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Game-based and Virtual Reality Sandboxes: Inclusive, Immersive, Accessible, and Affordable Learning Environments

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In a world that is constantly evolving, Damith believes that through the application of physics and engineering, we can steer the spear of innovation towards sustainability and technological advancements. Damith is a driven and hands-on learner, working towards a Bachelor of Space Engineering, constantly learning new skills in programming, hardware, and applied physics. Learning from his past experiences of taking on the role as a research assistant, working on passion projects, and being an engaged student, Damith focuses on continually honing his skills and knowledge to move the needle forward in the field of engineering and physics.

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GAME-BASED AND VIRTUAL REALITY SANDBOXES: INCLUSIVE, IMMERSIVE, ACCESSIBLE, AND AFFORDABLE LEARNING ENVIRONMENTS

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ABSTRACT:

Learning complex engineering concepts in varying fields, from learning how to prototype a circuit on a breadboard all the way to learning about the complex geological features that make up well known terrains, require hands-on experience as well as access to sophisticated equipment. In the former situation, many educational institutions can afford lab equipment such as electronic components and large laboratory workplaces. However, there are instances where purchasing expensive equipment for learning is not a viable option. In the latter case, learning about the geological features of a place such as the Grand Canyon is limited to using 2D topographic maps and 3D virtual models; students may not completely comprehend rock strata of terrain through readings and images. We have been developing a fully immersive virtual reality application to tackle these problems; to help students learn through an inclusive, immersive, comprehensive, and accessible environment. The application, called the VR Sandbox, makes use of the Oculus Quest 2 VR headset and the Unity game engine to simulate in-person lab settings and activities. Current developments include an electrical engineering lab where circuits can be modeled and simulated as if the user was in a real laboratory setting. Along with this is a mechanical engineering lab with the activity of assembling a drone and flying it using a radio controller. These tasks are done by wearing the VR headset, which provides a 360° viewing experience, while the handheld haptic feedback controllers are used to interact with the components. The Virtual Reality (VR) Sandbox also provides tours of key national parks such as the Grand Canyon and Swiss National Park, enabling users to visit these locations as if they were there in real life. With these developments, educational institutions that are not able to afford expensive lab spaces and equipment will have a more feasible option: purchasing low-cost VR headsets for students while still gaining a quality educational experience. For a more detailed analysis of terrains, in the field of Earth systems and civil engineering applications, we have been developing another technology called the Virtual Game based Sandbox (VG Sandbox). The VG Sandbox is a web-based computer application, developed using the Unity Game Engine, that teaches users about complex surface terrain model analysis by providing a combination of tools, tutorials, and examples in an intuitive, real-time digital environment. The application includes functionality for measuring horizontal and slope distances, angles, and generate parallel lines between points, visualizing planar structures with the three-point plane problem approach, dynamic topographic line mapping, and generating rivers using a particle-based fluid simulation. To further assist users in their analysis endeavors, each tool also contains a matching tutorial, and in some cases may contain example models to help users understand particularly difficult topics. User experience was of paramount importance; the application provides an intuitive user interface, as well as a robust camera controller for easily navigating the digital terrain model. Additionally, users are provided with functionality for drawing directly onto the terrain mesh itself, saving user progress, and exporting usage statistics.

1. INTRODUCTION

As the field of engineering is a broad one, containing many subdisciplines, catering University level courses to each field to be experiential and immersive can be quite costly and difficult. For this reason, many courses taken at the University level are purely theoretical, in that the content is taught through readings, lectures, images, and 3D virtual models. This format may be appropriate for certain courses that do not require hands-on experience. Most educational institutions are well funded and thereby able to reside funds for purchasing equipment and work-spaces for specific courses. A 2022 report showed that the average revenue of colleges across Canada was $13.3 billion (Statistics Canada, 2022). Equipment purchased for engineering courses may vary and can be, but not limited to, oscilloscopes, function generators, spectrum analyzers, microcontrollers, and 3D printers. More specifically, Civil Engineering programs may offer courses that provide field trips to locations near the intuition as a means of performing surveying experiments, live tours, and other extracurricular activities. Though this is helpful, students cannot visit many remote locations, and some locations may be too costly for students to travel to. Though travelling to locations provides a sense of scale for students, learning about rock strata, composition, and other geological processes may not be directly comprehensible or possible. This research paper will talk about the developments made by our research team to tackle the issues around immersive learning through the use of virtual and virtual reality (VR) game-based technologies.

