Evaluation of the Effects of Anxiety on Behaviour and Physiological Parameters in VR Fire Simulations

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***Abstract*— This study considers the use of virtual reality technologies both to evaluate the optimal exodus paths from buildings and to analyze the behaviour of people in emergencies through the monitoring of physiological parameters. The degree of realism with which VR devices can simulate highly anxiogenic scenarios is considered. The experimentation is carried out on a school building and tested through a pilot trial where saturation, blood pressure, heart rate as well as the time of exodus are monitored. The variations of the peak values of physiological parameters highlight the influence of anxiogenic elements in the participant's state of anxiety.**

Keywords— Virtual Reality, Anxiety, Physiological parameters, Building Information Modelling, Exodus

I. INTRODUCTION

Nowadays, there are more and more studies and applications that exploit Virtual Reality (VR) to investigate human processes in defined situations. In the medical and biomedical field, it is used for training of qualified personnel [1], cognitive and functional rehabilitation of patients [2], and therapies related to anxiety and panic disorders. The advantage lies in the fact that it allows interaction not only with imaginary environments but with real backgrounds in very delicate or dangerous situations [3] to be examined. This thread opens up new possibilities for the analysis of psychophysical reactions triggered by emergency or hazardous conditions that would be too dangerous to investigate outside of a simulated context. In recent years, many researchers have tried to analyze how the physiological parameters vary in a scary and anxiogenic situation [4]. Results are very different for each physiological parameter considered but with an overall tendency for them to have minor variations within the virtual simulation compared to those that would be had with a real experience. In particular, this is true for oxygen saturation, blood pressure and heart rate [5]. The same consideration can also be extended to research related to anxiety [6]. However, by combining physical and physiological parameters from a simulation in low-risk digital environments, anxiety symptoms can be reduced, thanks to specific studies conducted on the feedback released by users. The objective of this study is to check the exodus procedures of a building by using new technologies to simulate and assess the human behaviour in case of emergency. Equipping human beings with innovative tools guarantees a more significant increase in their persuasive capacity to dominate their emotional state. In these terms, new technologies for the simulation of the human movement assume nowadays a fundamental role in the control of anxiety and in the search for solutions that reduce panic. The user is supported by devices connected to sensors that monitor its emotional state and define the best solutions to share with other users during real events. Virtual Reality thus becomes a useful tool in the management of safety and security protocols. As an example, the 66% of the injured people and about half of the deaths in case of fire occur due to incorrect management of the emotional state and lack of knowledge of the places and exodus paths [7]. This fact happens because people are not trained on how to behave in such an event and lose time in activities that delay the start of exodus manoeuvres, drastically reducing the chances of survival. It is necessary to improve virtual exodus simulations according to a truthful and reliable experience to outline the best human behaviour. More data can be collected through virtual simulations; more actions can be taken to improve user behaviour. Currently, there is a gap between the design solutions and their effectiveness in the real context. Virtual Reality can overcome this gap providing the instrument to simulate better and manage emergencies. The following contribution takes into consideration the methodology and tools necessary to develop a digital model suitable for carrying out virtual exodus simulations in case of fire with the purpose to help users to control their emotional state during an emergency. Within this context, the Building Information Modelling (BIM) approach can extend the possibilities offered by the digitalization of the existing heritage to formulate an increasingly effective design and renovation scenarios by participatory processes.

II. METHODOLOGY

A. Case study

The objective of this study is to check the exodus procedures of a building by using new technologies to simulate and assess the human behaviour in case of emergency. As the highest number of fire deaths involves children under eleven years of age and older people [8], the case study is a compound of primary and secondary schools in Turin. The choice fell on this infrastructure as it presents a complex architectural conformation organized in three pavilions connected by large vertical distribution spaces. The coexistence of areas and activities of the two schools and the presence of several floors above ground requires particular attention for the analysis of the exodus routes. Moreover, the school is characterized by several types of users of different ages.

