MVC-EDUCATION 3D - A FRAMEWORK FOR DISTANCE EDUCATION VIRTUAL REALITY APPLICATIONS

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Recent advancements in the online course delivery for Distance Education(DE) program is evolving from day-to-day. Though DE programs cost less and also provide flexibility to students depending on their pace of learning, delivering lab experiments to them is always a challenging task for the instructors. Few hands-on experiments need students to visit campus in order to perform them. But amateurs who never had training experience, frequent on-campus visits can be more cost-effective.

We propose Model-View-Controller-Education-3D (MVC-E3D), a framework to develop virtual reality applications. This framework is similar to MVC architecture, but an additional component - Education (E) module, which has instructional content like lab manual, demo videos, quiz section and User Feedback System(UFS) required for training purposes, are added to the Model (M) component. Besides this, the framework illustrates how to broadcast course contents to students' machines remotely using Photon Unity Networking (PUN) plugin.

To show how the proposed framework works, we have implemented a pre-hands-on experiment for ladder safety virtual reality training class, where an instructor hosts a 3D environment based construction lab experiment on a server allowing Distance Education (DE) students to access and finish the training. Hosting a server can

reduce computational requirements for student computers. Each system component can be reused for other hands-on experiments. Students can gain experience in lab equipment and familiarize themselves with the preliminary steps before visiting on-campus lab training.

MVC-EDUCATION 3D - A FRAMEWORK FOR DISTANCE EDUCATION

VIRTUAL REALITY APPLICATIONS

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Chapter 1

Introduction

With significant advancements in the technology field, new ways of teaching have emerged. Mobile apps are one of these new ways since computer tablets and smartphones are becoming a vital part of the student's daily routine. Various education software for smartphones helps the students in their education process and makes education all the more interesting for students, mainly when it provides a 3D virtual environment making it more amusing for the students. Technological innovations like Chromebooks, student-response-systems (such as clickers), smartphones, and tablet computers have achieved significant progress in keeping the education and such tools relevant. One innovation that is driving its way into the mainstream is Virtual Reality (VR), known as realistic, immersive, 3-dimensional environments that include the visual response from the body movement. Virtual Reality is ready to be vastly influential; such as the industry is projected to hit trillion-dollar by 2035 as per market researchers.[1]

Virtual reality vows to provide more vivid, engaging experiences, with its applications in various areas, including entertainment, training, shopping, and education. Virtual Reality can address different types of education challenges. [2] Moreover, there are plenty of ways by which VR can assist in the education process. Above

all, it allows the students to picture unique ideas, to analyze events at planetary or atomic scales, and to visit the virtual environments and interface with occasions that time or distance factors make inaccessible. The sorts of exercises supported by VR advances the current educational process that helps students to become better able to master, retain as well as generalize new information when they are effectively involved in constructing such knowledge in an environment created by VR technology. Specifically, VR can: help increase student engagement, provide constructivist and active learning; expand the frequency of legitimate learning experiences; provide empathetic experiences; empower students to practice creativity, and provide an environment for visualizing their ideas concretely.

Distance Education(DE) program allows students to choose their learning pace, watch recorded lectures. It can save many resources like money, time than compared to the on-campus program. Despite its advantages, the DE program has some drawbacks. Few lab courses need students to be on-campus. To overcome this drawback, a well designed hands-on experiment can help students accomplish complicated operations. Students won't need to visit the campus to finish the hand-on experiment, which an instructor can supervise virtually. Some complex experiments may still require DE students to visit on-campus, which is an exception. It helps students to become familiar with experiment steps before they visit campus and provide an immersive experience.

In this paper, we have proposed a framework Model-View-Controller-Education 3D (MVC-E3D). In MVC, the Model (M) defines and manages the data. View (V) renders the interactions based on the data, and the Controller (C) coordinates actions and events that affect the Model and View. To the existing Model component, we

have added an extra module called the Education (E), which has Instructional content and User Feedback System (UFS) to make it MVC-E3D framework. This proposed framework is implemented using a VR application for ladder climbing safety training for Distance Education(DE) students to become familiar with experiment steps using the educational content before they visit a construction site to improve safety training. This safety training lab is hosted on the admin-instructor machine, and student's devices do not need to have a high computing power on their machine.

Using our proposed technology, students can repeat experiments in a 3D virtual environment and get familiar with the tools and ability to learn new things with the instructional content before their campus visit. They should already know about the fundamentals of the equipment and can save much time. Virtual Reality has been rabidly recognized as well as implemented in the field of education in recent years because of its advantages of providing an immersive and engaging environment. Timely feedback from the instructors can help students from learning misoperations.

Given the great need for improved training and the benefits of utilizing VR, our paper discusses the potential value of virtual reality technology to education, starting with previous related work in this area that includes analysis of related VR Education Development Frameworks and Construction Education applications. Moving forward, the MVC-Education3D framework is proposed, and the implementation of a Ladder safety using Virtual Reality based on the MVC-Education3D framework is discussed. Finally, the conclusion and future work relevant to this study are proposed.