The first of the two developed applications is the Virtual Reality Sandbox (VR Sandbox). The VR Sandbox is a VR application, that is developed using the Unity engine, which offers a variety of activities, catering to different fields of engineering. The

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application holds a main ”lobby room” where students can virtually walk around and select an activity of their liking. The activities include a virtual tour of a scaled down model of the Grand Canyon, located in Arizona, United States, and of the Swiss National Park, located in the Western Rhaetian Alps, in Switzerland. Other activities include a Mechanical Engineering lab room where users are provided with DC motors, an Arduino model, and a drone body. The task is to assemble the parts correctly, according to a diagram provided in the lab room, and use a radio controller, with user input systems, to fly the drone. There is also an Electrical Engineering lab room where students are provided with the following equipment: an LED, a resistor, a battery, a transistor, a DC motor, a signalling device, and jumper wires. The jumper wires can be used to connect the varying components together. Users can follow the circuit schematics provided to create a circuit that lights up the LED and/or a circuit that controls the rotation speed of the DC motor, via the signalling device. The VR Sandbox is developed using the Meta Quest 2 VR headset, which is shown in figure 1. A VR headset is a device that is worn on the head, with a high quality display covering the user’s eyes, enabling for full immersion into 3D scenes (VR Headset, n.d.). VR headsets are accompanied with handheld controllers that use haptic sensors to provide real-time feedback to the user. Very briefly on how the technology works, VR headsets are equipped with inertial measurement units (IMUs) such as an accelerometer, gyroscope, and magnetometer. These sensors work on unison to track the head movements and controller movements of the user (VR Headset, n.d.). The Unity game engine enables for development for various VR headsets including the Meta Quest 2, which how the VR Sandbox was built.

Figure 1. The Meta Quest 2 VR headset

For a more detailed analysis of terrains, in the field of Earth systems and civil engineering applications, a second application called the Virtual Game based Sandbox (VG Sandbox) was developed. The VG Sandbox is a web-based computer application, developed using the Unity Game Engine, that teaches users about complex surface terrain model analysis by providing a combination of tools, tutorials, and examples in an intuitive, real-time digital environment. The application includes functionality for measuring distances and slopes, visualizing planar structures with the three-point plane problem approach, dynamic topographic line mapping, and generating rivers using a particle-based fluid simulation. To further assist users in their analysis endeavors, each tool also contains a matching tutorial, and in some cases may contain example models to help users understand particularly difficult topics. User experience was of paramount importance; the application provides an intuitive user interface, as well as a robust camera controller for easily navigating the digital terrain model. Additionally, users are provided with functionality for drawing directly onto the terrain mesh itself, saving user progress, and exporting their usage statistics.

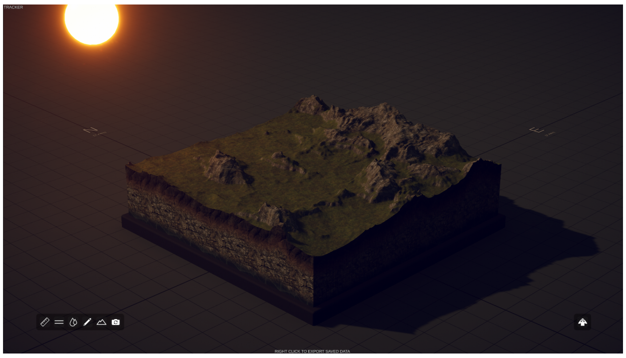

Figure 2. The Virtual Game-Based Sandbox sample scene

2. THE VIRTUAL REALITY SANDBOX

2.1 Creating Virtual Reality Tours of Remote Locations

When designing the VR Sandbox, our research team focused on ways to provide access to well known national parks. One of the most well known landmarks is the Grand Canyon located in Arizona, United States. Though people are able to visit this location, there is a fee required, and it also requires for travelling in a vehicle and/or expending energy walking around. Further, this location is the focus of study for many civil engineering courses for the means of understanding complex geological phenomena. With the development of the VR application, we aimed to model a portion of the Grand Canyon and scaling it down so as it still provides a sense of scale for the user, is quicker to explore, and is free to tour for anyone with a VR headset.