B. Workflow

Analyzing the structural conformation of the building, two different scenarios of simulations have been developed. The objective of the first scenario is to calculate the time needed to reach a safe place by verifying the effectiveness of the security signs placed in the field. The second case simulates unforeseen events along the exodus path that involve different reactions and decisions on the part of the user. These virtual experiences have been submitted to 25 candidates and parameters such as oxygen saturation, blood pressure, heart rate have been measured beside the time required for the exodus [9]. The comparison of the peak values is studied to evaluate how much the anxiogenic elements influenced the anxiety state of the participants within the VR simulations. The methodological workflow for the development of this study has involved the following steps: (i) data collection and survey, (ii) BIM model setting, (iii) digital environment simulation, and (iv) trail and scenario validation.

Phase 1: Data collection and survey

In the context of fire prevention, the identification of the best strategies for escape in case of emergency is one of the most critical factors to speed up evacuation procedures and limit risks and damage to people and assets in the building. Several data can be useful to analyze the flows and manage simulations optimally. The emergency plan drawn up during the risk prevention and assessment phase contains the most relevant information and procedures to consider for the management of dangerous situations in strategic buildings. As required by several Italian regulations, the evacuation plan for public buildings comprises the map of the building with the escape routes [10] and the relative emergency exits [11], the safe places and meeting points, and the location of the fire-fighting equipment [12], as well as the procedures to be put in place. In particular, for school facilities, the exodus routes in case of emergency must be followed in a single row, where the row opener is the one closest to the door while the row closer is the one farthest from it. The teacher has the task to make sure that no one is present in the classroom and help any students in difficulty [13]. Besides, the evacuation of some people, such as disabled students or those with temporary impairments, requires dedicated procedures. A field survey verified the information collected. On this occasion, the exodus routes were simulated, and the times were recorded. Besides, the researchers who carried out this study participated in one of the real evacuation tests that took place in the school complex. Based on these checks, three possible escape routes are available. Two require the use of external fire escape stairs leading to the large courtyard at the back of the building, while the one referring to the central block of the structure take instead of the internal stairs and leads to the street in front of the school complex. All these routes, carried out at a moderate pace following the signs and without getting in the way, are characterised by a journey time of about 80 seconds.

Phase 2: BIM model setting

To configure a simulation close to reality, it is necessary to set up a three-dimensional digital model of the building as a virtual environment. In this study, the BIM has been exploited to create a coherent repository for the case study.

The model provides a logical synthesis of heterogeneous sources collected: archive design drawings, actual state of the building, occupancy, emergency and evacuation plan. Data are inserted as informative attributes to characterize building components, internal and external areas. Parametric objects are used to map the exodus paths verifying the length, the number and the dimension of the emergency exits. In this way, this information can be managed and queried any time within the building lifecycle with different scope. As an example, the modelling of fire-fighting devices within a BIM system allows them to be managed for maintenance purposes. Within the area of this study, the graphic representation is very accurate to provide the virtual experience of greater realism (fig. 1). All the objects needed to make truthful the exodus simulation are included in the model, such as furniture, desks, chairs, as well as exodus path and exits. As signage, are a crucial element for users, they are carefully represented considering their typology, shape and colour. The signage has been reported in a consistent manner with respect to what is present in the building. However, the tools put in place provided the opportunity to design and test a ground lighting system that allows the user to reach a safe place even with poor visibility due to smoke. The elements are organized in the model in such a way that they can manage different scenarios. The advantage of having used this methodology lies in the interoperability of the model that can be exported into more accurate software for smoke and fire propagation simulations, exodus and structural analysis. Thus, a multitude of professionals can make a useful contribution to building analysis from the same information source.

