytical models to calculate the position variations of individual elements through the application of forces among them and the surroundings; (iii) and artificial intelligence-based where the decisions are made by individuals, called agents, that compose the crowd on an autonomous basis [9,54–56]. The former approach sometimes uses the multi-agent systems (MAS) concept [57] that resembles a society of several interacting entities and has inspired much research in the Social Sciences [58,59].

Gwyne published a survey in 1999 accounting 22 evacuation models [60]. The oldest date back from the 1980s (EXITT-A and Takahashis model). A great number of evacuation simulators were created since then, some just for academic purposes, others with commercial aim, some hybrid. According to Evacmod.net the Evacuation Modelling Portal , there are 64 reviewed evacuation simulators. Examples include: EXITT [61], Exit 89 [62], Evacnet, Simulex [63], EvacSim [64], Exodus [54], FDS+Evac, Pathfinder [9] just to name a few. More information can be found consulting reviews, analysis or surveys on evacuation simulators [9–11,54,65–67].

2.3 Serious games

The application of serious games, as a term, (SG) begins with the use of video games frameworks for rapid prototyping applications that aim for other purposes than mere entertainment, taking advantage of the use of appealing high-definition graphics and state-of-the-art software gaming technology. Such purposes include education as well as training. This term was presented by Clarck Abt [68] long before the use of computer games for entertainment. However, the idea of using games for serious purposes goes back to, at least, the XIX century, for military use. The Lieutenant Georg Leopold von Reiswitz and his son of the Prussian Army in 1812 devised a set of war games for training strategic skills [69]. They used the kriegsspiel (German word for war games) system for schooling officers on tactical manoeuvres (http://kriegsspiel.org.uk/).

SGs are currently used in a variety of applications including education, training, health, advertising or social change [19,70,71] in diverse domains from military [72] to the industry, encompassing medicine, aerospace, advanced sports (e.g. formula 1), among many others [73]. According to Freitas [74], combining SGs with other training activities include benefits such as: the learners motivation and completion rates are higher; possibility of accepting new learners; having the chance of creating collaborative activities; learn through doing and acquiring experience.

Games can be used for the rationale for quantitative analysis in games, as well as a method to collect *in situ* game data for that purpose. This approach made use of gamers' actions within the game as the basis for assessment of their learning [75].

2.4 Elicitation of human behaviour

The advent of Artificial Intelligence raises a great number of challenges. One of them is related to how knowledge is represented and the general processes operating on that representation. The process of knowledge elicitation is related with the ways of collecting from a human source information that is thought relevant to some application or domain [76].

According to the MacMillan Dictionary, elicitation is the process of getting information from someone. To what our research is concerned, we aim to elicit behaviour from experts or common people on their behaviour when in the presence of fire, at a building.

For decision support systems, for instance to understand how customers choose products and make decisions, the elicitation of users preferences is a primary issue for which various techniques may be used [77].

The knowledge elicitation phase of expert system development is considered to be a major hurdle especially as the expert knowledge is multifaceted since it has both explicit and objective knowledge as well as implicit [78]. Of the many techniques available, there is a methodology called Delphi process that is used for the elicitation of knowledge from experts of a certain field [79]. This method has been used to extract the knowledge of one or more experts with the goal of establishing a set of concepts and facts much needed to feed agents [80].

2.5 Use of serious games for human behaviour elicitation

Some research has been carried out at LIACC, University of Porto, in recent years towards the development of a SG-based Evacuation Simulator [19,69,81–85]. Due to some difficulties concerning the use of 3D building models, we had the idea of creating simpler scenarios that could be used for human behaviour elicitation. Instead of using complex buildings, with higher rate of errors and slowing the development phase, a new approach was devised.

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 part of the gamification concept, a way of using game mechanisms in a non-game context to engage users and solve problems [19]. These aspects briefly referred are a subset of the reasons that are intrinsic to SG-based applications and make them so common nowadays for many different uses, including human behavioural elicitation.

The elicitation of human behaviour in such situations will help stakeholders and planners forecast potentially dangerous situations and prepare the appropriate preventive actions [86].