Chapter 2

Related Work

This section provides an analysis of various related frameworks implemented in the field of education. Students can learn a lot more about technical education with the help of Virtual Reality (VR). VR is used in chemical engineering for developing virtual chemical plants. These plants helped students learn how the technology works and its effectiveness in engineering. Virtual laboratory accidents were created with the help of this project to demonstrate what happens when users do not follow safety guidelines. 3D computer applications have been of great interest to medical students studying human anatomy. To help human anatomy students learn better with the use of 3D models, a study was carried out, which revealed a positive effect of 3D technology on student learning. This technology has become more active and affordable as educational institutions utilize it for education and research purposes. A virtual physics laboratory was designed for students to conduct VR experiments in the year 1993, which was similar to how traditional laboratories included a workspace table in a spacious room[2]. There are many unique educational benefits offered by VR. Modern educators can adopt VR as a tool for connecting with more students in newer ways.

2.1 Related VR development framework

The world is continuously evolving, which results in constant changes in education, as well. Technological advancements have taken place due to these changes, which are now enabling students and educators to avail of newer opportunities. More and more learners are now benefitting from the instructional developments resulting from easily accessible tools that both students and educators can understand. Apart from Virtual Reality (VR) and Augmented Reality (AR), it seems that no other technology has created this level of excitement.

Various Model-View-Controller (MVC) architectures based VR applications have been proposed. Such as, Samir Benbelkacem[3] and Team proposed an MVC architecture which has an Interaction and Visualization. An Additional Library component that has a processing unit for algorithms and used to track speech, faces, and gestures and other complex simulation models and processes the data provided by View using a Controller. This MVC based framework has an iteration loop for Model to Notify the View and get the data from the Library and then query the data.

C.S Park and Team[4] introduce another MVC architecture based framework with a planning module that is in a loop with Visualization and Inspection Module. This Module has a Database with tasks and instructions but failed to validate with the Visualization model. This prototype model has been developed but still waiting for the final application to implement.

2.1.1   Construction safety training

It is ubiquitous to train all kinds of workers with the help of virtual reality. Road safety training and flight simulators are some examples where the effectiveness of VR was visible. VR simulation is also used to train professionals to perform surgical techniques to avoid endangering humans and animals in the training process. [5] Training on construction sites based on failed experiences makes it even more dangerous to train individuals considering the sensitive nature of the areas.

Purpose-built training facilities can be set up to solve this problem, which simulates a construction site physically. Facilities of this kind have been constructed in the UK, Netherlands, and Australia as well. As a component of the training process, construction workers can be exposed to accidents and dangerous situations with the help of iVe (vehicle system forensics) and VR systems. It becomes possible for the workers to assess hazardous situations, plan an appropriate course of action, and implement it to see immediate outcomes. The cognitive information processing that takes place, as a result, stays in the memory for a very long time. [6]

A Virtual construction safety training platform developed by Pedroet.al[7] allows the student to access information regarding the safety by Scanning QR codes using their Smart Phones. Park and Kim[8] proposed a Real-time Construction Safety Training that is handled by a Framework named SMVS – Safety Training and Visualization System that deals with BIM integration for Both VR and AR technologies. Pariafsai[9] introduced a game with interactions focused on the Construction Management process, which allows students to improve their problem solving and critical thinking in an unsafe real-world situation.

2.1.2 Equipment and operational task training

Field staff can be trained through VR for operation, maintenance and safety procedures and power transformer technical overviews with the help of a unique solution provided by GE. Real on-site experiences can be simulated through the GE virtual reality training modules jointly designed by experts of transformer and field technologies with digital training specialists at GE. Power transformer owners can anticipate maintenance requirements to maintain better condition of assets with the help of well-trained teams. To absorb, retain, and apply new competencies while keeping investment in training overhead low due to no real equipment being involved, VR training is preferred over other learning techniques due to the unique advantages attained. Cheng and Teizer [10] developed equipment and operational task training platform that help collect real-time data and visualizes in the field of construction regarding the equipment and operational tasks and shows demo regarding the safety of the user.

VR, over all other emerging innovations, has excellent potential to improve the education field. There are various applications already available for virtual reality in education, as discussed. Considering these related VR based applications, in this project, we have introduced a unique MVC architecture based framework, which is discussed in the following sections.

Chapter 3

Proposed Method

In this thesis, we aim to introduce a framework titled Model-View-Controller-Education 3D for Virtual Reality applications, which is based on a 3-Tier Architecture. In addition to these components, we add an extra module Education(E) to the Model(M) component. This Education module helps students by assessing their skills based on pre-quiz and presenting them some educational content like instruction manuals or lab manuals, demo videos and test their outcome based on post-quiz. During the post-quiz, a prefab - User Feedback System(UFS) presents possible outcomes to the choice in the form of a video or pictures to minimize the risk and help them learn better.

