Engineering Faculty

INDUSTRIAL ENGINEERING

Final Project – First Semester 2021

[203007] Design of a VR-based training system for the evacuation of an engineering laboratory building

Juan Fernando Castro Medina[a,c], Diego Andres Quintero Ardila[a,c], Carol Natalia Rangel Santamaria[a,c], Yulyana Rodríguez Bautista[a,c]

Sebastian Alberto Pelaez Gomez[b,c], Luis Andres Saavedra Robinson[b,c]

[a]*Industrial engineering student*
[b] *Professor, Project Director, Departament of Industrial Engineering*
[c]*Pontificia Universidad Javeriana, Bogotá, Colombia*

Engineering Design Summary

According to the National Unit for Disaster Risk Management, 12,896 people have been affected by structural fires in Colombia in recent years. In order to reduce the consequences of these disasters, different strategies have been proposed, such as evacuation drills. However, it has been shown that traditional methodologies are not as effective because they lack a practical component. For this reason, this project proposes and designs a training system to perform an evacuation due to the presence of a possible structural fire using virtual reality. The scenario selected for this exercise corresponds to the laboratory building of the Faculty of Engineering of the Pontificia Universidad Javeriana, Bogotá. Given its recent opening and the health emergency generated by SARS-CoV-2, evacuation drills have not been carried out since its inauguration.

In order to develop the proposal, the software and hardware tools with which the experiment was carried out were initially selected. This selection was made taking into account the criteria of the ISO 25010 Standard and the AHP methodology was used based on the opinion of some experts in the area. Then, two applications were designed, the first one corresponded to the learning scenario, in which the participants adapted to the virtual environment. The second was the main application containing the emergency simulation. Subsequently, a sample size of 67 people was obtained, who had to belong to the Faculty of Engineering. Finally, the application of the experiment was carried out, in which surveys were used as a method of data collection. Also, some times related to the performance of the participants were recorded.

Once the application of the experiment was completed, the Statistical Package for the Social Sciences (SPSS 28.0 version) software was used to analyze the data collected. The main statistical tests performed were: U by Mann Withney, Wilcoxon Signed Rank Test, among others. It should be noted that a confidence level of 95% was taken into account for the respective analyses. A significant difference was found between the mean time spent by men and women in the experiment. Also, the perception of the participants improved in factors such as the realism of the evacuation, motivation, knowledge and interest in disaster prevention. Likewise, 97.1% of the participants preferred the proposed evacuation methodology to the traditional ones.

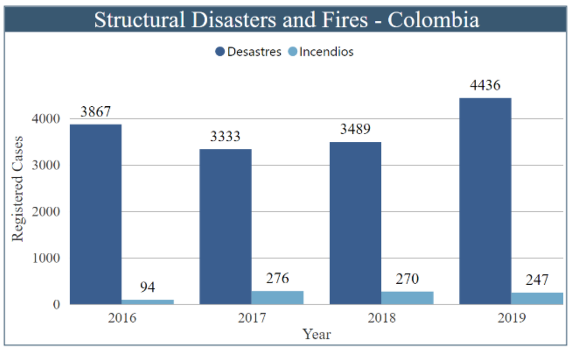
The application of the concept of serious games integrated with virtual reality significantly improves participants' learning by generating a higher level of immersion in the emergency. Given the average time it took the participants to learn the evacuation system of the building with the developed application, a positive impact was obtained in areas such as: productivity, economy, culture, health and technology. The above showed that the proposed methodology has greater advantages over traditional drills that have been applied so far.

Keywords: Virtual Reality, Serious Games, Evacuation Route, Evacuation Drill, Simulation, Structural Fires, Training System.

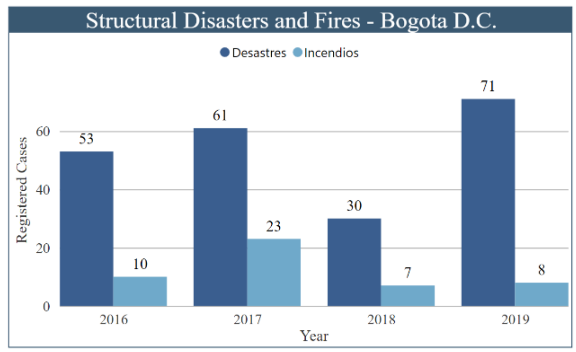
1. Justification and problem statement

Natural disasters such as earthquakes, tsunamis and hurricanes are unpredictable phenomena that can cause multiple damages, both material and human losses. In addition to these catastrophes, there are those caused by man, such as structural fires. The impact of these cannot be underestimated and people should be ready to face such adversities. Individuals with appropriate knowledge can help others respond accurately and prevent life-threatening outcomes [1]. Therefore, disaster awareness needs to be a key factor in reducing the number of deaths and negative consequences [2].

According to the National Unit for Disaster Risk Management (UNGRD), in Colombia during the last years, 15,125 emergencies were recorded. Based on these results, the most frequent disasters are fires with 51.03%, of which 887 correspond to structural fires as shown in *Graphic 2*. In these situations, 12,896 people were affected, 450 of them with injuries, and there were 80 deaths. In the Bogota's case, of the 215 disasters presented, 22% correspond to structural fires [3] as shown in *Graphic 1*.This demonstrates not only the effects of these incidents but also the need to develop various strategies to minimize their impact. Training is a possible solution. However, this disaster education is currently based on transferring basic concepts and theoretical knowledge to people. Two key challenges, therefore, arise: increasing the motivation of participants and transferring the experience of how to act in risk situations [1].



Graphic 2 - Structural Disasters and Fires - Colombia



Graphic 1 - Structural Disasters and Fires – Bogota D.C.

There are different ways to carry out training for the evacuation of personnel in the presence of a disaster such as informative talks, learning videos, evacuation drills, among others. Both informative talks and audiovisual components provide several instructions that should be followed in an evacuation, some of them are keep calm, do not run, have your hands free, and so on. Such instructions generate an opposite reaction to the above in a real scenario [4]. Despite the theoretical richness of these methods, they lack a practical component. Research has shown that traditional education on disaster prevention is not as effective as interactive methods, which if emphasized in improving people's first-hand experience [1]. For this reason, traditional evacuation drills are very common to train communities, institutions, and businesses.

Drills must ensure successful evacuation once a disaster occurs, arise to develop a healthy, reliable working environment, and an increase in the quality of life [5]. Despite those benefits that its application can bring, one of the main limitations is the big difference between the real world and training, because they omit many sensations and aspects that can make the learning limited [6]. Similarly, protocols can be costly, time-consuming, and lead to production delays. Therefore, any methodology that can reduce the cost will be of great use to many people, organizations, and industries [7].

Given the above, designing an educational package that can raise awareness of some kind of disaster is a promising challenge for institutions today [1]. As a consequence, a new training alternative through *Virtual Reality* (VR) emerges, which generates a greater user experience by immersing them in a real environment, since stimuli are created through the senses to experience greater immersion. This tool is very useful as it provides a platform for effective, flexible and affordable training in a variety of environments.

In general, VR can simulate real workspaces that strengthen occupational safety and health for educational and training purposes. This tool has been used in the field of medicine, as well as in the preparation of astronauts, soldiers and miners. In fact, the scenarios in which this training can be applied continue to increase, since it offers a great advantage over traditional training since it allows the total management of the environment in which the user is, giving experimental control allowing stakeholders to make adjustments and changes to analyze different situations [8]. Likewise, it has the ability to emulate scenarios that present a risk for staff, allowing them to face adverse situations, without running any danger to their security, that of third parties, material goods, among others [9].

However, there is an important concept called *Serious Games* (SG) that complements the education provided through VR. According to Michael and Chen, this concept refers to "a game whose main objective is education over entertainment"[10]. This tool is used today in successful educational processes since, it allows us to obtain data and information on the behavior of participants to analyze, make decisions and determine what factors affect their behavior [11]. Also, the advantage of combining SG and VR is that training realism can significantly improve the learning of participants [6].

Figure 2 - Virtual Reality Example. [12]

Figure 1 - Virtual Reality Example 2. [13]

Recently the Pontificia Universidad Javeriana headquarters Bogotá inaugurated the new building of engineering laboratories on January 20, 2020. This building has 15 floors and an additional floor of technical control. The occupational health and safety team of the Faculty of Engineering is currently designing the evacuation plan for this building. This place has active (alarms, sprinklers and fire extinguishers) and passive fire protection (structural designs and finishes). Given the opening, no evacuation drill has been conducted, so it is very useful designing a training system for safely evacuate students, professors, brigadiers and university workers to learn how evacuate the building in case of a fire. Thus, this building would be the first construction in the university to have a virtual training system for evacuation in case of a structural fire. In this way, the following research question arises: *How to design a training application for the evacuation in case of fire at the Engineering building by means of virtual reality?*

2. Literature review

Emergencies, like fires, earthquakes, floods, are events that have occurred throughout the history of humanity. However, over time, different alternatives have been implemented that seek to reduce the losses and consequences that those incidents bring. Thanks to technology, new tools have emerged to improve current learning processes. Several authors claim that traditional methods of education do not provide the expertise required to address these situations. Some of them propose a learning package for disaster prevention based on SG, which is based on the ELC methodology or Kolb stages: Concrete Experience (CE), Reflective Observation (RO), Abstract Conceptualization (AC) and Active Experimentation (AE). The results showed that this Kolb's methodology had a positive influence on student's level of interest in learning, disaster prevention skills, self-awareness and civic responsibilities [1].