2.6 Using Unity3D and the First Person Shooter concept to implement a SG

To make the environment as realistic as possible, a popular game engine framework, namely the Unity3D, was selected [82]. Some of the features that make Unity3D so popular, besides the free licence for academic purposes, consist on the powerful interface that allows visual object placement and property changing during runtime, especially useful to rapidly create new scenarios from existing models and assets and quick tweaking of script variables [87,88]. Moreover, the framework is customisable, giving the developer the ability to create code in JavaScript, C# or Boo [89]. Finally, it also provides a simple project deployment environment for multiple platforms, with no need for additional configuration, including the web, making it possible for a wider dissemination of the experiences through any web browser [83]. The game genre selected to be used for the experiments envisaged is the First Person Shooter (FPS), characterised by placing players in a 3D virtual world which is seen through the eyes of an avatar [90]. This attempts to recreate the experience of the user being physically there and exploring their surroundings, creating an immersive virtual reality ambience.

The controls for this game follow the common standards for the FPS genre, using a combination of keyboard and mouse to move the player around the environment. The complete action mapping is as follows:

- Mouse movement—camera control, i.e. where the player is looking at;
- W—move forward;
- S—move backwards;
- A—strafe to the left;
- D—strafe to the right.

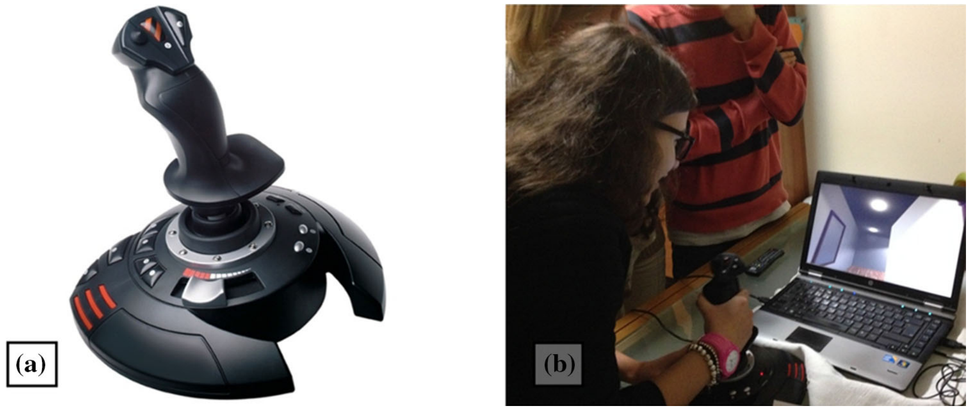

Fig. 1 **a** Thrustmaster joystick T-Flight Stick X PC/PS3 used in our game framework; **b** player testing the joystick

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 (see Fig. 1).

3 A methodological approach towards SPEED

3.1 The SPEED concept

The aim of the SPEED framework is to study the pedestrian dynamics and interactions, in what concerns reasoning processes, path planning, and all other aspects associated with pedestrian movement [19]. This kind of tool is important for urban planners as an aid for designing and evaluating urban spaces regarding comfort, safety, and other important issues, such as accessibility of public buildings. The importance of assuring the occupants' safety during an emergency situation is a critical issue.

SPEED consists of a methodological approach for capturing the complex and uncertain activities of pedestrians in the real-world, devised as a first-class abstraction for behaviour elicitation, using (i) agent-based simulators; (ii) virtual-reality simulators; and (iii) the real world (see Fig. 2). 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 simulation (ABS) 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 ABS 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 VR-based cave automatic virtual environment (CAVE) and

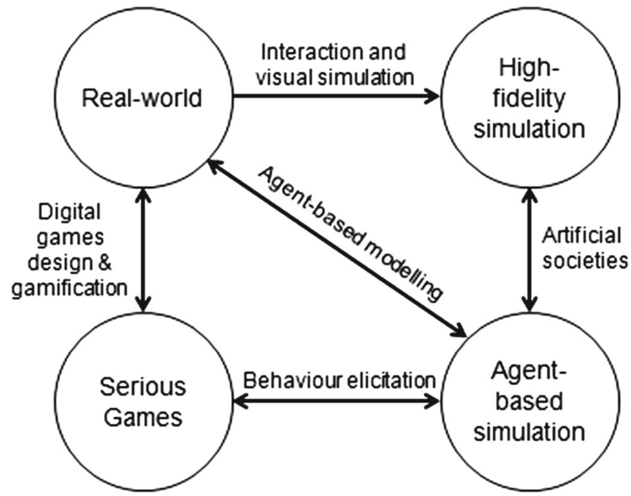

Fig. 2 Methodological perspective combining SG, ABS, behaviour Elicitation (adapted from [19])

other sophisticated virtual-reality technology [17] we propose the use of a simpler SG for behaviour elicitation. This allows for a quicker setup and development of these experimental scenarios, potentially serving as a means for initial validation of the experimental design prior to scaling it to a more refined and immersive version. As such, we do not mean to replace previous efforts and technologies, but rather complement them with SG techniques to enhance behaviour modelling and analysis [91].

