Adaptive Serious Games for Emergency Evacuation Training

Nicola Capuano
Dep. of Information Engineering, Electric Engineering and Applied Mathematics– University of Salerno, Italy
ncapuano@unisa.it

Richard King
Serious Games Institute
Coventry University Enterprises Ltd., UK
richard.king@coventry.ac.uk

***Abstract*—The preparation of evacuation plans for public buildings and the related training is mandated by law in many countries. The traditional approaches for providing people with the correct emergency information tend to be based on long, written instructions, posted on doors and walls that are not necessarily read by occupants and on evacuation drills that are costly, rarely performed and focused on specific scenarios. To overcome these limits we propose an engaging approach for evacuation training, targeted towards primary and secondary school students and based on adaptive serious games. The student is immersed in a virtual environment representing his/her school during an emergency with the aim of evacuating and adopting the correct behaviour. Any performed action is evaluated by the system, feedback is provided immediately and also when the game ends. Recovery training material is automatically arranged and provided to the student to explain any errors he/she made and to help reach better subsequent performances. Ontologies have been used to represent emergency skills and to relate them to possible actions within the game environment. Action-based assessment and sequencing techniques have been applied to arrange useful training material.**

Keywords—emergency training; adaptive learning systems; serious games; knowledge representation.

I. INTRODUCTION

As reported in [1], the U.S. fire departments responded in 2007-2011, to an average of about 5.700 structure fires per year in schools and educational buildings. In U.K. the number of fires in schools per year (in a report dated 2007) is estimated to be between 1.400 and 1.800 [2]. In Italy, the number of fire department operations in schools, limited to fires and gas leaks between 2012 and 2013, was estimated in about 1.300 [3].

In such hazardous situations, planning and education are vital to prevent and minimize the risk to public safety. In many cases (variable from country to country) such actions are mandated by law so students and personnel must be trained to evacuate quickly and respecting security rules. Despite that, current security training approaches may be ineffective in many cases, being mainly based on evacuation instructions, signs and drills.

As pointed out in [4] *"long, written instructions, posted on doors and walls are not necessarily read by occupants, and even if they are, there is no guarantee that a single reading will allow the occupant to remember them during an emergency"*. During a real emergency, moreover, the so-called *tunnel vision* phenomenon narrows a person's attention to a very limited number of details. This can leave signs unnoticed by the occupant before taking into account difficult visibility conditions (e.g. in case of smoke).

Evacuation drills are very important exercises as they help students learn evacuation routes and useful behaviours. Nevertheless, as they are conceived, drills are hardly capable of recreating truly panicked conditions and *"it is hard to take them seriously, to fully participate, to keep focused on the exercise and to learn all the necessary information in order to evacuate correctly"* [5].

In this scenario, serious games can be used as a tool to improve the outcomes of evacuation training. Serious games are challenging, immersive, highly interactive, and able to let users play in realistic scenarios, as well as interest them and provide immediate feedback to performed actions.

Based on these considerations, in this paper we describe an engaging system we developed for evacuation training, targeting primary and secondary school students, based on serious games integrated in a complete e-learning plan on emergency and evacuation training. The value of the serious game approach, in this context is even greater in view of the audience it is addressed to.

The developed system relies upon ontologies to describe emergency preparedness skills and to map them on possible actions the user may perform within the game. In such a way it is possible to use the game both to reinforce the skills learnt during the course and to assess newly acquired ones.

The paper is organized as follows. A brief discussion on related work is presented in section 2, then the theoretical components we defined to represent skills, perform action-based assessment and course sequencing are described in section 3. The prototype is then described in section 4 as well as different game scenarios adapted to six real Italian schools in the framework of a research initiative co-funded by the Italian Ministry of Education. Conclusions and the description of future planned work close the paper.

II. RELATED WORK

Serious games are defined in [6] as *"games that do not have entertainment, enjoyment or fun as their primary purpose"*. Even if the term was first introduced in 1970 [7], serious games (with the name of "war games") were already used by the army to train military strategic skills. Thereafter serious games have been applied to a broad spectrum of application areas like government, education, corporate and healthcare.