At Tokushima University in Japan, a fault-enhanced evacuation model was proposed based on Kolb's experiential learning theory with the use of VR. A preliminary comparative experiment focused on how simulated evacuees or NPCs (non-player character) influence the evacuation of participants. This model was intended to induce participants to succumb to conformity bias and not to evacuate during the first simulation. In the first scenario, an earthquake was simulated in a school with inactive evacuees, which means people who do not evacuate quickly or stay inside in the place. Subsequently, after feedback to the participants, a second fire scenario is simulated in a theatre. Results indicated that failure-enhanced evacuation training can successfully improve the training effect [12].

Other solutions proposed are aimed at finding the optimal evacuation route. For example, through Augmented Reality (AR), applications have been developed that provide the user with real-time guidance to safely evacuate. On the previous study, it is concluded that a sufficient amount of training information must be available if the accuracy of a fire recognition is to be improved [13]. Also, there is the possibility of obtaining the evacuation route by scanning a marker, arranged in the maps that are in each of the areas of the building. Depending on the device used (mobile phones, tablets, Microsoft Hololens), three scenarios were addressed in which the amount of information provided to the user varied, such as the specific location of the disaster, alternate evacuation routes, smart signs, among others. It was concluded that the model developed was not only easy to use, but also effective in generating patterns to evacuate a construction. Among the devices used, the Microsoft HoloLens (VR glasses) was preferred by users, because it allowed them to interact with real situations, which improved their experience [14].

It should be noted that not all tools have the approach mentioned above, some authors orient their research towards the design of mathematical models that allow understanding and optimizing variables such as time and speed of evacuation, the flow of personnel, density reported at critical points and total distance traveled [15],[16]. This objective is achieved through the development of heuristics and equation models to obtain the shortest exit route [17]. Other models focus on evaluating the efficiency of current evacuation plans, to implement the best of them, this tool is implemented in an airport comparing three different alternatives. This simulation platform is combined with a TOPSIS evaluation method to find the problems on time, improve emergency response capabilities and significantly improve the effectiveness of emergency drills at airports [18].

Kawai and Mitsuhara developed an AR-based evacuation game for the presence of an earthquake simulating different variables such as injured people, building cracks, fire, smoke, among others, finding that such a system can improve users recognition of emergency signals and motivate participants to learn about disaster liability [19]. Also, in 2019 Sukirman and Wibisono designed a VR-based app at a school in Indonesia for children to experience the sensation of an earthquake, 71% of the students who tested the application said that the simulation is interesting because they can interact with virtual objects, which makes the practice more realistic [2]. Similarly, Lovreglio and Gonzalez designed two SG prototypes based on VR. The first aims to analyze the behavior of the participants in the moment of the evacuation-drill, and the second focuses on earthquake´s evacuation training [6].

Several investigations have been carried out using VR on Occupational Safety and Health issues (OSH), this technology offers the possibility of making affordable and safe training in high-risk environments, in spaces where there is contact with electrical systems [20], chemical [9] and petrochemicals [21]. In the chemical industry, for its part, the training approach developed was not only used to educate and train new workers but also to preserve the skills of those who have already been with the company for a long time. However, Chen and Su developed an application for decision-making in high-risk urban facilities of a petrochemical, concluding that the software improves the sensitive cognition of users' accidents.

Concerning emergency fire simulations, Kilis 7 Aralik University in Turkey implemented HMD VR for university students in OSH to strengthen theoretical knowledge. As a result it is important that students are oriented to the VR simulation by introducing the environment to the students before the implementation [5]. Besides, in countries such as the Republic of Korea, two-way educational content based on AR has been proposed that can effectively educate Korean citizens about evacuation procedures, safe crisis resolution, and instructions for the use of fire extinguishers or descending devices, as well as the CPR (Cardiopulmonary Resuscitation) method [22].

It should be noted that the behavior of a fire depends on the space in which it is generated. Thus, this methodology has been applied in both closed places as a university and outdoors places as an airport. On the one hand, VR's systems such as HTC (High Tech Computer) Vive have been implemented to design game-based learning platforms for college students assessing limitations and different perceptions in participants. Approximately 70% of users believe that using VR can increase learning and interest in learning about disaster awareness [23]. On the other hand, with platforms, such as Unity 3D, the College of Air Management Civil Aviation Flight University of China developed an airport emergency fire rescue virtual platform to trainees, highlighting three important features of VR: ease of use, platform stability and real-time, which gives users a scene closer to the real emergency [24].

On the basis of a review of the existing literature on current training systems and the different scenarios used in each of them and the statistics presented on national disasters, it is decided for the particular case of this project, to simulate a structural fire scenario. This considering that it is the emergency that results in a major number of affected people after its occurrence. In addition, in order to accomplish the final work's objective, the application Unity 3D software will be evaluated since, as mentioned above, it has been the most used programming language in each of the projects, which has obtained good results. Finally, HTC Vive Pro will be evaluated as a hardware tool, this will allow greater immersion in the target training system.

3. Objectives

To design a training system for the Pontificia Universidad Javeriana's community through virtual reality tools, which facilitate evacuation in the event of a structural fire at the new Engineering laboratory building

1. Select the most accurate tools for the creation of the training system
2. Develop the application using the tools chosen
3. Apply the simulation to the Javeriana community's users (students, administrative and professional staff)
4. Analyze the results obtained through the simulation to determine its impact on the community

4. Methodology

First, an opportunity for improvement is identified in the current Evacuation Training Systems in an emergency as these lack the required immersion for the training to be fully effective. In addition, it was found that planning and executing a traditional drill requires considerable time and resources. Afterward, the tools (software and hardware) to be used in the development and implementation of the new training system through VR are selected. Subsequently, the simulation is applied to the selected sample; finally, the data obtained are analyzed to conclude the impact generated onto the community.

4.1. Specific objective 1

4.1.1. Software and hardware choice

The first stage of the project's development consists of the selection of the software and hardware tools that are used for the creation and implementation of the VR application. It is important to highlight that the software analyzed must allow the inclusion of virtual reality since many of these platforms do not have this possibility. The software to be evaluated are Unity 3D, Unreal Engine and Godot. Likewise, the hardware to compare are Oculus Rift 2015, HTC Vive 2020, Google Cardboard and Samsung Gear VR. For the selection process, the AHP methodology is used, which is a method based on the evaluation of different criteria (qualitative and quantitative) to rank the comparison process. For the selection of the software some criteria provided by ISO 25010 are taken into account:

- **Efficiency:** Represents performance relative to the number of resources employed under certain conditions, such as response and processing times, quantities and types of resources used when the software is running, among others.
- **Reliability:** Competence of a system to perform specific functions when used under certain conditions and periods. These conditions may be the ability of the system to be operational and accessible when required, to operate as intended in the presence of failures, among others.
- **Usability:** Capacity of the software product to be understood, learned, used and be attractive to the user when employed under certain conditions, which may be: product ability that allows the participant to learn its application, user interface ability to please and satisfy participants' interaction, among others.
- **Portability:** Ability of the product to be effectively and efficiently transferred from one hardware, software, operational or usage environment to another.

Moreover, the criteria selected for hardware analysis are as follows:

- **Availability**: Achievability of making use of the device at the time of project execution (present until July 2021).
- **Recognition:** Degree to which the device has been used for VR execution projects.
- **Ease of use:** Possibility for the user to run the simulator on this device in a practical and fast way.
- **Immersion:** Level of reality experienced by the participant into the scenario illustrated.

Taking into account the above criteria, two surveys were conducted with three experts on the subject: one for the software and one for the hardware. The above to obtain the corresponding weighting, and select the most appropriate tools for the given criteria and conditions. Surveys applied to experts can be found in *Appendix 1*.

4.1.2. User profile and informed consent

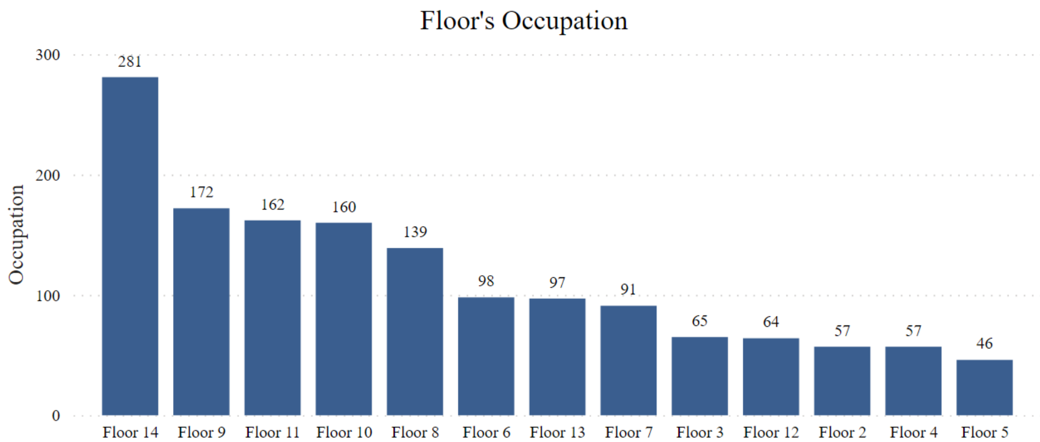
The application is evaluated on a sample of students, teaching and administrative staff of the engineering faculty of the Pontificia Universidad Javeriana, Bogotá. Thus, the participants must meet certain medical and demographic requirements that are detailed in the user manual where the precautions, recommendations and other important aspects are explained in detail for the proper use of VR equipment. Besides, informed consent is designed, which aims to record the voluntary participation of users, as well as to let them know the treatment of the information collected and other matters of concern.