To create the VR tour for the Grand Canyon, a 3D model of the location was first required. Unity enables the import of 3D models in the form of varying file types such as .fbx, .dae, .eds, .dxf, and .obj files (Unity Technologies, 2020). To create the 3D model, an application called ”Blender” was used. Blender is a 3D modelling and animation open source application with features such as modelling, rigging, rendering, and more (Blender Foundation, 2002). In order to get an accurate terrain mesh, satellite elevation data of the Grand Canyon was required. The ”BlenderGIS” tool was used for this task. ”BlenderGIS” is a free to use add-on that has many features, one being able to import geodata using web maps into Blender’s 3D view. This tool parses OpenStreetMap data which allows for objects such as buildings, roads, and rivers to be overlayed onto satellite elevation data using NASA’s Shuttle Radar Topography Mission (SRTM) (Domlysz, 2014). ”BlenderGIS” was used to first gather a texture of a segment of the Grand Canyon. Then, using the SRTM feature, the elevation data for that area of the location was imported allowing the texture to be overlayed on to a 3D mesh of the Grand Canyon. To complete the model, the mesh was extruded down on the z-axis (vertical) and some final modifications were made to the texture (fig. 3).

This model was then exported as a .fbx file and imported into Unity where it was integrated into the VR application. The VR application has a character controller that enables the user to

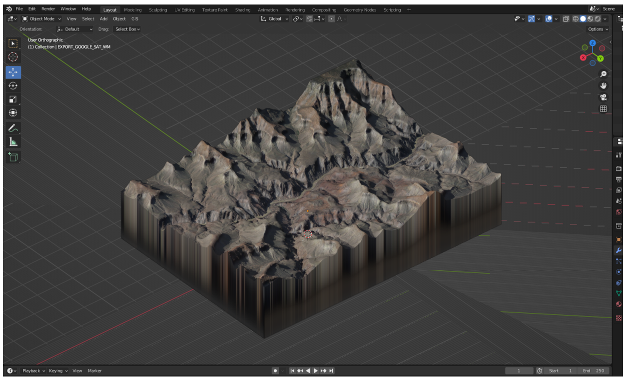

Figure 3. Model of the Grand Canyon created in Blender using the BlenderGIS tool

freely roam in this terrain, which was scaled down to increase in-game performance, using their handheld controllers to move and their VR headset to look around (fig. 4). Along with the Grand Canyon, our team created a VR tour of the Swiss National park, that is located in the Western Rhaetian Alps, of Switzerland (fig. 5).

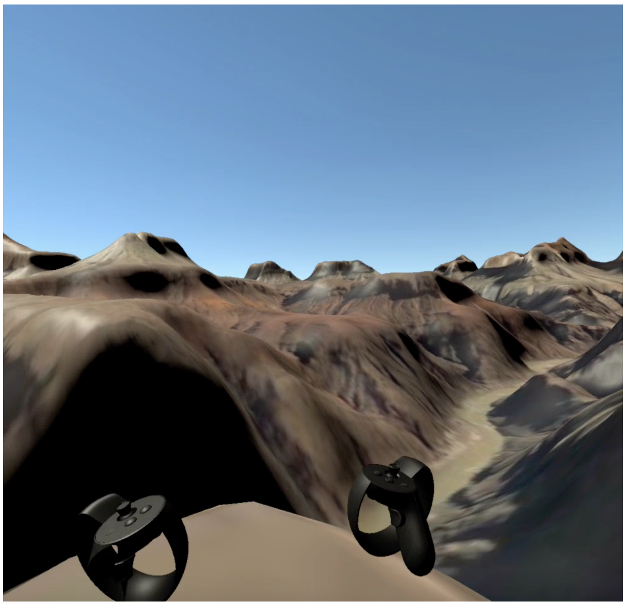

Figure 4. In-game view of the Grand Canyon using the Meta Quest 2 VR headset.

2.2 Drone Assembly Activity in a Mechanical Engineering Lab Setting

The VR Sandbox was extended from providing virtual tours to simulating lab activities using electronics equipment. The goal was to try and simulate a VR lab space that resembled a Mechanical Engineering laboratory. This included designing the 3D CAD models of varying equipment such as a micro-controller, DC motors, a drone body, radio controller, and lab space, through the use of Autodesk Fusion 360.

