

Supporting information for

# **Classification and Prediction of Miners' Emergency Response Competence Under Sudden Events Based on Seed k-Means and Stacking Learning Algorithm**

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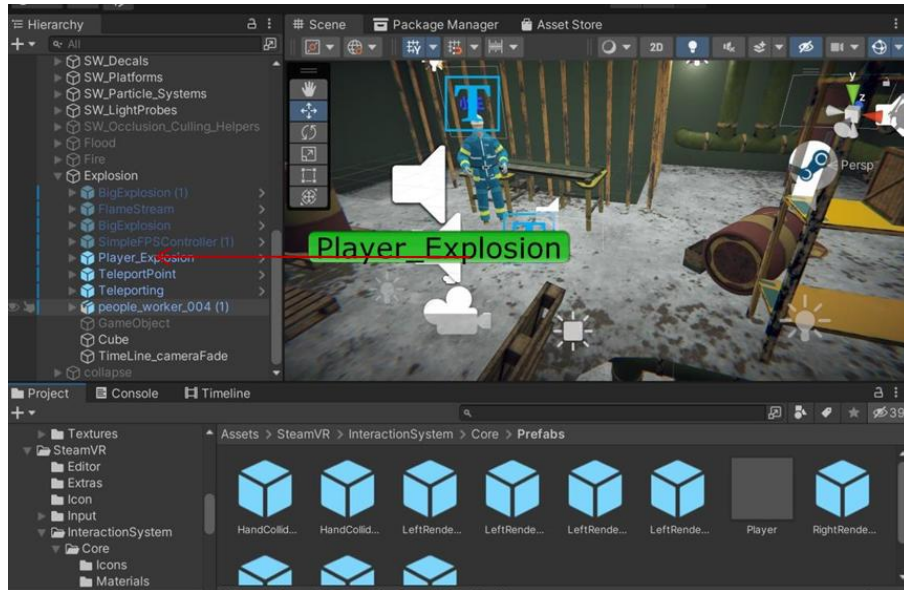
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## Appendix A: Construction of a model for four major accident scenarios in coal mines

### A.1 Coal mine gas explosion scene model

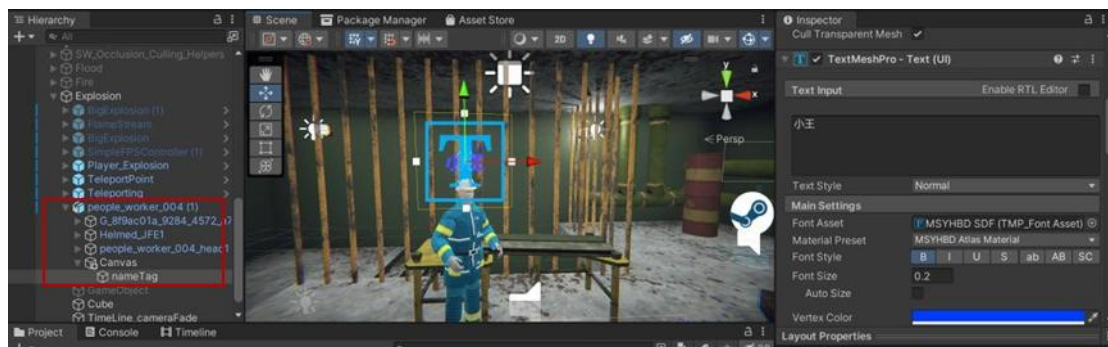
Initially, the Player component, which is provided with Steam VR, must be imported into the scene as the user's primary control component.



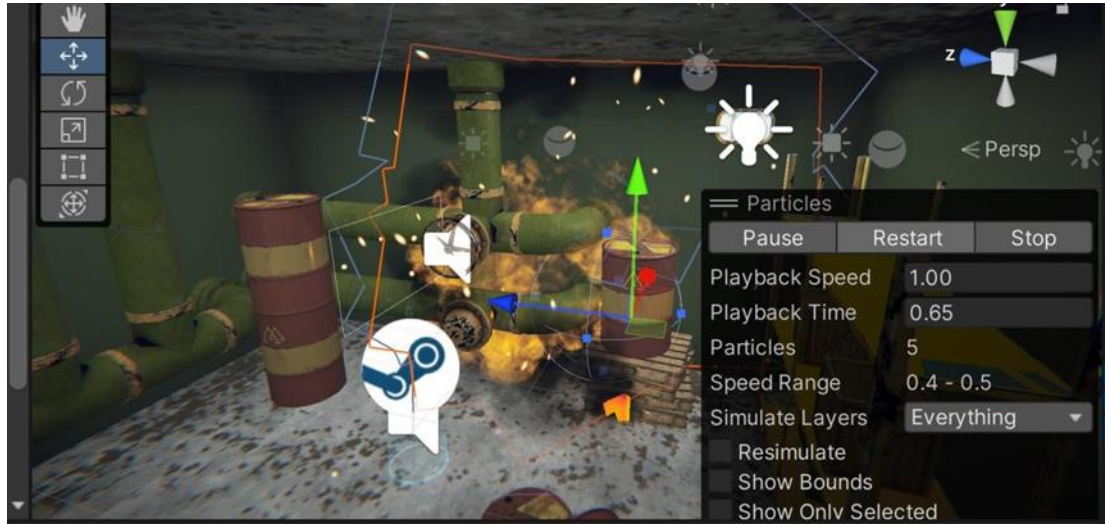
In the subsequent stage of the process, importing Teleporting and Teleport Point is necessary to ensure that the teleportation function is complete.