We choose MVC architecture to improvise, as it facilitates parallel development, and each layer is independent of others. MVC being a Test-Driven development approach, the Testability of the application is fast and flexible. The prototypes used in the application can be used to assess the framework with end-clients and to validate the technologies utilized in the framework. Utilizing the 3-tier Architecture with Education module, various components involved can be refined and reused independently.

3.1 Architecture Diagram

Model-View-Controller-Education 3D (MVC-E3D) is an architectural model used to deploy user interfaces on the computer system. It divides a given application into three pitifully interconnected parts. The Model(M) includes Assets and Education(E) modules as sub-components. The MVC architecture handles the way information is presented to the users. [11]

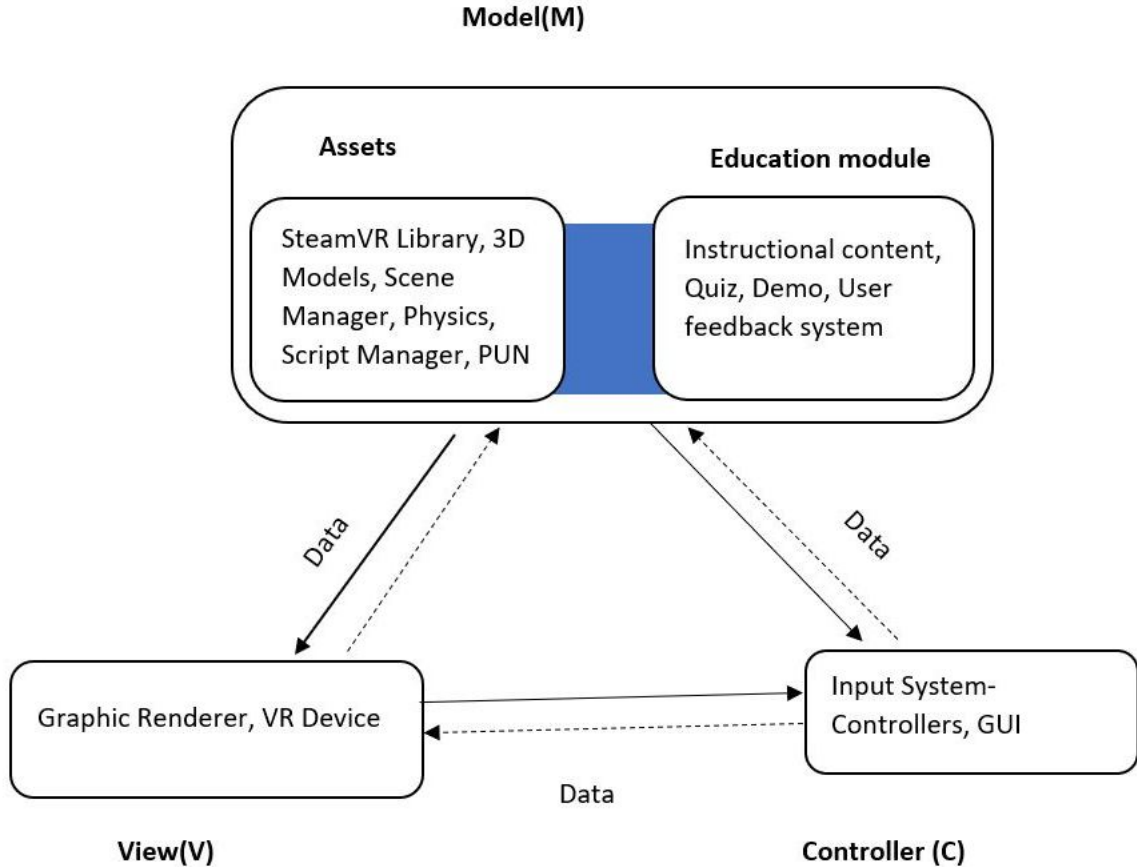The architecture diagram given below illustrates our proposed 3-Tier Framework.

Figure 3.1: Model-View-Controller-Education 3D Architecture Framework

3.2 Model

3.2.1 Assets

The Model (M) exemplifies the application data and various functionalities of the application through a series of public methods. The Model layer deals with the Business Logic of the application. The Assets module has the basic library prefabs and scripts required for a Scene development and to integrate with the View part of a display device. [12]. The model encapsulates the functionality of the application and responds to user queries. Assets can be downloaded from Asset Store or other websites. Unity's Asset store is an enormous collection of free and commercial assets created by Unity Technologies and also by members of the community.

3.2.2 Education Module

Our proposed framework mainly focuses on the Education (E) module, which has instructional content like User Interactable canvas with place holders for tutorials, study guides, quizzes, and other assessments. This allows the user to learn real-world problems/issues and implement them in the scene, making no mistakes.

We develop reusable prefabs which comprise of :

- Animated Curved Canvas with interactive and easily modifiable question & answer choice buttons for the Quiz section.