Once the 3D models had been designed, they were imported into Unity where scripts were written, using C, to give logic and functionality to the models. This enabled the user to make use of the handheld controllers to attach different equipment together. The mechanical engineering lab space also includes

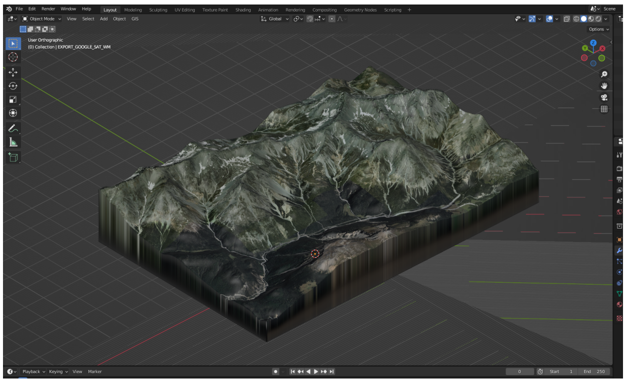

Figure 5. Model of the Swiss National Park created in Blender using the BlenderGIS tool

computer displays that show diagrams on how to complete the drone assembly activity. The user can follow the steps accordingly to assemble the drone and use the radio controller to fly the drone (fig. 6 and fig. 7). The activity was aimed to demonstrate the capability of using VR to replace traditionally costly equipment and testing that students may use in a real-life school lab setting.

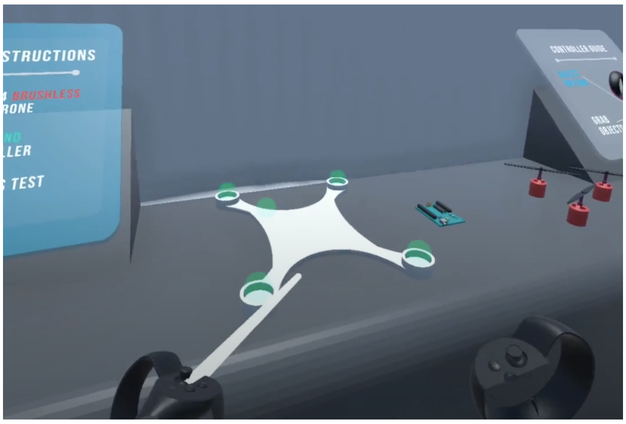

Figure 6. In-game view of the drone assembly activity

2.3 Circuit Design Activity in an Electrical Engineering Lab Setting

Using a similar approach to designing the drone assembly activity, more complex electronics equipment were designed (CAD design), through Autodesk Fusion 360, including an LED, a battery, a resistor, a metal–oxide–semiconductor field-effect transistor (MOSFET), and a more complex DC motor. The goal of the electrical engineering lab space was to try and demonstrate the ability to simulate circuit design in VR.

The second circuit activity also had a computer screen showing how to wire up the circuit. The DC motor speed control activity was designed to be a bit more complicated than the LED light-up activity. This was to challenge the student/user to get more familiarised with how signals can be varied to vary the output of peripheral devices. The main task consisted of wiring the battery to the transistor's drain and source pins and to the DC motor. The user is provided with a signal device, with a interactive slider that controls the input signal between 0-255, that is meant to connect to the gate pin of the MOSFET. Once the circuit was wired correctly, the user can vary the input signal to

Figure 7. In-game view of the radio controller controlling the drone

the gate pin of the MOSFET, by using the handheld controller to move the slider, to increase/decrease the speed of the motor's rotor (fig. 10).

The physical lab space consisted of two activities, one was to light up the LED and another was to control the speed of the DC motor. To light the LED, the user is provided with jumper wires and a computer display showing how to wire-up the battery, the resistor, and the LED, into a series circuit, through the use of the handheld controllers. When wired into a series circuit, the LED would light up, just like in real-life (fig. 8 and fig. 9).