The following step involves the importation of the worker model into the scene in the form of an NPC. This action should be accompanied by the creation of a new canvas for the NPC.



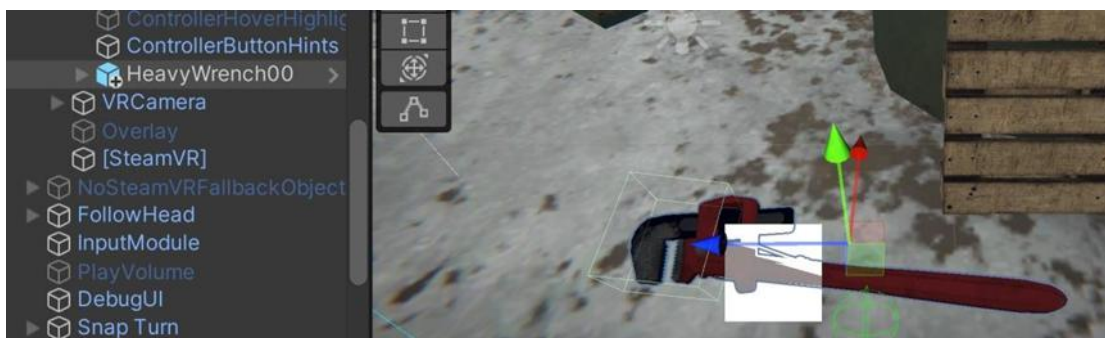
On this foundation, components pertaining to explosive effects are to be imported into the scene under investigation.



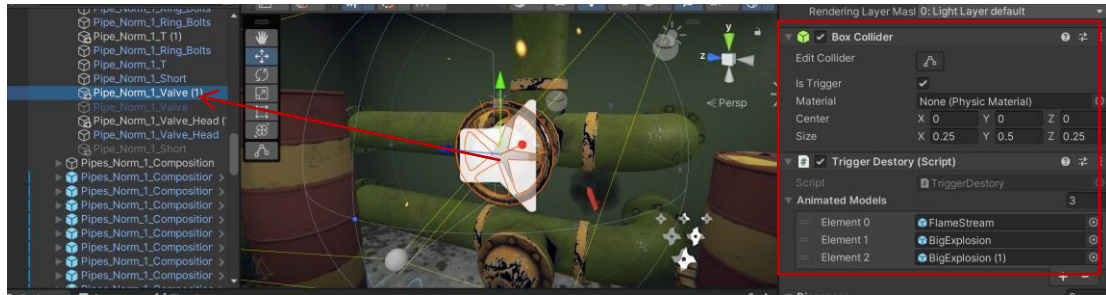
Following this, the required audio files must be imported into Audio Source.



The necessary wrench model must be imported, followed by the addition of collision bodies. These bodies must then be modified to their respective positions.

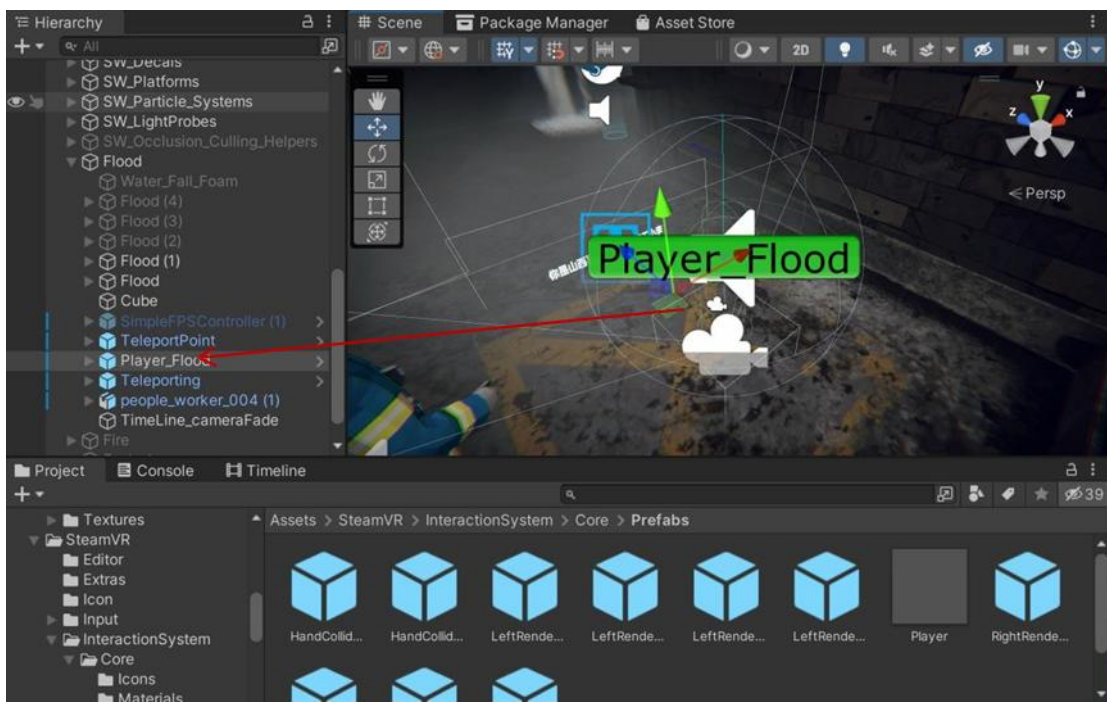


Finally, an empty object is to be set as the trigger and the corresponding script is to be attached.