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 by combining behaviour elicitation with the PDAs, allowing players to feature their peer agents with their own idiosyncrasy [19]. Our assumption relies on the fact that PDA is a better approach to model agent behaviours, when compared to traditional techniques based on the designer background and intuition. A more comprehensive methodology for the validation of agent behavioural models is included in our agenda for future work.

A full understanding of crowd behaviours would require exposing real people to the specific environment for obtaining empirical data, which is difficult since such environments are often dangerous in nature. In addition to studying crowd behaviour based on observations and historical records, computer simulation is a useful alternative that can provide valuable information to evaluate a design, to help the planning process, and for dealing with emergencies.

3.2 SPEED instantiation

This paper presents the first attempted partial implementation of the SPEED framework. The focus is solely on the SG component leaving the ABS for later development.

Traditionally human behaviour is elicited by means of questionnaires. However this method is prone to bias since the subjects are not submitted to the same stress and conditions of the real situation. To overcome this problem we propose using SG.

To tackle the exit-choice problem described before, we envisaged the following methodology, according to the SPEED concept:

(a) Conceive a set of scenarios typically presented in building evacuations.
(b) Specify all the variables and data to be assessed.
(c) Devise the SG and the questionnaire.
(d) Align the questions in the questionnaire with the scenarios in the SG.
(e) Submit both for Expert Panel validation.
(f) Feed-back the output from the Pilot test into the Final test.

Simply put, we can summarize the tasks to be accomplished into four main processes, as shown in the flowchart (Fig. 3). Basically the steps to be followed are: (i) conceiving the experiment; (ii) submit for validation by an expert panel; (iii) implement a pilot test; (iv) run the final test taking into account the knowledge gathered in the previous steps.

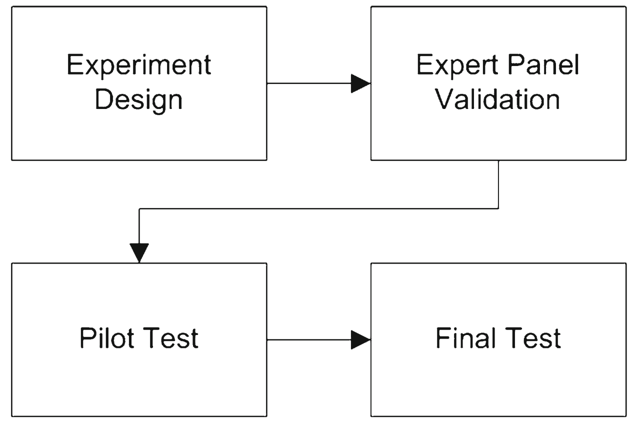

Fig. 3 SPEED instantiation flowchart

4 Experimental setup

4.1 Experiment description

We began to envision the scenario into which the subjects would be placed. This consists of an office room leading to a corridor with two possible exits. Both exit options (left or right) have the same length towards an exit door and are completely symmetrical. The test subject is placed in a hypothetical fire situation, where they have to evacuate the building as fast as possible. The subject begins the experimental scenario in said office, with no interaction other than moving and looking around being possible.

Their choice is in going left or right when leaving the room.

There are 5 scenes which take place in the same scenario. All have the same basis with slight differences:

1. Basic scenario, no cues or obstacles.
2. The only addition is an exit sign (pointing to one of the possible exits).
3. There is smoke coming from the side of the corridor to which the exit sign is pointing.
4. There is a fire in one part of the corridor (where there was smoke in the previous scene), making it impossible to use this path as the way out.
5. There are people running away from the side of the corridor into which the sign points, and towards the other exit.

It was determined that the exit sign would be pointing left. This decision was based on the empirical notion that most people would turn right in the first scene.