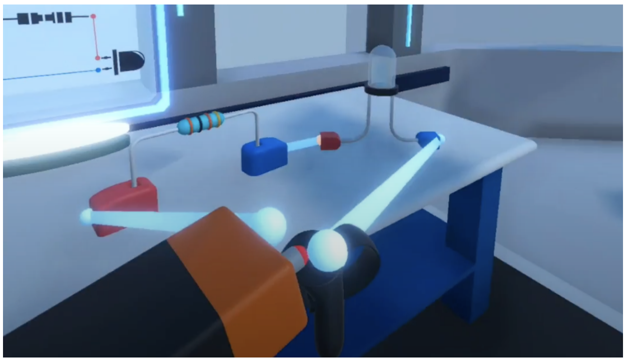

Figure 8. In-game view of the LED series circuit that is incomplete

2.4 Development Process

It is important to note that the current circuit simulations and drone assembly activity are not designed on a electrical physics engine. The goal of the activities were to demonstrate what is possible with VR in improving the current state of experiential education. For this reason, the circuits only function when wired in the appropriate manner. As per the LED light up lab, since it is a series circuit, meaning that all intermediate connections must have a logic HIGH for the output to be a logic HIGH, the underlying C scripting is checking that all jumper wire connections, to each component, have been made. A similar process is used for the speed control circuit as well as the

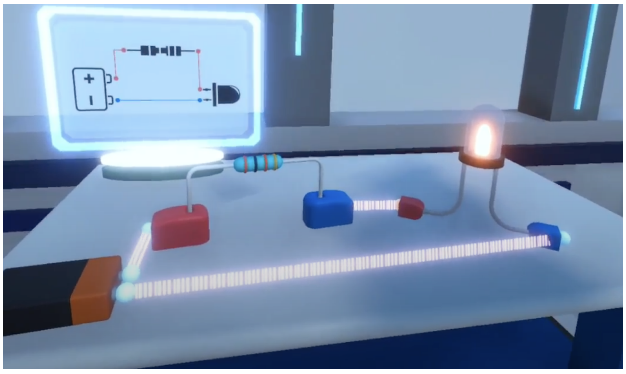

Figure 9. In-game view of the LED series circuit that is complete

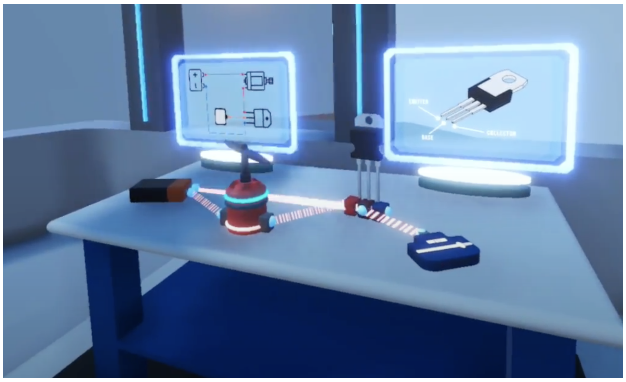

Figure 10. In-game view of the DC motor speed control activity

drone assembly activity. Current research is being conducted to extend these activities, specifically in the electrical engineering lab space, to follow the laws electrical physics. The aim is to provide an unconstrained lab for students to build and test any circuit they desire, without being restricted to a specific circuit schematic.

2.5 Applications of the VR Sandbox

At the time of writing, the VR Sandbox application has only been tested by the developers. The application is still under development as the goal is to have multi-disciplinary activities to provide immersive learning for students in all fields of STEM. Once more thorough development is conducted, by upgrading the capabilities of current activities and the addition of new activities, gearing towards fields such as aerospace engineering, software engineering, and physics astronomy, our research team will move towards a testing phase to enable students, in various fields, to experience the VR Sandbox application. An overarching goal is to have VR headsets, offered through the school, for students to borrow or use in class to enhance their learning experience.

3. THE VIRTUAL GAME-BASED SANDBOX

3.1 Terrain Mesh Generation

Terrain meshes are generated using the modeling software 'Autodesk Maya'. A highly tessellated plane is deformed using a greyscale heightmap image of a real-world terrain sample as a reference. The edges of this deformed plane are then extruded downwards to create flat sides for the final exported terrain model. It should be noted that this extrusion is created as a separate mesh from the deformed plane, as it needs to be recognized as its own mesh when imported into the Unity Game Engine so that it may use a separate material. Lastly, the deformed plane is subdivided into a grid of sixteen evenly sized partitions. This is a necessary step due to the deformed plane mesh being too geometrically dense and complex to create sufficiently accurate water physics colliders in Unity. Instead, a unique collider is generated for each partition of the terrain, and these combined physics colliders are then placed adjacent to one another in the final game scene.

