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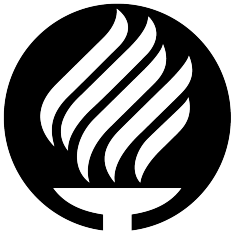

Tecnológico de Monterrey

# Using a virtual reality serious video game for teaching structural engineering concepts

by

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# *Acknowledgements*

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## Abstract

Civil engineering students in Mexico struggle a lot when they start to learn structural engineering concepts based on the Mexican construction norm because they have a difficult time visualizing the 2D drawings from the norm in real life scenarios. This dissertation addresses the problem by designing and developing a virtual reality serious video game for teaching structural engineering concepts. The game was developed in Unreal Engine 5, and it contains 10 different questions taken from the rules of the Mexican construction norm. The game was tested by a group of 25 civil engineering students from the university and a survey was used to evaluate their user-experience. The results from the experiment prove that VR serious video games can be effectively used for teaching or reinforcing structural engineering concepts.

# Contents

# Acronyms

| | |
|---|---|
| **UE5** | **U**nreal **E**ngine **5** |
| **VR** | **V**irtual **R**eality |
| **BIM** | **B**uilding **I**nformation **M**odeling |
| **BP** | **B**lue**P**rint |

# Chapter 1

# Introduction

## 1.1 Context

The research done in this project will discuss the use of Virtual Reality(VR), serious video games and structural engineering. A brief context on each of these topics will be given to allow readers to fully understand the project.

- **VR**: A technology that allows users to enter a simulated virtual world. It has applications in the education sector where it allows for very immersive experiences for students to learn.
- **Serious video games**: A genre of video games that are used for learning and educational purposes besides just pure entertainment.
- **Structural engineering**: A branch of civil engineering that focuses on designing safe and stable structures applying technical knowledge of different types of construction materials.

## 1.2 Research project

The remaining 6 chapters of this dissertation cover the research done to to combine these 3 areas to develop a VR serious video game for teaching structural engineering concepts. The contents of each chapter are the following:

- **Chapter 2** contains the current state of the art on the use of VR for educational applications in the construction engineering sector.

- **Chapter 3** outlines the main objective of the research and why it is important.
- **Chapter 4** describes the development of the VR serious video game done for the research.
- **Chapter 5** contains the methodology used for designing the evaluation used for the research of this project.
- **Chapter 6** discusses the results obtained from the experiment that was made and their interpretation.
- **Chapter 7** concludes the research done with the project and describes the future work that could be done with this research.

# Chapter 2

# State of the art

This chapter describes how VR has been used to create educational applications or games and the benefits of using this medium instead of the traditional one for teaching. This analysis shows how there have been several applications made specifically in the construction engineering sector.

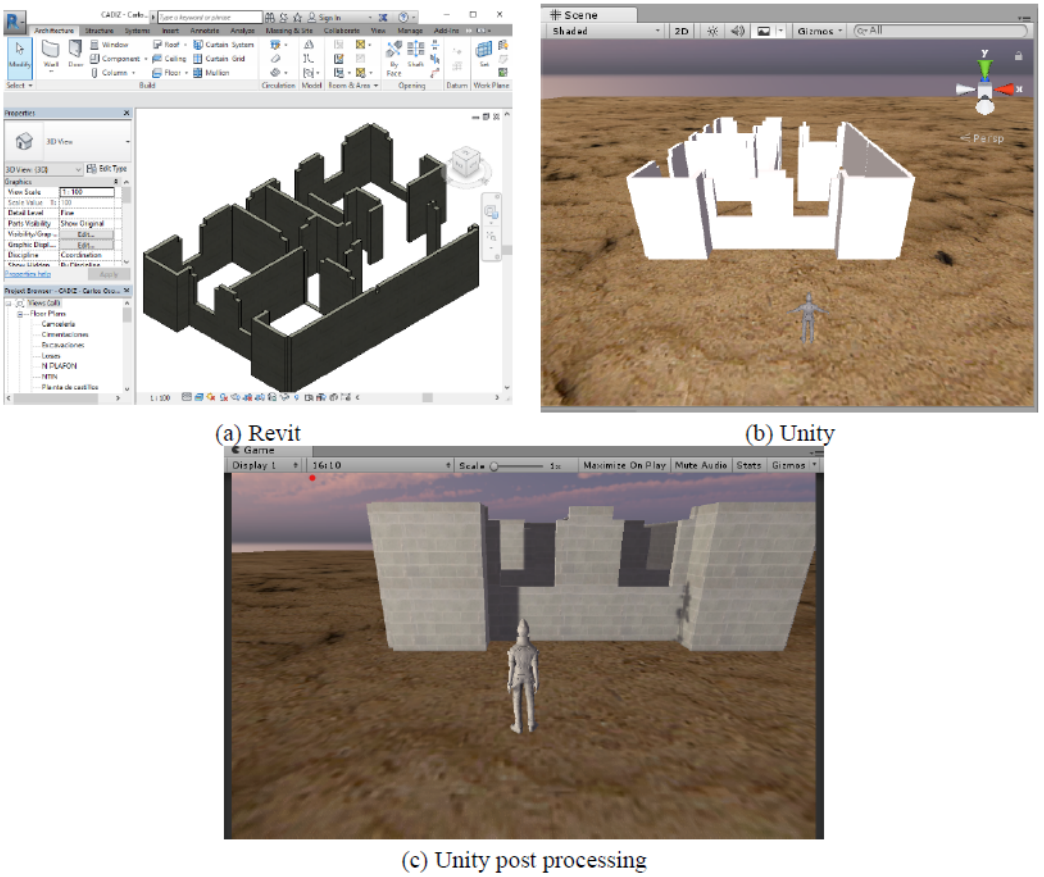
## 2.1 Previous Works

There has been plenty of research regarding the use of VR in construction engineering. However, the projects done by Arif (2021) [1], Beh et al. (2021) [2], & Osorio Sandoval et al. (2018) [12] are the most relevant for the research of this dissertation project. All these projects consisted of the creation of a VR interactive application or game within the construction engineering sector.

The first one, which was the only one that was done in a special VR inspector instead of Unity, consisted of having a bridge inspection module simulation. This was done using the Cave Automatic Virtual Environment (CAVE) system, which is an immersive virtual environment generated through the positioning of locations [1].

FIGURE 2.1: CAVE system [1].

The second project consisted of a simulator prototype of a single construction activity in order to visualize how its duration is affected by different interactive input parameters. It also uses a Building Information Modelling (BIM) software to create the models that are later integrated into the game engine used for development [12].




(a) Revit (b) Unity

(c) Unity post processing

FIGURE 2.2: Model built for the project [12].

The third project proposed a game-based virtual reality (GBVR) system for building utility inspection training. It compared the system that was created with a paper-based system to show the potential of overcoming the low practicality of paper-based training, proving that the GBVR system had higher realism and practicality for students as well as a higher motivation and engagement factor [2].


**(a)** **(b)**

FIGURE 2.3: Utility inspection scenario [2].

All these projects from the literature evaluate the time it takes students to complete the training as well as their accuracy. Besides, the user-experience that students have while playing the games is the focus of the evaluation and results. This is measured with the use of surveys that students answer after they play the game. Beh et al. (2021) [2] provide the most complete evaluation methodology for these types of projects. It consists of evaluating the system usability and user-friendliness of the game since it ensures that "the developed game-based experiential learning method does not have an over-complex user interface and is equipped with realistic building utility objects" while also gauging "whether the training provides a more attractive, motivating, engaging and interactive training method compared to the traditional paper-based training" .

This is evaluated with a survey that contains questions with a five-point Likert scale, 5 (strongly agree) to 1 (strongly disagree). The average of the results is measured and compared to evaluate each aspect of the methodology. Figure 2.4 shows the results from the evaluation methodoly of the literature project.

| | System usability | |
|---|---|---|
| | (Best score 5) | Results from literature (Beh, Rashidi, Talei & Lee, 2021) |
| | *1. Ease of use* | |
| | Ease of navigation | 4.1 |
| *(Best score 1) | System complexity* | 4.2 |
| | Comfort level | 4.1 |
| | *2. Visual output* | |
| | Practicality | 4 |
| | Clarity | 4.5 |
| | Distraction of information* | 4.5 |
| | Realism of objects | 4.3 |
| | *3. Knowledge retention* | 4.6 |
| | **User-friendliness** | |
| | *1. Attractiveness* | |
| | Fun learning method | 4.7 |
| | Beneficial learning method | 3.5 |
| | *2. Motivation* | |
| | Urge to continue the experience | 4.6 |

FIGURE 2.4: Evaluation methodology [2].

## 2.2 Comparison of previous works

Overall, all these works explain in detail how using a VR game enhance the learning experience of students and provide strategies for integrating tools used within the construction industry with the game. However, as seen in Figure 2.5, most of these projects use very specific or custom made technology such as the CAVE system [1]. Other works, use a different game engine (Unity) and they are developed for a very specific task within a classroom or a shop floor [12] [7]. This makes it difficult to adapt or use the existing work to the technical standards followed in the Mexican construction norm, which is the focus of my project.

| Advantages | Disadvantages | Research paper |
|---|---|---|
| + Explains benefits of using game engines<br>+ Provides strategies for integrating industry tools with game engines | - The prototype focused on 2 particular models of the industry<br>- Focused on the integration of the models instead of a serious video game | (Osorio Sandoval, Tizani & Koch, 2018) |
| + Environment built using unreal engine<br>+ Provides best practices for interaction in VR | - Not applied to structural or construction engineering<br>- Very simple VR scenes | (Holder, Carey & Keir, 2020) |
| + Provides recommendations for enhancing learning in VR<br>+ Describes a modeling methodology that could be useful | - Uses a very specific technology<br>- The use of the application requires a guide | (Arif, 2021) |
| + Provides different criteria for testing a VR serious game<br>+ Provides a framework for game-based virtual reality education | - Uses a different game engine<br>- The scenarios that were implemented are comlex. | (Beh, Rashidi, Talei & Lee, 2021) |

FIGURE 2.5: Advantages & Disadvantages of state of the art projects.

## 2.3 Conclusion

Even though the projects made in the literature are different than the proposed solution of this project, they still serve as references on what to do and what to avoid. Most of all, this analysis shows that the evaluation methodology used by Beh et al. (2021) [2] could be used to correctly evaluate the user-experience of the proposed game.

# Chapter 3

# Objective of Research

This research will address the problem that civil engineering students have when starting to learn structural engineering concepts based on the Mexican construction norm because it is difficult for them to grasp the knowledge by just looking at 2D drawings and complex statements of the construction norm. To accomplish this, the following general objective has been set: *To design and develop a virtual reality serious video game for teaching structural engineering concepts.* Besides, the following phases were proposed:

1. Investigate the state of the art in virtual reality serious video games.
2. Investigate about serious video games for structural engineering.
3. Design and develop a virtual reality serious video game that teaches structural engineering concepts.
4. Test and analyze with real users the usability of the serious video game.
5. Write a dissertation that informs the results of the investigation and tests of the serious video game.

## 3.1 Justification of the proposal

Using virtual reality for teaching allows the students to be more immersed in their learning experience. Besides, "the benefits of using educative VR applications include the promotion of skills development or knowledge acquisition as well as the enhancement of the learner motivation

and the whole teaching-learning process". Having this kind of learning approach helps reduce the cost of practical lessons that are common in engineering education[11].

In the words of Dr. Saúl Enrique Crespo Sánchez, who is the director of the Sustainable Technologies and Civil Engineering department at the university:

> "In the teaching of structural engineering and construction areas, the visualization of structural details and construction procedures is fundamental for the appropriation of the necessary knowledge and skills in students. The development of virtual reality applications has shown multiple benefits in educational, training and scenario simulation sectors. In this proposal, we will explore the development of a tool that connects these technologies with learning in this segment, taking advantage of all the benefits of these technologies for the development of competencies in students."

Besides, using a serious video game instead of just a normal application will increase the knowledge retention of students. "Serious games mimic real-world construction scenarios and processes and challenge students to employ their knowledge of theories and principles to bridge the gap between theory and application"[8].

# Chapter 4

# Solution

## 4.1 Technology stack

The development of the virtual reality serious video game was made using the Unreal Engine 5 (UE5) game engine and the architectural software Revit 2023. UE5 was chosen as the game engine for the following reasons:

- It is free to use.
- It has a lot of support for photo-realistic visualizations, which helps improve the immersion of players.
- I already had resources available for learning how to use the engine and how to create VR games in this engine.

To create the model of the game, the BIM software Revit 2023 was used because Dr. Saúl Crespo recommended it due to its ease of use for creating 3D models that represent structures and for being available for free using the university's student account.

As for the hardware used to develop the game, a laptop with the following specifications was used:

- Intel(R) Core(TM) i7-7700HQ CPU @ 2.80GHz
- 16GB RAM

- NVIDIA GeForce GTX 1060

An External M.2 NVMe PCIe SSD Enclosure with a 1TB M.2 NVMe SSD was also used. All of this is very important to take in consideration because using lower-end hardware than the one mentioned here could significantly slow down development. Besides this, an Oculus Quest 2 (now Meta Quest 2) was used for testing the game.

Out of all these hardware specifications, the following recommendations are made for anyone who wants to develop VR applications or games in UE5:

- Install UE5 in an SSD, otherwise the compile time of code can drastically increase.
- If possible, prioritize using a better multi-core CPU over a higher-end GPU. Due to all the compilations (code, shaders, lighting, etc...) that the engine must do during development, the CPU tended to be the bottleneck in the setup being used during the development of the game.

## 4.2 Learning curve

This small section contains references to the courses that I used to learn how to use UE5, how to develop VR games in the engine, how to use Revit 2023 and how to import Revit models into UE5. This serves as a recommendation for anyone interested in developing VR games using UE5.

### 4.2.1 UE5 courses

- *Unreal Engine 5 C++ Developer: Learn C++ & Make Video Games* by GameDev.tv
- *Unreal VR Dev: Make VR Experiences with Unreal Engine in C++* by GameDev.tv

### 4.2.2 Revit 2023 courses

- *Learning Revit 2023* by Paul F. Aubin
- *Revit to Unreal for Architecture, Visualization, and VR* by Simon Manning

## 4.3 Development of the solution

### 4.3.1 Questions design

The first part for developing the VR serious game was the design of the educational content that appears in the game. This was done in the form of 10 questions that refer to different rules contained in the masonry section of the Mexican construction norm. These questions were designed with the help of Dr. Saúl Crespo and can be found in Appendix A.