Each scene evaluates different variables and as such has different goals. The variables that were identified and selected as essential to be assessed in the overall experiment are as follows:

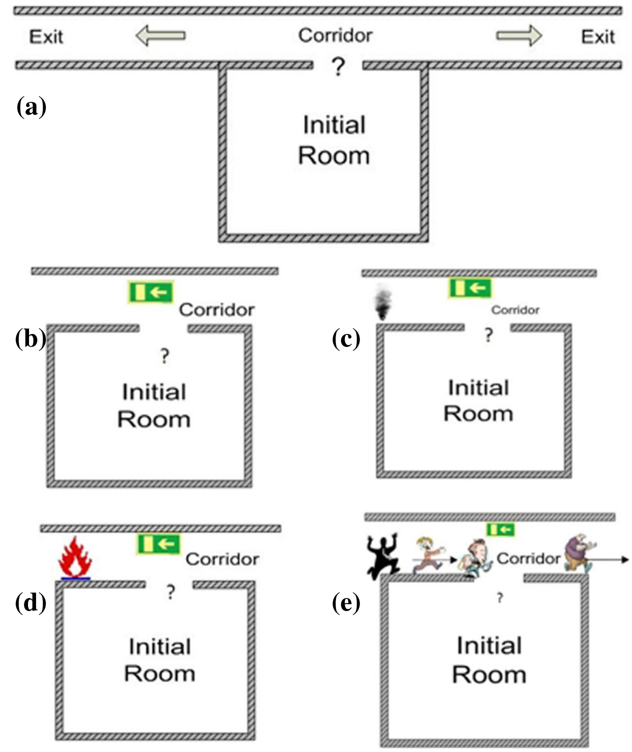

Fig. 4 Questionnaire scenarios **a** *1* no exit sign; **b** *2* exit sign pointing left; **c** *3* smoke; **d** *4* fire; **e** *5* people running opposite direction of exit sign

- Subject characterization: age, gender
- Fire knowledge (education/training)
- Tendency to turn right / or left at corridor intersections (scene 1)
- Tendency to follow signalling (scene 2)
- Tendency to take risks in emergency situations (go through smoke or go the other way scene 3)
- Tendency to trust & follow people (follow others test scene 5)
- Tendency to behave erratically (or change their minds: different answers at the same situations)

The questionnaire form was created using Google Docs. For each scene, the correspondent image is shown and the subject must select one option: either turn left or right (see Fig. 4). Results were saved in Google Docs and later exported to a spreadsheet file for statistical analysis.

The following step was to align the SG with the questionnaire. The SG must have the same sequence and challenges as the questionnaire to permit the comparison of results and thus the co-validation process. This fine tuning was an iterative process with the help of the experts who gave their insights and suggestions on the proper metrics and variables to be measured, the questions to be asked, and the expected answers for each question. Their remarks were the basis of the experimental setup for the pilot test.

Fig. 5 Bird's eye view of building layout: room with corridors leading to two possible emergency exits

The game starts with the player located at the middle of the room looking towards the door. The corridor has the same length for both sides (see Fig. 5). Whether the player chooses to go left or right, when exiting the room, they will have a 90° turn followed by a pathway leading to a double exit-door, with exit signs in the door and on top of it, as it would be in any real scenario. After a small period of time, the fire alarm triggers and the player is urged to exit the building as fast as possible, using the nearest exit. An invisible collider was put near the exit door so as to end the game level and start the next level or return to the main menu. All scenes or game levels can be seen in Fig. 6.

4.2 Expert panel

As part of the methodology described in Sect. 3.2, both the questionnaire and the SGs scenarios were presented to a group of experts for validation.

A total of 22 experts were contacted for live interviews and filling up a validation form, composed of four sections: I—subject characterization; II—knowledge on fire safety; III— psychological aspects; IV—Scenarios (questionnaire versus Serious Game). The experts were asked to evaluate every question using the typical five-level Likert-type scale (1. Strongly disagree; 2. Disagree; 3. Neither agree nor disagree; 4. Agree; 5. Strongly agree). A space for comments was included after each question.

The group consisted of fire safety engineers, fire commanders, experts from the fire safety industry and three international experts on buildings evacuation holding a PhD in the field. From the initial 22 a total of 16 responses were received.