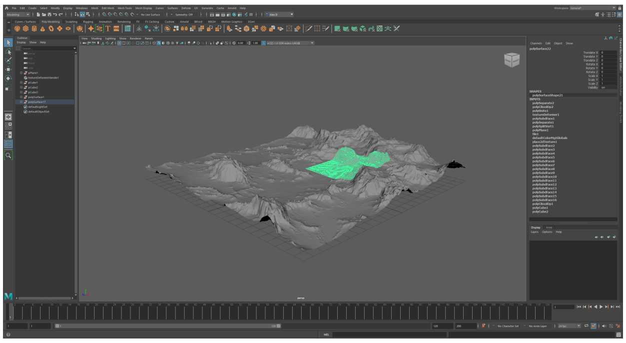

Figure 11. Terrain collider meshes in Autodesk Maya

3.2 Terrain Mesh Materials

The rendered terrain model in each scene consists of two custom shaders. The sides of the terrain mesh are rendered by projecting multiple layers of tiling textures and normal maps using the terrain mesh's UV maps as a reference. This ensures that each material conforms to the shape of the terrain itself as opposed to rendering based on worldspace height. In contrast, the top of the terrain model is rendered by projecting tiling textures and normal maps based on the mesh's normals and worldspace height. Essentially, the angle and height of a particular spot on the terrain mesh dictates what material will be painted. For example, in our sample scene grass cannot be painted on a steep cliff-side.

3.3 Scaling Calculator

Due to the steep performance cost of rendering terrain in Unity at a true one-to-one scale, it was advantageous to scale down the terrain mesh to a more manageable size. As an added benefit of this scaling, shadows render across the entire miniature terrain model without culling at far distances. A simple one one-hundredth calculator script is attached to the terrain object and referenced whenever measurements or XYZ coordinates need to be called. Furthermore, this function swaps the Y and Z values of its output so that Z, not Y, represents a coordinate's height. This function was implemented because the Unity game engine internally uses Y values to represent its height axis, which may have confused this application's intended audience.

3.4 Camera Controllers

Each scene contains two camera controllers: an overhead camera controller, and a first-person camera controller. Users can toggle between the two viewpoints on command.

To achieve smooth camera motion, similar to that of a real-life drone, the overhead camera controller operates with a velocity-based system; as opposed to input directly transforming the position of the camera and its pivot, the controller instead accelerates movement in a particular direction until hitting a predetermined peak speed. Once input is released, or the camera controller collides with the boundaries of the scene, the camera's velocity smoothly decelerates to a halt. This control system includes panning, rotation, and zooming in with a variety of input options. Furthermore, the overhead camera can be toggled to view the terrain from a 90° top-down angle, which is useful for more accurately using the various in-game tools provided.

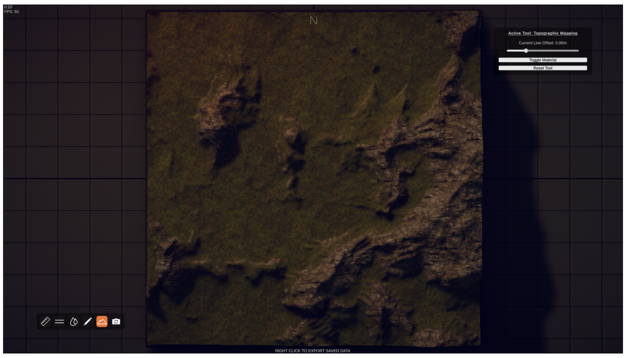

Figure 12. Top-down camera view

3.5 Additional Rendering Notes

Many materials in this project use High Dynamic Range color parameters. In combination with post-processing, many materials achieve a glowing appearance despite not having true emissive properties. Additionally, static lighting has been baked using Unity's progressive GPU lightmapper tool. Each scene also utilizes a reflection probe to provide an accurate cubemap for the water simulation's reflections.