- Render Texture materials to play demo videos, which can be used as a drag and drop in the future. Video canvas supports all common video file formats, including YouTube links.

- Trigger event buttons to reach checkpoints that help to assess his/her progress.

Instructional Content

An instructional content module comprises of playable demo videos or some instruction manuals given to the user before handling the equipment. In other words, a Pre-operational guideline is provided for safety requirements and posting a list of equipment manuals and workplace safety tips.

Quiz and User feedback system

The quiz section is a canvas which has a Multiple Choice Questions(MCQ) or True/-False based question, where a user has to choose the right answer. It is a way of assessment to provide students to perform self-assessment, obtain feedback, and revise their mistakes. To make the way of learning more effective, we implement a User Feedback System (UFS), which popups the alternative scenario of choosing a wrong answer, which in turn allows students to focus on learning from their mistakes.

3.3 View

In MVC architecture, the View (V) represents visual items of the application framework. User Interface Logic is the key aspect that is focused on the view component. Moreover, one of the key components of Virtual reality interfaces is to maintain the coherent connection between virtual models and the real world in real-time while consolidating heterogeneous hardware and software technologies. The view sends user gestures to the controller and allows the controller to select the respective view.

3.4 Controller

Moving forward, the Controller (C) handles the user actions and also plays a central role between Model (M) and View (V). Controller maps user actions to update the

model and also selects a view to check the response of the actions. It tracks the object using the X, Y, and Z-axis and uses Lighthouses or Sensors (a hardware component of a Virtual Reality device) to calibrate the student's interaction area in the real world. In other words, a controller calls a Model (M) to change its status value and notifies a registered View (V) about user interaction. The logic used here is called User Input logic or Controller Logic.

Chapter 4

Implementation

The key idea is to implement our proposed MVC-E3D framework using a Virtual Reality Hands-On Lab Experiment, which includes building a virtual 3D environment and performing object interactions based on the experiment requirements to handle industrial equipment for Distance Education (DE) and also On-Campus students. We have implemented this framework for a construction management department's safety class titled Ladder Safety training using Virtual Reality, which has the pretraining instructional content for a users, especially students, to get used to Ladder Climbing before visiting a construction site to avoid accidents. After successful training, students are prompted to finish a post-quiz to assess their progress in the safety training class by checking out the feedback provided by User Feedback System(UFS).

Unity3D engine has been used as an IDE for the project, and C# is used as a object oriented scripting language. Unity's Asset store for assets prefabs have been used for developing the scene. A plugin -SteamVR which is an open-source prefab library offered by the Unity3D engine for player movement. HTC Vive, a Head-mounted display, is used to run this Developed Virtual Reality application. GitHub is used as a repository and Git as version control to handle the project over cross platforms and on different machines. Photon Unity Networking (PUN) a network plugin is used to

host the application on a server and allow the end-user to access it to reduce their computation power.

The objects in the scene are organized based on the physics, properties as rigid bodies and functionality in a hierarchical way. Walls and Floor have a colliding property, whereas the User Interface canvas buttons and 3D ladder objects are inter-actable. Event triggers are also placed at a high level. This way of organizing objects helps us to identify the parent/root object from the child/sub-object.

4.1 Ladder Safety VR implementation using MVC-E3D framework

The interaction techniques of augmented and virtual reality interfaces can be implemented with the help of our adaptive design pattern. The Model-View-Controller design pattern can be extended by adding features that consider all VR and AR specific processes separately in the structure proposed here and then integrate both the real and virtual interactive devices with their corresponding environments. The classical MVC pattern has the benefit of separating visualization and interaction aspects of the user interface when the application is being designed. Furthermore, modular designs can be made possible, which can perform component modifications without affecting other components.

4.2 Application Work Flow

As illustrated in the diagram below, the workflow has been divided into 2 modules, such as; Admin and Student. Admin module is defined to design the scenes in Unity3D and adds physics, logic to the character and also to the models used in the scene. Admin also manages the Education module, like adding instructional video

and quiz questions to a designated scene. Admin is responsible for hosting the application on server using Photon Unity Networking (PUN) to allow remote students to use resources and reduce the computation.