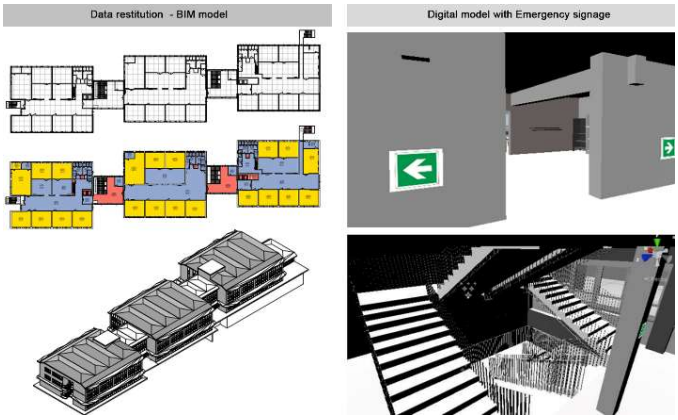

Fig. 1: BIM model implementation

Phase 3: Digital environment simulation

Once the BIM model is created, it is necessary to use other visualization platforms to increase the possible interactions with the virtual environment. The Unity software is chosen for the creation of the virtual reality application. To optimize model export, Autodesk 3Ds was used as bridge software. The standard exchange format used is FBX. Unity, as a cross-platform game engine, is used to develop interactive content. In the framework of this study, Unity has been exploited both to enable the user's movement inside the virtual building and to define its interaction with the environment, and to create some components that dynamically follow the interactions with the user.

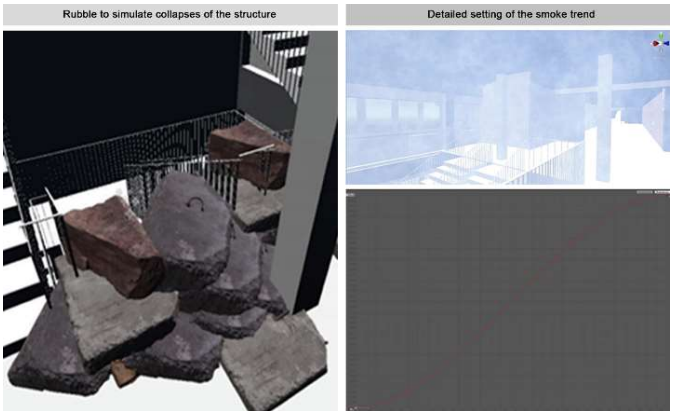

Fig. 2: Smoke propagation modelling

The most significant development indeed refers to the creation of a script for the modelling of the fire and smoke propagation. Their effects are intensified as a function of the time spent inside the environment. After 60 seconds, the smoke is so thick that it decreased the participants' depth of vision drastically (fig. 2). The simulated scenario foresees a fire spread over all floors. The smoke was therefore programmed to develop on all floors at the same time, with the same intensity and with the same rate of increase. In this way, whatever path the user followed would be exposed to the same amount of smoke. To make the simulation more complex and articulated, obstacles have been introduced along the exodus routes, such as rubble to simulate collapses of the structure. These elements force the user to make alternative choices according to the specific situation in which he is inserted, increasing the level of anxiety. As mentioned before, two different scenarios are implemented with varying possibilities of interaction by the users. The first one faithfully reproduces the exodus from classrooms in case of fire. It has been used to evaluate the realism of the simulation, besides to compare the exodus times recorded during VR experiences with measured in the school during the survey. In the second simulation, participants must select the escape route not only according to the signs but also concerning the presence of debris occluding the escape routes. This scenario increases the stress of the participants who have to spend more time inside the building to reach a safe place in an increasingly anxious virtual environment. The technologies used for this case are the HTC Vive immersive viewers connected to an omnidirectional platform, called Cyberith Virtualizer, that allows simulating human walking through sensors positioned on the floor and wearable. In this way, the user is completely immersed in the virtual scene and can control reactions with natural movements.

