CSCE Annual Conference
Growing with youth – Croître avec les jeunes

Laval (Greater Montreal)
June 12 - 15, 2019

AN IMMERSIVE ENVIRONMENT FOR BUILDING FIRE SAFETY TRAINING

Hani Alsharari[1], William W. Liou[2], and Osama Abudayyeh[3]

[1] Ph.D. Student, Department of Civil and Construction Engineering, Western Michigan University,1903 W Michigan Ave., Kalamazoo, MI, USA 49008; PH (269) 779-6290-; FAX (269) 276-3211; email: hani.b.alsharari@wmich.edu

[2] Ph.D., Professor, Mechanical and Aerospace Engineering Department; Director, Computational Engineering Physics Lab, Western Michigan University, 1903 W Michigan Ave., Kalamazoo, MI, USA 49008; PH (269) 276-3430; FAX (269) 276-3421; email: william.liou@wmich.edu

[3] Ph.D., P.E., Professor and Chair, Civil and Construction Engineering Department; Western Michigan University, 1903 W Michigan Ave., Kalamazoo, MI, USA 49008; PH (269) 276-3209; FAX (269) 276-3211; email: osama.abudayyeh@wmich.edu

Abstract: Building fire disasters have caused severe injuries and loss of life in addition to significant property damage that can amount to billions of dollars annually. Much research efforts have focused on ways to save lives and reduce property damages during building fire incidents. The main reason for death during fires is smoke as occupants either do not have enough time to evacuate from a smoke-filled building or make a wrong decision due to their unfamiliarity with evacuation paths. Building owners and managers need to develop effective emergency evacuation plans. These plans must include a training program for all occupants to facilitate a safe building evacuation in the event of a fire. However, conventional evacuation training through seminars, workshops, and fire drills may not be useful as they do not provide occupants with the sense of urgency associated with an emergency, resulting in less than desirable reactions to an incident. The purpose of the study discussed in this paper is to create a fire hazard immersive training system for buildings that simulates real incidents and provides scenarios for evacuation. In this system, a 3D building model is used along with a virtual reality platform to provide an immersive environment. The fire and smoke were mathematically simulated using a computational fluid dynamics method. They are then used to develop a virtual reality training environment. The system will then be used to evaluate participants' awareness of how they should behave during a fire incident.

1 INTRODUCTION

The importance of studying fire safety is that fire disasters cause fatal injuries and loss of life in addition to significant property damage that can amount to billions of dollars annually. In 2017 there were 1,319,500 fires were responded by the public fire department in the United States that resulted in 3,400 death, 14,670 injuries and around $23 billion in direct property loss (Evarts 2018). NFPA 2018 research shows there is a fire death every 2.5 hours and fire injury every 36 minutes in 2017. The rate of death and injury from fire is high since a fire outbreak is mostly unexpected. Also, Ren et al. (2008) said that there are two reasons occupants do not evacuate the building in time include an inappropriate layout of the building structure and the wrong choice due to fear or unfamiliar with building layout. During fire incident occupants usually, make a mistake by taking the wrong decision to evacuate the building or may choose the long path to exit from the building due to the stress from the emergency (Meng and Zhang 2014). Almejmaj (2017) stated in his study that cultures have an effect on pre-movement time and reactions when they hear the fire alarm, which led to a late evacuation from the building during a fire incident. It is hard to predict human thinking during a fire emergency incident. The learning and training of fire safety play a critical role in affecting the human response to the fire alarm. The study results indicate that people who had fire drill experience in the past were calmer and are more able to make the right decision than those who did not have any training (Almejmaj et al. 2017).

The fire drilling, training and educating classes are the best way to overcome these and reduce the number of deaths and fatal injuries. Many regulations and fire safety organizations require conducting fire training for the occupants from time to time to make occupants familiar with the evacuation process and the locations of fire exit doors. However, this training did not give the trainees sufficient sensation of the dangers since occupants tend not to take them seriously (Silva et al. 2013). Cao et al. (2019) conducted virtual experiments on a group of people, among which half of them were asked to evacuate due to fire emergency and the rest half left normally. The results show that the group under the fire emergency takes a long time to find the exit. Besides that, fire drilling training and life training have disadvantages such as high cost, limited repetitiveness, and inherent danger (Ren et al. 2008). Also, fire drilling is not always an ideal solution since occupants may not be available when the training is planned and the drills need significant efforts for preparation.