The student module performs actions like connecting to the server using the PUN app-id provided by Admin, attending the pre and post-quiz, watching instructional content and pre-training using education module, simulate ladder climbing, and trigger an event to finish the training.
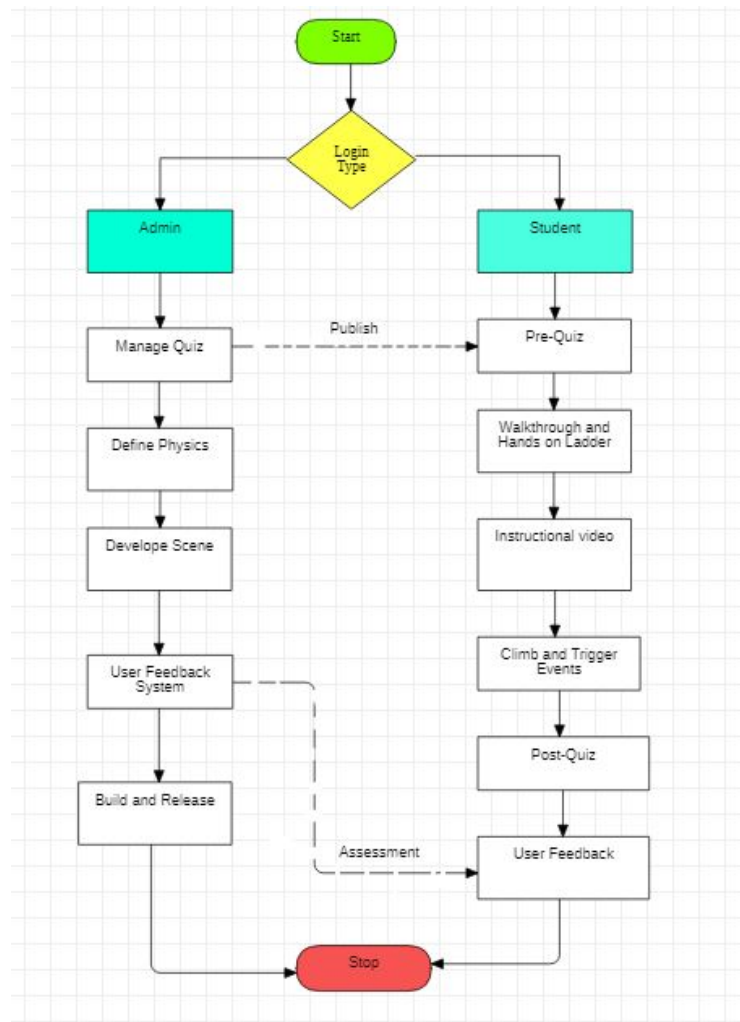

Figure 4.1: Application Work Flow

Our implementation of the framework has also followed the same workflow. After the initial proposal of the framework, we start developing the admin module and then the student module. Each of the model created during development is exported as a prefab and are meant to be reusable.

4.2.1 Model Component

In our proposed framework, the Model has a Scene Manager, Script System, Resource manager, Physics, and Logic System. The admin model has two components to handle: Logic component - which defines system behaviors, and Data Management component - which handles data storage and query. The logic component defines interactions between different objects, allows communications between students, and defines education workflow. Education workflow defines how 3D scenes are connected, how a student should interact with a ladder, when and where assessment questions are to be displayed. All data in the application is managed by the data management component, including 3D scene and models, student login information, and education data- such as tutorials, manuals guides, quizzes, recorded lecture videos, and feedback system.
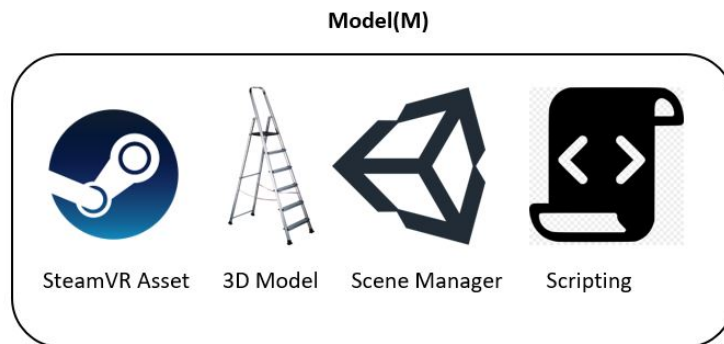

Figure 4.2: Model Component

As mentioned in the figure given, we use assets like SteamVR: a library that is made available by the Unity Asset store, which includes CameraRig and Player prefab. Photon Unity Networking V2 can also be downloaded from the asset store. Other assets include different 3D models, like a step ladder, extensible ladders, light poles, walls, floor, lights and other climbing equipment. Moving forward, the model includes a scene manager that allows rendering and loading the designated scene as programmed. Finally, there is a scripting part in which we use C# for the logic part to control the model and to enable the student to interact.
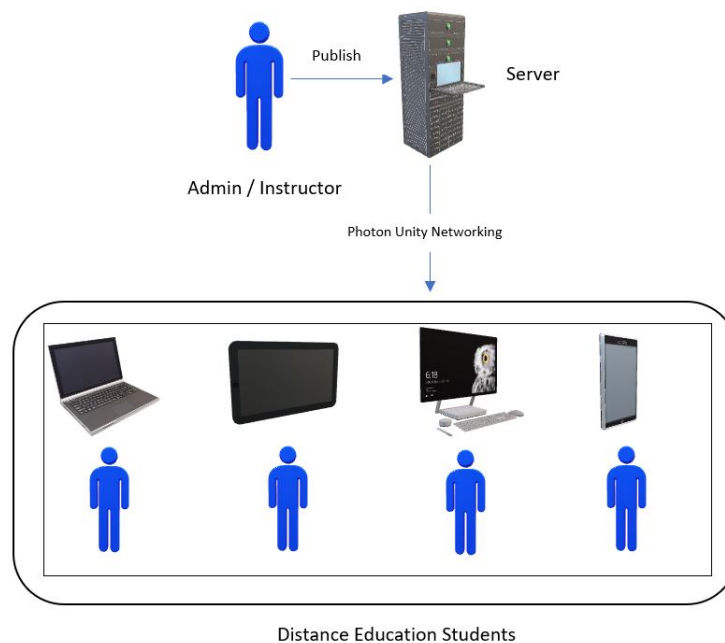