### 4.3.2 Revit model

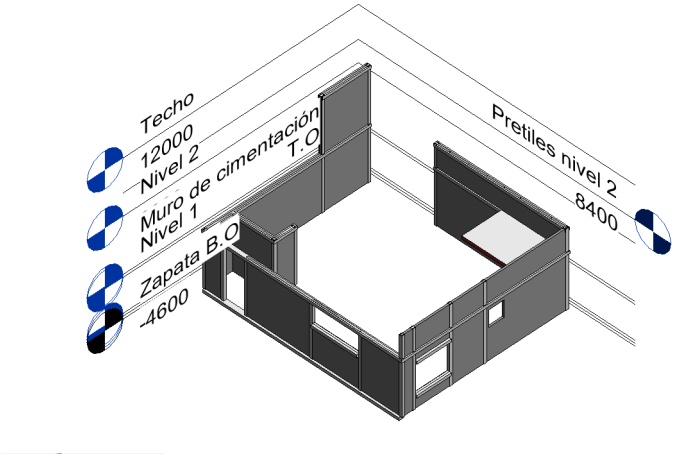



FIGURE 4.1: Model created in Revit 2023.

The next part of the development of the solution was creating the 3D model that is used in the game. The model was based on the floor maps shown in Figure 4.2 and Figure 4.3, which were obtained from the Mexican construction norm [6].

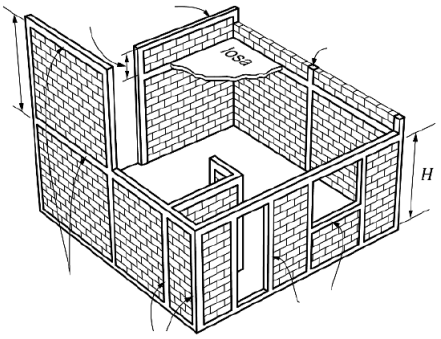



FIGURE 4.2: Isometric view floor plan used for creating the model.

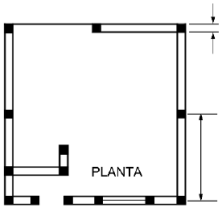



FIGURE 4.3: Top view floor plan used for creating the model.

### 4.3.3 UI design

Before starting the development of the game in UE5, the UI was designed following the conventions recommended in the VR course by GameDev.tv. This was done to ensure that the UI of the game would be adequate and comfortable for the users that play the game. The design, which can be seen in Appendix B, was done in an online design tool called Figma.

### 4.3.4 Development of the game in UE5

For the development of the game, a blank C++ UE5 game project was created with the project defaults set as shown in Figure 4.4. These settings were chosen over using the VR template because most of the interaction components were adapted from the projects created in the VR course by GameDev.tv.

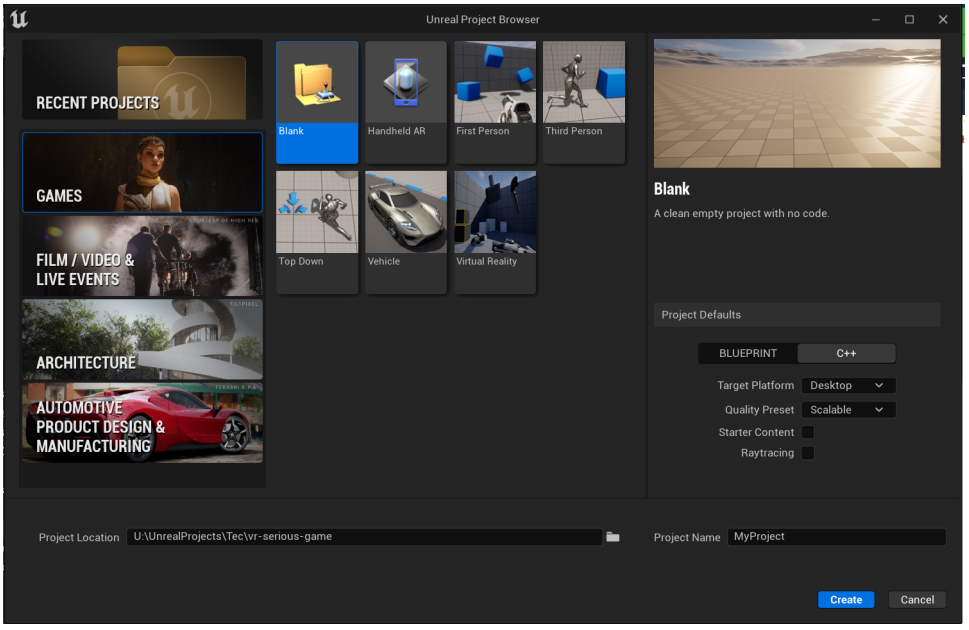



FIGURE 4.4: Project settings chosen when creating the game.

In order to develop and test the game for VR, the plugins in Figure 4.5 and settings in Figure 4.6 had to be enabled. The Oculus VR plugin was chosen over the SteamVR plugin because the testing environment during development and during the evaluation of the solution was done with Oculus VR headsets.

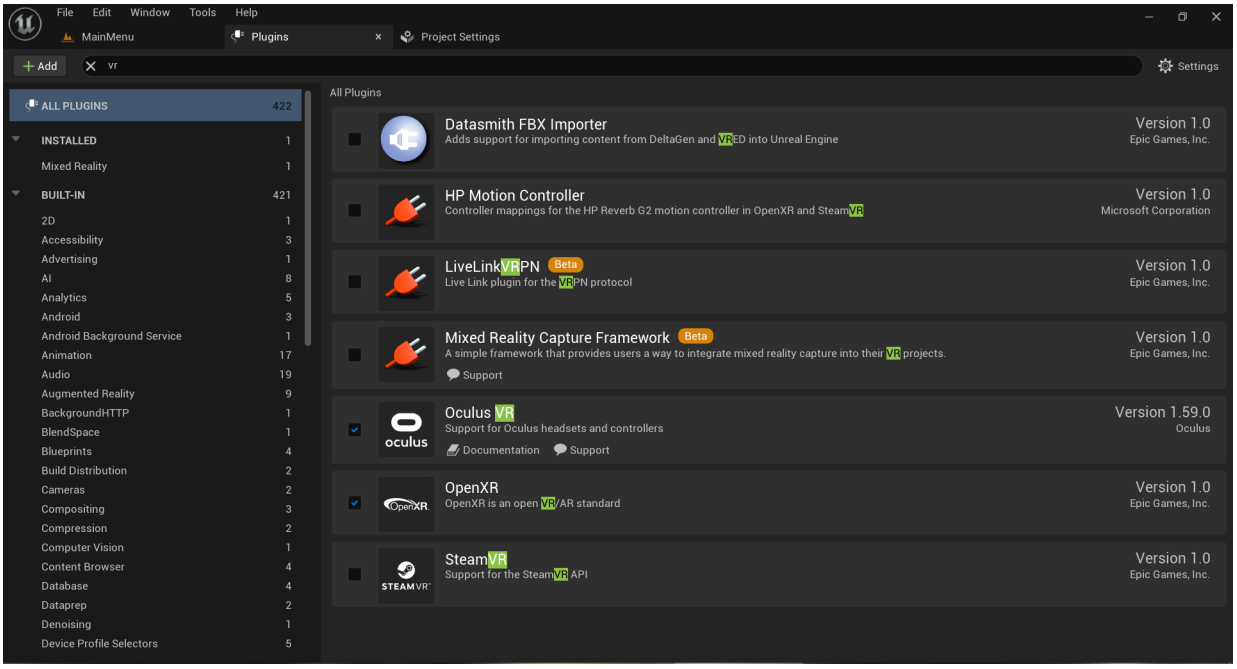



FIGURE 4.5: VR Plugins.

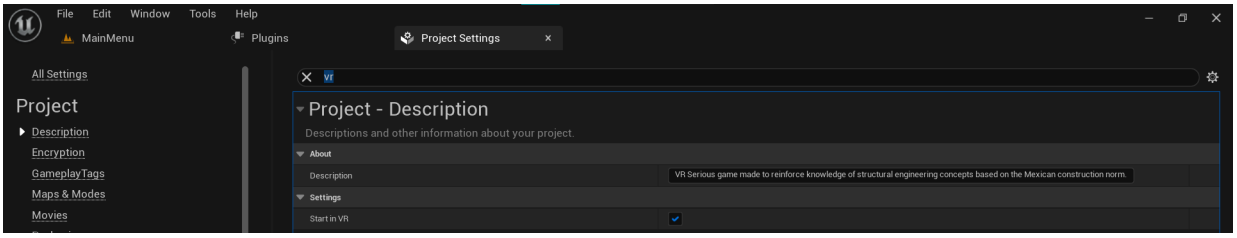



FIGURE 4.6: Start in VR setting.

Besides, as shown in Figure 4.7, the InputCore, HeadMountedDisplay and UMG dependency modules have to be added to the project in the .Build.cs file of the project.

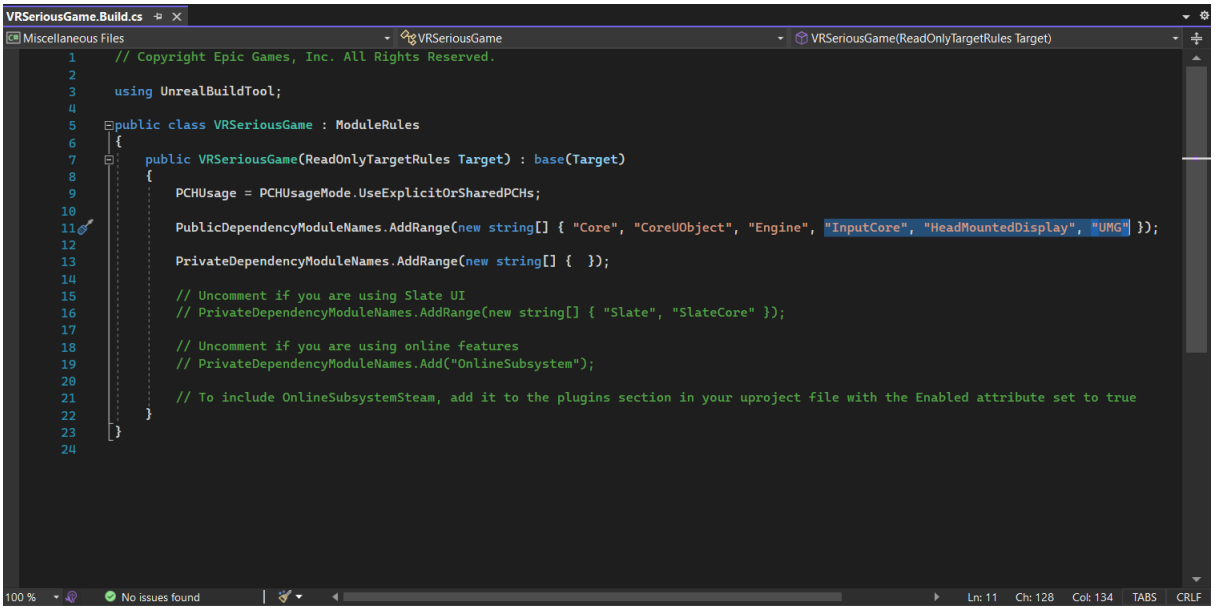



FIGURE 4.7: Dependency modules.

*Note:* Unless the development environment counts with high-end components able to support raytracing and all the newest technologies included in UE5, it is recommended to set the quality of the engine to low or medium as shown in Figure 4.8. This had to be set during the development of the game because UE5 sets everything to Epic quality on default.

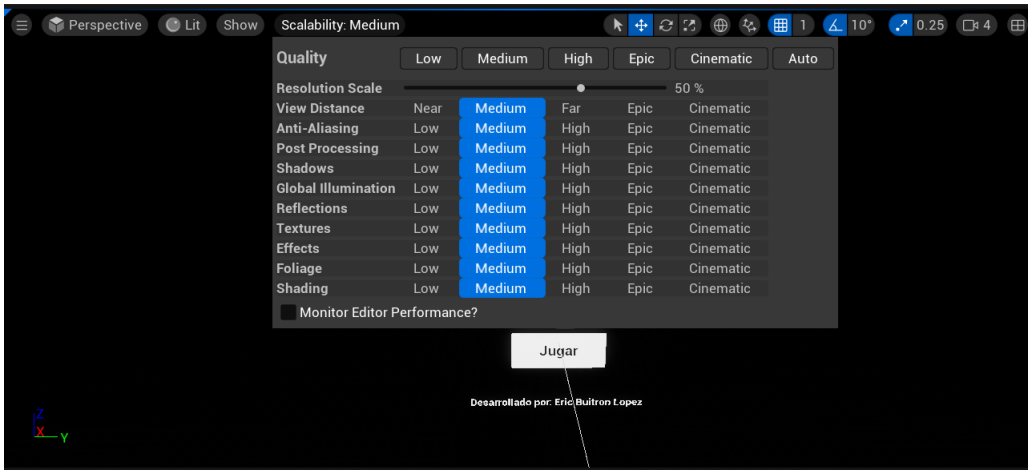



FIGURE 4.8: Editor Quality settings.

#### 4.3.4.1 Interaction components

The interaction components that were added to the game were adapted from the projects made in the Unreal VR course by GameDev.tv. This was done because these are simple but easily

scalable components that fit the requirements of interaction for the game since the interactivity of the game is only based on navigating through the UI. As shown in Figures 4.9 & 4.10, the components included classes for managing the hand input of motion controllers and the player pawn.