4.2. Specific objective 2

An application is developed for the training of an evacuation caused by a fire in the Engineering Building of the Pontificia Universidad Javeriana, considering the guidelines provided by the occupational safety and health team of the Faculty of Engineering.

4.2.1. Application design methodology

- **Virtual environment:** The location of the application scenario corresponds to some sections of the PUJ engineering building. The floors selected to simulate the evacuation are chosen taking into account the maximum occupancy of people on them, as shown in *Graphic 3*. The 14th floor, the last level of the building, is selected as a starting point since it represents the space with the greatest occupancy. This space is available for 281 people. Likewise, the 11th floor is chosen where there are spaces for students to develop their academic activities. Besides, it is among the three places with greater capacity of personnel. It should be clarified that the design of this scenario represents the first advance for future studies, in which the whole building is contemplated for the benefit of the OSH area.



Graphic 3 - Floor's Occupation - Engineering building PUJ

The 3D model of the building was delivered by the Faculty of Engineering in NWD format. Some internal building elements are imported from SolidWorks software. After that, these elements are converted to FBX format, which is compatible with Unity 3D. Items such as doors, plants and other accessories are obtained from different packages from the Unity Asset Store. The final adjustments to the model are completed directly in the software. Finally, to generate the user's movement, door opening, sound implementation, control of the commands, among other functions, the programming is used in Visual Studio C#. In *Figure 3*, you can see the process explained above:

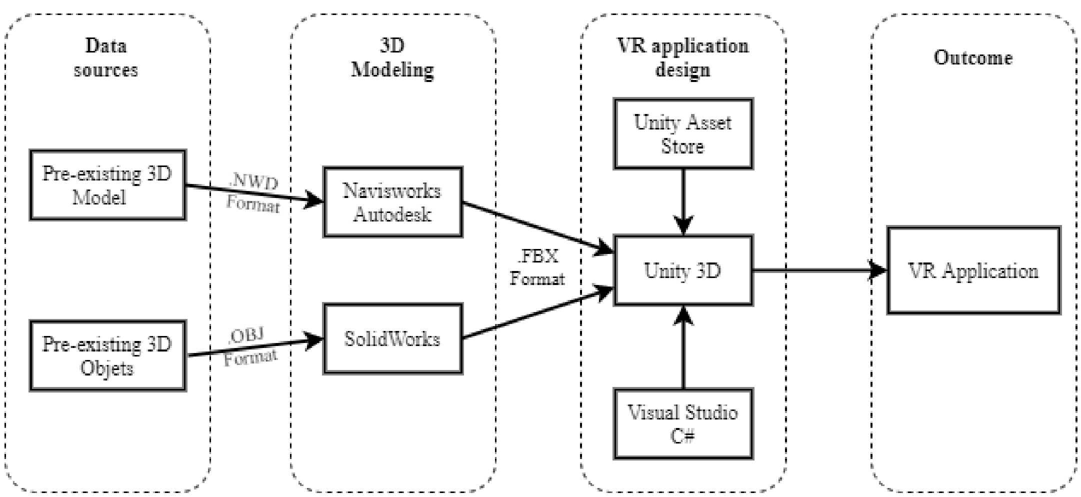


Figure 3 - Development implemented to create the virtual environment

For the user to adapt to the interaction with VR, a learning scenario is designed. In this course, the participant learns how to use the commands and becomes familiar with the use of the viewfinder. This scenario consists of a small room where it is possible to move freely, go downstairs, observe some objects randomly arranged and be placed spatially in an environment with VR. The implementation of such learning scenario is highly relevant, as it allows users to adapt to movements and experience the feeling of participating in a VR simulation by identifying their symptoms. It also equalizes the users' knowledge conditions for the actual application, thus avoiding bias in the performance times.

- **User interaction with the application:** The incorporation of VR into this project is generated by the HTC Vive Pro device, which is shown in *Figure 4*. It has an adjustable viewfinder and a pair of controls for the user to make different commands in the middle of the simulation. For the configuration of these and the correct interaction with the environment it is necessary to have the Steam VR application and programming in Visual Studio C#. With the above, the touchpad of the right controller is related to the user's mobility which is configured with an average speed for all participants. Similarly, for door opening, a script is linked which is associated with the trigger on the left controller.

Figure 4 - HTC Components and Associated Controls

- **Fire and emergency simulation:** Fire and smoke are simulated by a package imported from the Unity Asset Store. The emergency occurs due to an explosion in the 14th-floor cafeteria area. Immediately afterward, fire is generated in nearby areas, in turn, the smoke is located along all the stairs between the 14th floor and the 11th floor of the building. For the visualization of both fire and smoke (*Figure 5* and *Figure 6),* a script is programmed to control its activation time.

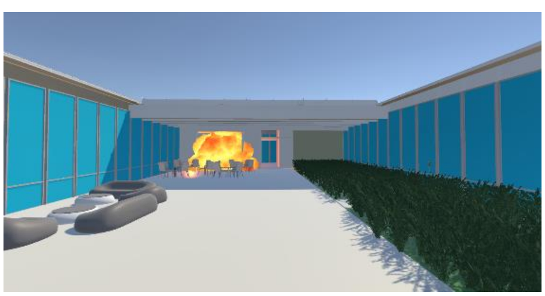


Figure 5 – Fire Simulation

Figure 6 – Smoke Simulation

At the entrance to the 11th floor of the building, by the stairs of the south side, the fall of a structural object caused by the fire is simulated to hinder the descent down this route. The participant is forced to cross this floor which is completely covered by smoke. It is important to note that once the explosion occurs, the fire alarm sounds. Finally, the sensation of heat generated by the fire is stimulated by an electric heater that researchers manipulate.

- **Building evacuation process:** Currently, the engineering building has evacuation routes and their respective signals. For this reason, all signs are located in the same places of the building in the virtual environment. Participants before starting the test do not receive any instructions on how to evacuate the building, as this may affect their behavior. That is to say, the participants only have the evacuation signs previously located in the virtual model of the building. The meeting point in case of an emergency in the engineering building is under study, however, the OSH team contemplates that the most viable option is the square located in front of the Faculty of Dentistry. To make this meeting point known to the user, a 360° image of the place is taken so that, at the end of the simulation, the user is redirected there.

4.2.2. Experimental protocol

An experimental protocol is designed, which establishes the objective of the tests' application and the number of people to whom it is applied. It defines in detail the phases that are carried out with the population under study, together with the duration of each one. Likewise, it establishes all precautionary and biosecurity measures in the implementation of the experiment at all stages. In addition, it contains the user manual and the informed consent given to each participant. These documents are submitted to the Research and Ethics Committee of the Faculty of Engineering to authorize the application of tests within the Engineering Laboratory Building.

4.3. Specific objective 3

- **Sample size:** To have a significant proportion of the population and to be able to conclude on it, the appropriate sample size for the study is calculated. According to data provided by the engineering faculty for the year 2021, the total number of members corresponds to 4171 people, subdivided into three large groups: administrative, undergraduate and graduate students. Taking into account the above, a sample size of 67 people is stable, using the confidence of 90%, a percentage of heterogeneity of 50% and a margin of error not exceeding 10%. The number of people expected is shown below.

Type of participant	Percentage of the population	Number of people
Administrative	12,1%	8
Graduate	18,9%	13
Undergraduate	69,0%	46

Table 1 - Division of the sample

- **Application of the simulation:** In the initial stage of project implementation, participants are contacted by e-mail, social networks and through a direct invitation to people who are in person at the faculty. After this, the place and date where the tests are carried out are defined, these are carried out on the 4th floor of the engineering building of the PUJ between May 11 and 27, 2021. A protocol is established for the experiment, to provide users with the necessary biosafety measures and the correct execution of this, which is described below.

Once the participants schedule the day in which they can attend the university, through a confirmation email is attached the user manual, link of the epidemiological follow-up survey required by the university, time and place of meeting. In addition, some additional recommendations are sent to carry out the test comfortably. When the participants enter the simulation room, the corresponding disinfection of their hands is performed, to prevent the spread of the virus due to the SARS-CoV-2 pandemic. After this, users are asked to sign the informed consent and complete a survey before the simulation. Then, the person is informed of the handling of the controls and general recommendations to start the learning scenario. Having been taught about the VR team and trained in how to interact with the environment, participants begin the application. When the simulation is completed, participants are asked to complete a final survey to assess their experience.