Figure 4.3: Architecture of a PUN server

The above figure shows how Distance Education(DE) students are connected to the server to access the application. The student's device needs to install view and control modules. The instructor's server should have a model, view, and controller Modules. Simulation data is transported from the instructor's server to students' device.

4.2.2 View Component

View comprises of Graphic Rendering Unit, GUI display system, Sound System. According to our proposed framework, the user can view updates from the model, and it enables users to view the virtual world using Head Mounted Display(HMD) in a Calibrated Room Space. It renders the Designated Scene with HTC Vive Device or Oculus Quest and Graphic Card connected to a PC.

Figure 4.4: View Component

4.2.3 Controller Component

Controller component has Input system and UI events system. VR logic control system is defined for simulation of objects and this logic control unit detects the objects which are either collision defined or interactable and updates the virtual reality scene in a loop and is flexible. Controller bindings are defined based on the user's device.

VRlogic control is developed to make the run application run faster and make sure the compiler understands and differentiates the objects based on the properties. We use C# as a hybrid scripting language for our project, which is developed using the Microsoft Windows platform and .NET framework on Windows to work. Controller buttons allow the user to Grab, Climb, Interact, and Walk around the Scene Area.
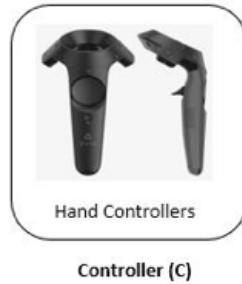
Figure 4.5: Controller Component

4.2.4 Education Module

Education module allows students to train the safety program by using a quiz based game. The Pre-Quiz has been designed for students to experience safety risks before the on-site visit. A player walks through the scene, chooses the model, and watches an instructional video on how to handle the equipment to avoid risky situations. After watching the video, the Student goes to the activity area to trigger events using the equipment. A Post-Quiz has the same question to answer type regardless of whether workers choose the right or wrong answer, the User Feedback System (UFS) presents possible outcomes to the choice they made in the form of a video or pictures to minimize the risk and help them learn better.
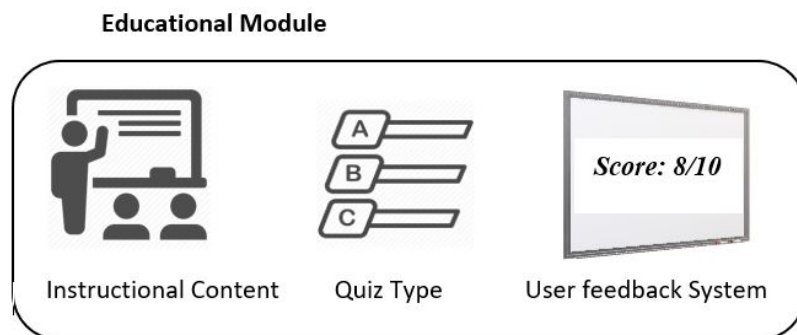

Figure 4.6: Education Module

4.3 Ladder Safety VR screenshots

4.3.1 Home and Login

We developed a Virtual Reality application that allows admin/instructor to login and add, delete or update the scene components like 3D models, quiz questions, update the user feedback system. Online Students can also log in through the same screen, which calls the networking function to connect the PUN server.

Figure 4.7: Login page for Admin and Student

4.3.2 Photon Unity Networking

Photon Unity Networking (PUN) is a plugin available in the unity asset store, used to support network access and host a server for distance education students to access the virtual reality application. This can reduce the computational power. PUN based applications need an AppId which can be generated using the Photon Engine. The photon server's logic can be customized using C#. The performance and stability of the server can be monitored using the Photon's logs. An abstraction of Low-level functionality and adding any extra features can be easily handled.
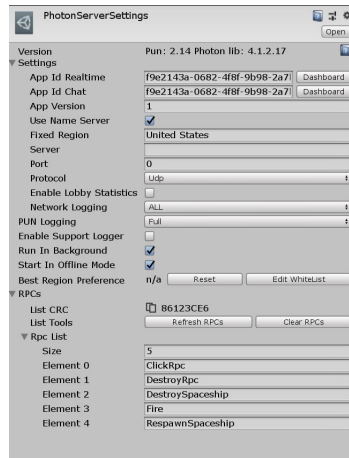
Figure 4.8: Photon Unity Networking (PUN) server settings