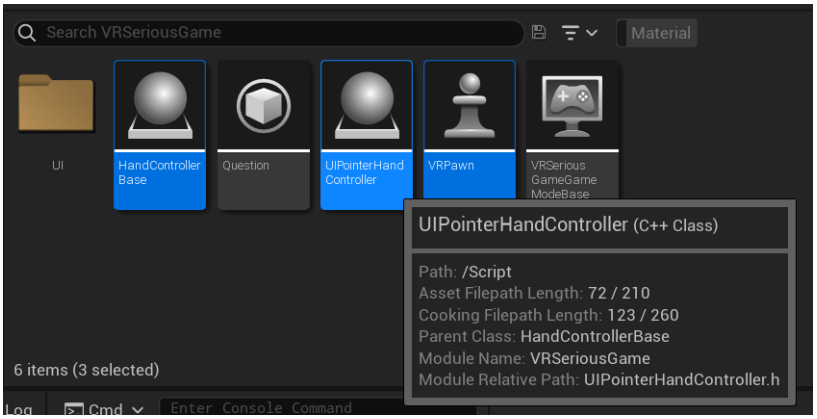



FIGURE 4.9: C++ classes created for interaction components.

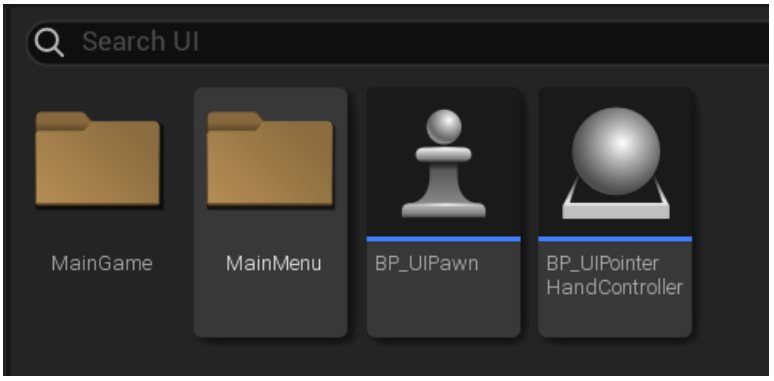



FIGURE 4.10: UE5 Blueprints created for interaction components.

The most notable change done to the interaction components that were adapted for the game was the addition of a laser beam particle effect in the BP_UIPointerHandController [9]. This was done to have a visible pointer in the final build of the game since the pointer adapted from the course was only visible when testing the game inside the editor.

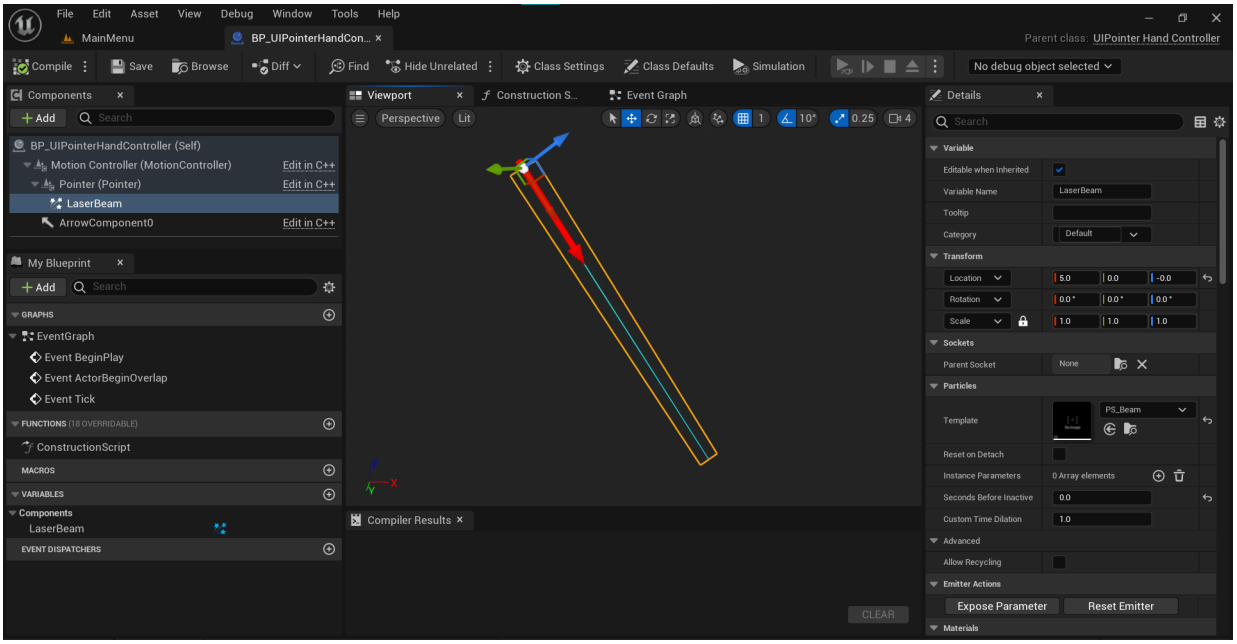



FIGURE 4.11: Laser Beam particle effect.

#### 4.3.4.2 Menu components

The design of the game required the main menu to have a virtual keyboard since this is where students will input their student ID which is used for saving the results of the game. UE5 does not have a pre-made virtual keyboard which is why one had to be created from scratch [5]. As seen in Figure 4.12, the virtual keyboard consisted on only the valid characters for a student ID and delete & enter buttons.

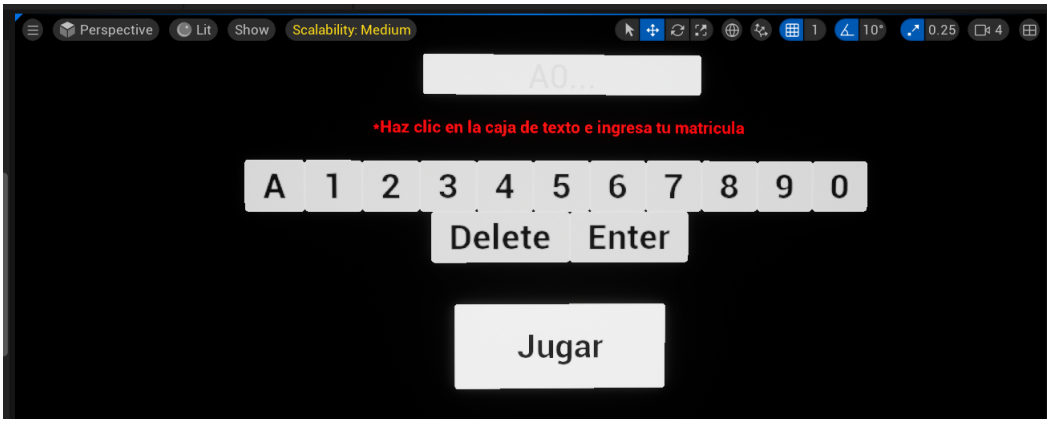



FIGURE 4.12: Virtual Keyboard.

#### 4.3.4.3 Game components

The development of the main game level consisted of three parts. The first one was setting up the scene as seen in Figure 4.13 with the BIM model created in Revit. The following material packs were also imported into the project from the Unreal Engine Marketplace to provide a harmonious playing environment:

- Megascans - Construction Brick Vol. 1
- Grass Landscape Material Vol. I

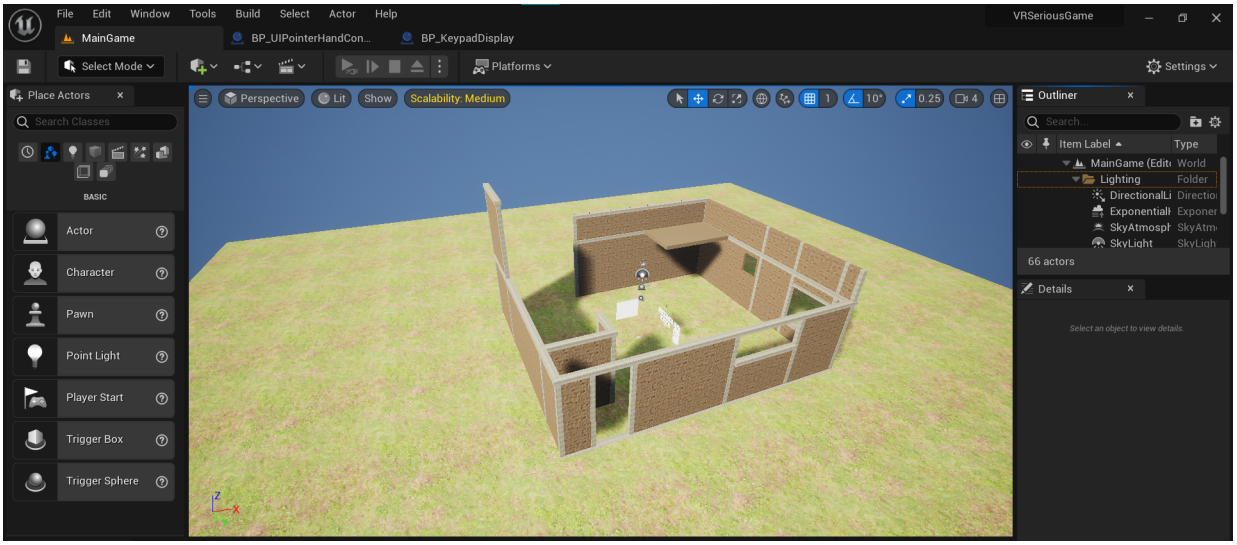



FIGURE 4.13: Main Game scene setup.

The next part consisted in the creation of the model for the questions that appear in the game. For this, a C++ class based on the UObject class of the engine was created to hold all the relevant properties such as the question text, answer, and score value. The header of the Question.cpp file can be seen in Appendix C. As seen in Figure 4.14, the design of this class is not scalable since the questions are hard coded. This was done due to the time constraints present when developing the project.

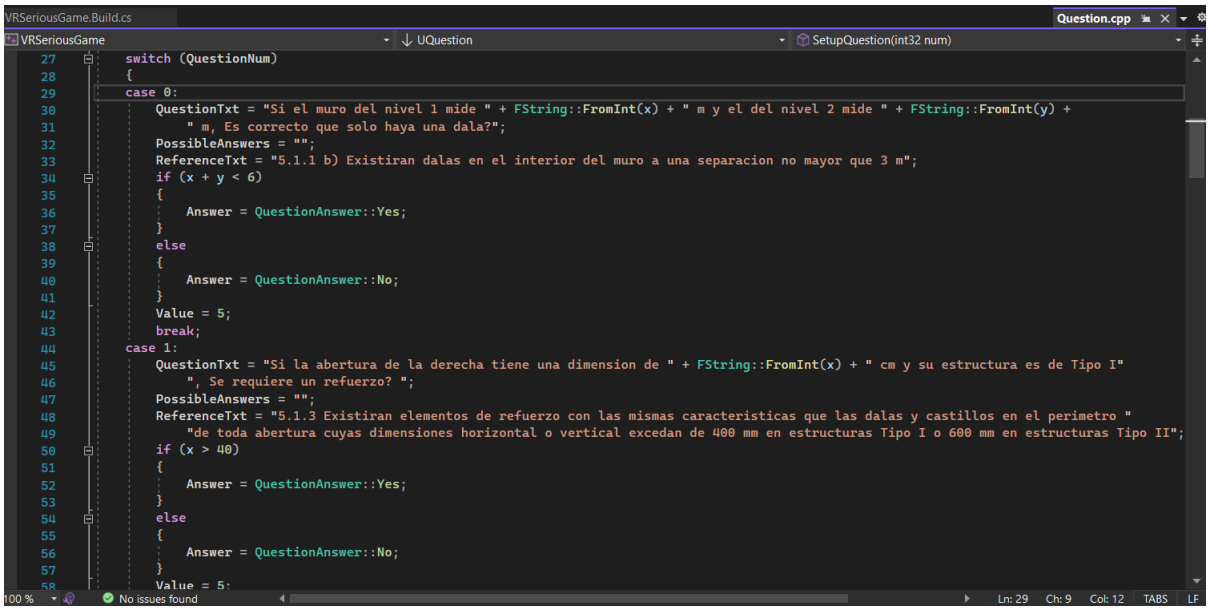



FIGURE 4.14: Question C++ class.

Another important thing to note is that most of the logic of the game was done using UE5 BP classes. This was done because it was the most appropriate approach when developing the game while adapting the interaction components from the projects in the VR course from GameDev.tv. This led to some important points that need to be considered. One of those considerations is not being able to display the text from the questions and answers with characters that do not belong to the English alphabet. This was due to the BP function that was used to obtain the text from the Question C++ class.

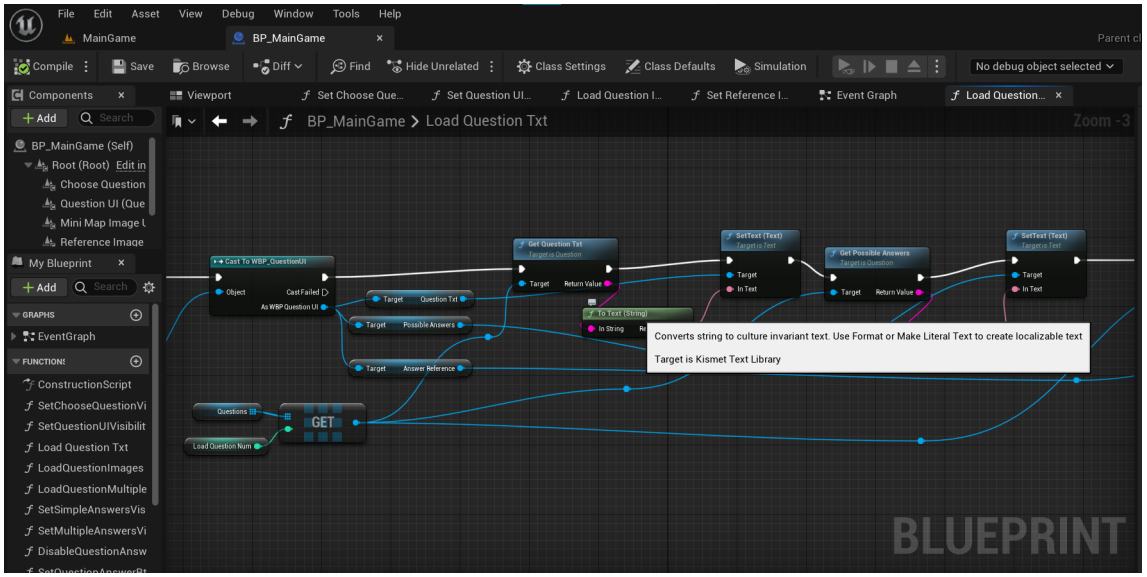



FIGURE 4.15: *To Text* BP function problem.