4.4. Specific objective 4

4.4.1. Data Collection

The method to collect the information consists of two surveys. It is necessary to apply them to all participants before and after the simulation. In the initial stage, the user follows a form to collect the following information: personal data, experience in traditional simulations, participation in some VR applications and knowledge of the meeting points of the building (*Appendix 2*). The most relevant personal data for the study are *gender*, *age* and *occupation*. In like manner, users who have experienced a traditional simulation must respond to their perception of the *fear*, *realism*, *interest*, *usefulness* and *motivation* that it can generate. Furthermore, four possible meeting points are presented for the participant to select which they consider correct. These points are: East side of the Baron building, Soccer field, first-floor square Building of Engineering Laboratories and square in front of Faculty of Dentistry.

Once the simulation is over, participants are asked to answer a survey to evaluate the VR application. This includes questions about *fear*, *realism*, *interest*, *usefulness* and *motivation*. Similarly, the user is asked about the meeting point and is expected to select the option "in front of the entrance of the Faculty of Dentistry", since it corresponds to the current meeting point and is the scenario shown at the end of the simulation by means of a 360° image. Another relevant question corresponds to the participant's preference between traditional simulations and simulation through VR. Also, users perform simulation feedback, mentioning improvement points for the application. Simultaneously with the development of the experiment, a record of three times is made: the first corresponds to the duration passed from the welcome to the beginning of the real scenario; the second moment refers to the completion of the simulation; and finally, the time at which the experiment ends.

4.4.2. Data Processing

Through *Microsoft Excel*, the results obtained in the surveys are organized, and the answers to the most relevant questions for the study are selected to create a database containing the information encoding. This is done so that the *Statistical Package for the Social Sciences* (SPSS) software can be used for statistical analysis. Additionally, *Microsoft Power BI* is used to interpret and present the information since it allows to visualize the results dynamically according to the variables of interest.

Once the data is imported to SPSS, the variables are declared, assigning to each one the name, type, value labels and measure (Ordinal, Nominal or Scalar). Subsequently, a descriptive analysis is performed for some variables, especially for those that allow us to understand the sociodemographic environment of the sample. This analysis includes the frequencies of nominal and ordinal variables. In the case of scalars, measures of central tendency and dispersion are obtained. Likewise, the chart that best suits to illustrate the results achieved (bar, circular and dispersion diagrams) is shown.

The inferential statistical analysis is then performed. First, the Kolmogorov-Smirnov (K-S) test is applied, a non-parametric test that allows determining if any of the probability distributions (Normal, Uniform, Poisson or Exponential) fits the data of a variable. This allows knowing if they are parametric or not parametric, which facilitates the choice of tests that are implemented. Contingency tables are used to measure and analyze if there is an interaction between two ordinal or nominal variables. Taking into account the above, relationships are established between the parameters evaluated for a traditional simulation and a simulation with VR.

To establish if there is a difference between the means of the groups of a dichotomous variable concerning a scalar variable, the Test-T or U Mann-Whitney is used depending on whether they are parametric or non-parametric. Similarly, to evaluate the relationship between a scalar variable and a polytomous variable, the ANOVA or H test of Kruskal-Wallis can be used depending on whether the data to be compared follows a distribution. Finally, to determine if there is a difference between two related categorical variables, the Wilcoxon Sign Range Test is used.

5. Results

5.1. Specific objective 1

5.1.1. Selected tools

After having applied the surveys to the experts, the AHP methodology was implemented for the selection of the tools to be used, as shown in *Appendix 3*. The criteria comparison matrix shows that the most important component for hardware was availability (54%). In the case of software, the most important criteria were efficiency and usability with 37.5% each. The results obtained from the evaluation of each alternative are shown below:

Criterion	Availability	Recognition	Usability	Immersion	Total
Oculus Rift 2015	0,313	0,500	0,224	0,263	**29,56%**
HTC Vive 2020	0,313	0,167	0,130	0,558	**34,78%**
Google Cardboard	0,063	0,167	0,484	0,057	**12,41%**
Samsung Gear VR	0,313	0,167	0,161	0,122	**23,24%**
Weightly	0,540	0,047	0,138	0,275	**100%**

Table 3 - AHP methodology for Hardware

Criterion	Efficiency	Reliability	Usability	Portability	Total
Unity 3D	0,643	0,643	0,380	0,643	**54,48%**
Unreal Engine	0,283	0,283	0,936	0,232	**52,15%**
Godot	0,074	0,074	0,082	0,084	**7,82%**
Weighting	0,375	0,125	0,375	0,125	**100%**

Table 2 - AHP methodology for Software

5.1.2. User manual and informed consent

The user's manual sent to all participants prior to the simulation can be found in *Appendix 4*. Users were expected to read it to learn about the requirements, precautions and recommendations to be taken into account. Similarly, in *Appendix 5*, the informed consent form filled out by the participants on the day of the experiment can be seen. This was done in order to proceed with the data collection, completion of surveys and photographic record throughout the experiment. These documents signed by each participant can be consulted in *Appendix 6*.

5.2. Specific objective 2

5.2.1. Virtual reality application

5.2.1.1. Learning scenario

Figure 7 shows the test scenario that was implemented for the users of the experiment. It consisted of three floors, two staircases located at the ends of the room, some tables and chairs on each of the levels. At the start of the application, the participant was located in a corner of the third floor. The participant had to walk up and down the stairs using the mobility instructions given to him/her before starting the test. During this phase, participants resolved their doubts in terms of handling the equipment and visualizing the scenario, understanding how their body position and view orientation integrates with the virtual environment.

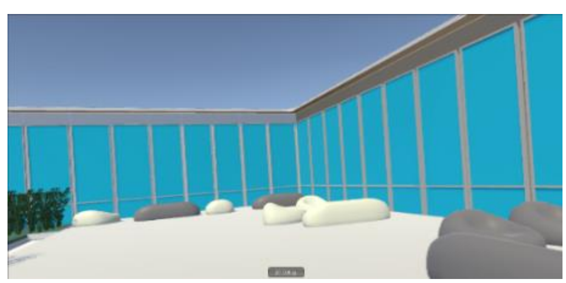
Figure 7 - VR learning scenario

At the end of the simulation, the user was assessed to see if he/she felt dizzy or had a loss of balance. This was done in order to ensure that the participant was in optimal conditions for the development of the emergency application. In addition, for those who wore prescription glasses, they were allowed to decide whether they preferred to experience the simulation with or without them. Similarly, it was observed that none of the participants presented symptoms due to the immersion in virtual reality. It was also identified that they were able to understand how to operate the controls and the viewer. In addition, the average time from the time the participant started the experiment until the end of the test scenario was 10.68 minutes. The executable of the test application can be found in *Appendix 7*.

5.2.1.2. Real scenario

As mentioned in the methodology, the application consists of a walkthrough along the 14th and 11th floors of the engineering building. *Figure 8* shows the comparison between the quality of the model obtained through Unity 3D and the real photos of the scenarios. Also, in image A, the terrace of the building can be seen, which corresponds to the initial point of the application, where seconds later the explosion can be seen. As mentioned before, the eastern stairs are obstructed by the fire, so the participants had to go down the stairs on the south side as shown in image C:

(A)



(B)

(C) (D)

Figure 8 - Comparison between virtual model and real photographs

Once the participants descend the stairs on the south side, they must evacuate until they reach the 11th floor *Figure 9*. At this point, they are forced to enter because the route is obstructed by a structural object. Once they are on this floor *Figure 10*, they must walk along the corridor and experience the sensation of smoke until they reach the eastern stairs of the building, where the application ends with the 360° image of the viable meeting point. *Appendix 8*, contains the executable of the real application, in which the process described above can be observed together with the additional functions it has. It is important to clarify that this file is only compatible with computers and that the use of HTC glasses and all its complements is required for total immersion.

Figure 9 - 11th floor stairs

Figure 10 - Hallway 11th floor

5.2.2. Experimental protocol

Appendix 9, contains the Experimental Protocol, which establishes the phases that were taken into account in the test, starting with the welcome and explanation, the VR simulation, and ending with the disinfection and completion of the final survey. Initially, it was envisaged that the execution of all the stages would take 45 minutes, however, when the experiment was applied, on average the participants took 18.5 minutes. This difference can be explained by the fact that the time taken to set up the devices and remove them was shorter than anticipated. Similarly, the time taken by users in the VR evacuation drill was 73.1% less than stipulated in the protocol.

Also, in this document, it was envisaged that the simulation would be applied to a convenience sample of 30 people, taking into account the current pandemic situation. Nevertheless, by the time the tests were applied, conditions improved and the study population of 67 people was reached. 98.5% of the users who participated in the test stated in the final survey (*Appendix 10*) that all relevant biosecurity measures were complied with, such as social distancing, maximum capacity, disinfection of equipment and the permanent use of face masks.

5.3. Specific objective 3

5.3.1. Case of study

Initially, a sample size of 67 people was obtained, however, the experiment was applied to 68 participants. *Figure 11* shows the socio-demographic description of the sample: 61.8% of the users belonged to the male gender and 38.2% to the female gender. Likewise, the ages ranged between 17 and 43 years, thus having 7 intervals with a range equal to 4. As can be seen, the interval with the highest number of participants corresponds to the ages between 21 and 24 years, both for men and women. The above figures are due to the fact that 79.41% of the participants were undergraduate students, 16.18% belonged to the faculty's teaching and administrative staff, and the remainder were postgraduate students. It can be seen that the percentages obtained in the occupation variable are similar to the target population, since the aim was to make them similar to the data provided by the faculty.