On the other hand, classrooms training is another solution, but it is not sufficient (Smith and Ericson 2009). The information learned from a classroom environment are not kept well since fire safety information are not used regularly and the trainees tend to forget. To retain the information longer requires life training. This approach is costly and less safe for nonprofessionals. This could be an alternative to overcome challenges in training occupants for fire emergency, but they are not the best. This approach is costly and less safe for nonprofessionals. Immersive virtual reality (IVR) technology provides a virtual, but immersive, environment. For fire emergency training, it can safely bring the trainees closer to the dangers posed by fire and smoke than other delivery methods. IVR is a new approach that makes the fire emergency training relatively easy and cost-effective.

2 THE PROBLEM

Building owners and managers need to develop effective emergency evacuation plans. These plans must include a training program for all occupants to facilitate a safe building evacuation in the event of a fire. The conventional evacuation training approach such as classroom training and drilling, and live fire training are not the best way to implement and to improve occupants' safety perception **(**Smith and Ericson 2009). The availability of the resources is what determines the availability of classroom training and live fire training (Barowy 2010). Live training exercises are performed in groups only, instead of individually. Moreover, live fir training requires mobilization of resources and it stops all regular activities at the location where it takes place (Silva et al. 2013). For example, if a fire drill training is to be

implemented in an education building, it will affect classes activities. For hospitals, the disruptions can be even more severe.

The preparation of conventional training needs time, effort, and budget, which limits of live training. Classroom training required qualified instructors (Barowy 2010). In addition, the regulation of the government and safety organization such as the National Fire Protection Association (NFPA) recommend avoiding some of the fuel material, such as pressure treated wood, rubber, plastics, and straw or hay treated with pesticides in fire training. However, these types of materials could be found in any building. The new approaches that employ virtual reality could avoid government regulation and recommendation made by the safety organization. It creates a virtual environment like the real fire scene that can be used repeatedly to train building occupants.

3 VIRTUAL REALITY

Many researchers attempt to develop new technologies that provide more extensive options with fewer limitation on regulations, safety, and resources. The game engine is the most popular simulation software recently to implement simulated fire experiments. The virtual environment created looks like the actual environment and can simulate scenarios of fire that gave the users the sensation of a real fire. Virtual reality (VR) is a simulation of an environment in 3D and allows the user to interact with the content of that environment (Behzadi 2016, and Li et al. 2018). VR technology can be divided in general into two main categories which are immersive and non-immersive (Vergara et al. 2017). The immersive VR is that the user immerses entirely in the virtual environment and can interact with virtual elements. Also, it can be divided into two subcategories based on the visualization tools, including the head-mounted display (HMD), and the cave automatic virtual environment (CAVE). On the other hand, in the non-immersive type, the user can only visualize through.

The VR application in the recent decade considered from researchers particularly for dangers experimental or in experiments that impossible to have a subject in a real event (Smith and Ericson 2009). The use of the VR training is exciting for the participants. The participants are also nowhere near any dangers in case of software failure during a VR training.

4 METHODOLOGY

The proposed system is to develop users' training modules to improve their perception of fire safety and how to act during a fire incident. To develop and validate the training system, the study methodology is divided into three main stages as shown in Figure 1. In stage A, the system will be created from the 3D building model to develop the scenes of the experimental setup. The college building 3D model will be created and converted into the Unity 3D software. The fire and smoke motion and spread out will be mathematically simulated using a computational fluid dynamics method and then converted into the fire scenarios in Unity 3D. In stage B, a pilot evaluation will be developed after a small sample of participants are recruited with approved human subjects compliance protocols. Finally, in stage C the scenarios will be finalized based on the experience from the pilot study, and a sufficient sample of human subjects will be recruited to evaluate the effectiveness of such training.