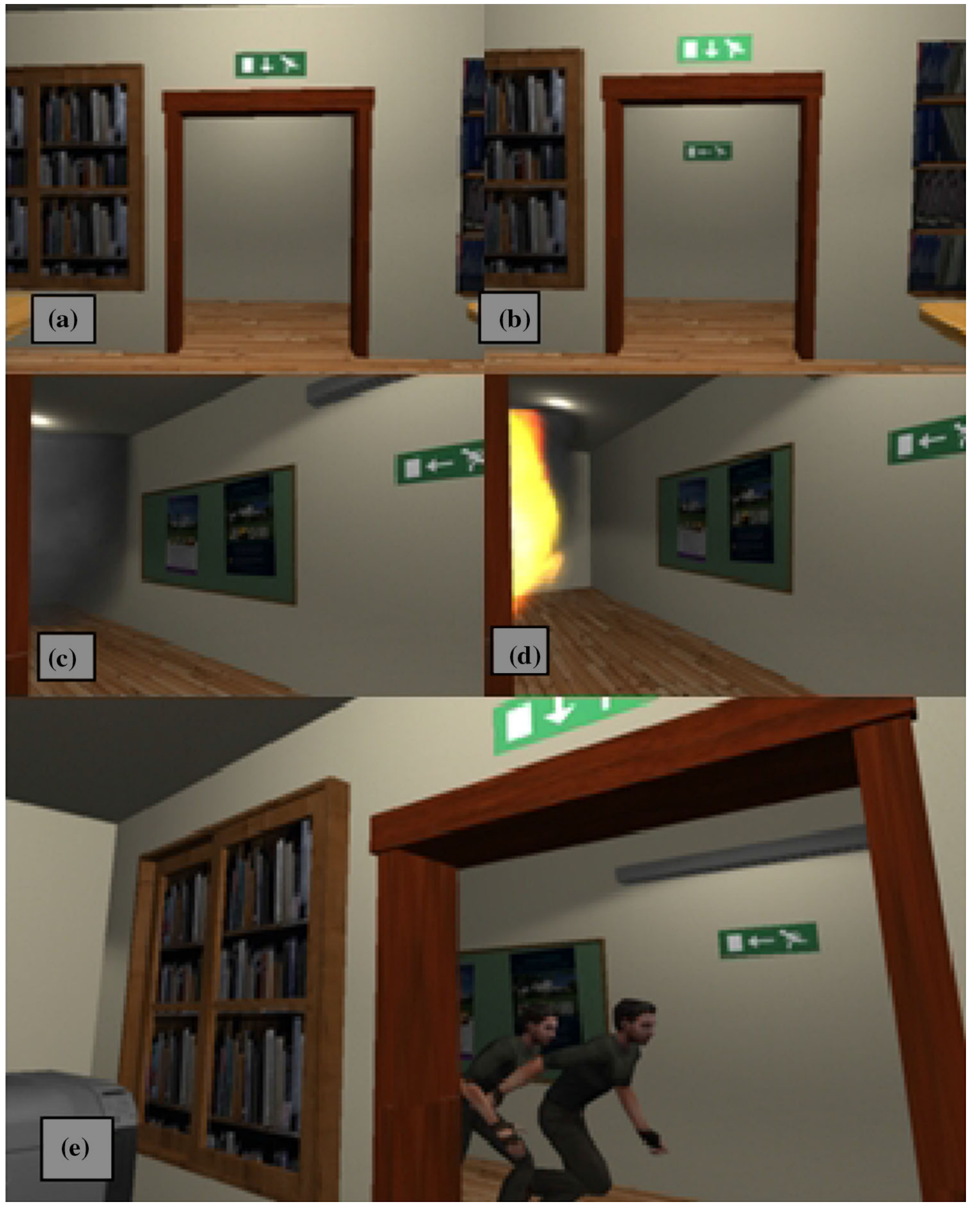

Fig. 6 Game levels **a** *1* no exit sign; **b** *2* exit sign pointing left; **c** *3* smoke; **d** *4* fire; **e** *5* people running opposite direction of exit sign

4.3 Pilot test

A pilot test was developed and two groups of volunteers were selected. The first group had to answer the questionnaire and later play the SG. The second did the same but in reverse order.

A total of 22 subjects were selected for the pilot test, eleven in each group. Mean age was 35 years (SD = 14.6; min age = 14; max age = 55; 13 males; 9 females). Results were already published [86,91]. These results can be seen in Table 1.