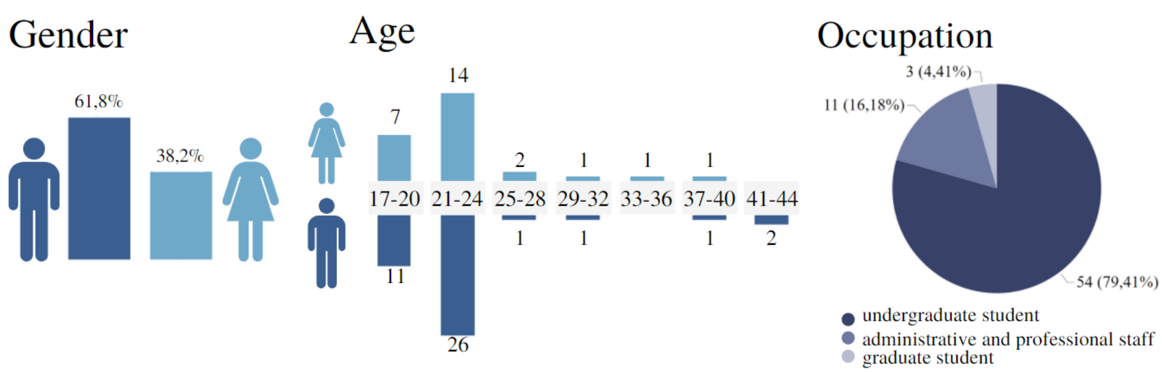


Figure 11 - Socio-demographic description

Within the sample, there were four brigades belonging to the teaching and administrative staff. Although two of them are external to the Faculty of Engineering, they are involved in OSH issues and provide the necessary support in any emergency. *Figure 12* shows the integration of the users with the application and the corresponding VR equipment. *Appendix 11*, shows some of the users' sensations and reactions to this experience, which not only included sound and visual effects, but also sensory effects that made the participants feel even more immersed in the structural fire caused by the virtual fire.

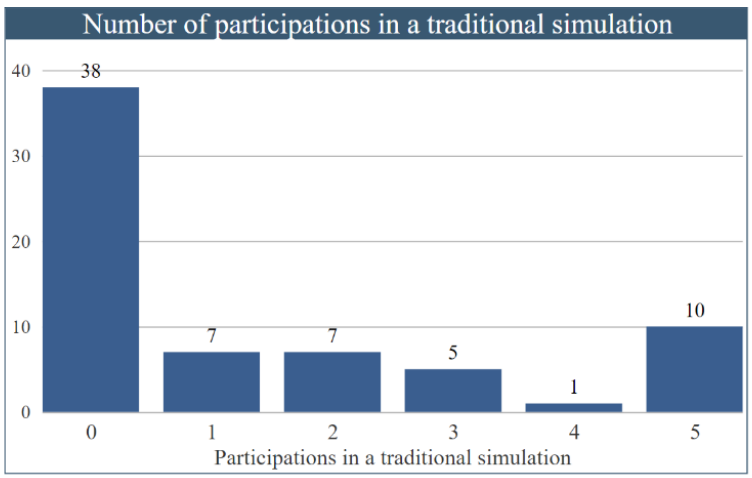
Figure 12 - Integration of users with the application

5.4. Specific objective 4

5.4.1. Analysis of results

The experiment was applied to a total of 68 people. Based on the information collected, a statistical analysis was carried out with the measured data and information obtained through the surveys (*Appendix 12*). This study took into account 36 variables classified as follows: 5 scalar, 19 nominal and 12 ordinals. It should be noted that prior to the analysis, a data cleaning and transformation was carried out for the correct reading and conclusion of the data. Depending on their previous experience with the traditional simulations, the participants answered or did not answer all of the questions.

The initial survey showed that all participants filled out the informed consent form, underwent a disinfection process and fulfilled the requirements established for admission to the university. With regard to traditional drills (evacuations, talks, conferences, videos), only 44.1% of users have taken part in them, which corresponds to a total of 30 people. These users rated their willingness to participate in a drill of this type, obtaining an average of 1.43, which is obtained on a scale of 1 to 5, where 5 represents strongly agree and 1 represents strongly disagree. The above represents a very low level of liking for this type of methodologies that have been implemented in the PUJ so far. Complementing the above, *Graphic 4* shows the estimated number of traditional simulations that the participants have experienced.

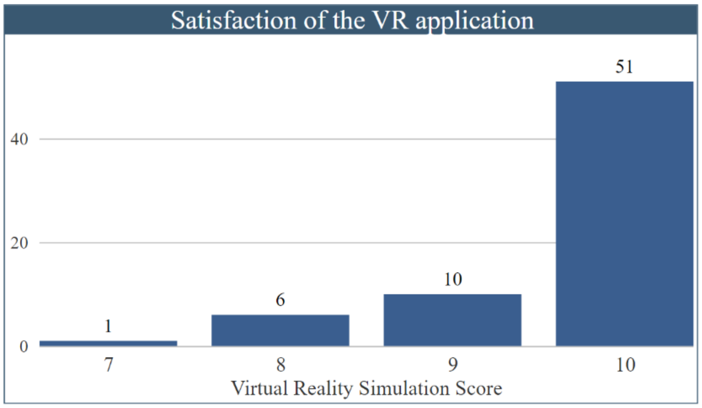


Graphic 4 - Number of traditional drills that participants have experienced

Besides, only 4.4% of users have participated in drills with different methodologies that correspond to field practices and real drills (fires, earthquakes, spills, among others). This percentage corresponds in its entirety to brigades, therefore, it is inferred that those who would intervene in these emergency scenarios have acquired good tools given that they are provided with a practical component in their learning. Furthermore, 97.1% of the participants had never experienced immersion in virtual environments. Thus, it was pertinent to present a learning scenario prior to the real application, in order to reduce any errors in the measurement due to lack of knowledge in the use of these VR tools.

After the participants experienced the real application, the following perceptions were obtained based on what was documented in the final survey. All the participants consider that this type of simulation is important for the university and they would also like to participate again in training in emergency situations that involve methodologies such as the one proposed in this project. This is relevant to the study since, according to verbal testimonies of brigade members and teachers participating in the experiment, in traditional drills that have been carried out at the university, users do not have the relevant seriousness and in most cases not everyone evacuates the building.

For an evacuation drill, 97.1% of the participants preferred the training system as opposed to traditional methodologies. Furthermore, on a scale of 1 to 10, where 10 represents the highest satisfaction with the application, the average score obtained was 9.63 points. A sample standard deviation of 0.71 was obtained, which explains that most of the sample data tend to be clustered close to the expected value. This is evident in *Graphic 5*. As a result, the participants' welcome for integration with emerging technologies for the disaster prevention domain was demonstrated. Furthermore, they preferred the experiential immersion of the simulated emergency with VR tools.



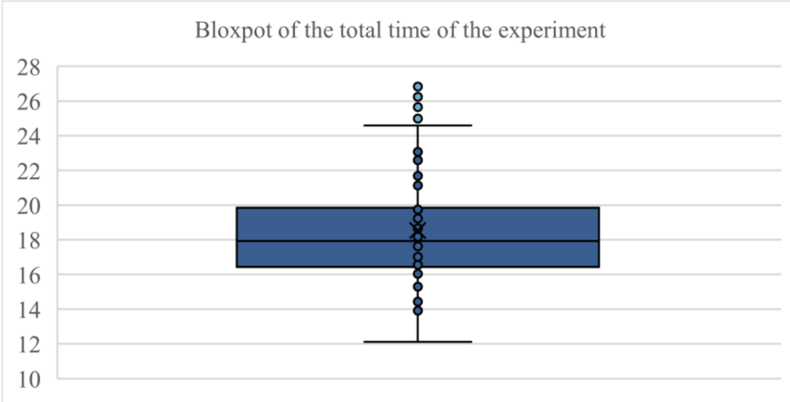
Graphic 5 - Score obtained from the virtual reality application

Subsequently, in order to measure the degree of agreement between the distribution of the data and a specific theoretical distribution, a goodness-of-fit procedure was performed using the Kolmogorov-Smirnov test. This test was applied to the scalar variables of the experiment (Age, Number of participations in a traditional simulation, Application time, Total experiment time and Simulation score), contrasted with the Normal, Uniform, Poisson and Exponential distribution. For this non-parametric test, a significance level of 0.05 is established with the aim of rejecting or not one of the hypotheses set out below to find a possible distribution of the variables under consideration:

- H_0: The analyzed data follows a D* distribution.
- H_1: The analyzed data does not follow a D* distribution.
- D*: Normal, Uniform, Poisson or Exponential.

For all of these variables, no p-value for each distribution was greater than the established significance, which implies that the null hypothesis (H0) of this test is rejected and the alternative hypothesis (H1) is true, therefore, the data analyzed do not follow a specific theoretical distribution. For the population analysis, confidence intervals were used to obtain the range in which the parameter is likely to lie.