978-1-4673-7695-2/15 $31.00 © 2015 IEEE
DOI 10.1109/INCoS.2015.32

According to several authors (like in [8] and [9]), serious games, when applied to education and training, have the potential of improving learning outcomes thanks to the level of engagement, motivation, role playing, and repeatability (i.e. failed strategies can be modified and tried again). Thanks to these benefits, the research about *Digital Game-Based Learning* is acquiring even more interest within e-learning, especially when directed to young learners.

As pointed out in [9] in fact, the current generation of students are *"native speakers in the language of digital media"* and have experienced new forms of computer and video game play that *"has shaped their preferences and abilities and offers an enormous potential for their learning, both as children and as adults"*.

In addition to the teaching function, serious games can play a role in assessment too. During the game, players take decisions that lead them to performing actions to overcome some challenge. Such actions can be recorded and used a-posteriori to appraise such decisions and, basing on that, to assess learning outcomes. This is the inspiring principle for the *Information Trails* framework defined in [10].

The idea of using serious games in emergency training is not new. For example, the *Firefighter Command Virtual Training Environment* described in [11] is aimed at training fire-fighter commanding officers. It allows the player to move in a virtual 3D environment representing a house on fire, to command fire-fighters and to watch how fire and smoke behaviour react to performed actions.

A different system aimed at a similar task (training of fire-fighters) is *Sidh* [12], a serious game based on a *Cave* simulator where the player interacts through a set of sensors with the game, moves in a virtual building on fire with the aim of visiting all rooms and evacuating all victims within the maximal time allocation.

These initiatives are similar in that they are targeted to emergency professionals and first responders rather than to common citizens with few or no prior knowledge about safety and risk management. Conversely, in [4], authors proposed a serious games aimed at acquiring basic personal safety skills by reproducing a situation in which occupants of a University building (professors, students, administrative staff) have to evacuate in case of a fire emergency.

The game is played from a first-person perspective and the character can move within the building and interact with available objects with the goal of evacuating the building following emergency signs and, at the same time, avoiding erroneous actions like taking an elevator, inhaling smoke, etc. When the game ends the system displays a report detailing the success or failure of the player, the time required to play the scenario, and the correct and incorrect actions, also explaining why they were deemed correct or incorrect.

A similar approach is presented in [13], where a serious game named *EVA*, recreating a virtual fire evacuation drill is proposed. The player starts in a given room of a building on fire and has to traverse the building to go outside as quickly as possible, choosing from one of the possible exits. Several emergency signs are in place so as to help the player to identify the nearest exit to his/her current spot.

In all the reported initiatives, serious games are seen as stand-alone training resources rather than parts of complete training plans on emergency and evacuation training. The assessment potential of such tools, the ability of discovering incorrect behaviours and the possibility to correct them with targeted training actions is underused when not completely disregarded. Our work aims at overcoming these limitations as detailed in the next sections.

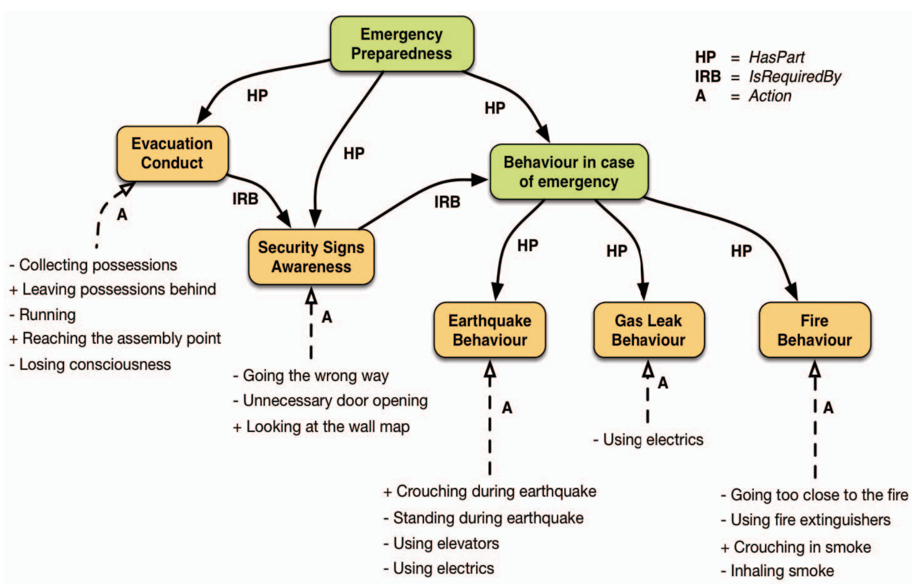

Figure 1. The ontology-based skill model.