Phase 4: Trial and scenario validation

The simulations carried out were tested and verified through a structured trial. The twofold objective is both to validate the virtual model and the timing of the exodus simulation with respect to the real configuration of the building, and to analyse human behaviour in dangerous situations. For this purpose, a sample of 25 participants from different age groups and cultural backgrounds was recruited. In this experimental stage, it was not possible to submit the simulation to the children actually attending the school. However, the participants were selected to best represent middle school students, teachers and operators. As the participants were not familiar with the technologies used, it was considered appropriate to carry out preparation for the immersive path, through a comforting scenario. It consists of a large floor with some high geometric blocks within which users can move around freely. This prior experience does not present any stimulus or anxiogenic element, but it is useful to gain confidence with the movement on Cyberith Virtualizer. Recreating a comfort and psychophysical well-being situation is necessary to be able to monitor vital parameters and compare them in moments of great emotional and physical difficulty.

Before moving on to the two simulation scenarios, the physiological parameters of the participants were recorded. In particular, oxygen saturation, blood pressure and heart rate, have been considered. These were measured respectively with an oximeter, a wrist sphygmomanometer and a smartwatch. With the aim to collect more information from the test, the users were divided into two groups. To the first one, composed of 15 people, no information is provided regarding the content of the fire exodus simulation. In contrast, the second group of 10 people was trained in-depth on dangers and evacuation methods. The choice to divide the sample into two parts was of fundamental importance for the comparison of the parameters. In particular, the behaviour of those who are not prepared for an unforeseen situation is different. To make the participants' behaviour comparable, the simulation was conducted for everyone from the same classroom, located on the second floor of the central block. This scenario is more interesting to consider than other possible ones because the exodus route is indoor and does not make use of external emergency stairs. Although mapped within the BIM model, fire-fighting devices have been overlooked for virtual simulation to discourage any attempts by the user to extinguish the fire. Context sounds, such as the siren of a fire alarm, the screams of children and a fast beating heart, have been reproduced via the Bluetooth headset of the sensors. When the participant is immersed in smoke, there are coughing and choking sounds. Furthermore, participants were exposed to a heat flow, realized with a space heater, to generate more stress during all the exodus simulations (fig.3). This latter was only used when attendee wore the HTC Vive so that they weren't aware of what was happening. All these elements have contributed to the multi-sensory nature of the simulation, guaranteeing a realistic and immersive experience. The sight is certainly the most stimulated sense, but also the touch is guaranteed by the possibility of movement and the perception of heat given by the heater, the hearing through the sounds delivered and the olfactory is triggered by the slight smell of burning emanated.


Fig. 3: User during the virtual simulation.

The peak value of each physiological parameter recorded before was then compared with that obtained from the fire exodus simulation. The comparison allowed evaluating the physiological effect of the virtual anxiogenic stimulus on the state of anxiety of the candidates. At the end of the virtual experience the participant is asked a series of questions through a questionnaire to assess the degree of immersion, perception and level of anxiety generated by the simulation.

III. Results

The simulation time returns the first indications. Both groups recorded timeframes superior but comparable to those recorded during the survey (80 seconds) for the first scenario. In particular, Group 2, which was aware of how the simulation was carried out, reached a safe location in an average time of 90 seconds. Group 1, on the other hand, despite not having received any information, immediately recognized the situation and sensed the need to evacuate from the building thanks to alarm recognition, with the exception of one case. The average time was 100 seconds. All participants complied with the indications of the safety signs, getting a realistic timeframe for the exodus. The realism of the simulation has influenced this result. The more significant is the accuracy of the representation, the greater is the probability of inducing behaviours similar to those that one would have in reality.

As for the second scenario, in which unexpected obstacles are introduced, the timing has increased considerably. The average time of exodus recorded was 273 seconds for group 1 and 233 seconds for group 2. These values highlights the hypothesis that sudden danger situations even if only virtual can significantly affect the control of anxiety and panic, leading to non-rational choices and unpredictable behaviour (fig.4). The higher time of participants is conditioned by several factors such as familiarity with the immersive technologies and virtual walk, recognition of the places and the signage, besides the appearance of anxiety or panic.