The last part of the development of the game was connecting the UI with the logic of the game in the BP_MainGame blueprint. This included adding a score counter and an in game clock that was used to know how much time was spent answering the questions in the game.

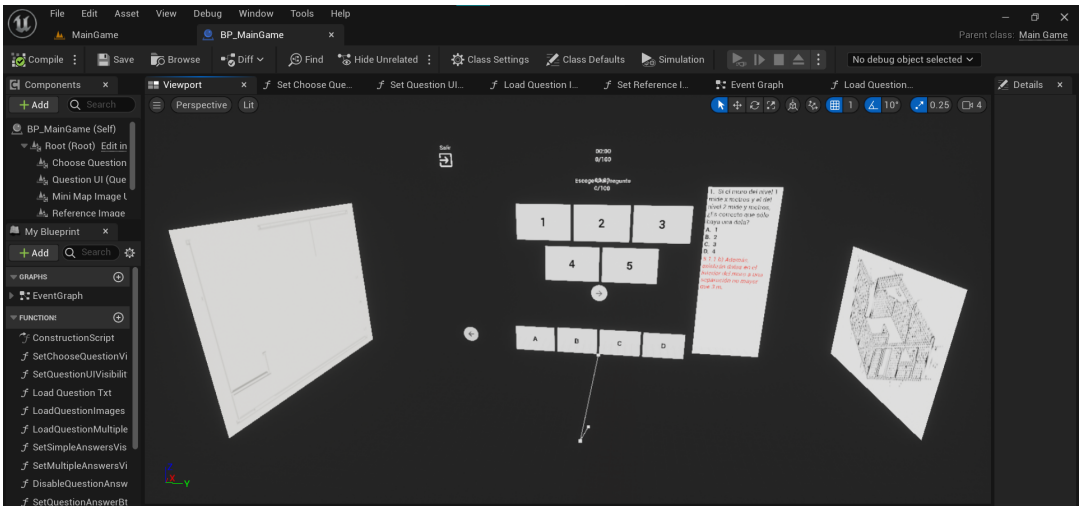



FIGURE 4.16: Main Game BP.

## 4.4 Final solution

The final solution consists in a VR game were players must enter their student ID in the Main Menu as shown in Figure 4.17.

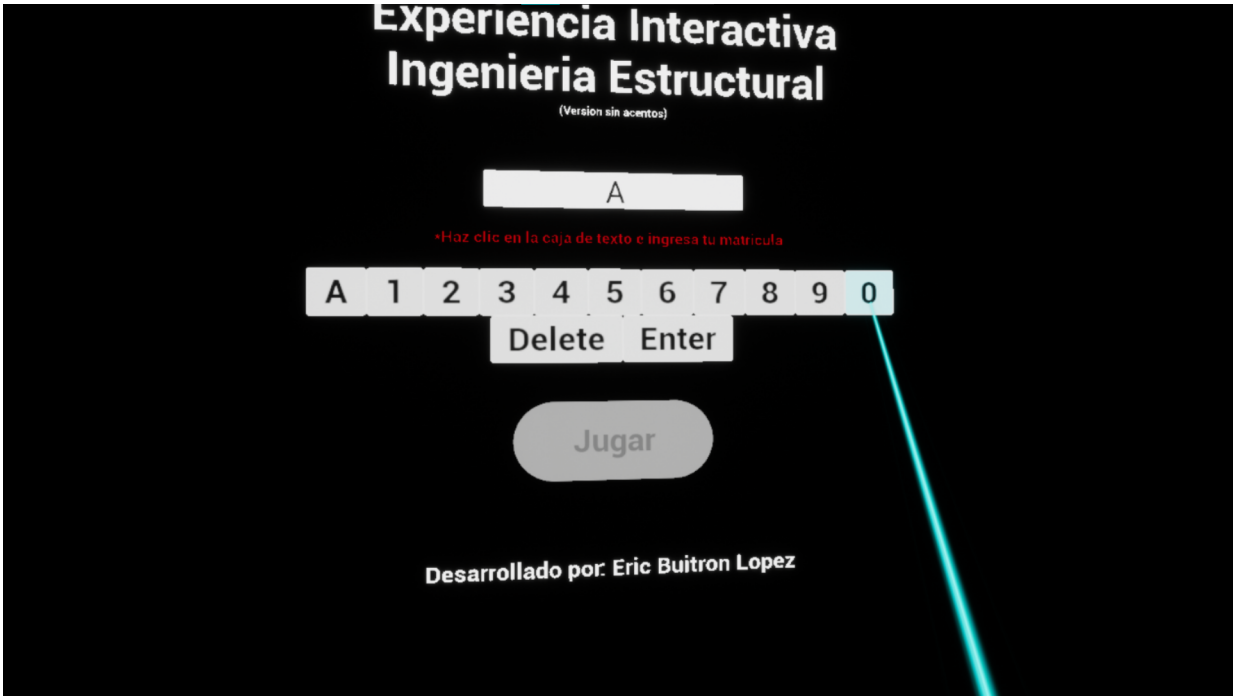


FIGURE 4.17: Main Menu.

Then, players must answer each of the 10 questions of the game. When they select a question, they are teleported to the location that best represents the content of the question. They can answer the questions in any order and they can also check their progress, and if they answered correctly or incorrectly.

FIGURE 4.18: Question 2 left view.

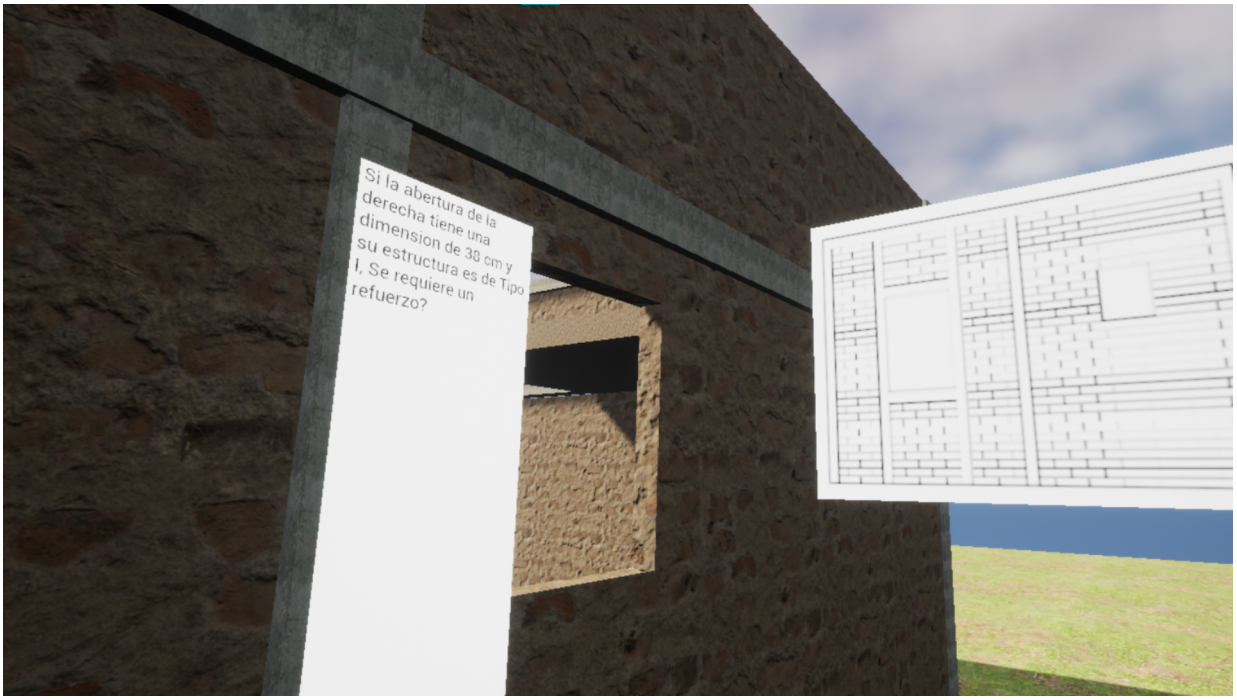



FIGURE 4.19: Question 2 right view.

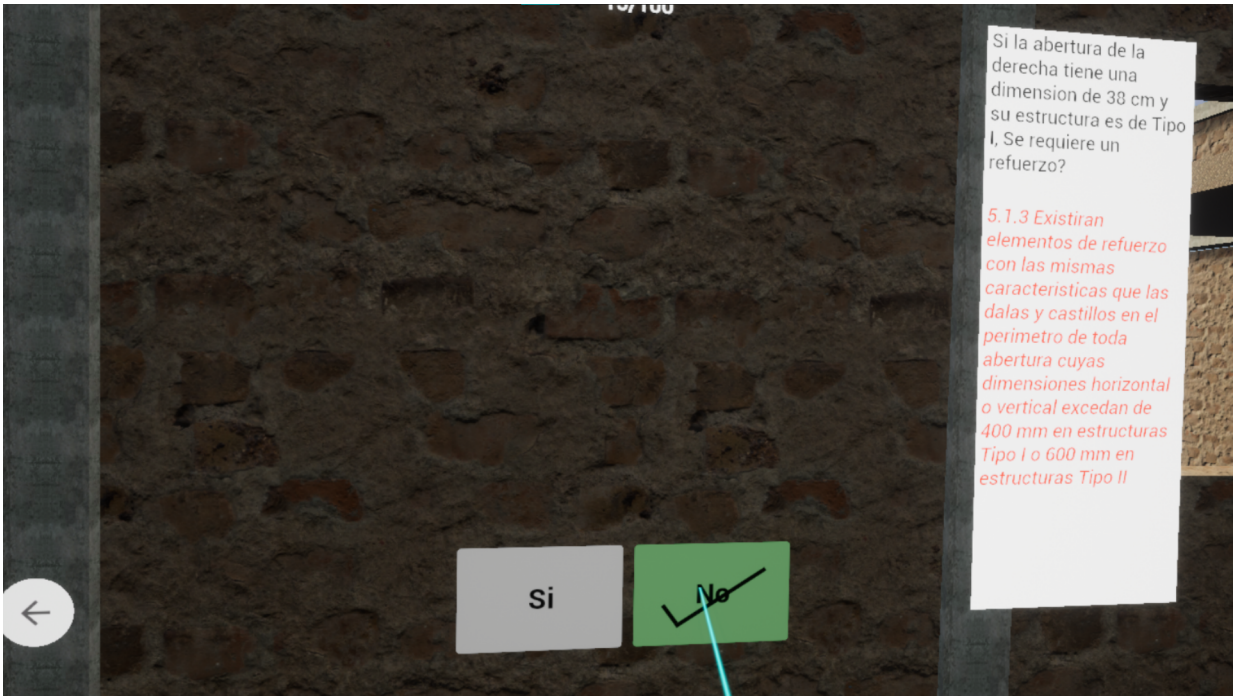



FIGURE 4.20: Question 2 answered.

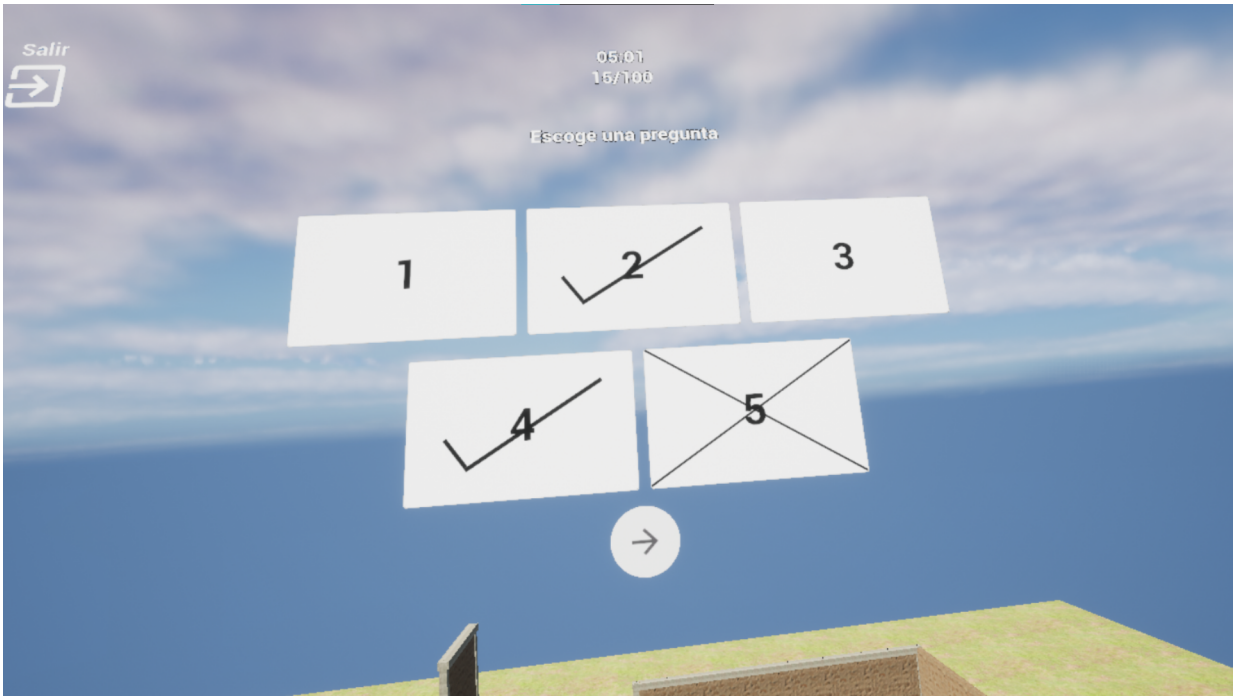



FIGURE 4.21: Choose Question.

Every time the player answers a question, their progress is saved in a .csv file such as the one shown in Figure 4.22. The progress is saved in .csv files because it provides an easy and accessible way for teachers of evaluating the results of students that get to play the game.

| | A | B | C | D |
|---|---|---|---|---|
| 1 | Matricula | A01704340 | | |
| 2 | Puntaje final | 100/100 | | |
| 3 | Numero de pregunta | Resultado | Puntaje obtenido | Tiempo |
| 4 | 4 | Correcto | 10 | 00:34 |
| 5 | 5 | Correcto | 10 | 01:05 |
| 6 | 1 | Correcto | 5 | 01:14 |
| 7 | 2 | Correcto | 5 | 01:25 |
| 8 | 3 | Correcto | 10 | 01:32 |
| 9 | 6 | Correcto | 15 | 01:49 |
| 10 | 7 | Correcto | 15 | 02:02 |
| 11 | 8 | Correcto | 15 | 02:23 |
| 12 | 9 | Correcto | 5 | 02:38 |
| 13 | 10 | Correcto | 10 | 02:50 |

FIGURE 4.22: Sample .csv file.