To level all players, the time of execution was not recorded. In previous similar experiments [13,92], the evacuation time was as an important metric to evaluate the performance of

Table 1 Data collected—questionnaire and Serious Game (pilot test)

Questions / game levels	Questionnaire		Serious Game	
	Left	Right	Left	Right
(1) No sign on corridor	6	16	8	14
(2) Sign pointing left	20	2	21	1
(3) Sign pointing left + smoke	4	18	12	10
(4) Sign pointing left + fire	1	21	0	22
(5) Sign pointing left + people running at the opposite direction	6	16	6	16

a player. However, we realized that the additional stress on steering the character and the unbalanced game experience among players biases the results, so in this setup the focus was on understanding and eliciting user choices, as well as their reasoning behind the way-finding process.

Some comments regarding the character controls, either using the keyboard or the joystick were considered and improved for the final test. For instance, the rotation speed of the joystick was considered to be too slow. Another aspect was that some players, noticeably the ones more used to playing this genre of games, did the path so quickly that they missed the emergency sign pointing left. There was one player that only saw it in the last scene.

4.4 Final test

For this final test a total of 86 subjects were selected. Similarly to the pilot test, the population sample was divided in two groups with the same purpose. One group filled the questionnaire first and later played the SG; the other group did the same but in reverse order. From these only 62 accomplished to complete both tasks. Each group had precisely 31 subjects.

These testers can be classified according to the parameters presented in Table 2. This data was collected in a questionnaire presented to the subjects at the end of the game.

The mean age of the sample group is 33 years (SD 13.33), the youngest being 12 and the oldest 76 years old. The gender distribution is 55% males and 45% females. Almost all subjects have some sort of IT experience with computers; only three admitted having almost no knowledge in this area. Almost half of the subjects, more precisely 29, claimed to be frequent video game players (46.8%); 20 subjects admitted having played some video games but were not frequent players (32,2%) whilst the remaining 13 had little or no game expertise (21%). Sixteen subjects reported having some sort of fire safety knowledge and training (25.8%) while the remaining 46 confessed having none or very little fire knowledge or training (74.2%).

To ensure a minimum time distance between playing the game and answering the questionnaire, at least two weeks were required. The date of each activity was recorded, so we could be sure that, except for two subjects that had only 11 and 13 days between tests, this was accomplished. The minimum number of days between each test was 19 days (except the two subjects referred previously) and the maximum 36 days; the average was 27 days and the mode 31 days.

Table 2 Sample characteristics

Data	Values
Number of subjects	62 (100%)
Male subjects	34 (54.8%)
Female subjects	28 (45.2%)
Minimum age	12
Maximum age	76
Mean age	33
Age SD	13.33
IT experience (as user)	59 Yes / 3 None or little
Video game expertise	29 Yes / 33 None or little
Fire safety training	16 Yes (25.8%) / 46 No (74.2%)

5 Results and discussion

5.1 Players' perspective

After the pilot test, all participants were told to recount their experience and give their contributions on how to improve the game. The use of the joystick was an improvement compared with previous experiments [13,92] that some of the subjects experienced.

Subjects that are frequent game players had no problems in controlling the character, using the keyboard plus mouse combination. Three persons had some difficulties to control the character even using the joystick.

For the final test, the questionnaire was not changed, but the game was improved to reflect the comments and suggestions made previously. The starting point was changed from the right-side workstation to the center of the room. This change made it easier for the players to steer the character, not having to go around the desk towards the exit. It also eliminated the bias that was noted by some players to move towards the left, because they were coming from the right and had the tendency to follow that path. The colliders to end each scene were moved slightly further from the end of the corridor, to make each the sequence shorter. At the end, the intention was to collect the player's decision and not if they were able to go all the way through the end of the corridor.

5.2 Results analysis

Results of the questionnaire and the SG are presented in Table 3. Although the distribution is similar overall, there are some differences that cannot be ignored.

The goal of the first question (1st level in the SG) is to try to establish a pattern of occupants when leaving a room, if there is a trend turning right or left. We had the preconceived idea that most people prefer right instead of left. And over 63 and 72% (respectively in the game and questionnaire) evidenced that theory. However there are more left turners than initially expected. Behavioural tests will be performed in the future to try to establish a correlation, if any, with character aspects.

Table 3 Data collected—questionnaire and Serious Game (final test)

Questions / game levels	Questionnaire		Serious Game	
	Left	Right	Left	Right
(1) No sign on corridor	21	41	26	36
(2) Sign pointing left	62	0	62	0
(3) Sign pointing left + smoke	18	44	30	32
(4) Sign pointing left + fire	0	62	0	62
(5) Sign pointing left + people running at the opposite direction	16	46	22	40

The goal of the second question is to counteract that reaction and force subjects to turn left. Whilst in the pilot study there was one player that missed it and turned right, in this final test all subjects followed the sign both in the questionnaire and in the SG.