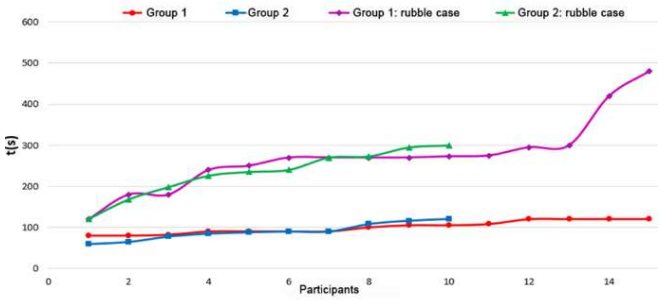

Fig. 4: Exodus Time

Regarding the physiological parameters, it is possible to highlight strong fluctuations of the recorded values, especially for the second scenario and for group 1 compared to group 2, with a great interpersonal variability. In particular, the heart rate and blood pressure showed considerable percentage variations moving from the comforting scenario to the exodus simulations. This is true most of all for the heart rate for which it was recorded a mean percentage change of 15% for group 1, more than the double than group 2 variation. In addition, systolic blood pressure also presented significant percentage variations, with some percentage points less than those recorded for heart rate. The oxygen saturation and the diastolic blood pressure instead did not have remarkable variations, most of all regarding group 2. Analyzing the results, a trend of group 1 to show greater variations than group 2 was observed. The main example is the maximum percentage variation of the heart rate, which was 43% for group 1 and only 15% for group 2 (fig. 5). As general considerations, the smaller variation of the group 2 parameters is due to the consciousness of what participants were supposed to do in the simulation. Heart rate of group 1 subjects recorded the highest variations, because of the surprise effects leads to stress and therefore an increase in heart rate even before the simulation starts. The same happens for blood pressure, being intimately correlated parameters. Concerning the participants' level of anxiety, no situations of hyperventilation or hysteria were detected. Some subjects in group 1 showed more evident effects. Only one participant lost lucidity of reasoning and could not find the exit. Two people climbed to the upper floor of the building in search of a way out. This fact denotes irrational behaviour dictated by initial symptom of an emerging panic condition even if there is a lack of knowledge of the behavioural rules to be followed in such circumstances. However, considering the increase in vital parameters, it emerges that Virtual Reality can be used to arouse strong emotions in the user even if not to the point of inducing totally irrational or breathless behaviour. The high timeframes are due to the poor predisposition of some people to make effective decisions quickly in case of stress. As confirmed by 90% of user feedback, the multi-dimensionality obtained by various means has facilitated the immersion in the virtual setting and represent a significant added value providing a much greater contribution than only a high graphic detail.

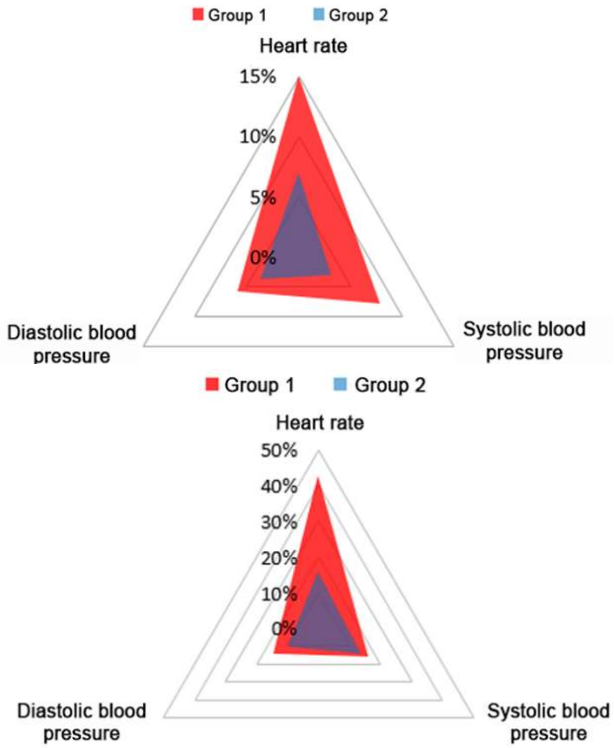

Fig. 5: Mean and maximum variation of physiological parameters peak values recorded in the scenario 2