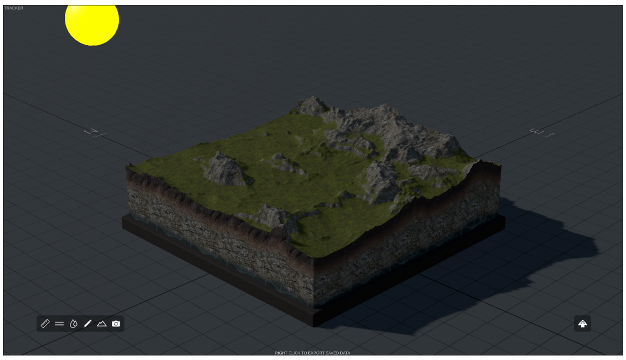

Figure 13. In-game visuals without baked lightmaps or post-processing

3.6 User Interface

It was necessary to organize the game's various tools into an easily approachable UI system. Tools can be toggled via a graphic toolbar along the bottom of the scene window, and each button employs a unique symbol and color to represent its tool.

As an additional note, many in-game UI prompts are rendered as physical objects within the scene as opposed to being part of a screenspace overlay. The is intended to allow users to more easily understand the relationship between smaller UI elements and the in-game objects they are describing.

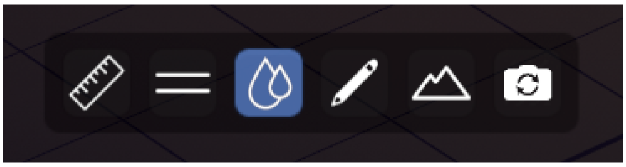

Figure 14. The main UI Toolbar with the Hydrology tool selected

3.7 'Ruler' Tool

Users can measure the horizontal distance, vertical distance, hypotenuse, and angle between any given two points on a 3D terrain model. Information and controls are provided through a UI prompt in the top right corner of the scene. Users can also visualize parallel horizontal lines at various distances to further help with terrain measurements.

The tool's visuals are represented by an assortment of 3D cylinders and spheres that scale and rotate based on the measurement they need to represent. These meshes use an assortment of custom materials that that render based on whether they should be occluded from view; when a mesh is unobstructed from view its material will appear to be glowing, whereas when it intersects with the terrain it instead uses an unlit shader.

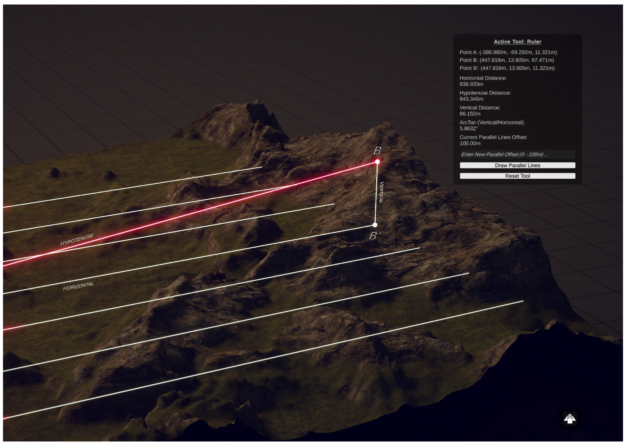

Figure 15. The 'Ruler' tool is visible through walls by using custom renderer features

3.8 Three-Point Plane Tool

Users can visualize the Three-Point Plane problem on the given terrain model by placing three points at locations of their choosing. Furthermore, they are provided with an example model that demonstrates the meaning of 'dip' and 'strike' angles in a 3D context.

Once the three points have been placed the tool can be used to render a plane that intersects with each point and culls at the edges of the terrain model. The plane itself uses a depth texture to help users recognize its relation to the terrain underneath it. Additionally, horizontal parallel lines that intersect with each point are rendered to assist with gauging height differences.

3.9 Topographic Line Mapping

Utilizing a shader that renders its material parameters based on worldspace height, and then giving users the ability to modify these parameters, an effective topographic line mapping tool was created.

