Serious Games for the Elicitation of Way-finding Behaviours in Emergency Situations

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Abstract—Understanding human behaviour in emergency evacuation from buildings is of utmost importance for fire safety designers, architects and engineers as they elaborate on strategies to improve the emergency paths to exits. This paper describes an experiment designed to elicit human behaviour when facing the urgent need of exiting a room of an unknown building. This test is part of a methodological approach that aims at the creation of a framework coined SPEED (Simulation of Pedestrians and Elicitation of their Emergent Dynamics). A population sample of 22 subjects was used to test such a methodological approach, which consists in having the subjects answering a questionnaire and later on, in playing a Serious Game. The game environment presents the same scenarios shown in the questionnaire using more elaborated 3D rendering to provide players with a sense of realism. The game was developed under the Unity3D game engine and based on the Serious Games concept. 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 signalling.

Keywords: serious games; way-finding; emergency planning; building evacuation; human behaviour elicitation.

I. INTRODUCTION

The egress of buildings when facing emergency situations is a hot topic of research within the academic community as well as practitioners: architects, engineers and building emergency managers. 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 emergency, is one specific field of research that has been keen of attention and for which no definitive theory is available [1,2,3].

Studies refer that 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, that are unknown and hard to determine [4,5].

Building safety designers use to define the egress paths based on the shortest way to the outside and other safety issues. But the possibility that the predefined route is blocked due to some unpredictable situation, such as fire, smoke or even partial collapse due to earthquake is a possibility that 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 find rapidly the best and safest way out of the building [8].

In this paper we present a preliminary experiment that was envisaged to elicit human behaviour patterns when leaving a room: they 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 SPEED: Simulation of Pedestrians and Elicitation of their Emergent Dynamics. A methodological approach was envisaged and is presented briefly, explaining the context in which the experiment described in this paper is part of.

To validate this experimental setup, a group of 16 experts on fire safety, emergency planning and building evacuation, were consulted. This group comprise Portuguese as well as foreign experts (from UK, Brazil and Italy). Professional experience includes firelighters, researchers and university lecturers (with MSc and PhD in fire safety), engineers and architects, industry (passive and active fire safety). 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 hereby described in this paper.
A population sample of 22 subjects played the game developed using Unity 3D and filled a questionnaire having the same scenario possibilities. Results were saved and analysed. Players’ were also asked to comment the experience, both the game as well the questionnaire. These will be used to enhance some game features and to prepare other scenarios as future work. Part of the data recorded is expected to be used further to drive the artificial agents trying to recreate the 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 underline 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.

II. BACKGROUND AND RELATED WORK

A. Way-finding in building evacuation

Pedestrians when evacuating a building 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 [9]. This scenario gets worse in case an emergency should arise, such as fire, blackout, terrorist attack, gas or chemical leak [10].

The behavioural process of occupants searching the best and adequate exit in such emergencies situations has been studied by many researchers for the past decades [1,2,5,6,7,8].

To correctly represent pedestrian flow, both the collective and the individual issues should be addressed such as route-choice [13]. 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 [8] has deeply studied human behaviour under emergency situations and brought some insights on this matter regarding human behavioural process during evacuation from buildings, proposes a method combining the perception of cues, interpretation of situation and risk, decision making and actions, to model human behaviour. Some authors state the evidence of leaders emerging during the evacuation process [12].

Hui Xie research was the influence of emergency signage in the way finding process during building egress [10]. His goal was to determine the impact upon pedestrian and evacuee performance and the interaction of people with signage to validate and improve existing evacuation simulators such as Exodus.

B. Serious Games

The advent of Serious Games (SG) begins with the use of video games frameworks for rapid prototyping applications that aim 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 educational as well as training. This term was presented by Clark Abt [13] long before the use of computer games for entertainment.

SGs are nowadays used in a variety of applications including education, training, health, advertising or social change [14,15,16]. According to Freitas [17], combining SG with other training activities include benefits such as: the learners’ motivation is higher; completion rates are higher; possibility of accepting new learners; possibility of creating collaborative activities; learn through doing and acquiring experience.

Loh et al. suggest that 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 [18].

C. 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 [19,20,21,22,23,24,25]. 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 [16]. These aspects briefly referred, are a subset of the reasons that are underlined in SG-based applications that makes them so common nowadays for many uses, including human behavioural eliciting.

III. A METHODOLOGICAL APPROACH TOWARDS SPEED

In the introduction we briefly presented the SPEED framework, which aim is to study the pedestrian dynamics and interactions, which concern reasoning processes, path planning, and all other aspects associated with pedestrian movement in a variety of mobility settings. 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.