Figure 2. Example of micro-learning resources.

III. The Theoretical Model

The serious game we propose in this paper relies on a set of theoretical components to effectively connect the game environment with external training resources and to detect correct and wrong actions performed within the game for training assessment.

In particular an ontology-based model has been defined to describe and organize the skills the learner has to acquire; a skill assessment method, based on the analysis of actions performed within the game has also been defined as well as an algorithm, based on the defined model, able to arrange micro-learning resources to reinforce missing or weak skills detected after the assessment. The following sub-sections elaborate on each of these components.

A. Ontology-based skill model

An ontology-based model has been defined in order to describe and relate the skills needed to safely perform an evacuation during an emergency. The defined model is a structure composed of nodes representing skills and edges representing competency relations.

More formally it is defined as a graph O (S, R_1,… R_n) where S is a set of skills and each R_i is a set of edges, each corresponding to a relation type. In accordance with [14] and [15], we used the following (reduced) set of relations:

- *HasPart*(s_1, s_2) means that the skill s_2 *is part of* s_1 i.e. s_1 is acquired if and only if every s_2 that is part of s_1 is acquired;
- *IsRequiredBy* (s_1, s_2) means that the skill s_1 *is required by* the skill s_2 i.e. in order to acquire s_2 it is needed to have acquired s_1 before;

The defined ontology is shown in figure 1. As it can be seen, the skill *emergency preparedness* is composed of three sub-skills: *evacuation conduct*, *security signs awareness* and *behaviour in case of emergency*. The latter skill is in turn composed of three sub-skills: *earthquake behaviour*, *gas leak behaviour* and *fire behaviour*. Moreover, the requisite relations state that the *evacuation conduct* must be acquired before the *security signs awareness* that, in turn, must be acquired before the *behaviour in case of emergency*.

For each skill, one or more micro-learning resources are connected as well as a set of possible correct and incorrect actions that may be performed in the game environment. Some examples of micro-learning resources connected with the skills *evacuation conduct* (up) and *security signs awareness* (down) are shown in figure 2.

Correct and incorrect actions are shown in figure 1 directly connected with the related skills with the additional relation *Action*. For example, positive actions (marked with a + sign) connected with *evacuation conduct* are *leaving possessions behind* and *reaching the assembly point* while negative actions (marked with a – sign) are *collecting possessions*, *running* and *losing consciousness*.

B. Actions-based assessment

Each action a has an associated mark m_a where positive actions have a positive mark and negative actions have a negative mark. Marks are usually settled to values belonging in the range (-2, 2). Moreover, each skill s has an associated evaluation e_s representing the degree of achievement of the skill s reached by a given learner. Evaluations are initially settled to 0 and may become positive or negative according to actions performed by the player within the game.

The aim of the action-based assessment is to estimate the value e_s for each s based on actions $\{a_1, \ldots, a_n\}$ performed by the player in the serious game. To do that, after every interaction with the system a general evacuation mark m is calculated with the following equation:

$$m = \begin{cases} \max\left(0, \dfrac{\tau - t}{\tau}\right) & \mathit{if\ the\ evacuation\ succeeded} \\ -1 & \mathit{otherwise} \end{cases}$$

Where t is the time spent by the player to successfully finish the game (i.e. to evacuate the building) while τ is the time limit expected for the played scenario.

Intuitively, the less time spent to complete evacuation, the higher is the score obtained. In case the player does not finish the game, m is settled to -1. After that, the value of e_s

is calculated, for each skill s, according to the following equation:

$$e_s = km + \sum_{a \in A(s)} n_a m_a$$

where n_a is the number of times the action a has been made within the game by the player, $A(s)$ is the set of the actions connected to the skill s (as reported in the skill model) and k is a constant (usually settled to a value between 1 and 5) that regulates the impact of the player's global performance on the skill evaluation.