4.3.3 Pre-Quiz

An interactive curved animated canvas with a Multiple Choice Question (MCQ) or True/False based questionnaire is displayed to let the instructor assess the knowledge of the students before the start of a training program. We export this canvas as a prefab, which can be reused for other application development.
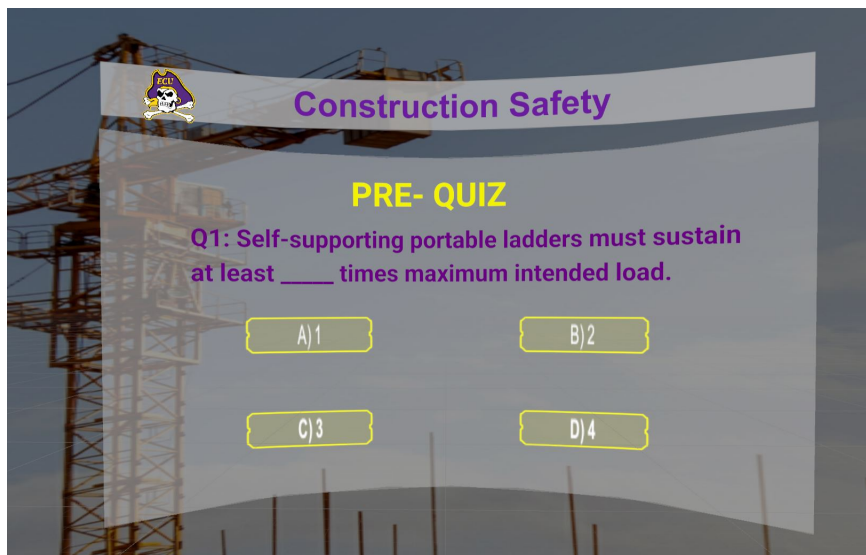

Figure 4.9: Pre-Quiz UI canvas

4.3.4 3D Virtual room

A virtual room is built importing the required assets from the unity's asset store. 3D models like ladders, bricks, etc. are placed to let the user interact with them.

Figure 4.10: Virtual environment scene with 3D models

4.3.5 Instructional Content

The following canvas shows the information of ladders placed in the scene which comprises of ladder types, length, and workload handled by the ladder, so the student can get to know the equipment before carrying out a real-world experiment.

Figure 4.11: Canvas shows information about ladders

Even after reading an instructions manual, the student still needs to visualize the working model and get a clear image of the equipment, which is a ladder in this case. So, we create a render texture prefab for a demo video to play during training on the canvas. Implemented render texture supports the most common video encoding formats, including YouTube video links.

Figure 4.12: Canvas for a demo video

4.3.6   Climbing Activity

The below snaps show the training session of a student to grab, walk, and climb a ladder after watching the demo videos. Using the Virtual Reality device's hand controllers, the student can simulate climbing the ladder. The trackpad is used for the movement of the player in the scene and grab the ladder using the Hair Trigger button. Alternating the trigger between left and right controllers allows the student to transform character's vertical position.

Figure 4.13: Student climbing the ladder

4.3.7 Trigger Events

A trigger event is a User Interactable (UI) button that, upon interaction/click, carries out the task of activating-deactivating an object. It creates a checkpoint and allows the instructor to track the progress of the student.
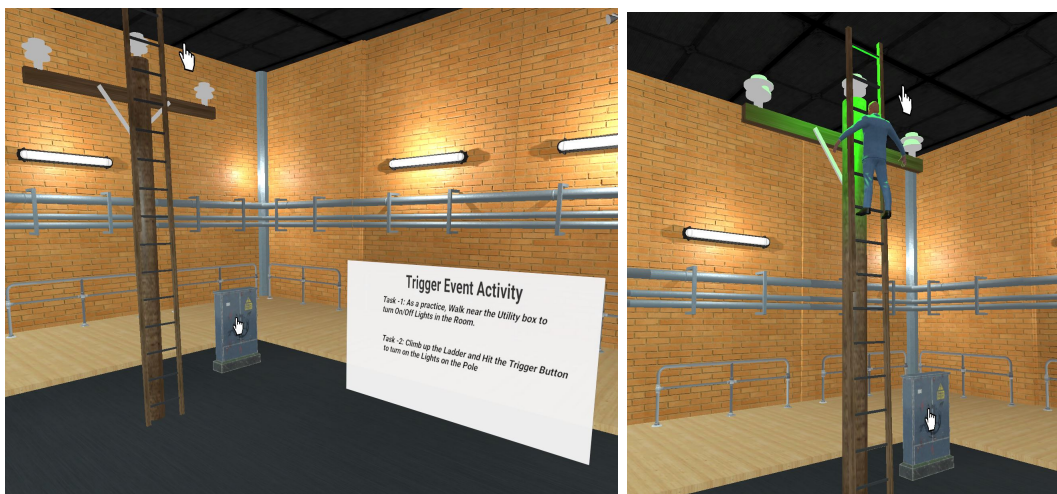

Figure 4.14: Light pole Triggering Event

Above mentioned screenshot shows the pre and post-trigger event. The student climbs the ladder to trigger a checkpoint event, which in turn activates the green-colored pole light as a successful triggering.