The purpose of the third question 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? In this scene there is some discrepancy when comparing the questionnaire answers to the SG selections. Almost 50% of the SG players turned left, going through the smoke whilst only 29% choose that option when answering the questionnaire. Some players said that the game should have a command to lower the character and pass right through the smoke. We think that a possible explanation is smoke isn't thick enough when payer move into it. The immersion process fails by lacking the smell of the smoke and the higher air temperature.

The fourth question is similar, but this time fire appeared more intimidating and all players decided to go back and turn to the right exit. In this scene there are no discrepancies between the questionnaire and the SG.

The last question presents another dilemma: people are running to 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 chose to follow the people running, more than 63%, some said they would prefer to go the opposite direction to avoid the crowd and follow the sign.

In order to observe the association between the results of the game and of the questionnaire, the Chi-Square test was applied and when the assumptions where not fulfilled the Fisher's test was the alternative used. A significance level of 0.05 was used for the statistical evidence. To evaluate the differences between the individuals' options in the game and answers in the questionnaire the McNemar's test was used. G1 to G5 refers to the SG levels and Q1 to Q5 to the questionnaire questions.

Table 4 Association between the game and the questionnaire

Association between	P value (Chi-Square)	P value (McNemar)
G1 vs Q1	0.143	0.405 (C)
G2 vs Q2	NA	NA
G3 vs Q3	0.007 (C)	0.012
G4 vs Q4	NA	NA
G5 vs Q5	<0.001 (C)	0.109

Legend: *C* Chi-Square for independence test with continuity correction, *NA* not applicable

Table 5 Differences between gender

Association between	P value (chi-square)		P value (McNemar)	
	Male	Female	Male	Female
G1 vs Q1	0.587 (C)	0.2 (F)	0.791	0.508
G2 vs Q2	NA	NA	NA	NA
G3 vs Q3	0.463 (C)	0.001 (F)	0.180	0.031
G4 vs Q4	NA	NA	NA	NA
G5 vs Q5	0.001 (F)	0.001 (F)	0.125	1

Legend: *C* Chi-Square for independence test with continuity correction, *F* Fisher test, *NA* not applicable

All SG and questionnaire scenes are statistically similar except for the first one for which there is not enough evidence.

Table 4 shows the association between the game options and the questionnaire answers except in the first scene. In terms of differences between the individuals' options in the game and answers in the questionnaire only the third question has significant differences. The McNemar test was used for paired samples to evaluate the answers from the same subject to questionnaire and SG (see Table 4 3rd column). This showed enough evidence to say that only in scene 3 was there a significant difference between the questionnaire and the SG.

Dividing the sample according to the gender (see Table 5) we can observe that in question 3 there is a significant change among females (p value McNemar test = 0.031). The same can be seen for the chi-square test (p value = 0.001).

Table 6 shows the association between the scenes (both SG and questionnaire) and with fire training. Behaviour is consistent in the 3rd question: here we can verify that subjects with fire training experience have the same response in both the SG and questionnaire whilst the others don't have the same uniformity. This is a possible explanation for the differences noted: subjects without fire training have an erratic behaviour while others will take the same actions in a more consistent way. It is also interesting to note that of these 16 subjects only 5 are female.

Eighteen of the pilot test subjects were also part of the final test. Analysing their responses in detail (see Table 3), it was found that half of them changed at least one or more

Table 6 Fire training experience

Association between	P value (chi-square)		P value (McNemar)	
	Yes	No	Yes	No
G1 vs Q1	1 (F)	0.176 (C)	0.219	1
G2 vs Q2	NA	NA	NA	NA
G3 vs Q3	0.315 (F)	0.025 (F)	1	0.007
G4 vs Q4	NA	NA	NA	NA
G5 vs Q5	0.035 (F)	0.001 (F)	1	0.125

Legend: *C* Chi-Square for independence test with continuity correction, *F* Fisher test, *NA* not applicable