Skills showing an evaluation $e_s > 0$ are considered as acquired by the learner while skills so that $e_s \leq 0$ have to be supported by micro-learning resources that are arranged according to the algorithm described in the next sub-section.

C. Arrangement of micro-learning resources

The arrangement of micro-learning resources is done soon after the action-based assessment step described in the previous sub-section, starting from the set of target skills $T = \{s \in S \mid e_s \leq 0\}$. The process, according to [16], is made in three subsequent steps.

The *first step* is aimed at building, from the ontology O, the simplified graph $O'(S, HP', IRB')$ where HP is the set of edges corresponding to the inverse *HasPart* relation while *IRB'* is initially settled to include every edge corresponding to the *IsRequiredBy* relation but it is then modified applying the following rule: each arc $ab \in IRB'$ is substituted with arcs ac for all $c \in S$ such that there exist a path from c to b on the arcs from HP'. The figure 3 shows the graph O' obtained from the ontology reported in figure 1.

The *second step* is aimed at building the graph $O''(S', R)$ where S' is the subset of S including all skills that must be acquired according to T i.e. S' is composed by all nodes of O' from which there is an ordered path in $HP' \cup IRB'$ to nodes in T. R is initially set to $HP' \cup IRB'$ but all arcs referring to concepts external to S' are removed.

The *third step* finds a linear order between nodes of O'' by using depth-first search so by visiting the graph nodes along a path P as deep as possible. Then it deletes from the path all internal nodes i.e. all nodes a so that $ab \in HP$ for some b. This ensures that only leaf nodes (with respect to the HP relation) are part of path P. The figure 3 shows the graph O'' obtained when T = {*Earthquake Behaviour*} as well as the obtained path P.

The system then finds feasible micro-learning resources linked to each skill of P and builds the *training path* that must be followed by the learner to acquire useful supporting knowledge for detected missing skills. The learner can then play again with the serious game in a different random scenario.

IV. THE SERIOUS GAME

The developed serious game adopts a three-dimensional environment where the player has freedom of movement to explore in a first-person perspective. Built with the *Unity 3D Game Engine*, the game has been customized on the maps of 6 different Italian schools from 2D architectural schematics guided by photos taken inside school buildings and used to increase visual fidelity.

The architectural schematics have been imported into a 3D modelling application and adapted to create a coherent structure suitable for first-person rendering. They were then imported into a game engine. This import path presented several challenges in adapting a model originally unintended for real-time rendering to be suitable for a real-time and exploratory environment: polygon counts and textures had to be managed to allow adequate performance, and corrections made to the model to support freedom of movement through the building.

Collision meshes have been implemented and a simple physical model for the player camera, ensuring the player is constrained by gravity and solid objects. Light sources are positioned by the designer and walls are textured using images coming from interior photos. Similarly the floor is retextured, using specular and normal mapping to emphasise the divisions between individual boards.

The figure 4 shows the process of creation of the school building from blueprints (a) to the complete 3d model (b). The interior (d) has been designed and textured to be as close as possible to available photos (c) also taking into account performance constraints.

In order to improve game performances, scenario paths have been drawn: the areas of the building through which the player is allowed to navigate have been mapped in advance for each scenario (see figure 4a). In this way it was possible to increase the fidelity of these areas and remove extraneous content through occlusion culling.

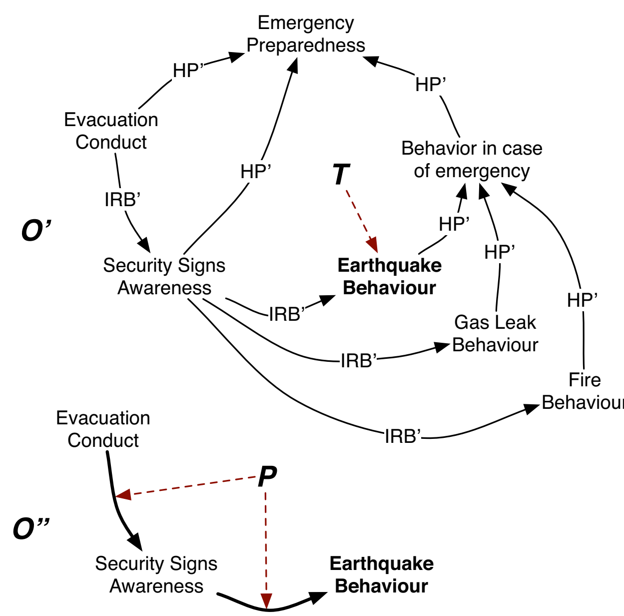

Figure 3. Example of training path generation.