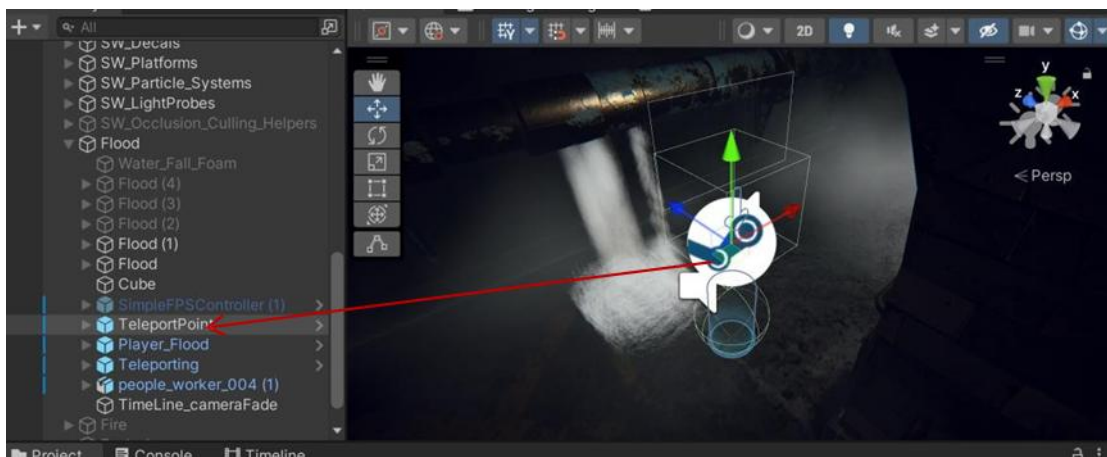


## A.2 Coal mine water intrusion accident scenario model

Initial steps should be taken to import the Player component, as provided with Steam VR, into the scene, thus establishing the main control component for the user.



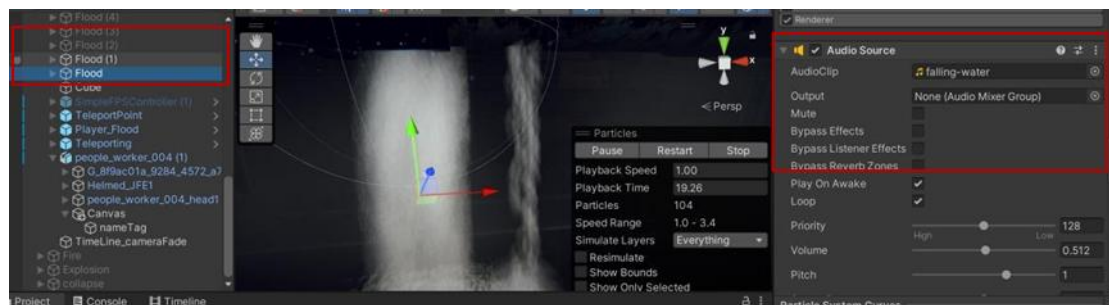
In the second instance, it is necessary to import 'Teleporting' and 'Teleport Point' in order to complete the teleportation function.



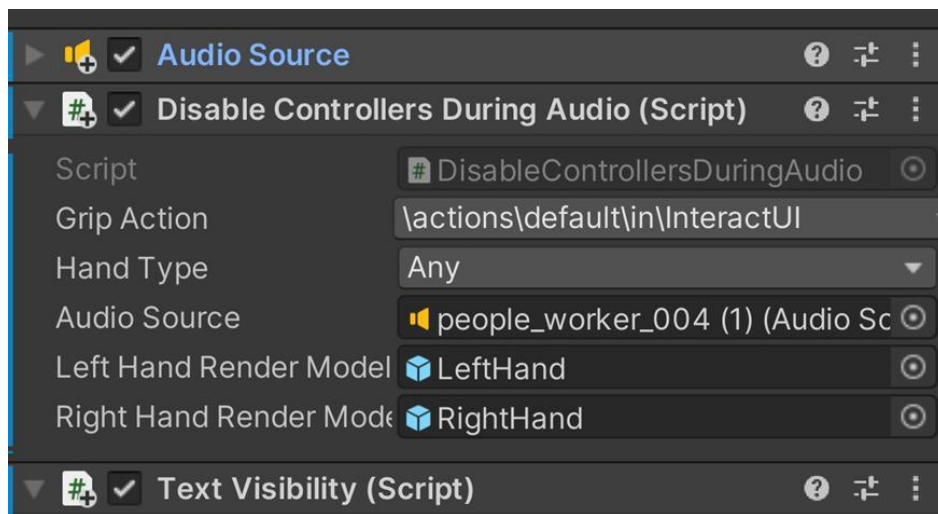
The subsequent stage of the process is to import the worker model into the scene as an NPC (Non-Player Character), and to create a new Canvas for the NPC.