# Chapter 5

# Design of Evaluation

## 5.1 Methodology

To test the usability of the game an evaluation in the form of a survey consisting of 13 questions was made and answered by the students after they completed the interactive experience in the game. The questionnaire can be found in Appendix D. Each question (except the feedback for future works) contains a scale ranging from 5 (strongly agree) to 1 (strongly disagree). The questions in the evaluation were based on the research done by Beh et al. (2021) [2] where they described that a correct evaluation of VR serious games includes the following aspects:

- System usability:
  - Ease of use:
    - Ease of navigation
    - System complexity
    - Comfort level
  - Visual output:
    - Practicality
    - Clarity and distraction of information
    - Realism of objects
  - Knowledge retention
- User-friendliness:

  - Attractiveness:
    - Fun learning method
    - Beneficial learning method
  - Motivation:
    - Urge to continue the experience
  - Feedback

- Training method:
  - Mean score

The only aspects that were not part of the evaluation survey were regarding the training method since this was obtained from the resulting .csv files of the students that participated in the evaluation.

Another aspect that they mentioned that is important to consider is the gaming frequency of students since research has usually supported the theory that this has a direct impact on the system usability score of a VR game. "Learners who play games 'often' rated the lowest system usability score, supporting the theory that educational content contradicts conventional entertainment games. Learners who play games 'sometimes' have higher acceptance toward the education game and rated the highest system usability score for the GBVR training system. As for learners who 'rarely' play games, an intermediate system usability score was rated, indicating the acceptance of educational games but had a lower familiarity with the game system" [2]. At the end of the survey, two open ended questions were added to know which aspects of the game could be improved and what other topics regarding structural engineering could be evaluated using this medium.

System usability and user-friendliness are important aspects to evaluate within the VR serious game. However, it is also important to evaluate the actual score that the students obtained and how long it took them to complete the experience. This information is recorded in the .csv files generated by the game, which gives teachers of the subject the capability of using the game as an actual evaluation tool of the topics covered in class.

## 5.2 Design of Experiment

The experiment that was planned for the evaluation of the game consisted of having 32 civil engineering students from the "Integration of projects in the built environment" course playing and answering the evaluation survey. The evaluation environment will consist on having the following 6 VR headsets:

- Oculus Rift S (2 headsets)
- Oculus Quest (2 headsets)
- Oculus Quest 2 (2 headsets)

5 of these headsets will be available in the VR zone of the university while one of the Oculus Quest 2 headsets will be used with my laptop. Students will have to form groups of 5-6 people to pass and play the game. The groups that are not playing will be asked to go somewhere else to not have biased data. Meanwhile, the groups that finish the game will be asked to stay in the zone and answer the survey. Each group will have 5 minutes to answer as many questions as they can in the game.

# Chapter 6

# Results & Analysis

## 6.1 Experiment

The actual experiment consisted of having a group of 25 students test the game. They were all in their 3rd semester of civil engineering and part of the "Integration of projects in the built environment" course. It is important to note that the students told me after playing that they had not seen yet most of the topics covered in the game. The evaluation was done in the VR zone of the university and the environment consisted of the following 6 VR headsets:

- Oculus Rift S (2 headsets)
- Oculus Quest (2 headsets)
- Oculus Quest 2 (2 headsets)

During the experiment, the students were separated into five groups of 4-6 people to pass and play the game. When they played the game, the students were given 5 minutes to complete as many questions as they could within the game. After this, they were asked to answer the 13 question survey that can be seen in Appendix D. While one group was playing, the rest of the students were asked to go back to their classroom to avoid having biased data when they played the game.

FIGURE 6.1: Evaluation in the VR Zone.

## 6.2 Results

### 6.2.1 Academic results

After the experiment concluded, the .csv files that the game generated were used to obtain the average score that the students obtained. As Figure 6.2 shows, the average was 43 points out of 100.

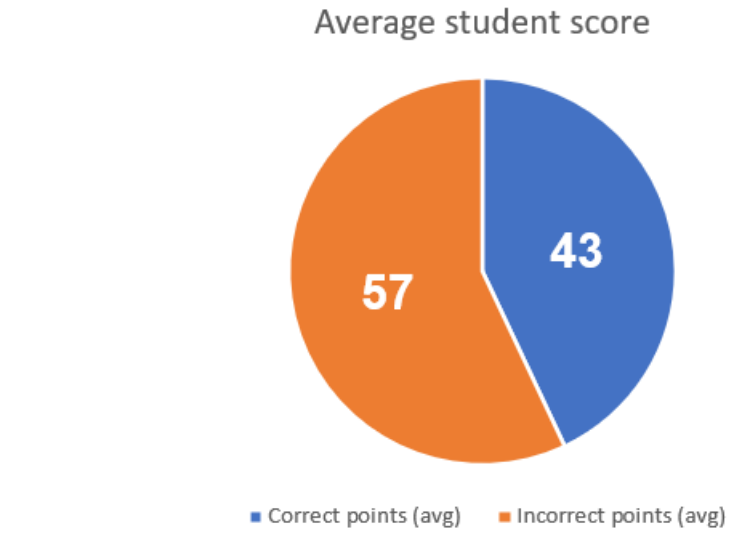



FIGURE 6.2: Average student score.

### 6.2.2 User experience survey results

While 25 students played the game, only 22 answered the survey at the end of their play testing session. Out of these 22, only 13 students answered the first feedback question and 11 answered the second feedback question. Overall, the user experience in the game had good ratings having an average score, of the scale ranging from 5 (strongly agree) to 1 (strongly disagree), **above 4.5**. Figures 6.3, 6.4 & 6.5 show some of the results of the survey. The complete survey results can be seen in Appendix E.

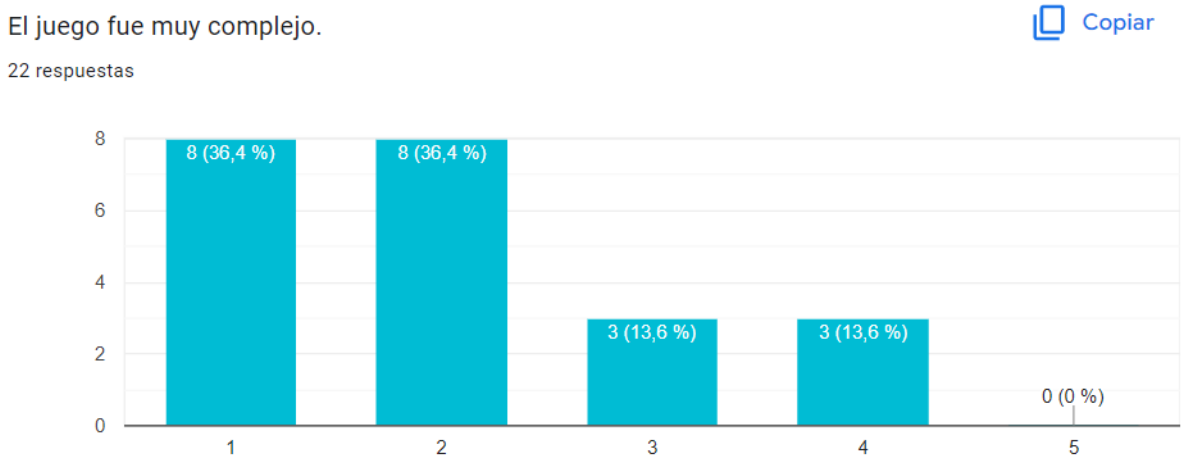



FIGURE 6.3: System complexity question.

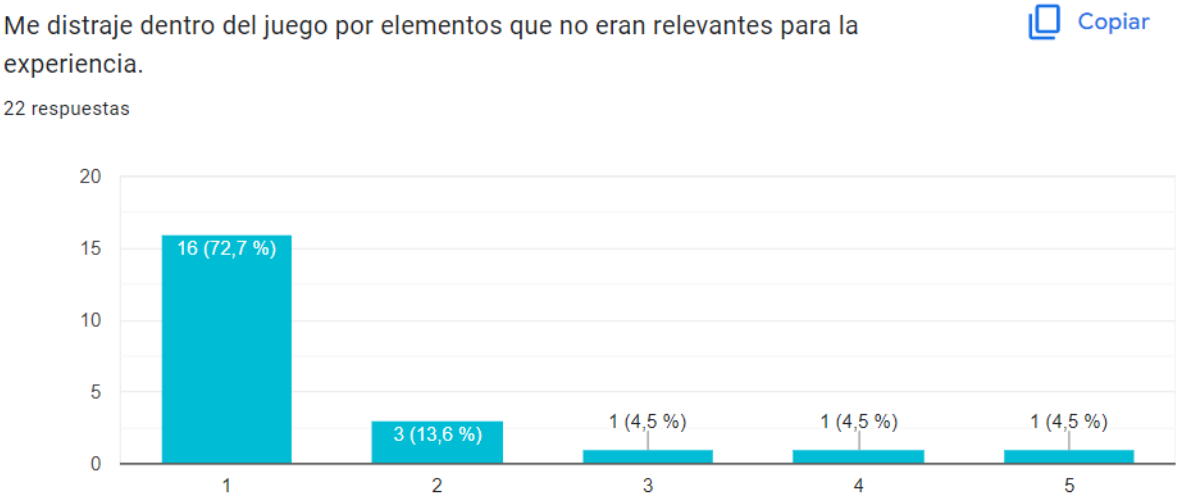


FIGURE 6.4: Distraction of information question.

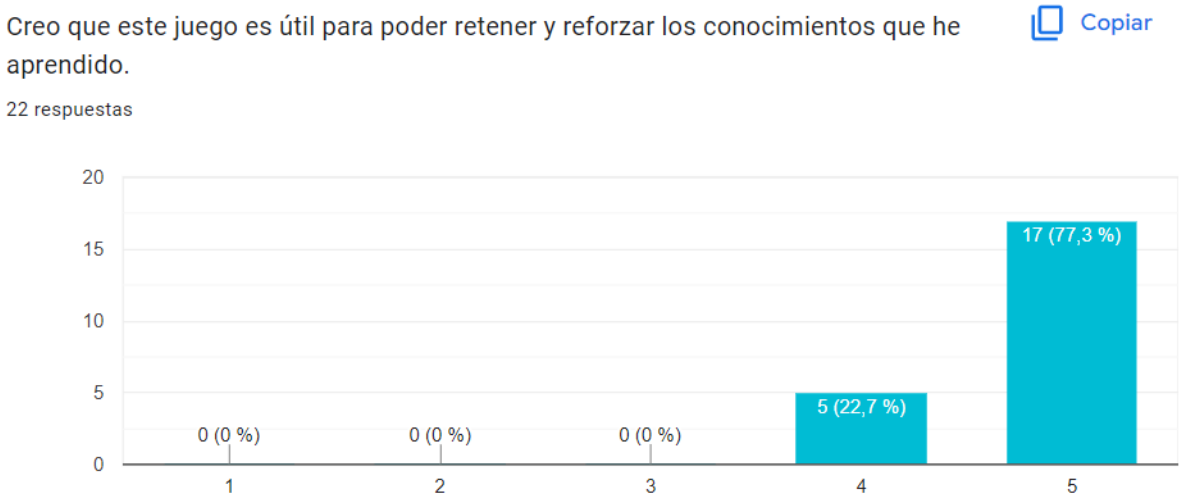



FIGURE 6.5: Knowledge retention question.

## 6.3 Analysis & Interpretation

The poor academic performance of the students can be due to the fact that they had not seen most of the topics of the game before playing. However, the important part of the research was to understand their user experience when using a VR serious video game. In this aspect, the results show that the students had a great experience when playing the game. Figure 6.6 shows a comparison between the results obtained with the proposed solution and the results obtained in the literature in which the evaluation methodology was based on [2].

| *(Best score 1) | System usability | | |
|---|---|---|---|
| | (Best score 5) | Solution | Results from literature (Beh, Rashidi, Talei & Lee, 2021) |
| | *1. Ease of use* | | |
| | Ease of navigation | 4.95 | 4.1 |
| | System complexity* | 2.05 | 4.2 |
| | Comfort level | 4.95 | 4.1 |
| | *2. Visual output* | | |
| | Practicality | 4.64 | 4 |
| | Clarity | 4.73 | 4.5 |
| | Distraction of information* | 1.55 | 4.5 |
| | Realism of objects | 4.82 | 4.3 |
| | *3. Knowledge retention* | *4.77* | 4.6 |
| | **User-friendliness** | | |
| | *1. Attractiveness* | | |
| | Fun learning method | 4.95 | 4.7 |
| | Beneficial learning method | 4.77 | 3.5 |
| | *2. Motivation* | | |
| | Urge to continue the experience | 4.91 | 4.6 |

FIGURE 6.6: Comparison table.

The average score of the aspects being evaluated is close to the best score expected in every category and very similar to the results obtained in the literature. The only outliers are the system complexity and distraction of information aspects, where the proposed solution appears to have a better score. However, this would not be a fair comparison because the solutions address very different scenarios. The serious video game created during this research focuses on rules from the Mexican construction norm while the solution from literature focuses in other areas of construction engineering.

While research suggested that the gaming frequency of students would have a direct impact on their user experience, Figure 6.7 shows how the gaming frequency of the students that played the game varied and this did not have an impact when they rated the user experience of the game. However, it would have been more interesting to ask how frequently they use VR applications or games since playing in consoles, PC or mobile phones is a very different experience than playing in a VR environment.