4.3.8 Post-Quiz and User feedback system

The following screenshots show the Post-Quiz section and an implemented User Feedback System(UFS), which popups the alternative scenario of choosing a wrong answer in the form of a text or a small video. Based on this feedback, students can learn from their mistakes.
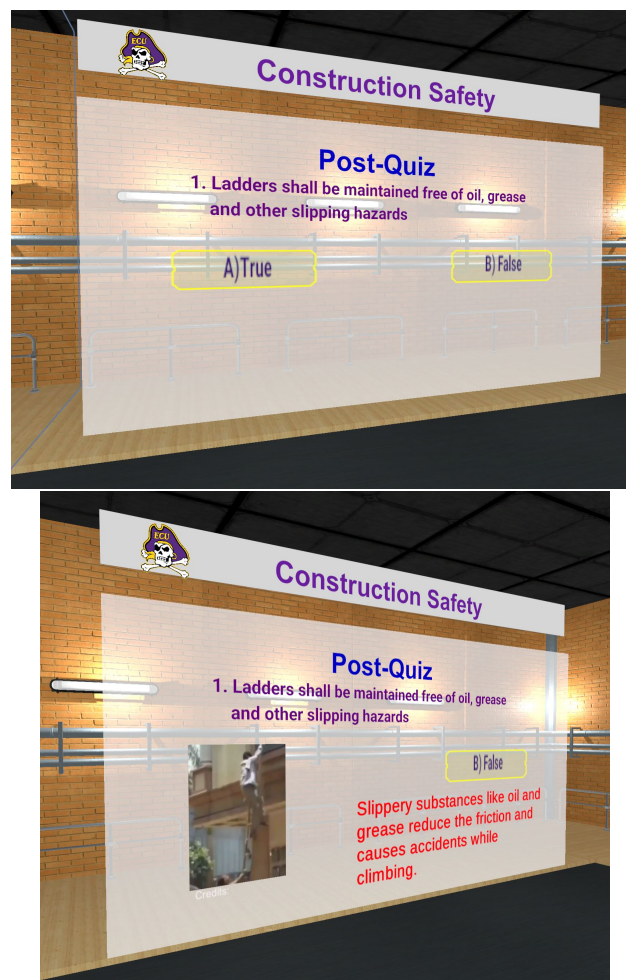

Figure 4.15: User Feedback System for a wrong choice

Chapter 5

Conclusion and Future work

Our proposed Model-View-Controller-Education 3D framework has been successfully implemented using a Virtual Reality application and can be found at `https://github.com/chegireddyy18/Construction_Safety_VR`- a GitHub repository.

With the fast-developing innovation, we should embrace and leverage better strategies to convey the best learning experiences. Educators have started to embrace Virtual Reality and its vast potential outcomes for learning as the innovation quickly moves to the mainstream. As discussed above, Virtual Reality is particularly helpful for providing students with several opportunities: expanding student commitment, giving constructionist, authentic experiences to enhance student identity, taking into consideration new perspective-taking and compassion, as well as supporting creativity and the capacity to envision the problematic models.

This thesis provides an analysis of various related works in the area of virtual reality based education, including development of frameworks, and VR based construction education programs. Moving forward, the paper includes our proposed MVC- E3D framework that is focused on student's pre-training to use any equipment to nullify accidents and assess his progress through quiz-based experience in a virtual world.

The proposed framework is implemented for the Distance Education (DE) program for Ladder safety training in a construction management department class, where the instructor hosts the developed virtual reality training application in a server that remote students can access with different type of devices for an immersive experience and become familiar with experiment steps before they visit campus and improve their live training. Hosting the application on a server can reduce the computation carried out by the student's machine. Including the User Feedback System (UFS) in the application allows users to learn from their mistakes, improvise and move forward with their training.

In our opinion, VR has great potential to advance these strategies with stunning animated visuals and interactive simulations that immerse the students in the authentic learning experiences. Virtual Reality technology can push the limits of the traditional learning system to be creative, responsive, and engaging to the needs of the students. Our proposed MVC-Education 3D framework fulfils these requirements. But this framework is mainly designed to help Distance Education or online students with pre-training. However, based on our progress with this project, the limits are still being explored. A user study needs to be carried out, which reveals a positive effect of 3D technology on student learning. Unfortunately pandemic caused by Covid-19 has forced us to delay the IRB approved user study. With innovative experiences, we aim to develop this framework by adding more features like Multiplayer feature, where multiple users can join in the same room and assist each other to perform a task. Additional feature like PUN's voice chat, where an students can interact with available instructor regarding any queries at specific part of training virtually.

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