IV. Conclusions

Previous studies [14] [15] [16] in the literature have shown that one of the main limitations of VR experience is the difficulty to bring out in users the same psychophysical reactions that they would experience in reality. Thanks to the state of the art technologies used for this study and the multi-sensory and multi-dimensional approach, it has been tried to overcome this limitation by introducing elements that guarantee an involving virtual experience as close as possible to reality. Among the strengths are undoubtedly the use of the Cyberith Virtualizer that enables the user's natural movement and the use of BIM digital model, which can be implemented for other purposes to achieve realistic environments quickly. Within the exodus simulations, it emerged that finding oneself suddenly in a dangerous situation, even if only simulated in VR, significantly affects the state of stress of the subjects, even more than the emergency itself. The participants faced unexpectedly in a dangerous situation present more significant increases on average in their physiological parameters as well as a substantial increase in the measured exodus times. However, given the intrinsically destructive nature of fires, there are no real data with which to compare whether the level of anxiety recorded is comparable to that which would occur in reality. Nevertheless, the analysis of the results revealed the possibility of generating highly stressful conditions for people subjected to anxious virtual simulations. On the basis of the results obtained, future activities are planned to further investigate the correlation of the parameters to the situations, also by expanding the number of users involved [9]. Being able to test a dangerous situation, in a safe place is an excellent possibility to rationally manage events and control movements and ways of thinking that could intervene in a real emergency [6]. According to this potential of VR technology, new areas of use of these devices can be glimpsed. Activities such as qualified experts training for the management of dangerous situations, including firefighters, and the education of students and users to evacuate a public building or infrastructure in case of fire or emergency are among those that arouse the most interest. This method can entail not only a reduction in costs since everyone could carry out the same training in the same place but also the possibility of repeating as many times as desired the most critical parts of the virtual simulations without risk to the safety of any of the subjects. In this way, the contingencies can be limited, and above all, panic management can be improved better, controlling the emotional state thanks to practice. By combining the use of Building Information Modelling and Virtual Reality, the scientific research gains a great possibility and tools to enrich the evaluation concerning the physiological processes triggered by emergencies that would be too dangerous to handle outside of a virtual simulation.

Acknowledgment

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References

[1] Gupta S. C., Patchva S., & Aggarwal, B. B. (2013). Therapeutic roles of curcumin: lessons learned from clinical trials. The AAPS journal, 15(1), pp. 195-218, 2013.

[2] De Luca, D., & Ugliotti, F. M. (2020, September). Virtual Reality to Stimulate Cognitive Behavior of Alzheimer's and Dementia Patients. In International Conference on Augmented Reality, Virtual Reality and Computer Graphics (pp. 101-113). Springer, Cham.

[3] Patil A., Sapre A., Sathe M., Singhvi A., Sinha R., Rathi V. (2012). Earthquake Disaster Simulation in Immersive 3D Environment, In: proceedings of the15th World conference on Earthquake, Mumbai, India, pp. 1-2.

[4] Blankendaal R., Bosse T., De Jong T., De Man J., Gerritsen C., Are Aggressive Agents as Scary as Aggressive Humans? in: Proceedings of the 14th International Conference on Autonomous Agents and Multiagent Systems, Amsterdam, pp. 557-559, 2015R. Nicole, "Title of paper with only first word capitalized," J. Name Stand. Abbrev., in press.

[5] Bissonnette J., Dubé F., Provencher M.D., Sala M.T., The effect of virtual training on music performance anxiety, International Symposium on Performance Science, Laval Univeristy, Canada, Published by the AEC, pp. 586-589, 2011.

[6] Chittaro L., Zangrando N., The Persuasive Power of Virtual Reality: Effects of Simulated Human Distress on Attitudes towards Fire Safety, in: Persuasive Technology, Copenhagen, © Springer-Verlag Berlin Heideberg, pp. 58-68, 2010.

[7] Kuligowski E., Predicting Human Behavior During Fires, in: Fire Technology Vol.49, National Institute of Standards and Technology, Gaithersburg, MD, USA, Springer Science+ Business Media, LLC, pp. 101-103, 2013.