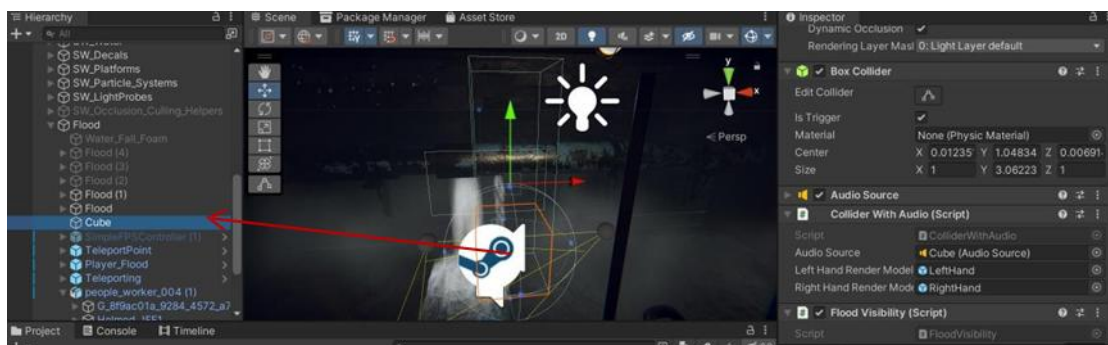
The water seepage components must be imported into the scene, after which the audio must be attached to them. It is recommended that components be concealed to ensure their activation is only triggered when required.



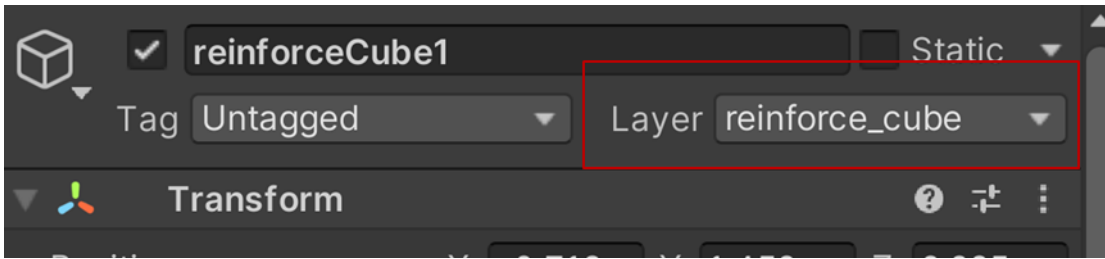
Simultaneously, the required voice files should be imported into Audio Source and sound events should be triggered through specific cases.



In the final step of the process, it is necessary to establish an empty object as the trigger and to affix the relevant script.

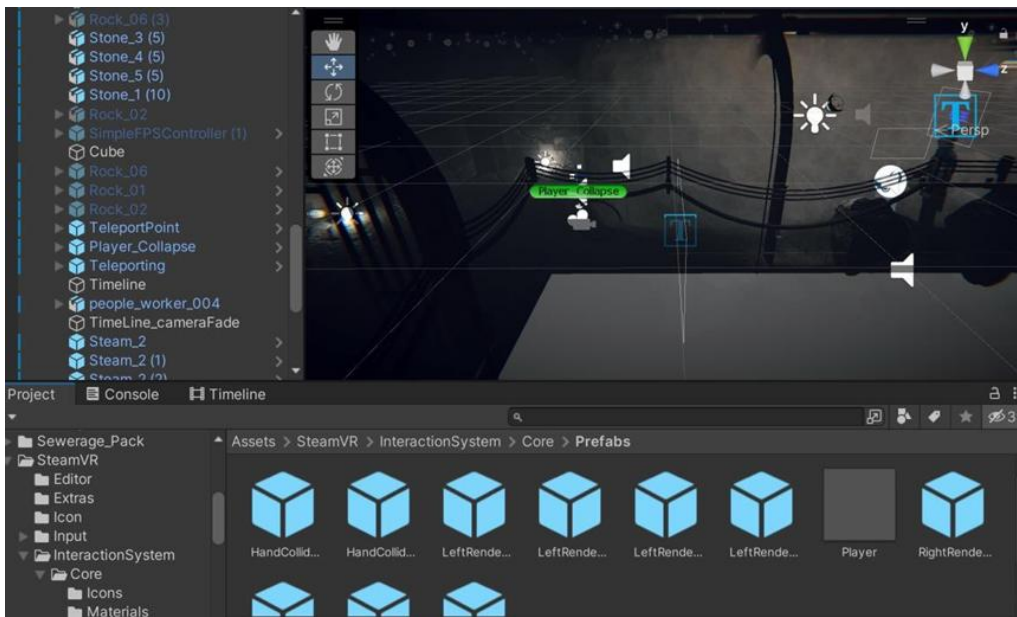


Concurrently, modify the layer of the object so that the corresponding event is triggered exclusively when it collides with the specified object.