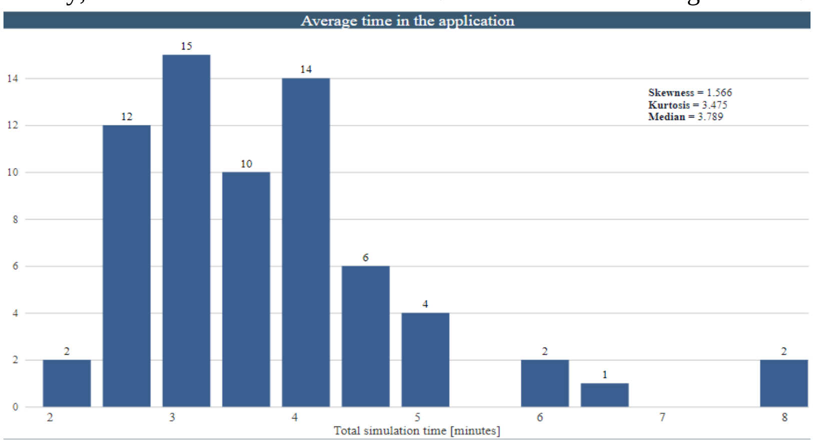
During the testing stage of the experiment, it could be noticed that there are several factors involved in the measured time. Some examples could be the quick reading of the participants, the communication with the researcher and possible differences in the time measurement. Therefore, in *Graphic 6*, the construction of the boxplot for this variable is presented. A central position or median value of 17.93 minutes, an interquartile range of 3.26 minutes describing 50% of the central data and 5 outliers greater than the upper limit of mild outliers were obtained. A confidence interval was used to determine the range to conclude the appropriate time to complete the protocol for this experiment. Therefore, with 95% confidence, it can be stated that the average time of the experiment is between 17.76 and 19.33 minutes.



Min	12.118
Max	26.826
Q1	16.508
Q2	17.933
Q3	19.774
RI	3.266
Mild atypical	
Min	11.608
Max	24.675
Extreme outliers	
Min	6.707
Max	29.575

Graphic 6 - Bloxpot total time of the experiment [minutes]

On the other hand, as illustrated in *Graphic 7*, the average time it took participants to complete the actual application from the starting point to the meeting point was 4.04 minutes. The skewness, being greater than zero, denotes that the majority of participants' measured times are to the left of the mean, suggesting a lower-than-average time. The Kurtosis coefficient shows that the data are distributed in a leptokurtic manner, therefore, there is a large concentration of values around the mean. With the above, it took the users approximately 4 minutes to know the different evacuation routes of the building and the meeting point in case of emergency. Finally, the shortest time recorded was 2.14 minutes and the longest was 8.49 minutes.



Graphic 7 - Total simulation time

Since no scalar variable followed a normal distribution, the non-parametric Mann-Whitney U and Kruskal-Wallis H tests were used to compare means with dichotomous and polytomous variables, respectively. The corresponding hypotheses are shown below:

U by Mann Whitney

- H_0: Time is not different between the groups analyzed
- H_1: Time is different between the groups analyzed

H by Kruskal-Wallis

- H_0: There is no difference between the groups analyzed
- H_1: There is a difference in at least two of the groups analyzed

With a confidence level of 95%, a p-value lower than the significance level was obtained, so that the total time of the experiment and of the actual application is different for men and women. Thus, with a p-value equal to 0.002, the null hypothesis of the test is rejected. Consequently, the total time of the experiment for people who had previously participated in a traditional simulation is different from those who had not. This shows that factors such as gender and previous experience in traditional drills influence the speed with which the experiment unfolds. Finally, given the occupation to which the participants belonged, there was no significant difference in time between the groups analyzed. In conclusion, being a brigade member, teacher, administrative staff or student does not influence the time it takes the user to develop the entire experiment and the actual application. *Table 4* shows the p-values obtained:

Comparative Variables		**p-value**
Total Application Time	Gender	0.002
	Participation in traditional simulation	0.100
	Occupation	0.328
Total Experiment Time	Gender	< 0.001
	Participation in traditional simulation	0.002
	Occupation	0.134

Table 4 - p-values obtained in the tests

It is important to take into account and analyze the learning component of the VR simulation. For this, before the simulation, users were asked to fill in the survey which was the meeting point in case of an eventual emergency situation. Similarly, the same question was asked of individuals after they had participated in the simulation. This was done in order to have the proportion of people who knew the correct meeting point before and after the application.

44.12% of the respondents answered correctly before using the application. However, after participating in the simulation, 95.58% got the correct meeting point. This reflects a large difference in these proportions, which could be evidence of the high degree of learning in people after the simulation. However, for greater certainty in the analysis, McNemar's test was performed to compare whether these proportions have a statistically significant difference. The hypotheses are shown below:

- H_0: Knowledge about the meeting point did not change after the simulation
- H_1: Knowledge about the meeting point changed after the simulation

A p-value equal to zero was obtained, which, being less than the significance (5%), reflects that the null hypothesis is rejected. It can be affirmed that the proportions of correct answers before and after the application are significantly different. Taking into account the above, it can be seen that there was a positive change in the users' learning after the simulation with respect to the knowledge of the meeting point of the engineering laboratory building.

To evaluate the effectiveness of the simulation, the following components were analyzed: the realism of the simulation, the fear it generates, the interest it arouses in the users, how to act in an emergency situation and the motivation of the participants. All these variables were analyzed before and after using the application. The average score of the rating that the users answered in the surveys of the experiment was taken into account. It is important to note that this comparison is made with the 30 individuals who had participated in at least one traditional simulation. The Wilcoxon Signed Rank Test was used to compare the average score of the two moments (before and after). The hypotheses of this test are presented below:

- H_0: The rating in component C* after running the simulation is equal
- H_1: The rating in the C* component after the simulation is not equal
- C*: Realism, Fear, Interest, Knowledge or Motivation

According to *Table 5*, given the significance level established, the only component that does not have a significant difference, taking into account the two moments, is fear. The p-values of the other components, being less than the significance level (5%), indicate that there is a difference between the mean scores collected. Furthermore, it is evident that the lowest mean score that users rated at the end of the simulation was fear. Therefore, this analysis reflects that the simulation generated a positive impact on people's perception for most of the components.

Component	Moment	Average score	p-Value
Realism	Before	2.97	0.000
	After	4.26	
Fear	Before	2.27	0.116
	After	2.61	
Interest	Before	3.37	0.000
	After	4.74	
Knowledge	Before	3.87	0.047
	After	4.45	
Motivation	Before	3.67	0.002
	After	4.42	

Table 5 - p-values obtained in Wilcoxon test

Finally, several suggestions were collected from the participants at the end of the simulation. First, users expressed that they would like to be able to vary the speed at which they moved. Given the emergency conditions, if at some point the players felt the need to bend down, they could do so. Users also suggested that the virtual environment should include NPCs and more interaction with the different objects in the simulation, and that the signage should be more intuitive and clearer when it comes to evacuating the building. Likewise, some suggestions suggest the simulation of different disasters.

Finally, based on the results obtained and the review of the existing literature, similarities were found with the project developed through the implementation of SG [1]. In this study, based on an assigned score, it is also concluded that there is a significant difference in the performance of men and women, and that the average score of men was better than that obtained by women. It was also observed that there is a positive influence on the level of users' interest in learning about disaster prevention. This behavior was repeated in the experiment conducted using HTC Vive in the simulation of a fire [23], in which more than 70% of the students believe that the use of a VR platform increases interest in learning and usefulness in training in emergency situations. In contrast to the present study, all the participants think that the simulation they experienced is important for the university and increases factors of interest, knowledge, motivation and realism compared to traditional methodologies.

5.5. Analysis of the impact

- **Productivity**

So far, no evacuation drill has been conducted in the Engineering building due to the current contingency. However, according to figures provided by the OSH department, the last drill conducted at the university was carried out at the San Ignacio University Hospital, with the participation of the Faculties of Medicine and Nursing. This took around 42 minutes as shown in *Figure 13*. For this particular case, in terms of productivity, such simulation had a high impact since, when multiplying this time by the 628 people who participated in it, the result was 439.60 hours, equivalent to 18.32 days, during which people ceased to be productive in their environment.

Simulacro de Evacuación

Oficina Seguridad y Salud en el Trabajo
Dirección de Gestión Humana

RESULTADO SIMULACRO DE EVACUACIÓN, 07 - 2019

RESULTADO SIMULACRO EDF. HUSI		
Fecha		Martes 29 de Octubre de 2019
Hora de inicio		10:30 am.
PUNTO DE ENCUENTRO	Primero en Llegar HUSI.	10 :33'
	Último en llegar HUSI	10 : 42'
	Primero en Llegar PUJ.	10 : 35' : 20"
	Último en llegar PUJ.	10 : 37' : 31"
Hora de finalización		11: 02' a. m.
Tiempo total ejercicio		42" Minutos
Personal evacuado PUJ		**60** Participantes
Personal Total Evacuado HUSI		**568** Participantes.