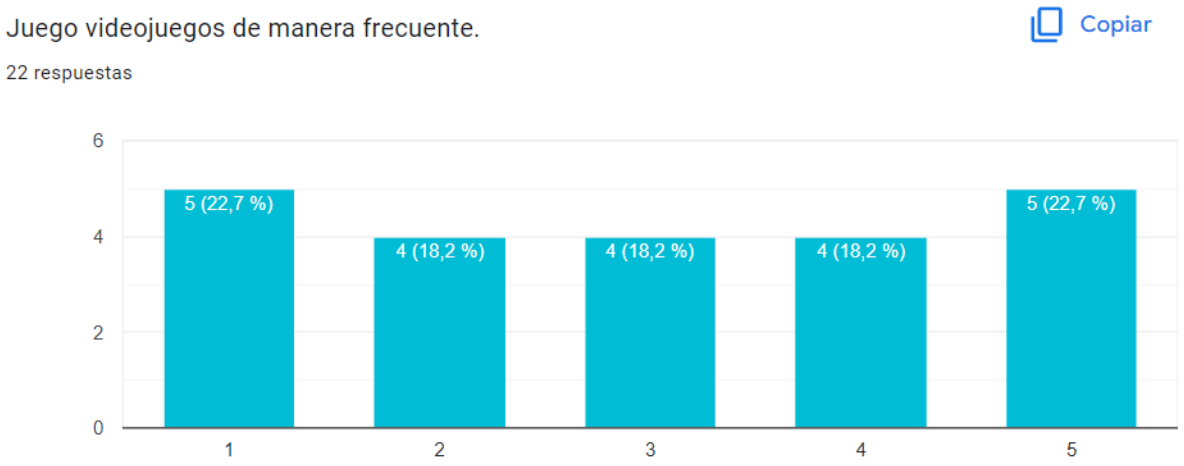



FIGURE 6.7: Video game playing frequency question.

## 6.4 Contributions

The results from the experiment prove that the proposed solution, which is a VR serious video game, can be effectively used for teaching or reinforcing structural engineering concepts from the Mexican construction norm. Besides, the game is now installed and available for future use in the VR zone of the university.

# Chapter 7

# Conclusions & Future Work

The research done with this project, alongside the created solution, which is a VR serious video game with concepts of structural engineering, demonstrate that VR and serious video games can be combined to create experiences for teaching and reinforcing the knowledge of students. The game that was created for this project has comparable results with those from the literature. This means that the focus and contents of a VR serious game, which in this project was the use of the Mexican construction norm, can be varied and students will still be able to retain knowledge.

## 7.1 Future Work

Even with the positive results obtained from this research, there are plenty of areas that could still be improved or further researched. This can be separated into 2 different categories: *Evaluation improvements* & *Game improvements*.

### 7.1.1 Evaluation improvements

Regarding the evaluation of the game, two more experiments could be made to further evaluate the created game. These are:

- Perform a play-testing session with students that have already seen the topics covered in the game to evaluate their academic performance.

- Make a paper based evaluation based on the same questions that the game has and make a comparison between the VR environment and the paper based environment.

### 7.1.2 Game improvements

Regarding the game, the following improvements, which were suggested by the students after they tested the game, could be made:

- Improve the resolution of the images taken from the construction norm because they were not very clear.
- Modify the transitions when being teleported to elevated areas to avoid vertigo sensations.
- Allow movement throughout the level or add more ways to interact with the environment.

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# Appendix A

# Questions designed for the game

Most questions contain variables that are set randomly within a predetermined range.

1. Si el muro del nivel 1 mide x metros y el del nivel 2 mide y metros, ¿Es correcto que sólo haya una dala?
2. Si la abertura de la derecha tiene una dimensión de x cm y su estructura es de Tipo I, ¿Es correcto que requiere un refuerzo?
3. Si la altura del pretil es de x cm, ¿Es correcto que lleve una dala?
4. Si la estructura es de tipo x, ¿Es correcto que el espesor de los muros sea ¿= 11 cm?
5. ¿Es correcto que los castillos sólo van en los extremos de los muros?
6. Si el muro mide x m de longitud y la altura entrepiso es de H, ¿Cuántos castillos deberían de colocarse en el muro?
7. Si el espesor del muro reforzado interiormente es de x cm, ¿Cuánto tiene que medir la separación del refuerzo vertical en su interior?
8. Si la distancia entre los 2 muros reforzados interiormente es de x m, ¿Cuántos pares de refuerzo de celdas consecutivas con refuerzo se deberán colocar?
9. ¿Cuál sería el mejor material para el muro no estructural (divisorio) de esta zona?
10. Si la dala tiene una longitud de x cm sobre un muro de espesor t cm, la separación de los estribos deberá ser menor o igual a:

# Appendix B

# UI design of the game


Figure B.1: Main Menu UI.

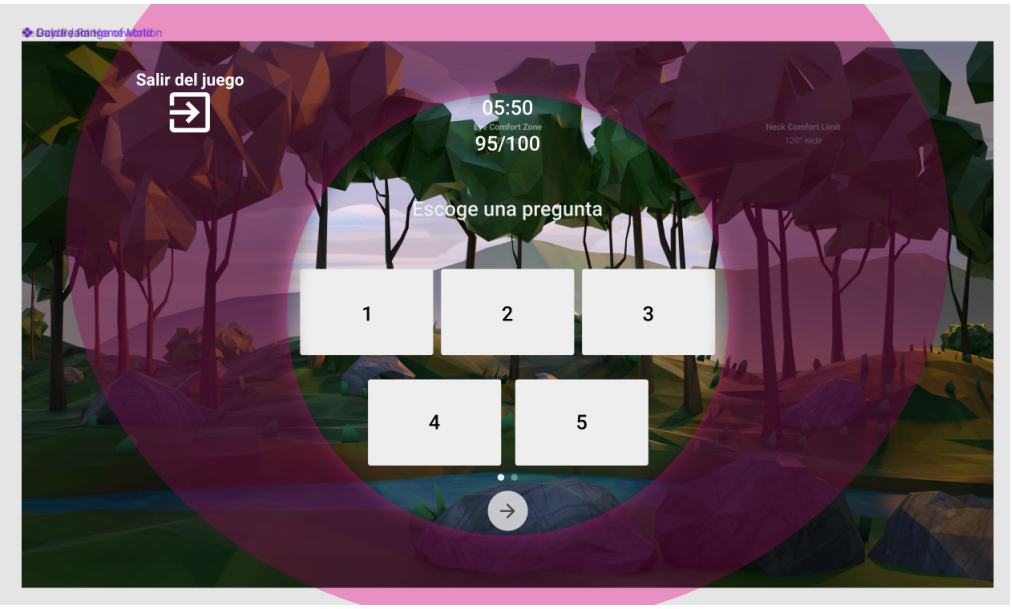


FIGURE B.2: Choose Question UI.

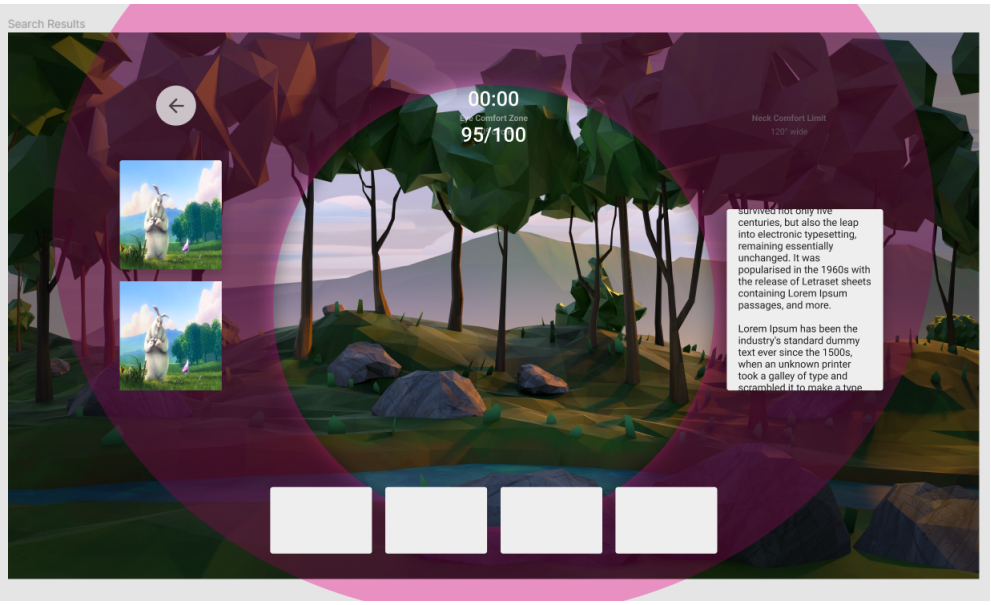


FIGURE B.3: Question UI.

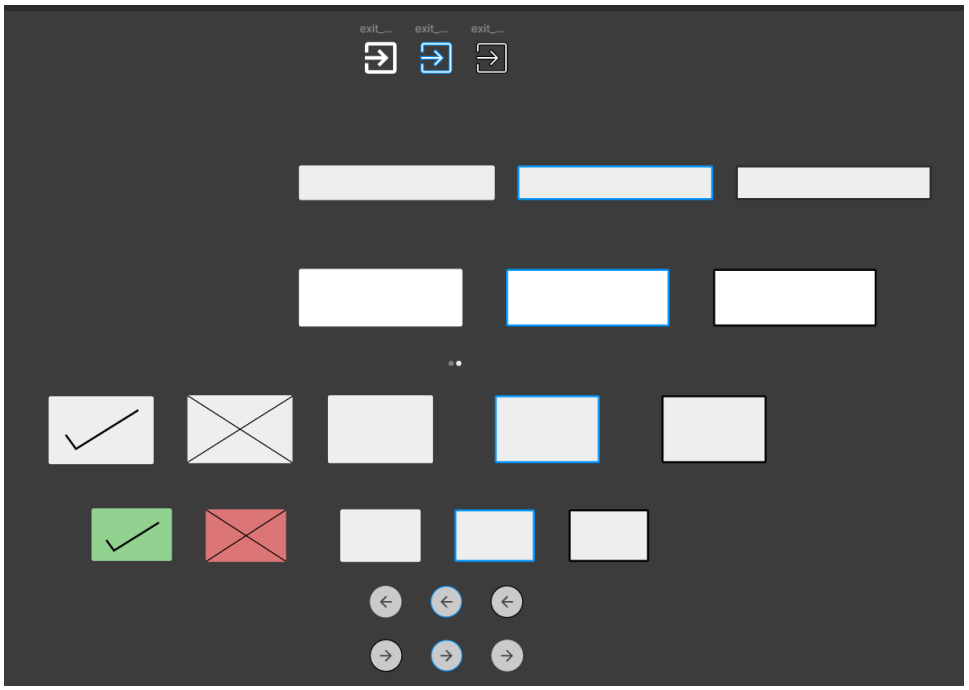

FIGURE B.4: UI Components used in UE5.

# Appendix C

# Question.h file

```
#pragma once

#include "CoreMinimal.h"
#include "UObject/NoExportTypes.h"
#include "Question.generated.h"

UENUM(BlueprintType)
enum QuestionAnswer
{
   Yes,
   No,
   A,
   B,
   C,
   D
};

/**
 *
 */
UCLASS()
class VRSERIOUSGAME_API UQuestion : public UObject
{
   GENERATED_BODY()
public:
```

```
void SetupQuestion(int32 num);
int32 CalculateX();
int32 CalculateY();

UFUNCTION(BlueprintCallable)
FString GetQuestionTxt() { return QuestionTxt; }

UFUNCTION(BlueprintCallable)
FString GetPossibleAnswers() { return PossibleAnswers; }

UFUNCTION(BlueprintCallable)
FString GetReferenceTxt() { return ReferenceTxt; }

UFUNCTION(BlueprintCallable)
int32 GetQuestionNum() { return QuestionNum; }

UFUNCTION(BlueprintCallable)
int32 GetValue() { return Value; }

UFUNCTION(BlueprintCallable)
bool GetIsMultipleChoice() { return bIsMultipleChoice; }

UFUNCTION(BlueprintCallable)
bool GetQuestionIsAnswered() { return bQuestionIsAnswered; }

UFUNCTION(BlueprintCallable)
void SetQuestionIsAnswered(bool isAnswered) { bQuestionIsAnswered = isAnswered; }

UFUNCTION(BlueprintCallable)
bool GetUserAnsweredCorrectly() { return bUserAnsweredCorrectly; }

UFUNCTION(BlueprintCallable)
void SetUserAnsweredCorrectly(bool val) { bUserAnsweredCorrectly = val; }

UFUNCTION(BlueprintCallable)
QuestionAnswer GetAnswer() { return Answer; }
```

```
    UFUNCTION(BlueprintCallable)
    QuestionAnswer GetUserAnswer() { return UserAnswer; }

    UFUNCTION(BlueprintCallable)
    void SetUserAnswer(QuestionAnswer answer) { UserAnswer = answer; }

protected:
    int32 QuestionNum;

private:
    //Properties
    FString QuestionTxt;
    FString PossibleAnswers;
    FString ReferenceTxt;

    int32 Value;

    bool bIsMultipleChoice;
    bool bQuestionIsAnswered;
    bool bUserAnsweredCorrectly;
    QuestionAnswer Answer;
    QuestionAnswer UserAnswer;
};
```

# Appendix D

# Evaluation survey

1. Fue fácil navegar dentro del juego (1 representa que estás completamente en desacuerdo- 5 representa que estás completamente de acuerdo).

2. El juego fué muy complejo (1 representa que estás completamente en desacuerdo- 5 representa que estás completamente de acuerdo).

3. Me sentí comod@ durante mi experiencia con el juego (1 representa que estás completamente en desacuerdo- 5 representa que estás completamente de acuerdo).

4. Me parece práctico utilizar este tipo de juegos para evaluar mi conocimiento (1 representa que estás completamente en desacuerdo- 5 representa que estás completamente de acuerdo).

5. La información fue presentada de manera clara (1 representa que estás completamente en desacuerdo- 5 representa que estás completamente de acuerdo).

6. Me distraje dentro del juego por elementos que no eran relevantes para la experiencia (1 representa que estás completamente en desacuerdo- 5 representa que estás completamente de acuerdo).

7. Los objetos dentro del juego fueron representados de una manera realista (1 representa que estás completamente en desacuerdo- 5 representa que estás completamente de acuerdo).

8. Creo que este juego es útil para poder retener y reforzar los conocimientos que he aprendido (1 representa que estás completamente en desacuerdo- 5 representa que estás completamente de acuerdo).