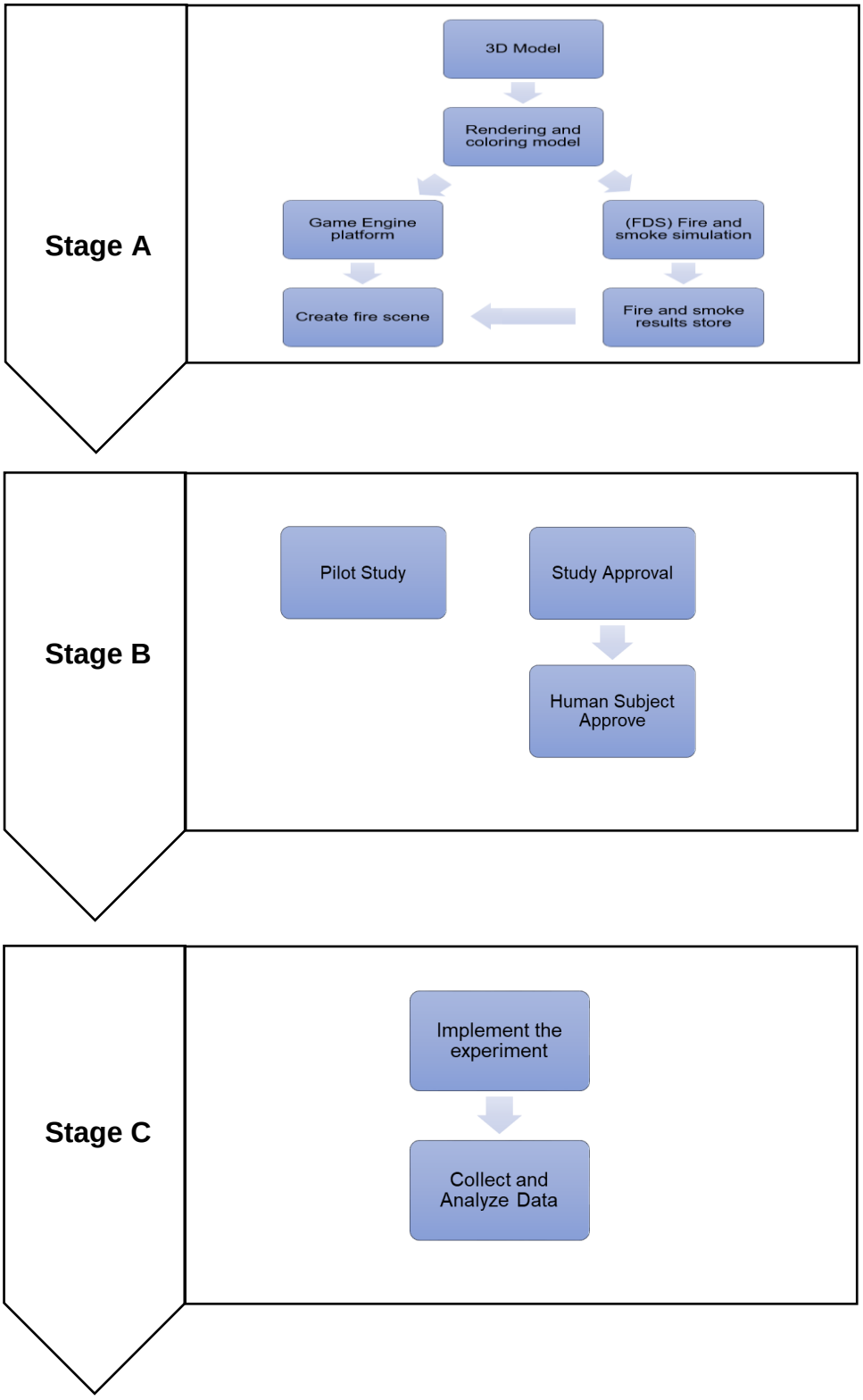

Figure 1: The proposed methodology framework diagram

6 THE EXPERIMENT DESIGN AND EXPECTED RESULTS – WORK IN PROGRESS

In this fire safety study, users are immersed in a virtual environment with virtual fire and smoke to study their reaction, behaviors, time of egress, and finding way in a fire incident. The goal of this study is to train the building occupants to evacuate safely in case of a fire incident. The study will have pre-quiz and post-quiz to evaluate the experiment. The experiment should not take a long time, due to the high stress level of the participants, although participants will adapt to the virtual simulation (Meng and Zhang 2014).