The elicitation of human behaviour in such situations will help stakeholders and planners forecast potential dangerous situations and prepare the appropriate preventive actions.
The first step was the design of several preliminary scenarios that are typically present in building evacuations. These scenarios were then presented to a group of experts for validation. Their remarks were the basis of the experimental setup presented in this paper, for the pilot test. Afterwards, a questionnaire and SG were created. A group of volunteers played the game and answered the questionnaire. The evaluation of the results will be used to improve the experiment and as a basis for the development of more experiences to come. The final test will have a larger group of subjects to widen the number of responses and increase the validity of the expected results. The behaviour elicitation part integrates agent-based modelling, social simulation, and serious games, which is used both as a training tool and an important observation aid. We thus intend to the knowledge from behaviour elicitation with the peer-designed agents (PDAs) that will populate a synthetic population for evacuation simulators, the final goal of SPEED.

The SG to be conceived for the Final Test shall have a set of scenarios to simulate the various situations to be measured and tested. These scenarios will be defined on the basis of consulted literature and validated by experts. The goal is the SPEED framework, allowing experts to recreate different situations based on the set of scenarios pre-defined, consisting on a powerful tool for behaviour elicitation.

IV. EXPERIMENTAL SETUP AND RESULT ANALYSIS

A. Experiment description

The first experiment for the Pilot Test phase, described in the previous section, consists on trying to study if there is a trend on occupants’ behaviour of turning right or left when leaving a room. Common sense and some non scientific research led to the idea that most people prefer right instead of left. In the initial setup no cues are given, except that both options are equally valid, leading to safe exits.

Then, the same scenario is presented but having a left turn signage. This time, it is expected that subjects follow that indication.

The next step is to present again the same scenario, with left pointing sign, but having smoke coming from that direction. What should one do? Follow the exit indication, or avoid the smoke and go right?

This scenario experiment was an improvement of the first shown to the experts’ panel, having both smoke and fire. It was proposed by a few, to distinguish smoke from fire and test people’s reaction to both separately.

The last dilemma consists on having one sign pointing one direction (this case, left) and watching people running from that same direction! Now, what is the most reasonable action to take? Turn left or follow the crowd?

To compare the SG and questionnaire results, each subject of the selected population had to do both, play the game and complete the questionnaire. The characteristics of the sample were accessed by statistical measures, such as mean, standard deviation, minimum and maximum. The association about the answers in the questionnaire and the results obtained by the serious game was determined with the Fisher’s Test. A significance level of 0.05 was considered for the statistical evidence.

B. Population Sample

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

<table>
<thead>
<tr>
<th>Data</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of subjects</td>
<td>22 (100%)</td>
</tr>
<tr>
<td>Male subjects</td>
<td>13 (59%)</td>
</tr>
<tr>
<td>Female subjects</td>
<td>9 (41%)</td>
</tr>
<tr>
<td>Minimum age</td>
<td>14</td>
</tr>
<tr>
<td>Maximum age</td>
<td>55</td>
</tr>
<tr>
<td>Mean age</td>
<td>35</td>
</tr>
<tr>
<td>Age SD</td>
<td>14.95</td>
</tr>
<tr>
<td>IT experience (as user)</td>
<td>20 Yes / 2 None or little</td>
</tr>
<tr>
<td>Video game expertise</td>
<td>6 Yes / 16 None or little</td>
</tr>
<tr>
<td>Fire safety training</td>
<td>5 Yes (23%) / 17 No (77%)</td>
</tr>
</tbody>
</table>

The average age of the sample group is 35 years. The percentage of males is 59% having 41% of females. Almost all subjects have some sort of IT experience with computers; only two subjects admitted almost no knowledge in this area. Six are frequent video game players whilst the rest have little or none game expertise. Only five said having some sort of fire safety knowledge and training.

C. Game scenario

The game starts with player inside the office room. Looking at the image (see Fig 1a), player starts located in the desk that is positioned at right side, when looking towards the door. Corridor has the same length for both sides (see Fig.2). Either the player chooses to go left or right, when exiting the room, 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 (providing that fire codes are correctly implemented). When moving towards the exit, an invisible collider was thoroughly put in place to end the game level and move forward to next or return to the main menu.

Fig. 1 a) Screen view of the initial scenario b) Exit at the end of the corridor.

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. In the first time this scenario is shown, only
one exit sign on the top of the office entrance is presented. No other cues are given on which direction to take. Player can choose equally to turn left or right (see Fig.2). The player is urged to go as quickly as possible to the outside and to find a route to exit the building (Fig. 1b). This game level will end as soon as the player reaches a valid exit.

The next level starts exactly at the same point, the fire alarm triggers and the player must repeat the process to steering his avatar towards the nearest and safest exit. This time, however, there is an emergency sign pointing to the left (Fig. 3b). The player is expected to follow the exit sign direction but there is no deterrent if chooses the other way.

Fourth level is again similar to the previous one. The only difference is that besides the smoke, there is also fire (Fig. 3d). To prevent that player tries to pass through the fire this object is set with a collider and is insurmountable. So, all players on this scenario have no other option than escape using the right corridor.