9. Creo que el juego es un método divertido para aprender (1 representa que estás completamente en desacuerdo- 5 representa que estás completamente de acuerdo).

10. Me sentí motivad@ a completar el juego y con ganas de continuar con la experiencia (1 representa que estás completamente en desacuerdo- 5 representa que estás completamente de acuerdo).

11. Juego videojuegos de manera frecuente (1 representa que estás completamente en desacuerdo- 5 representa que estás completamente de acuerdo).

12. ¿Qué es algo que mejorarías en el juego y por qué?

13. ¿Qué otros temas o conceptos crees que se podrían beneficiar de utilizar este tipo de juegos de realidad virtual y por qué?

# Appendix E

# Evaluation survey results

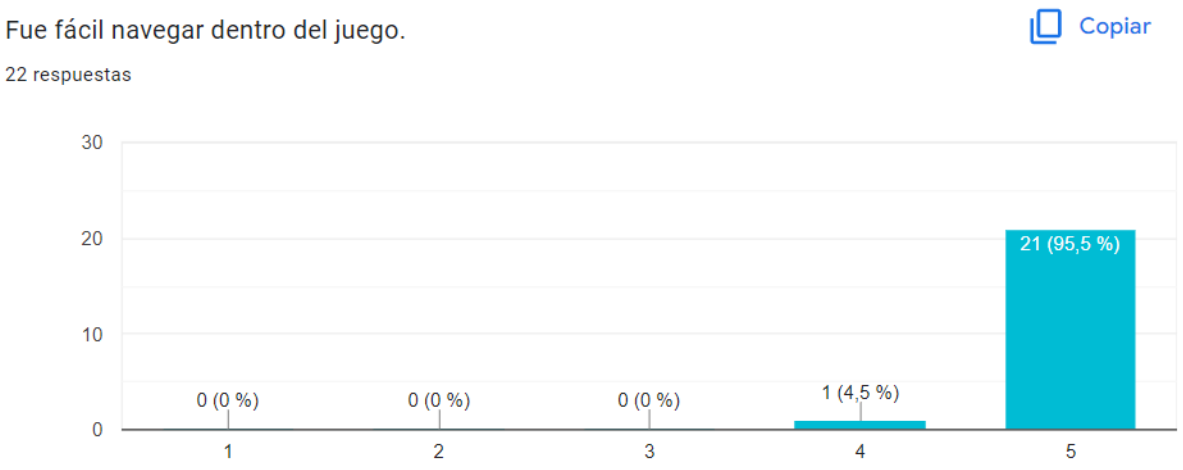


FIGURE E.1: Ease of navigation question.

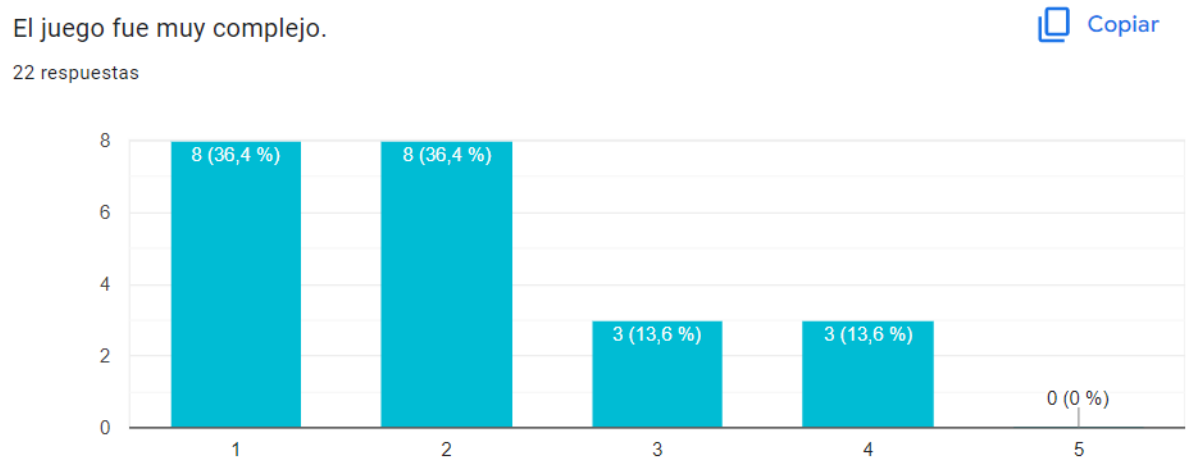


FIGURE E.2: System complexity question.

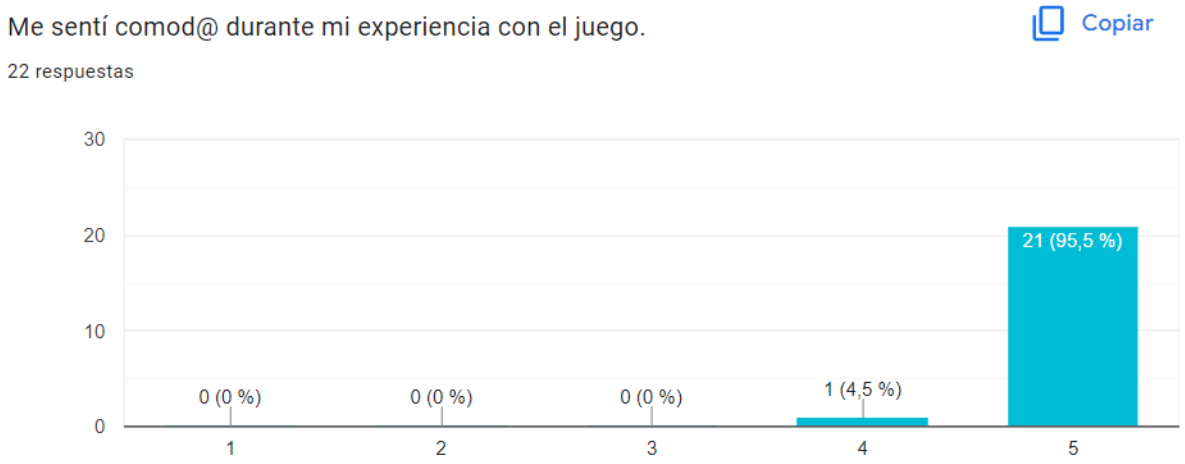


FIGURE E.3: Comfort level question.

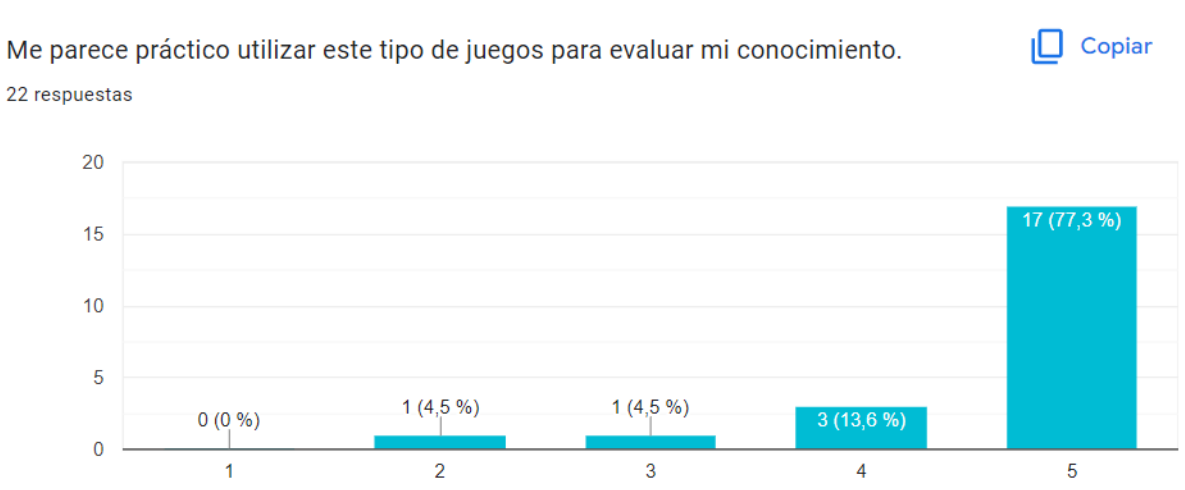


FIGURE E.4: Practicality question.

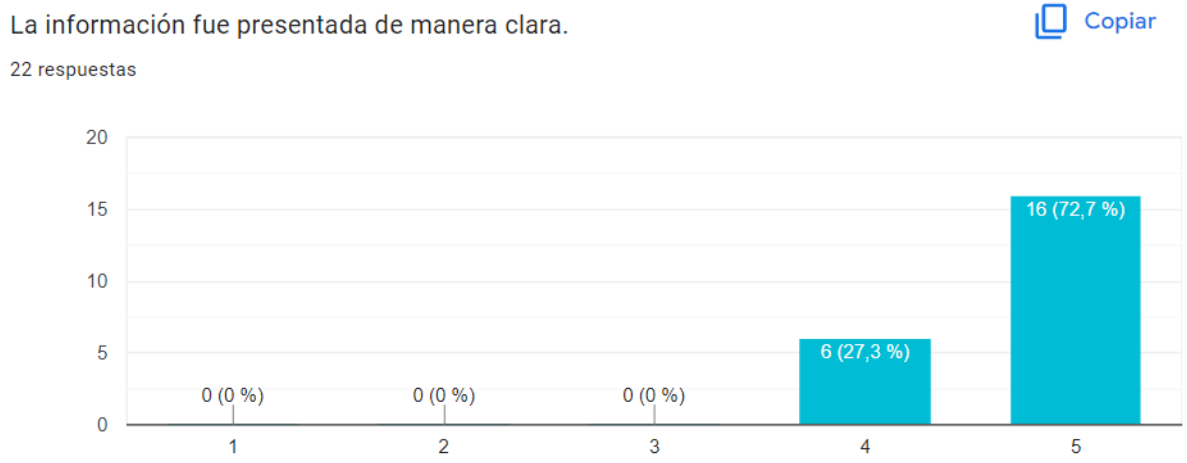


FIGURE E.5: Clarity question.

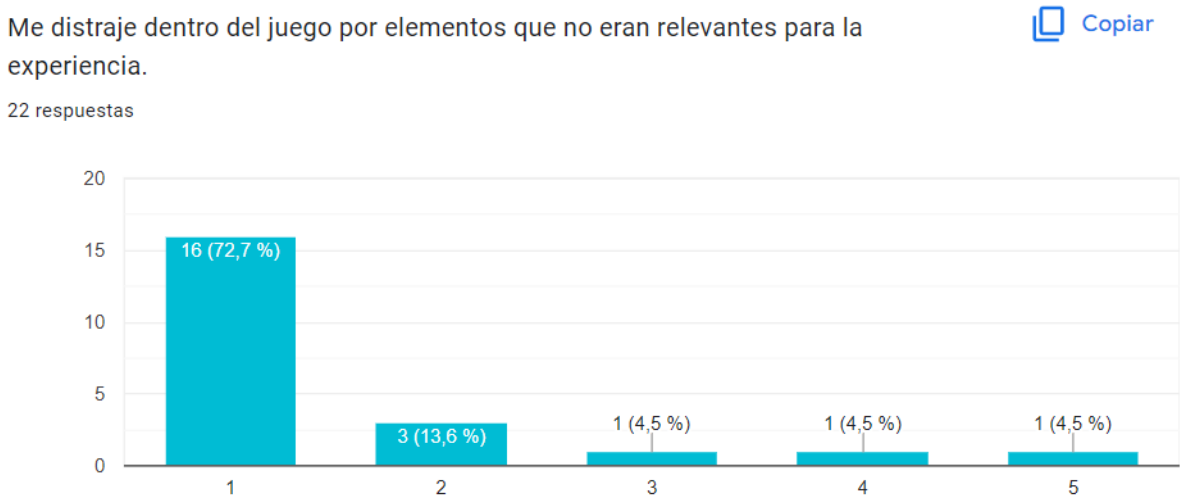


FIGURE E.6: Distraction of information question.

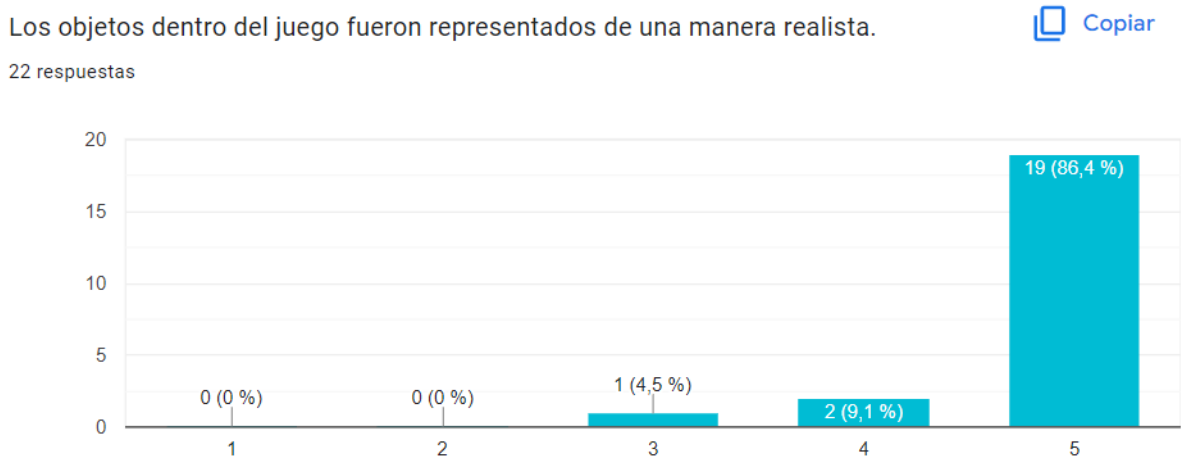


FIGURE E.7: Realism of objects question.