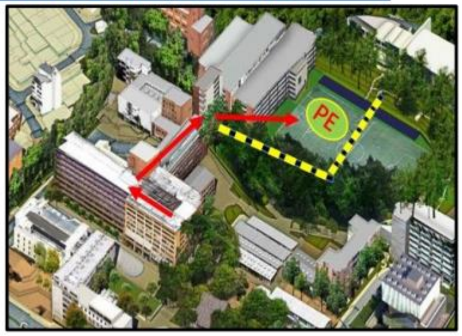


Figure 13 - Data from the evacuation drill conducted in 2019 at PUJ

With the methodology proposed in this project, only the average of the total time of the real application would be taken into consideration, as the other activities carried out in the experiment were carried out with the aim of collecting information for the study and maintaining the safety of the participants. For the same number of people in the simulation carried out at the university, assuming that each person would take 4.04 minutes, we have an unproductive time equal to 42.29 hours, equivalent to 1.76 days. This is a discrepancy of 16.56 days. In conclusion, the large difference in the above measurements invites to rethink the evacuation methodologies used so far in the PUJ facilities.

- **Economical**

This is a factor closely linked to the previous one, as the time taken for the simulation will have an influence on the associated cost. Consequently, if a cost per hour elapsed is assigned, for example, taking as a reference $30,285 Colombian pesos, which is equivalent to the minimum daily wage stipulated in Colombia. And in financial terms, if the 628 people participating in the simulation were being paid a monthly minimum wage. With traditional methodologies, at least $554,821 would be spent, since it is a mandatory non-productive period, but with the methodology proposed, $49,970 would be spent, which represents a saving of $504,851.

In addition, in traditional drills, the entire building in question must generally be evacuated and vacated, and the time involved not only affects the productivity of the people involved but also all the activities and processes that must be halted as a result of the drill. With the designed application, only a room of at least 10 square meters, the VR equipment and at least one power source are needed. In this way, it is not necessary to stop the entire operation while the training of the personnel is being carried out, thus incurring lower costs. Finally, for proper training, it was found that with only one researcher in charge, it was possible to perform the simulation for each participant. Therefore, with this methodology, the costs of the personnel in charge of disaster prevention drills are also reduced.

- **Health**

The implementation of virtual reality in evacuation drills, apart from the advantages and benefits already mentioned, can also contribute to the well-being, safety and health of people. This can be evidenced by the current contingency caused by SARS-CoV-2. To prevent contagion, one of the suggestions is to avoid crowds, which makes it impossible to conduct traditional face-to-face drills, thus demonstrating a notable advantage of the application of VR. Similarly, there is an opportunity to apply these tools in other fields that put people's health at risk, such as work with electricity, hazardous energies, in confined spaces and other areas of application.

- **Cultural**

Building a culture of prevention and emergency response is not a common theme, but it is vitally important. Perhaps, the probability of having to live through such a situation is minimal, however, being prepared or not to face such an adversity can make a difference in the severity of the consequences. This is why the application presented in this project is valuable, as it provides a new way to train and gradually generate that much-needed culture. It will also allow people to train in a short time, in a didactic way and, if desired, from home. In conclusion, in time, there will be no justification for not being trained in disaster prevention.

- **Technological**

As is well known, technology is currently experiencing exponential growth worldwide. According to the Bancolombia Group, between 2014 and 2019, the number of companies that make up Industry 4.0 increased by 7.7% [25]. This, being a project based on the increase of emerging technologies, is part of the aforementioned boom. Thus, 97.1% of the people who participated in the experiment stated that they preferred this methodology over traditional simulations. Analyzing the above, it was evident that the majority of people liked to participate in simulations carried out with emerging technologies, due to their content and attraction. This project opens the doors to technology, and shows the great importance it currently has. It is important to continue to use technology in scenarios involving risks or situations that can be prevented.

6. Limitations, Conclusions and Recommendations

Being prepared for an emergency situation is essential to reduce the consequences generated by an unexpected disaster. Therefore, the objective of this project is to design a training system for the Pontificia Universidad Javeriana's community through virtual reality tools, which facilitate evacuation in the event of a structural fire at the new Engineering laboratory building. A learning scenario and evacuation application were created using Unity 3D software and HTC Vive Pro hardware. The simulation was developed as a serious game, with the purpose of generating a learning experience for the participants. For a greater immersion of the user, a sensation of heat was generated with the help of an electric heater.

In order to have a significant proportion of the population, the experiment was applied to a sample of 68 people belonging to the Faculty of Engineering. This number of people includes students, brigade members, teachers and administrative staff, however, it is suitable for any person who satisfies the requirements of the VR tools. With a confidence of 95%, it can be affirmed that the average time of the experiment is between 17.76 and 19.33 minutes, this contemplates the duration from the welcome to the participant until the final survey is completed. Likewise, the average time of the emergency application is 4.04 minutes, which indicates that it contemplates the user's learning to know the emergency exits and the meeting point of the building. One of the results obtained shows that gender influenced the duration of the participants in the measured times, the respective averages show a longer duration of women in the experiment and in the simulation.

The evacuation application developed compared to traditional drills shows, with a significance level of 5%, that factors such as the realism of the evacuation, motivation, knowledge and interest of the participants are different in comparison to the proposed methodology. For an evacuation drill, 97.1% of the participants preferred the VR training system over traditional methodologies, and the application obtained an average score of 9.63 points out of a possible 10. In addition, the results show a positive impact on factors such as: productivity, economy, culture, health and technology. This is due to the fact that the application can be carried out individually, the application time is flexible, it can be performed in a reduced space and it is not necessary to evacuate the building or stop the activities that are being developed.

This project is limited to the design of a VR training system through the HTC Vive system, so the application is only compatible with this tool. This is due to the configuration and assignment made in the initial stages of the project, so it cannot be easily changed unless the appropriate programming is used. Another important constraint is the number of respondents. Although the required number was achieved, it was not possible to address a larger number due to the current SARS-CoV-2 contingency. This was due to the fact that the biosecurity protocols and the provisions of the Mayor's Office of Bogota limited the number and dates to be taken into account for the development of the project.

This project is a breakthrough in disaster prevention education with Industry 4.0 tools and techniques. As recommendations, it is important to continue the incursion of this type of experiments for other types of disasters, such as earthquakes, tsunamis, chemical disasters, among others. A challenge that future researchers can take into account is the inclusion of NPCs in the simulation with VR. The interaction of NPCs with the user can generate more parameters to be analyzed, since crowding, blockages at exits and delays in evacuation times can occur. Also, the complete evacuation of the building can be included or cover more spaces and different types of buildings.

Another recommendation that a project of this type can take into account is the incursion of more functions related to the participant, for example, interaction with objects on the stage, bending down to reduce the effect of smoke, among others. Likewise, it is important to adapt the simulation to other hardware and software tools to make these projects more inclusive. Similarly, to increase the accuracy of the statistical results of the experiment, it is recommended to increase the number of participants in the simulation. Finally, taking into account the comments and suggestions of the users, it is recommended to program changes in the speed of movement of the user and better signage in the building. All this in order to have a greater reach and impact of the use of VR for evacuation drills.

7. Acknowledgments

We would like to thank engineers Wilson Alonso Hernández Martínez and Christian Ricardo Zea Forero for their time and willingness to lend us the equipment and rooms used in the degree work. We would also like to thank the Center for Ergonomics Studies for the help provided, which facilitated the appropriate development of this study. To the professors Sebastián Alberto Peláez Gómez and Luis Andrés Saavedra Robinson for their work as tutors during which they have demonstrated not only great knowledge, but also comprehension and empathy without which the work would not have been possible. Finally, to all those who participated in the experiment despite all the conditions and restrictions that were occurring in the country.

8. Glossary

Below are the most relevant set of concepts for the development of this project, and their respective definitions:

Augmented Reality: It is the union of the real and virtual worlds to create new conditions for the image, where physical and digital objects coexist and interact in real-time [26].

ELC methodology: Kolb's Experiential Learning Cycle (ELC) works on two levels: a four-stage cycle of learning and four separate learning styles. Much of Kolb's theory is concerned with the learner's internal cognitive processes [27].

Evacuation Drill: It is defined as the action of orderly and planned to vacate a place and is performed by occupants for safety reasons in the face of a potential or imminent danger [28].

HMD: A head-mounted display (HMD) is a type of computer display device or monitor that, as the name implies, is worn on the head or is built in as part of a helmet [29].

NPC: A Non-Player Character (NPC) is a video game character that is controlled by the game's artificial intelligence (AI) rather than by a gamer. Non-player characters serve a number of purposes in video games, including: as plot device, for assistance and often serve as save points, item stores, health regeneration points and so on [30].

Serious Games: Serious game is a recreational exercise based on real scenarios, where a role is assumed in the real or virtual world, to obtain learning or awareness about a particular problem [31].

Simulation: It is a method of approaching reality. Its usefulness is manifold, especially for educational, training and research purposes [Bolton as cited in 35].

UNGRD: Short of The National Unit for Disaster Risk Management directs the implementation of disaster risk management, taking into account sustainable development policies, and coordinates the operation and continuous development of the national system for disaster prevention and response – SNPAD [33].

Unity 3D: The availability of game engines such as Unity3D provides a quick way for prototyping 3D scenarios and performing experiments to elicit human behavior in such emergency situations [11].

Virtual Reality: It is a computer simulation that can be experienced as a physical place and that interacts with the user's senses to create an alternative reality [34].