[8] Barillo D.J., Goode R., Fire fatality study: demographics of fire, in: Burns Vol.22, Newark Fire Department and Edwin Albano Institute of Forensic Science, Newark, New Jersey, USA, Elsewer Science Ltd for ISB, pp.85-87, 1996.

[9] Lodo, F., (2019). Effetti dell'ansia sul comportamento e sui parametri fisiologici in simulazioni VR di incendio. Caso studio di esodo in edificio scolastico. Master thesis in Biomedical Engineering, Politecnico di Torino.

[10] UNI. (2008).UNI 7546-5:2008. Segni grafici per segnali di sicurezza - Parte 5: Percorso verso uscita di emergenza.

[11] UNI. (2008). UNI 7546-9:2008. Segni grafici per segnali di sicurezza - Parte 9: Uscita di emergenza.

[12] UNI. (1978). UNI 7546-6:1978. Segni grafici per segnali di sicurezza. Ubicazione estintore.

[13] Barone, T., (2019). Prove di evacuazione a scuola: come svolgerle e quante volte.

[14] Çakiroğlu, Ü., & Gökoğlu, S. (2019). Development of fire safety behavioral skills via virtual reality. Computers & Education, 133, 56-68.

[15] Smith, S., Ericson, E. Using immersive game-based virtual reality to teach fire-safety skills to children. Virtual Reality 13, 87–99 (2009). https://doi.org/10.1007/s10055-009-0113-6.

[16] Kinateder, M., Ronchi, E., Nilsson, D., Kobes, M., Müller, M., Pauli, P., & Mühlberger, A. (2014, September). Virtual reality for fire evacuation research. In 2014 Federated Conference on Computer Science and Information Systems (pp. 313-321). IEEE.

[17] De Luca D., Fonsati A., and Osello A., "Virtual Reality for training the public towards unexpected emergency situations," 2019 IEEE 9th International Conference on Consumer Electronics (ICCE-Berlin), Berlin, Germany, 2019, pp. 343-347, doi: 10.1109/ICCE-Berlin47944.2019.8966171.

The approach outlined in the study is the result of a research activity, validated in a practical way through a real case study treated through a thesis. Francesca Maria Ugliotti edited the methodology adopted, Daniela De Luca investigated the state of the art and the definition of the virtual setting, while Filippo Lodo reported the results of the trial carried out.

-------Answers to reviewers------

Reviews 1
The authors present the evaluation of behavior and physiological in VR fire simulations.

The text has been entirely revised to optimize the content, improve the logical sequence of information and the quality of English.

Reviews 2
This paper provided a virtual simulation inside a school building in case of fire which can simulate highly anxiogenic scenarios based on virtual reality technologies and BIM (Building Information Modelling). This paper used this simulation to analyze the different for each physiological parameter and the effects of anxiety on behavior. This application showed a great potential of VR technology to simulate dangerous environment. However, there are still some questions:
Three physiological parameters (oxygen saturation, blood pressure and heart rate (HR)) were recorded during the exodus simulation. Please describe the meaning of the difference value of group 1 and group 2.
Please describe more details about the effects of anxiety on behavior. Based on the paper, it only shows the exodus time. Do the participants do something else during the exodus simulation? (ex：Screaming.)
Most of the figures are not clear enough, especially Fig. 4. Please replace them with clearer versions.

According to the reviewer, considerations on results are revised and implemented. In particular, the difference in values of the physiological parameters recorded between the two groups of users examined refers to the starting condition in which the participants were placed. The surprise effect for group 1 leads to a stress condition even before the simulation starts. Concerning the participants' level of anxiety, no situations of screaming or hyperventilation were detected. However, some participants starting to have an initial symptom of an emerging panic through non-rational behaviour. Only one participant lost lucidity of reasoning and could not find the exit. Two people climbed to the upper floor of the building in search of a way out.

Out-of-focus images have been replaced and additional ones are implemented.