This study will focus on answering several questions related to building fire safety. The data that will be collected will include information on users' knowledge about fire safety prior to training and after training. Additional information will include necessary basic data such as age, gender, and level of education to assess the impact of training on participants. The expected experimental results include an evaluation of the participants' perception and increased awareness about how they should behave during a fire incident.

The study is currently underway. The 3D model of the college building was created with doors and windows. model has been converted to the game engine platform see Figure 2. We are currently simulating the fire and smoke using fire dynamics simulation (FDS) see Figure 3. The results from these simulations will then be used to create fire and smoke scenarios in the virtual reality environment

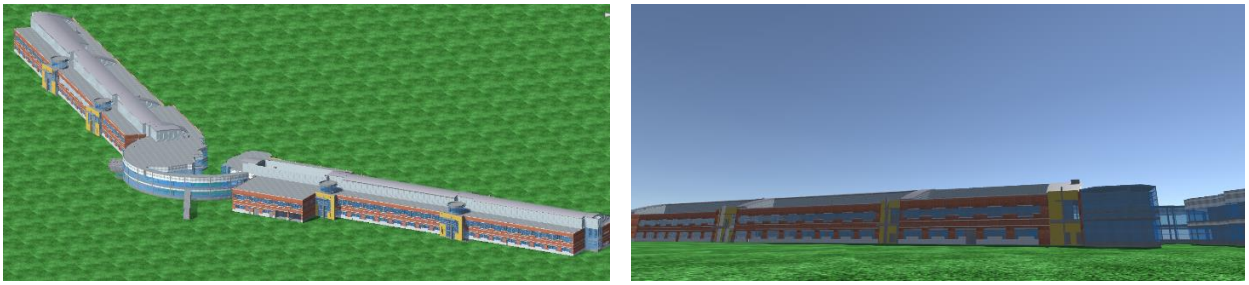

Figure 2A: The 3D model external view

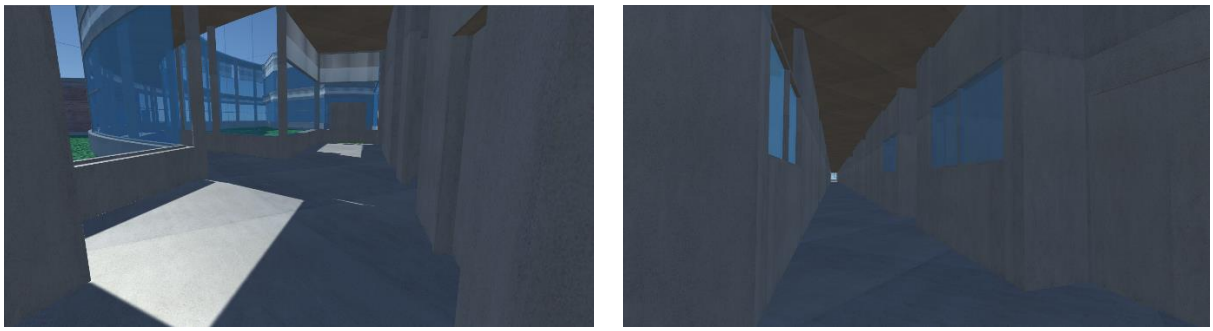

Figure 2B: The 3D model internal view

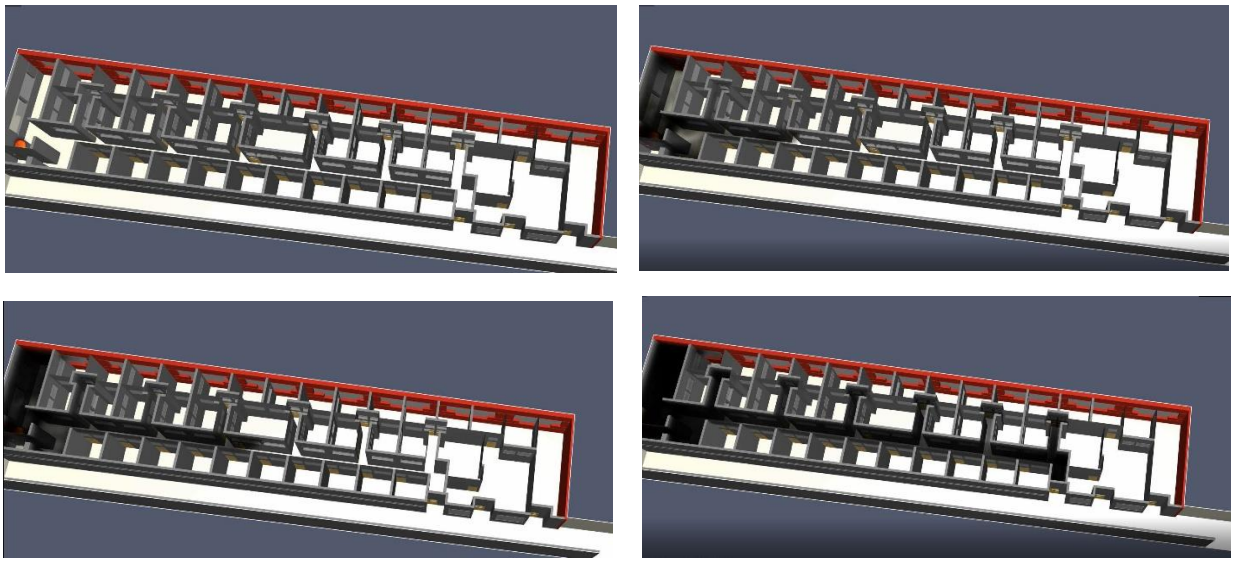

Figure 3: The ignition fire and smoke distribution

7 CONCLUDING REMARKS

This study will focus on the fire safety of an educational building to evaluate fire planning. 3D model immersive virtual environment is being used in conjunction with mathematically simulated scenarios using a computational fluid dynamics method to model the fire and smoke motion and spread. The participants' behavior will be recorded and analyzed to improve their fire perception in egress. The ultimate goal from this study is to develop; training modules that can increase users' awareness of safety around fire incidents and to teach how to evacuate safely.

8 REFERENCES