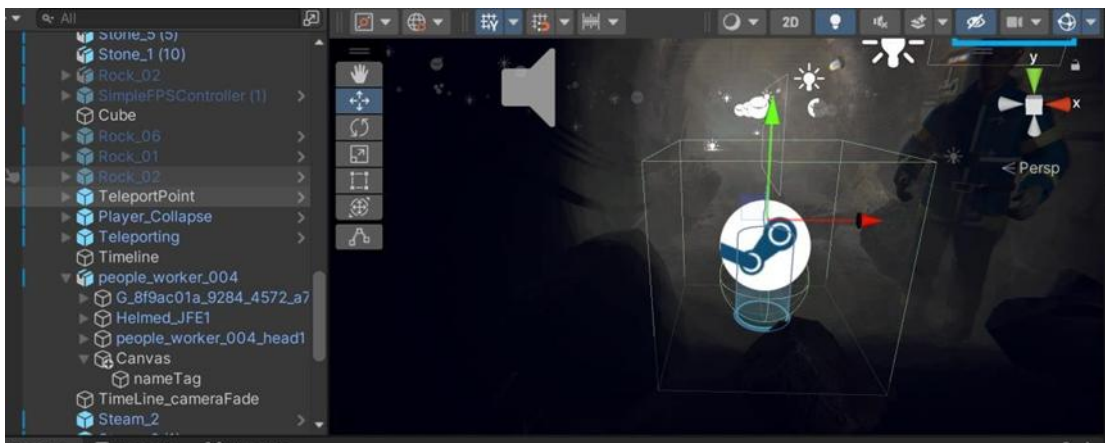


### A.3 Coal mine roof accident scene model

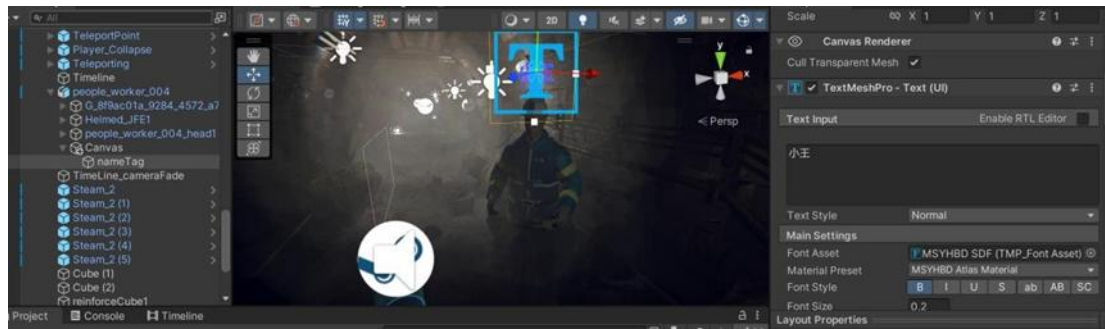
Initially, the 3D Unity software should be utilized to import the player component that is provided with Steam VR into the scene, thereby establishing it as the user's primary control element. The specific operation settings are illustrated in the following figure.



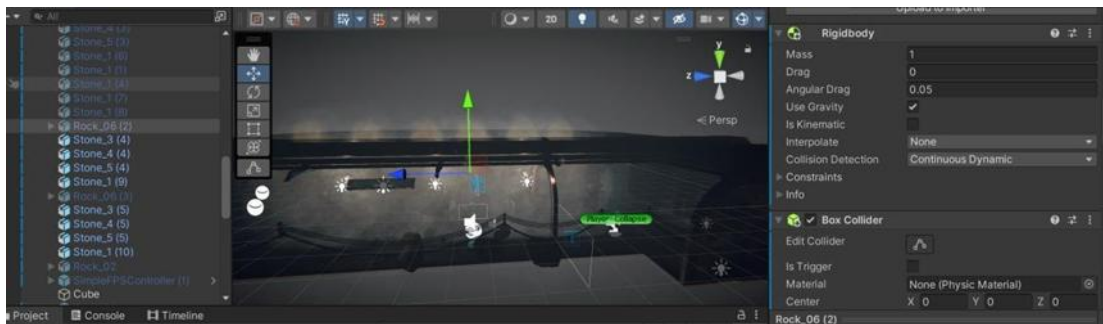
Secondly, the importation of Teleport Point is required to facilitate the completion of teleportation.



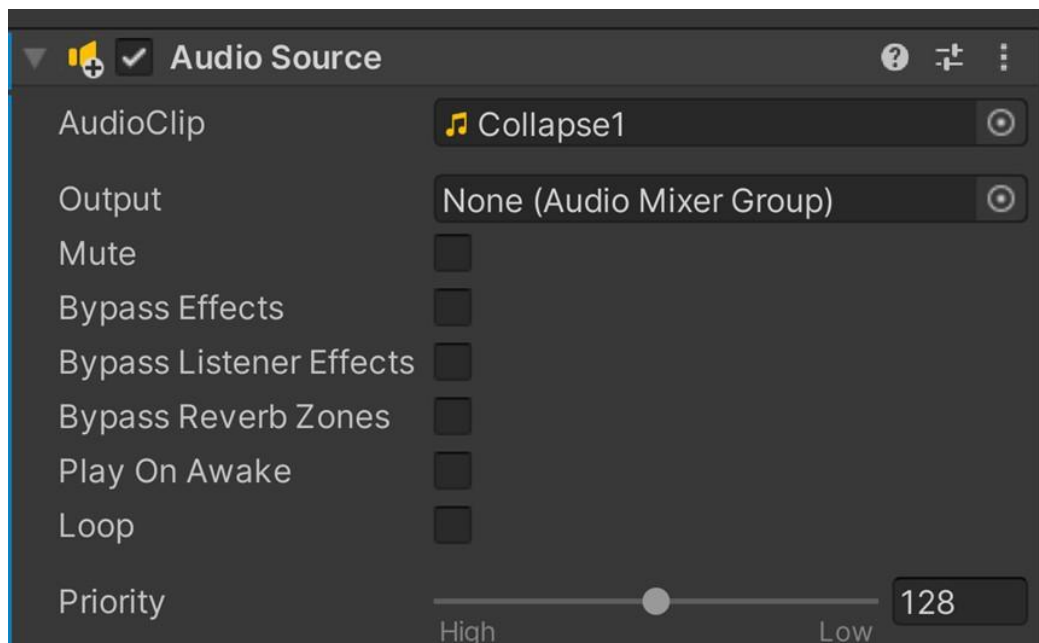
Next, import the worker model into the scene as an NPC and create a new Canvas as the NPC name.