9. Appendix

Appendix	Concept	Description
1	Software and Hardware Survey	Survey applied to the experts to make the choice of software and hardware.
2	Preliminary Survey	Initial survey applied after signing the informed consent form.
3	Choice of tools	Development of the AHP Methodology for hardware and software selection.
4	User profile	User manual sent to participants by e-mail
5	Informed Consent Form	In this hyperlink, you will find the informed consent form used in the experiment.
6	Informed Consents signed by each participant	Informed Consent of each participant signed and a compendium of the same.
7	Learning scenario	Executable learning scenario and a short video demonstrating user mobility in this environment.
8	VR application	The executable of the simulated emergency situation and a video showing the route to be followed by each participant to reach the meeting point are presented.

Appendix	Concept	Description
9	Experimental Protocol	Experimental protocol submitted to the Research and Ethics Committee of the Faculty of Engineering. Endorsement document for the execution of the experiment
10	Final Survey	Final survey applied at the end of the implementation of the VR application.
11	Multimedia files	Photos and videos of some participants during the simulation
12	Data analysis and visualization	Results obtained after analysis of the data in SPSS and visualization of the data using PowerBI
13	Folder of Appendix	Main folder contains all the attachments mentioned above.

10. References

[1] M.-H. Tsai, Y.-L. Chang, J.-S. Shiau, and S.-M. Wang, “Exploring the effects of a serious game-based learning package for disaster prevention education: The case of Battle of Flooding Protection,” *Int. J. Disaster Risk Reduct.*, vol. 43, 2020.

[2] Sukirman, R. A. Wibisono, and Sujalwo, “Self-Evacuation Drills by Mobile Virtual Reality Application to Enhance Earthquake Preparedness.,” *Procedia Comput. Sci.*, vol. 157, pp. 247–254, 2019.

[3] UNGRD, “Consolidado Anual de Emergencias,” *Unidad Nacional para la Gestión del Riesgo de Desastres (UNGRD)*, 2019. .

[4] Corporación Universitara Lasallista, “Plan de Emergencias,” 2014.

[5] T. Tepe, D. Kaleci, and H. Tuzun, “Integration of Virtual Reality Fire Drill Application into Authentic Learning Environments,” *World J. Educ. Technol. Curr. Issues*, vol. 10, no. 4, pp. 72–78, 2018.

[6] R. Lovreglio *et al.*, “Prototyping virtual reality serious games for building earthquake preparedness: The Auckland City Hospital case study,” *Adv. Eng. Informatics*, vol. 38, pp. 670–682, 2018.

[7] A. D. Kaplan, J. Cruit, B. D. Sawyer, P. A. Hancock, M. Endsley, and S. M. Beers, “The Effects of Virtual Reality, Augmented Reality, and Mixed Reality as Training Enhancement Methods: A Meta-Analysis,” *Hum. Factors*, 2020.

[8] R. Lovreglio and M. Kinateder, “Augmented reality for pedestrian evacuation research: Promises and limitations,” *Saf. Sci.*, vol. 128, 2020.

[9] D. Manca, S. Brambilla, and S. Colombo, “Bridging between Virtual Reality and accident simulation for training of process-industry operators,” *Adv. Eng. Softw.*, vol. 55, pp. 1–9, 2013.

[10] J. Belger *et al.*, “Immersive Virtual Reality for the Assessment and Training of Spatial Memory: Feasibility in Individuals with Brain Injury,” *2019 International Conference on Virtual Rehabilitation (ICVR), Virtual Rehabilitation (ICVR), 2019 International Conference on*. pp. 1–2, 2019.

[11] J. E. Almeida, R. J. F. Rossetti, J. T. P. N. Jacob, B. M. Faria, and A. Leça Coelho, “Serious games for the human behaviour analysis in emergency evacuation scenarios,” *Cluster Comput.*, vol. 20, no. 1, pp. 707–720, 2017.

[12] H. Mitsuhara, C. Tanimura, J. Nemoto, and M. Shishibori, “Failure-enhanced evacuation training using a VR-based disaster simulator: A comparative experiment with simulated evacuees,” *Procedia Comput. Sci.*, vol. 159, pp. 1670–1679, 2019.

[13] G. H. Nam, H. S. Seo, M. S. Kim, Y. K. Gwon, C. M. Lee, and D. M. Lee, “AR-based Evacuation Route Guidance System in Indoor Fire Environment,” *2019 25th Asia-Pacific Conference on Communications (APCC), Communications (APCC), 2019 25th Asia-Pacific Conference on*. pp. 316–319, 2019.

[14] S. Sharma, J. Stigall, and S. T. Bodempudi, “Situational Awareness-based Augmented Reality Instructional (ARI) Module for Building Evacuation,” *2020 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW), Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW), 2020 IEEE Conference on*. pp. 70–78, 2020.

[15] Y. Tao, Q. Peijun, W. Xin-Bing, J. Feng, Z. Qihua, and J. Shao-En, “Personnel Evacuation Computer Simulation for Scientific Research Building Under Emergency Condition,” *2019 16th International Computer Conference on Wavelet Active Media Technology and Information Processing, Wavelet Active Media Technology and Information Processing (ICCWAMTIP), 019 16th International Computer Conference on*. pp. 455–460, 2019.

[16] J.-P. Wang, M.-R. Wang, J.-L. Zhou, Q.-J. Zuo, and X.-X. Shi, “Simulation based optimal evacuation plan in vertical ship lift: a case study.,” *Eng. Comput.*, vol. 37, no. 5, pp. 1757–1786, 2020.

[17] D. Gianni, P. Bocciarelli, A. D'Ambrogio, and G. Iazeolla, "A model-driven and simulation-based method to analyze building evacuation plans," *2015 Winter Simulation Conference (WSC), Winter Simulation Conference (WSC), 2015*. pp. 2644–2655, 2015.

[18] H. Xu, S. Wang, and L. Wang, "Quality Evaluation Method for Airport Emergency Plan by Virtual Drill Simulation," *2019 6th International Conference on Dependable Systems and Their Applications (DSA), Dependable Systems and Their Applications (DSA), 2019 6th International Conference on*. pp. 450–454, 2020.

[19] author Junya Kawai, author Hiroyuki Mitsuhara, and author Masami Shishibori, "Game-based evacuation drill using augmented reality and head-mounted display," *Interact. Technol. Smart Educ.*, vol. 13, no. 3, pp. 186–201, 2016.

[20] G. Santamaría-Bonfil, M. B. Ibáñez, M. Pérez-Ramírez, G. Arroyo-Figueroa, and F. Martínez-Álvarez, "Learning analytics for student modeling in virtual reality training systems: Lineworkers case," *Comput. Educ.*, vol. 151, 2020.

[21] W. Chen, H. Su, Y. Yong, and Z. Hu, "Decision support system for urban major hazard installations management based on 3DGIS," *Phys. Chem. Earth*, vol. 110, pp. 203–210, 2019.

[22] T.-J. Kim, J.-H. Huh, and J.-M. Kim, "Bi-directional education contents using VR equipments and augmented reality.," *Multimed. Tools Appl.*, vol. 77, no. 22, pp. 30089–30104, 2018.

[23] S.-C. Lin, T.-J. Lee, H.-W. Wang, and H.-C. Chan, "Developing the Immersion Virtual Reality Platform Based on Experiential Learning Cycle - Using Fire Disaster Prevention Education as an Example," *2018 7th International Congress on Advanced Applied Informatics (IIAI-AAI), Advanced Applied Informatics (IIAI-AAI), 2018 7th International Congress on, IIAI-AAI*. pp. 948–949, 2018.

[24] H. Xu, X. Zhu, and J. Wan, "Airport Fire Emergency Rescue Virtual Drill Platform Based on Virtual Reality Technique," *2019 IEEE 1st International Conference on Civil Aviation Safety and Information Technology (ICCASIT), Civil Aviation Safety and Information Technology (ICCASIT), 2019 IEEE 1st International Conference on*. pp. 63–66, 2019.

[25] Grupo Bancolombia, "Industria 4.0 en Colombia impulsa la reactivación económica," *Bancolobia Web Page*, 2021. .

[26] K. Terán Korowajczenko, "Realidad Aumentada Sus Desafíos Y Aplicaciones Para El E-Learning," no. June, 2012.

[27] S. McLeod, "Kolb's Learning Styles and Experiential Learning Cycle," 2017.

[28] I. D. H. LASCARES, "Evacuación," *J. Chem. Inf. Model.*, vol. 53, no. 9, pp. 1689–1699, 2013.

[29] Thecnopedia, "What does Head-Mounted Display (HMD) mean?," 2017.

[30] techopedia, "Non-Player Character (NPC)," 2020.

[31] J. F. C. Lobo, "Juegos Serios: Alternativa Innovadora," *Conoc. Libr. y Educ.*, vol. 2, no. 2, 2014.

[32] G. Texson, "Diseño de un simulador de vuelo para la compra y venta de acciones en el mercado accionario mexicano," pp. 5–28, 2005.

[33] ICDE, "Infraestructura Colombiana de Datos Espaciales," 2017.

[34] P. Raesfeld, "Aplicación de mapas cognitivos difusos a VRML en un ambiente virtual," 2000.