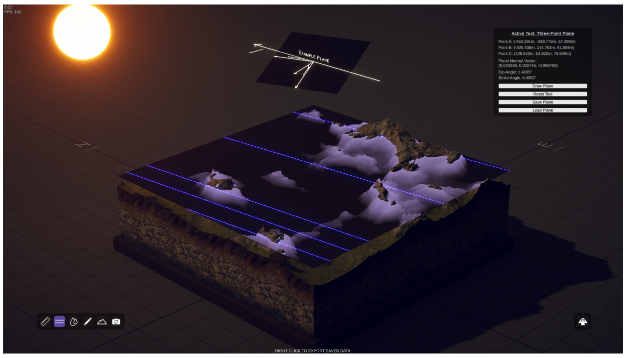

Figure 16. The Three-Point Plane tool in use, alongside its 3D reference diagram

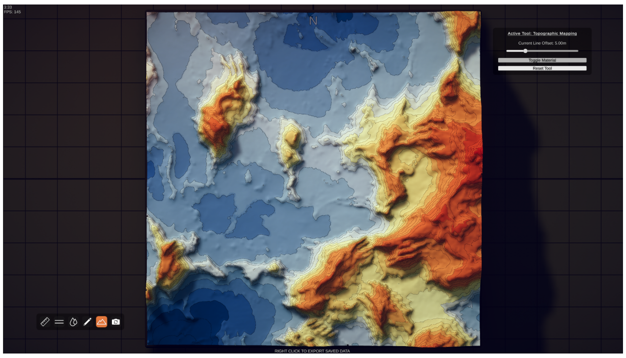

Figure 17. Top-down viewing of Topographic contour Map

3.10 'Pencil' Tool

The 'Pencil' tool allows users to draw lines directly onto the terrain material itself. It operates using an orthographic camera placed above the terrain and rotated straight down in combination with a hidden trail particle system. This camera can only detect the particle system, and outputs a greyscale render texture based on what it can see – this render texture is then used as a mask for projecting a glowing material onto the terrain. The particle system spawning is controlled by the user's input, which allows them to decide when and where they wish to draw on the terrain.

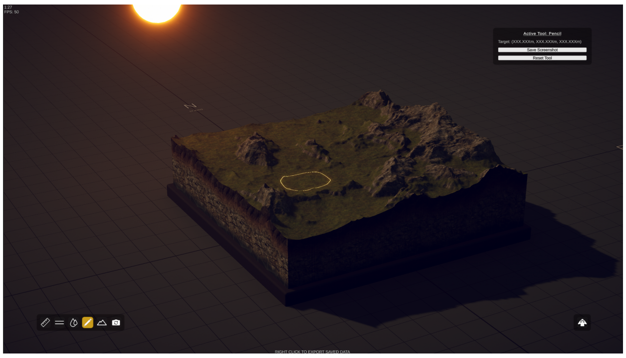

Figure 18. The 'Pencil' tool after being used to mark a section of the terrain

3.11 Hydrology and water simulation Tool

Real-time water simulations were achieved with Zibra AI's "Zibra Liquids" plugin – a highly customizable fluid simulation tool that primarily uses GPU performance to render its simulations. As a result of this optimization, complex water rendering is still attainable on modest hardware.

The water simulations are particle-based, so after finalizing the water simulation's parameters the volume of each particle had to be calculated. When the user adjusts the volume of water they wish to simulate their request is processed through a script that converts their input into an equivalent particle count before starting the simulation.

3.12 Saving and Exporting to .JSON files

Unity supports exporting to the .JSON open standard file format. User's login information, cumulative frame-rate average, time played, selected terrain scene, and tool states can be saved, loaded, and viewed in any external text editor.

4. CONCLUSION

Current educational institutions are able to provided limited experiential learning activities that can otherwise be replaced or simulated using virtual reality or virtual game-based learning methods. This includes the development VR lab spaces and activities, virtual tours, and comprehensive web-based applications to perform complex calculations and analysis of terrains and other phenomena. The advantage of using virtual reality is that it enables users to be completely immersed in a virtual environment while being able to complete activities that are costly and/or that require access to remote locations.

The VR Sandbox tool has enabled users to take virtual tours of key landmarks such as the Grand Canyon and the Swiss National Park. Further, it enables users to be immersed in mechanical and electrical engineering lab spaces to perform activities such as assembling and flying a drone, as well as creating complex electrical circuits and observing their output in real-time, in the safety and comfort of a VR headset.

The overarching goal of the VR Sandbox is to create an application that is able to perform complex circuit designs to a level where designing and testing, for real-world engineering applications, can be done in VR and the all the user would need to do is build it, using the test data, in real-life. This will rid of the need to buy and test different types of equipment and components as well as reduce the cost of learning and testing drastically for educational institutions and for individuals.

In addition, the VG Sandbox has provided users with an accessible solution to learning about complex surface terrain model analysis problems. Due to its 3D presentation and intuitive user interface, problems that would otherwise be very difficult to visualize in a classroom environment are now easily approachable.

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