Almejmaj, M, Jeanine LM Skorinko, and Brian J. Meacham. "The effects of cultural differences between the us and saudi arabia on emergency evacuation—Analysis of self reported recogntion/reaction times and cognitive state." *Case Studies in Fire Safety* 7 (2017): 1-7.

Barowy, Adam M. *Heat and Smoke Transport in a Residential-Scale Live Fire Training Facility -- Experiments and Modeling*. PhD diss., 2010.

Behzadi, Ajang. "Using augmented and virtual reality technology in the construction industry." *American Journal of Engineering Research* 5, no. 12 (2016): 350-353.

Cao, Lijun, Jing Lin, and Nan Li. "A virtual reality based study of indoor fire evacuation after active or passive spatial exploration." *Computers in Human Behavior* 90 (2019): 37-45.

Evarts, Ben. "Fire loss in the united states during 2017." *National Fire Protection Association, MA* (2018).

Li, Xiao, Wen Yi, Hung-Lin Chi, Xiangyu Wang, and Albert PC Chan. "A critical review of virtual and augmented reality (VR/AR) applications in construction safety." *Automation in Construction* 86 (2018): 150-162.

Meng, Fanxing, and Wei Zhang. "Way-finding during a fire emergency: an experimental study in a virtual environment." *Ergonomics* 57, no. 6 (2014): 816-827.

Ren, Aizhu, Chi Chen, and Yuan Luo. "Simulation of emergency evacuation in virtual reality." *Tsinghua Science and Technology* 13, no. 5 (2008): 674-680.

Silva, José Fernando M., João Emílio Almeida, António Pereira, Rosaldo JF Rossetti, and António Leça Coelho. "Preliminary experiments with eva-serious games virtual fire drill simulator." *arXiv preprint arXiv:1304.0726* (2013).

Smith, Shana, and Emily Ericson. "Using immersive game-based virtual reality to teach fire-safety skills to children." *Virtual reality* 13, no. 2 (2009): 87-99.

Vergara, Diego, Manuel Rubio, and Miguel Lorenzo. "On the design of virtual reality learning environments in engineering." *Multimodal technologies and interaction* 1, no. 2 (2017): 11.