The subsequent stage of the process is to import the falling rock components into the scene. Following this, rigid bodies and collision bodies must be added so that the falling rocks can fall and collide.

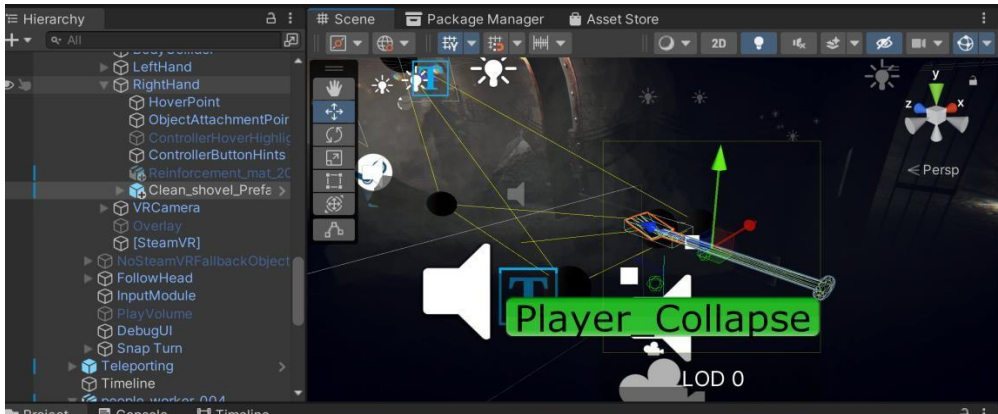


The next step is to import the required voice files into the Audio Source.

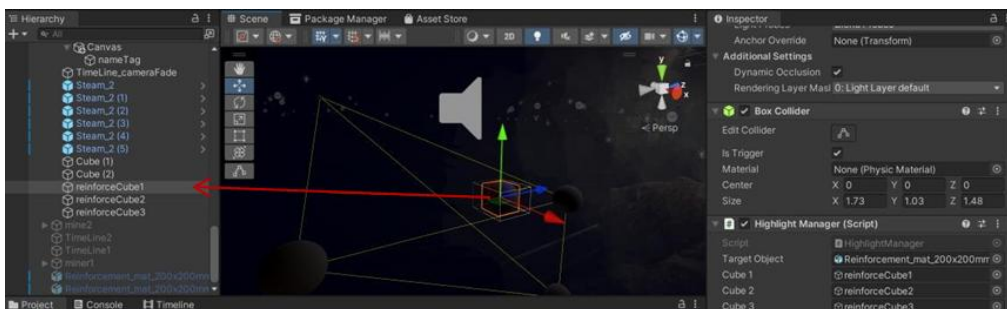


The importation of the requisite shovel and bracket models is to be conducted, with the subsequent addition of collision bodies. These bodies must then be modified to their appropriate positions.

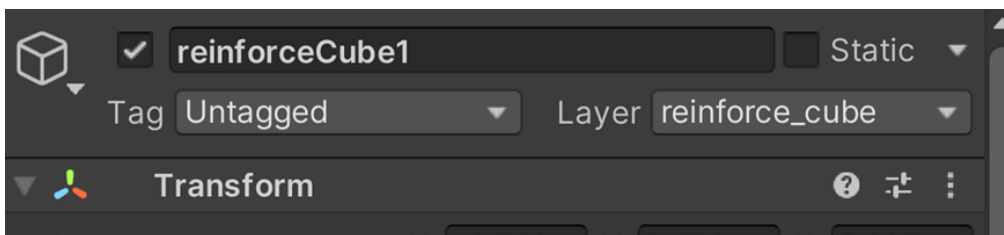




It is recommended that, on this basis, an empty object be designated as the trigger and the corresponding script be attached.