The last level, the fifth, presents a different challenge. There is no fire or smoke, but people running from the left towards the right side of the corridor. Goal is to see the reaction of players when having to select between following the exit direction shown in the sign (left) or follow the crowd moving in the opposite direction (see Fig. 3e).

All subjects were tutored in the game controls usage, keyboard and mouse or joystick, and were given a small time to adapt on controlling the FPS character and how to move around the scenario. The players had no previous knowledge of the scenario and, to keep them the same chances, each player had only one run, to capture first reactions to the game experience and its controls, to avoid biased the data. All subjects played alone and others were kept away to avoid contamination or influence on behaviours. This aspect is an important one to be stressed because it was our expectation to acquire genuine reactions and register genuine choices.

Main menu is very simple having 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 level (five); iv) exit button (to end the game).

D. Questionnaire

A few days after playing the game, the subjects were asked to fill a questionnaire with a set of questions representing the same situations they had face previously in the virtual environment.

The form was created using Google Docs Form, and the questionnaire was easily deployed on line and made available to all subjects by e-mail. Answers were completed through a browser. A reduced number of subjects were assisted to complete the questionnaire, but their answers were totally free and independent.

In addition to the sample’s characterization questions (such as name, age, gender, education) shown previously in Table 1, some pictures were shown, each one corresponding to the five levels presented in the game, shown in Fig.4. Each one has direct correspondence with the game levels shown in Fig.3 and follows the same order.

All results were stored and compared with the ones obtained with the game. Table 2 summarizes the choices, turning left or right, of each subject.
E. Players’ perspective

After the experiment participants were told to relate their experience and give their contributions on how to improve the game. The use of the joystick was an improvement compared with previous experiments [19, 20] that some of the subjects’ experienced. However, the rotation speed of the joystick was considered to be too slow. This aspect will be improved and turning speed will be further calibrated in upcoming versions. 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 scenario. In future versions the starting point will be changed to avoid such situations.

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.

F. Results Analysis

Results of the questionnaire and the SG are presented in Table 2. It is curious that although the distribution is very similar, there are however some differences that cannot be ignored.

The first question (game 1st level) goal is to try to establish a pattern of occupants when leaving a room, if there is a trend turning right or left. Non-scientific research led to the idea that most people prefer right instead of left. And over 63% and 72% (respectively in the game and questionnaire) evidenced that theory. We suspect the initial location led some players to go forward and left, further tests are needed to corroborate this hypothesis. However there are more left turnsers than initially expected. Behavioural tests will be performed in the future to try to establish a correlation, if any, with character aspects.

The goal of the second question 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. When answering the questionnaire, two people choose to turn right, despite the sign, our believe is that they missed the sign and choose the same answer they gave in the first question/scenario.

Table II

<table>
<thead>
<tr>
<th>Questions / game levels</th>
<th>Questionnaire</th>
<th>Serious Game</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) no sign on corridor</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>2) sign pointing left</td>
<td>20</td>
<td>21</td>
</tr>
<tr>
<td>3) sign pointing left + smoke</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>4) sign pointing left + smoke</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>5) sign pointing left + people running at the opposite direction</td>
<td>6</td>
<td>16</td>
</tr>
</tbody>
</table>

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? 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 Unity 3D limitations; smoke is dark but gets thinner when approaching thus allowing to be surpassed. When responding the questionnaire, the number of subjects turning right increases a lot compared with the game (18 vs 10, or 81% vs 45%).

Fourth question is similar, but this time fire is strong and all players decided to go back and turn to the right exit using the game (they had no other possibility) but one said would go left facing the fire. We assume that as the previous scenario, that subject either missed the point or decided to challenge giving an unexpected answer.

The last question presents another dilemma: people are running the opposite direction pointed by the exit sign; what should one do? Follow the runners or ignore them and go 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. Results to this question were the same at the game and the questionnaire.

After the statistical test assumptions verification, the Fisher’s test was applied in order to show the significance of the association between the results in the questionnaire and the decisions in the serious game by the individuals. There are statistical evidences to affirm that in the first level the answer in questionnaire and the decision in the game are associated (p
value < 0.001). Although in the rest of scenarios there was not statistical evidence of the association, the distribution of answers is similar pointing to the future to use the questionnaire as a tool to acknowledge the behaviour of people in scenarios as here described.

V. 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 preliminary results that are promising although further research are work is needed.

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 wayfinding in the evacuation of buildings, comparing the results with stated-preference questionnaires.

The population sample is relatively small, and can hardly be representative of the Portuguese population, so results must be analysed with caution. Tuning and improvements of the game scenario will foster better results, we expect. 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 produce results of great importance for researchers of the fire safety field.

The very next steps in this research are two-fold: improve this experiment using the players’ comments and implement other scenarios 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 issue of the exit-selection is of great importance. Since the knowledge in this field is still very little, all contributions are of great value.

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REFERENCES