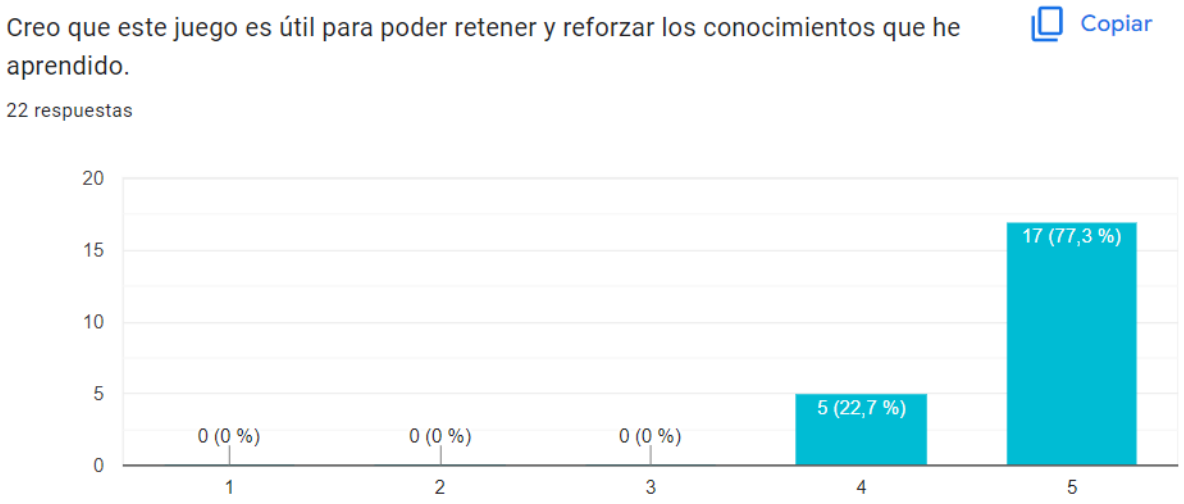


FIGURE E.8: Knowledge retention question.


FIGURE E.9: Fun learning method question.

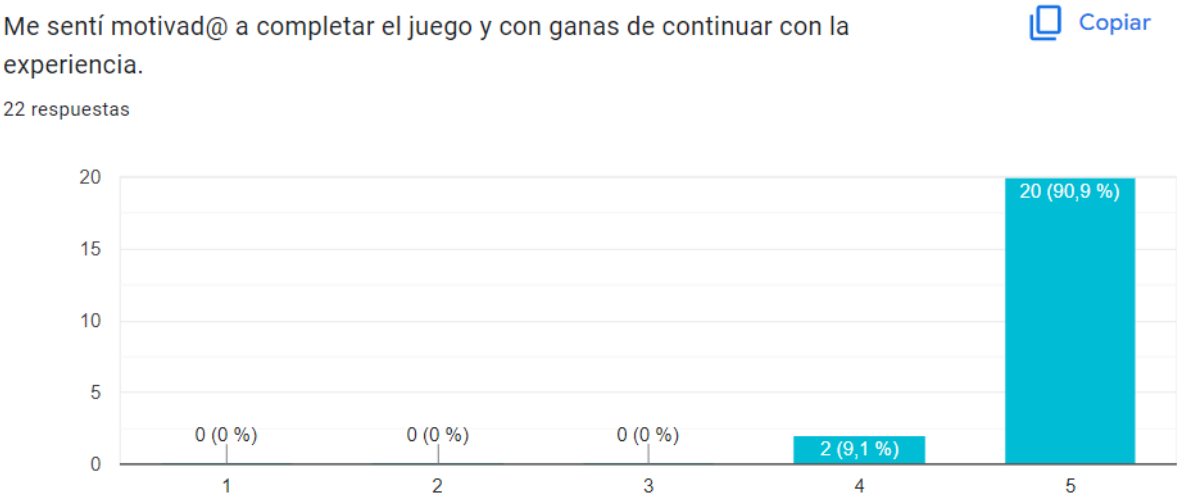


FIGURE E.10: Urge to continue the experience question.

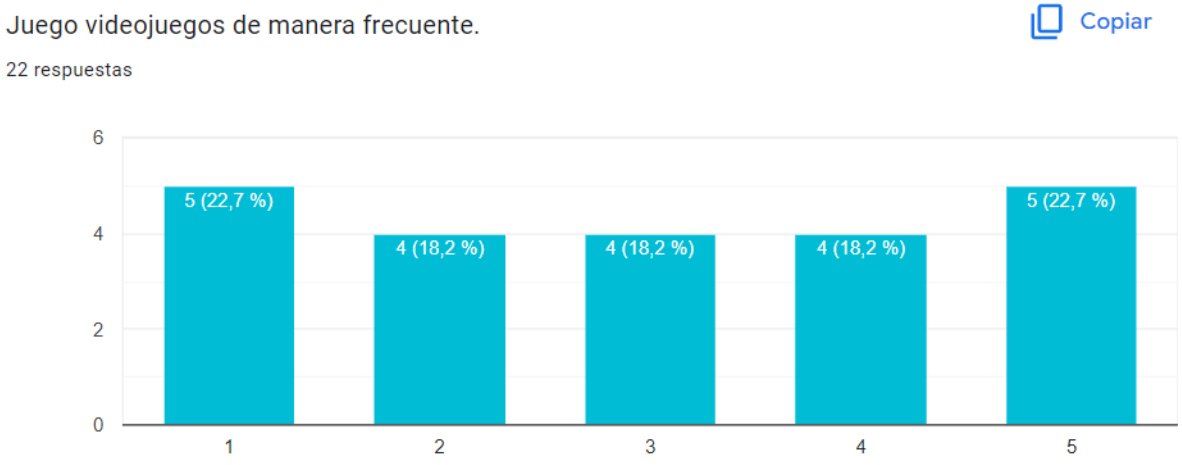


FIGURE E.11: Video game playing frequency question.

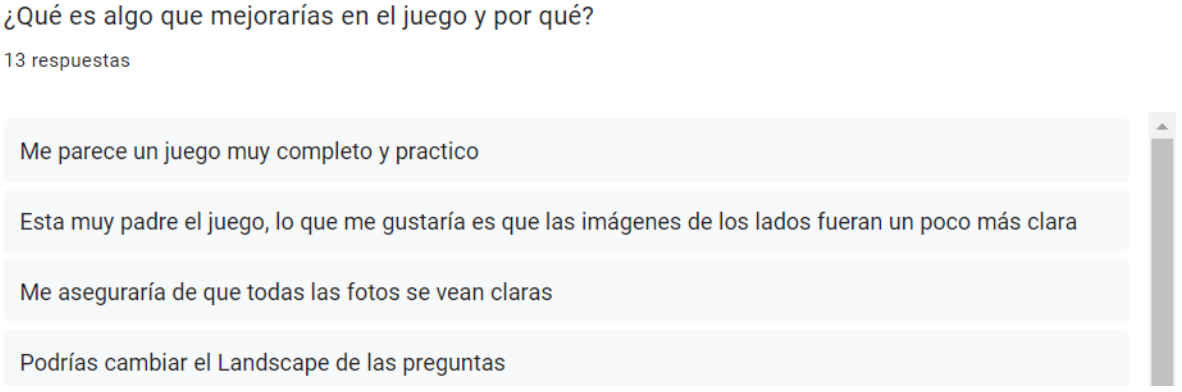

FIGURE E.12: First feedback question part 1.

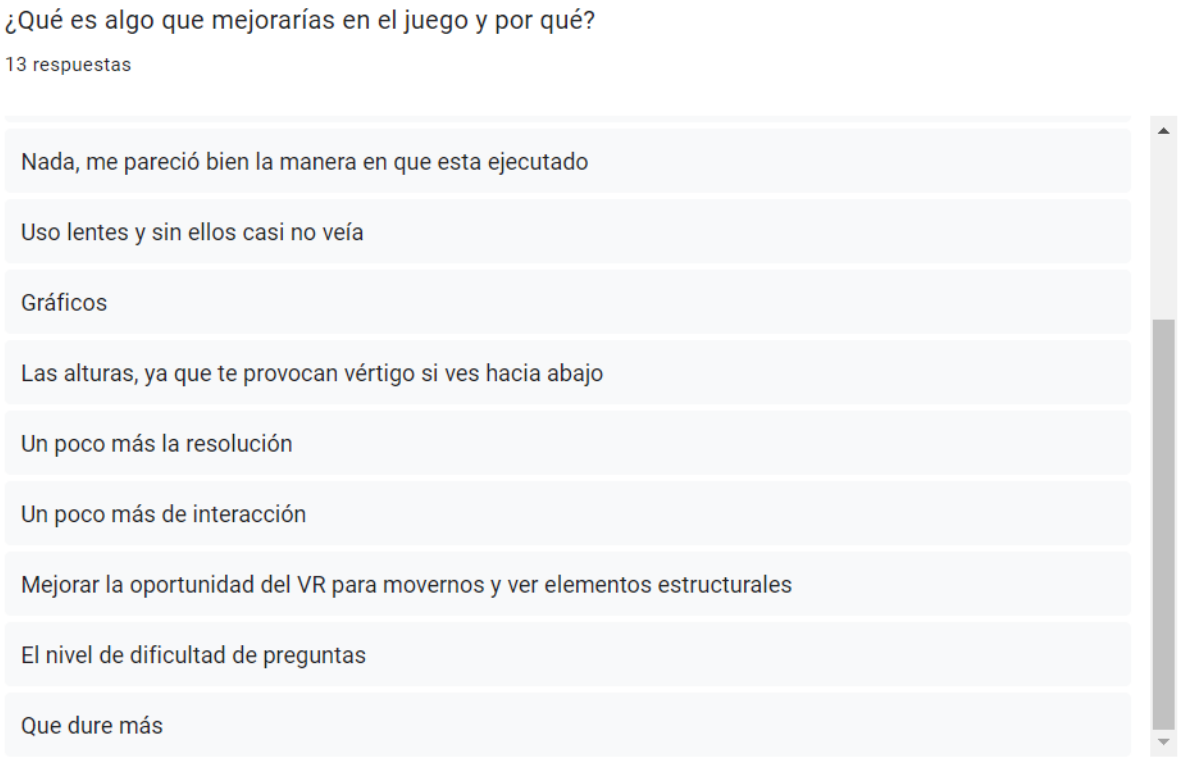


FIGURE E.13: First feedback question part 2.

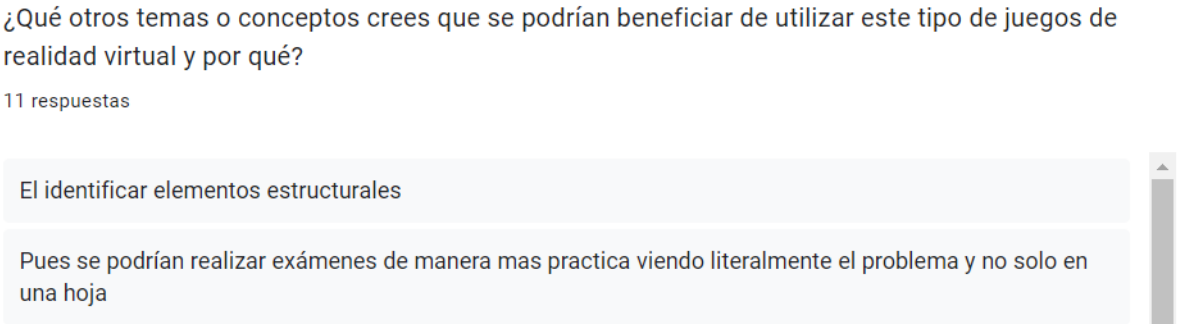


FIGURE E.14: Second feedback question part 1.

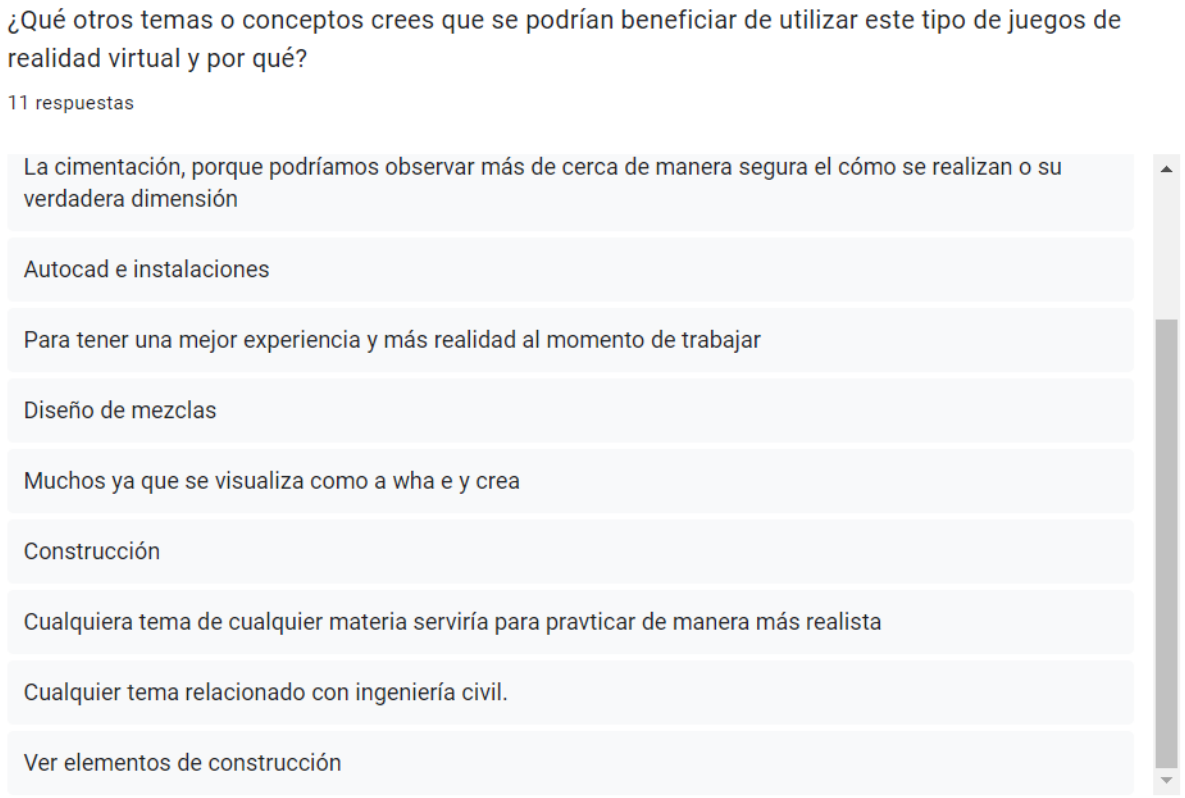


FIGURE E.15: Second feedback question part 2.