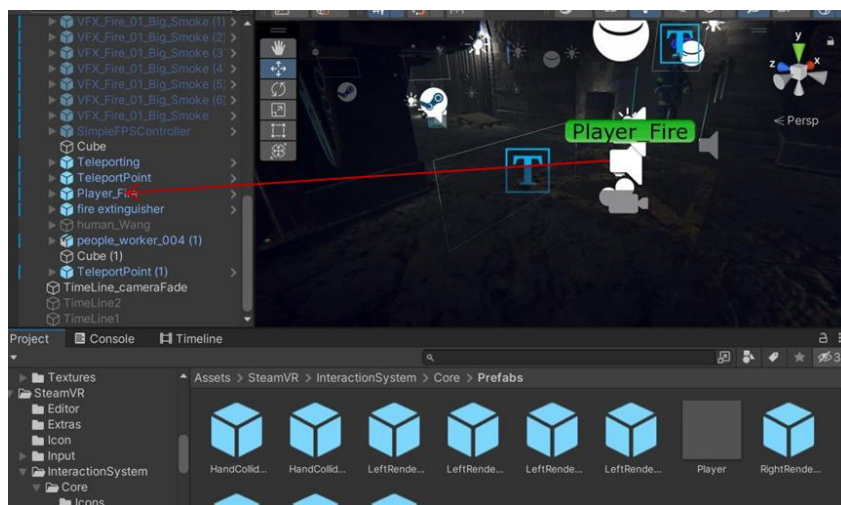


In conclusion, it is necessary to modify the layer of the object in question so that the corresponding event is triggered exclusively in the event of a collision with the specified object.

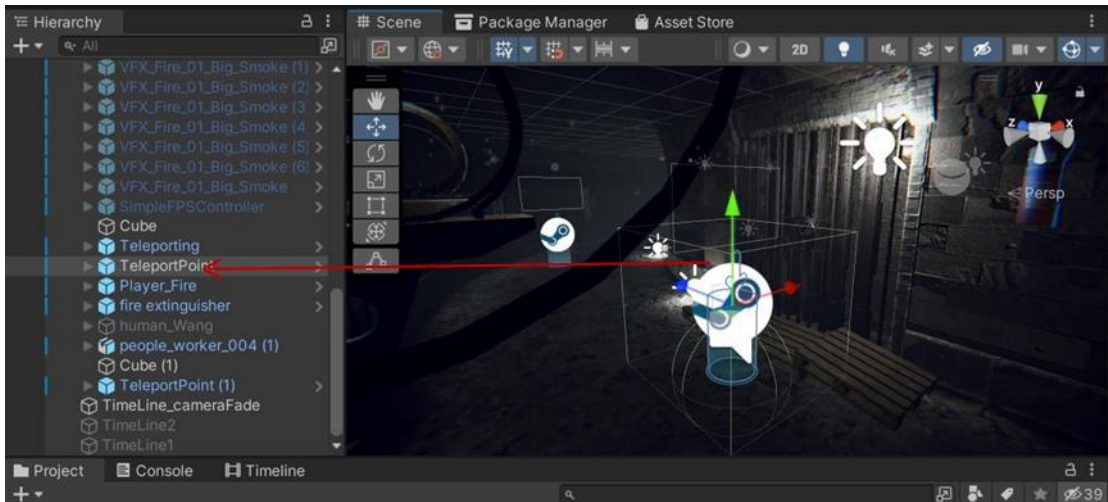


#### A.4 Coal mine fire accident scene model

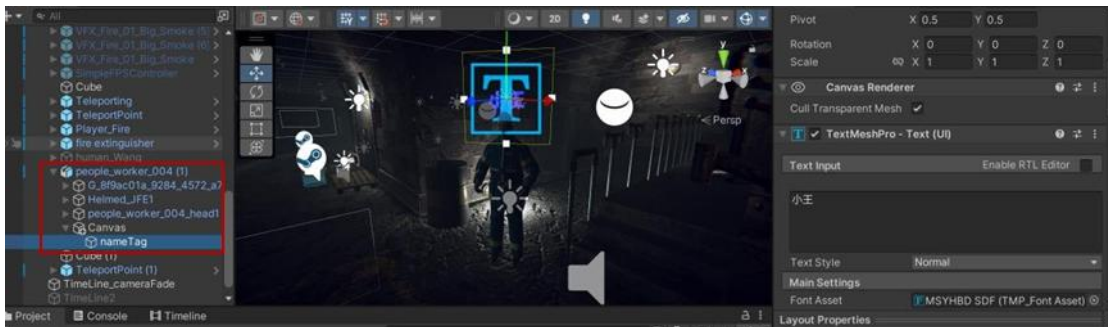
Initially, it is essential to import the Player component that is provided alongside Steam VR into the scene, thus establishing it as the user's primary control component.



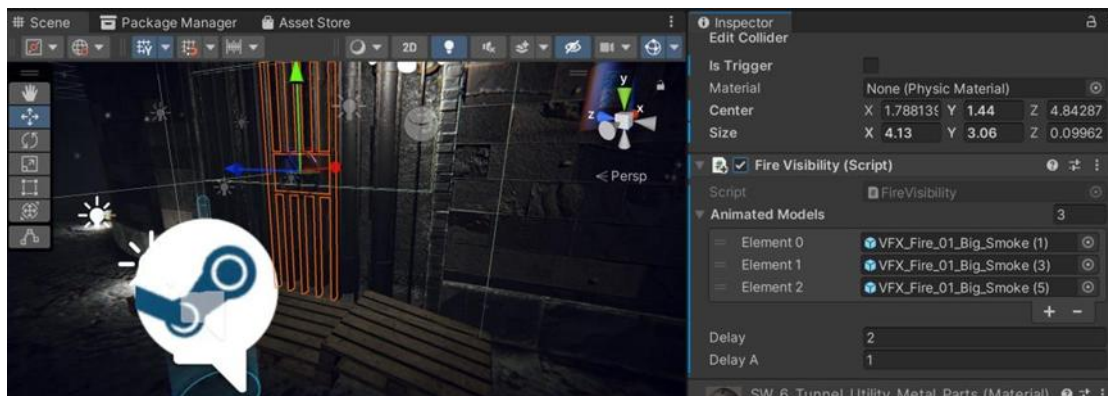
In the second instance, it is necessary to import Teleporting and Teleport Point in order to complete the function of teleportation.