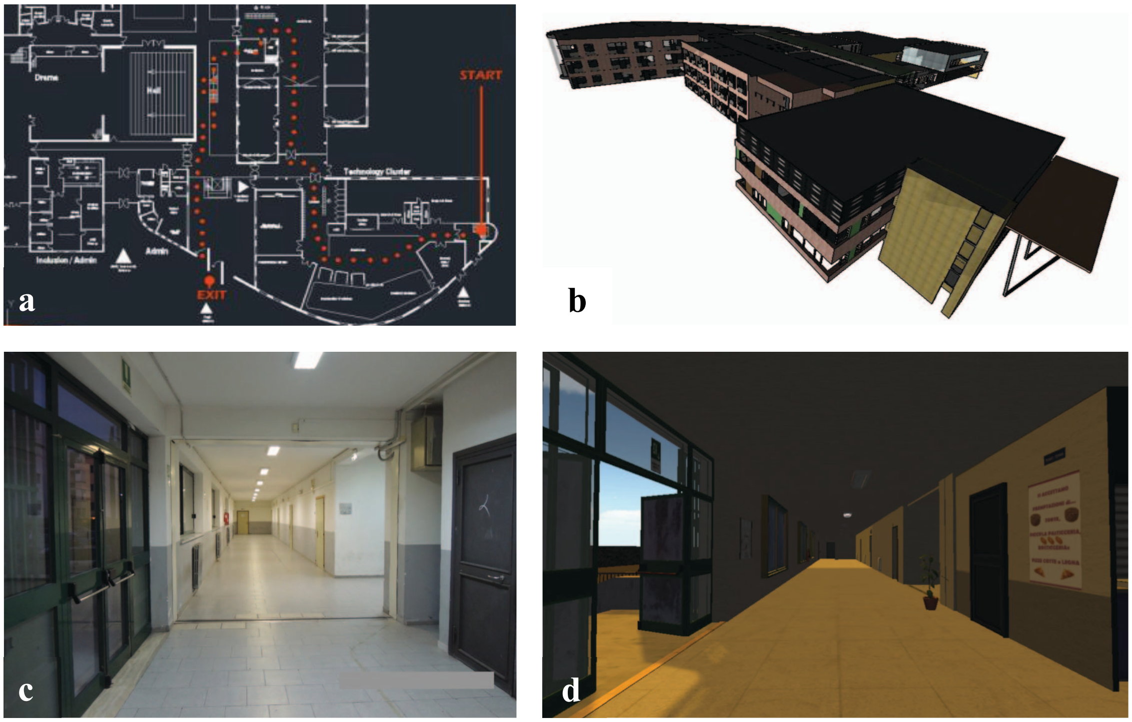

Figure 4. Virtual 3d model creation: (a) building blueprint; (b) the 3d model; (c) interior photo; (d) interior model.

The environment is populated with simulative objects in the form of three dimensional models and textures. Objects like fire and smoke (see figure 5a) are capable of inflicting damage to the player. Image post-processing is used in order to distort and obscure vision upon exposure to smoke, this is accompanied by a *health bar* that shows the level of smoke exposure. The implementation of these overlaid elements, which include a timer, are examples of game-based elements being introduced, reducing the fidelity of simulation towards the goal of creating an effective gameplay model.

Several other interactive elements have been included in the game like evacuation maps (see figure 5c), elevators, extinguishers, fire alarms, doors, etc. To improve the fidelity, in the earthquake scenario individual ceiling tiles are added and given physical behaviours using the same model applied to the player; as the simulation starts these tiles fall and collide with the floor (see figure 5b).

The game monitors and identifies key actions through the implementation of virtual *checkpoints* within each scenario, recording players' time and state as they pass within a radius of a single point within the virtual space.