Table 7 Comparing the results between the pilot test and the final test

Association between	P value	
	Fisher	McNemar
G1 Pilot test vs G1 Final test	0.533	1
G2 Pilot test vs G2 Final test	NA	NA
G3 Pilot test vs G3 Final test	0.576	0.227
G4 Pilot test vs G4 Final test	NA	NA
G5 Pilot test vs G5 Final test	0.107	1
Q1 Pilot test vs Q1 Final test	0.008	1
Q2 Pilot test vs Q2 Final test	NA	NA
Q3 Pilot test vs Q3 Final test	1	1
Q4 Pilot test vs Q4 Final test	NA	NA
Q5 Pilot test vs Q5 Final test	0.553	1

Legend: *C* Chi-Square for independence test with continuity correction; *F* Fisher test, *NA* not applicable

answers. This is an evidence that some people change their minds and give different answers to the same questions at different times. However, as shown in Table 7 the difference between the answers to the pilot test and final test is not statistically significant. It is interesting to notice though that the only scene without association is the first scene in the questionnaire; for the SG at the same scene there is an association, meaning that the responses are similar.

To better understand the reasoning process in decision-making and to test if there is any association between the responses and psychological factors, some of the volunteers were asked to do a 16 PF-5 test [93].

This test consists of profiling some of the personality characteristics, by means of a questionnaire. As a result of years of factor-analytic research, sixteen personality factors were identified (16 PF). Based on this normal-range personality traits for which the instrument is named, there are five broad dimensions - also known as the "Big 5" factors: (i) Extraversion; (ii) Anxiety/Neuroticism; (iii) Tough-Mindedness; (iv) Independence; (v) Self-Control.

Table 8 shows p values resulting from the application of the Fisher's test, to the association between the scenes (both

Table 8 Relation between the questionnaire results and psychological dimensions

Association between	Ext	Ans	Tou	Ind	Sel
G1	1	0.588	0.188	1	0.637
G2	NA	NA	NA	NA	NA
G3	0.066	0.588	0.664	1	0.153
G4	NA	NA	NA	NA	NA
G5	0.038	1	1	0.620	1
Q1	0.316	0.245	0.638	0.620	0.620
Q2	1	1	0.444	1	1
Q3	1	1	0.152	0.131	0.620
Q4	1	1	0.444	1	1
Q5	0.596	1	1	0.294	0.294

Legend: *Ext* extraversion, *Ans* anxiety, *Tou* toughness, *Ind* independence, *Sel* self-confidence, *NA* not applicable

SG and questionnaire) and the five personality dimensions for the eighteen volunteers (of the initial 62 sample) that performed the 16 PF-5 test.

The only statistical evidence of association is in scene 5 (but only for the SG) and Extraversion. Perhaps the sample is too small or effectively there is no association between the personality factors and the scenes presented to the subjects at this test. Nevertheless, this correlation found seems promising and a sign that there are possibly other correlations between psychological factors and human behaviour in way-finding situations. Further studies on this subject are necessary.

6 Conclusions and future work

In this paper, we describe an experimental setup designed for human behaviour elicitation, using questionnaires and the serious games concept. The analysis of the data collected gave us some promising results although further research is needed. The five scenes designed with the help and validation of an expert panel have shown a strong correlation between the questionnaire and SG, except for the first one. This may be because responders answered randomly as there was nothing to guide them in choosing a side for the exit.

Further analysis showed that in scene 3 female subjects answered differently to questionnaire and the SG. Also in this scene, subjects without fire training responded differently as well.

The main goal of this experiment was to implement a preliminary test of the methodological approach for human behaviour elicitation using SG in the specific domain of way-finding in the evacuation of buildings, comparing the results with stated-preference questionnaires.

More important than the experimental results, was conceiving the methodological approach and instantiating it, which proved its feasibility.

Fine-tuning and improvements of the game scenario will leverage better results. Comments and further analysis of subjects' behaviour will be important contributions. Furthermore, expanding the experiments to more people and other scenarios might lead to better results that can be of great importance for researchers in the fire safety field. Finally, the collection of additional data that can be used to establish possible correlations (such as subject handedness or emotional response) is to be collected in future developments of this research.

The very next steps in this research are two-fold: to implement other scenarios and to use massive data collection for a larger sample of subjects to play. Expected results will be thoroughly analysed in order to try to establish some standard behaviour that might emerge from the data. For fire scientists and researchers, the human behaviour when facing the urgent need of evacuating a building is of great importance. Since the knowledge in this field is still very little, all contributions are of great value.

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