This allows for a number of metrics. For example total evacuation time is assessed in terms of time from starting to exit checkpoints; placing multiple path checkpoints, route selection is analysed; checkpoints linked to individual items, e.g. an elevator call (see figure 5d), indicate whether a player activates the item and registered the action for assessment.

The implementation of these checkpoints is invisible to the player. Data gathered through checkpoints is used both immediately to provide feedback about performed actions and at the end of the game to build the list of actions that are sent to the *action-based assessment* module together with the total playing time. The specific action *Reaching the assembly point* states that the evacuation succeeded.

At the end of the game the general score *m* is calculated according to the equation provided in section 3 and displayed to the learner. A personalized message is then built and displayed according to reached goals. Micro-learning resources are then arranged according to performed actions and provided as a support to improve evacuation behaviour.

Communication between the *Unity 3D Engine* and the assessment and micro-learning components is performed through the *Unity Scripting API* invoked by *Javascript* code embedded in the player Web page. Assessment and learning components have been developed in C# and integrated in an existing learning system named IWT [17].

V. CONCLUSIONS

According to several studies serious games are effective tools able to support training for emergency preparedness. Their immersive approach lead in fact to the player acting as if situated in a real scenario while, adding game elements, results in increased learning transfer and retention thanks to engagement and focus on specific tasks.

Basing on these premises we developed an interactive serious game for evacuation training targeted to primary and secondary school students and based on thought integration with an adaptive training engine able to discover incorrect behaviours based on the analysis of learner actions within the game and to correct such behaviours through the on-the-fly arrangement of ad-hoc micro-learning modules.

The game has been customized on maps coming from 6 different Italian schools in order to provide the maximum level of fidelity also taking into account the position of the emergency signs and exits. An experimentation with real students coming from these schools is planned for the beginning of the next school year.

REFERENCES

[1] Campbell, R., *NFPA's Educational Properties report*, 2013.

[2] Wade, P., Teeman, D., Golden, S., Wilson, R., Woodley, V. *The impact of school fires, a study of the wider economic and social impacts on schools and the local community*, 2007.

[3] Vigili del fuoco. *Annuario statistico del corpo nazionale dei Vigili del Fuoco*, 2014.

[4] Chittaro L., Ranon R. *Serious games for training occupants of a building in personal fire safety skills*. Int. Conf. on Games and Virtual Worlds for Serious Applications, IEEE, 76-83, 2009.

[5] Ribeiro, J. Almeida, J.E., Rossetti, R.J.F., Coelho, A. Coelho, L. *Using Serious Games to Train Evacuation Behaviour*. Conferencia Ibérica de Sistemas y Tecnologías de Información, 771-776, 2012.

[6] Michael, D., Chen, S. *Serious Games: Games That Educate, Train, and Inform*. Course Technology PTR, 2005.

[7] Abt, C. C. *Serious Games*. Viking Press, 1970.

[8] Corti, K. *Games-based Learning; a serious business application*. PIXELearning Limited, 2006.

[9] Susi, T., Johannesson, M., Backlund, P. *Serious Games - an overview*. Technical report, HS-IKI-TR-07-001, University of Skövde, 2007.

[10] C. S. Loh, Anantachai, A., Byun, J., Lenox, J. *Assessing what players learned in serious games*. 10th Int. Conf. on Computer Games: AI, Animation, Mobile, Educational & Serious Games, 2007.

[11] Julien, T.U.S., Shaw, C.D. *Firefighter command training virtual environment*.Conf. on Diversity in Computing, Atlanta, Georgia, USA: ACM, 30-33, 2003.

[12] Backlund, P., Engstrom, H., Hammar, C., Johannesson, M., Lebram, M. *Sidh – a Game Based Firefighter Training Simulation*. 11thInt. Conf. on Information Visualization, IEEE, 899-907, 2007.

[13] Silva, J.F., Almeida, J.E., Rossetti, R.J.F., Leca Coelho, A.*Gamifying evacuation drills*. 8thIberian Conf. on Information Systems and Technologies, IEEE, 1-6, 2013.

[14] Capuano, N., Gaeta, M., Miranda, S., Orciuoli, F., Ritrovato, P. *LIA: an Intelligent Advisor for e-Learning*. Lecture Notes in Computer Science Series, Springer-Verlag, 5288, 187-196, 2008.

[15] Capuano, N., Gaeta, M., Ritrovato, P., Salerno, S. *Elicitation of Latent Learning Needs Through Learning Goals Recommendation.* Computers in Human Behavior, Elsevier, 30, 663-673, 2014.

[16] Capuano, N., Salerno, S., De Maio, C. *A Knowledge Based System for Guidance and Training on Legal Concepts*. 6thInt. Conf. Intelligent Networking and Collaborative Systems, IEEE, 498-503, 2014.

[17] Capuano, N., Longhi, A., Salerno, S., Toti. D. *Ontology-driven Generation of Training Paths in the Legal Domain*. Int. Journal of Emerging Technologies in Learning, 10 (7), 14-22, 2015.

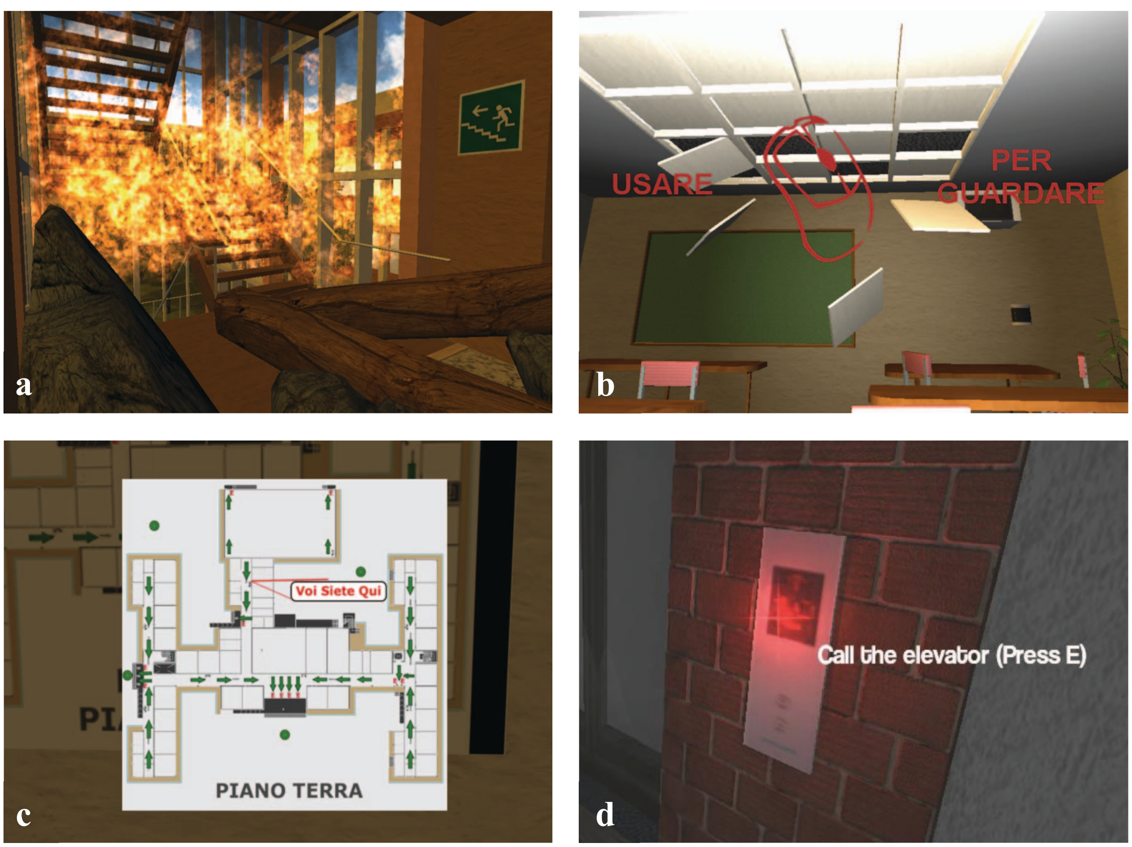

Figure 5. Screenshots from the serious game