The subsequent phase of the procedure involves the importation of the worker model into the scene as an NPC, with the creation of a new canvas for the NPC's name.



In light of the aforementioned point, the flame component should be imported into the scene and hidden. Subsequently, a script should be written to make the flames appear in specific situations.



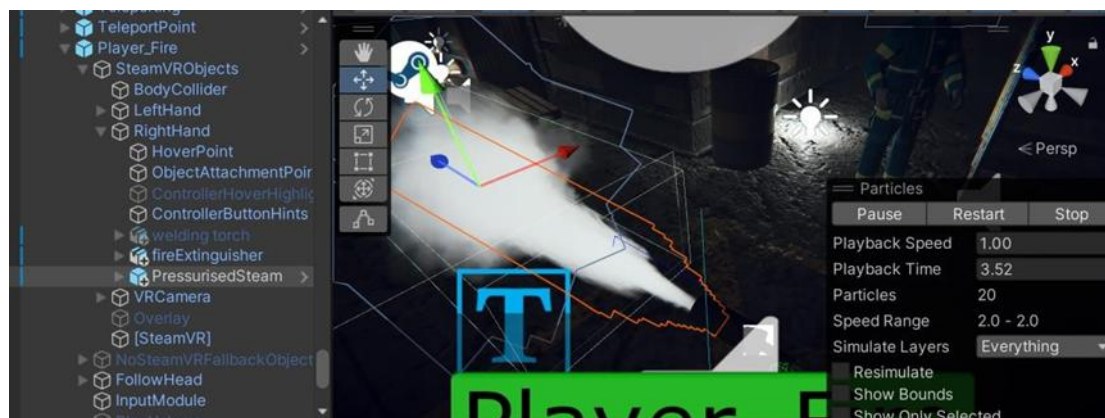
Subsequently, the requisite audio files must be imported into the designated Audio Source.



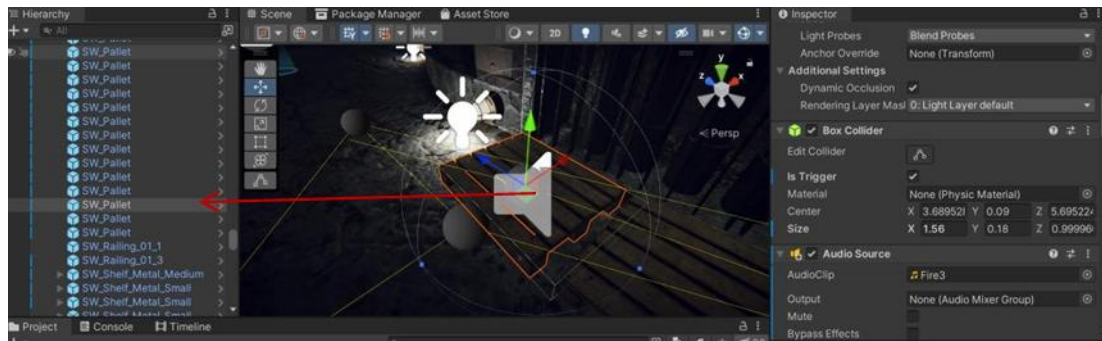
The following models of welding torch and fire extinguisher must be imported and modified to the appropriate positions.



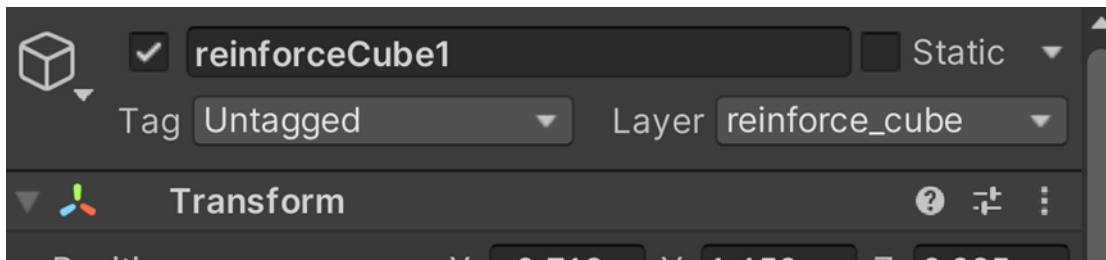
The integration of corresponding special effects, such as sparks and smoke, in conjunction with the welding torch and fire extinguisher, is paramount. Furthermore, the incorporation of collision bodies is essential to ensure the authenticity of the simulation.



The required objects are to be set as triggers and the corresponding scripts attached. When the aforementioned effects intersect with the objects, the scripts will be initiated.



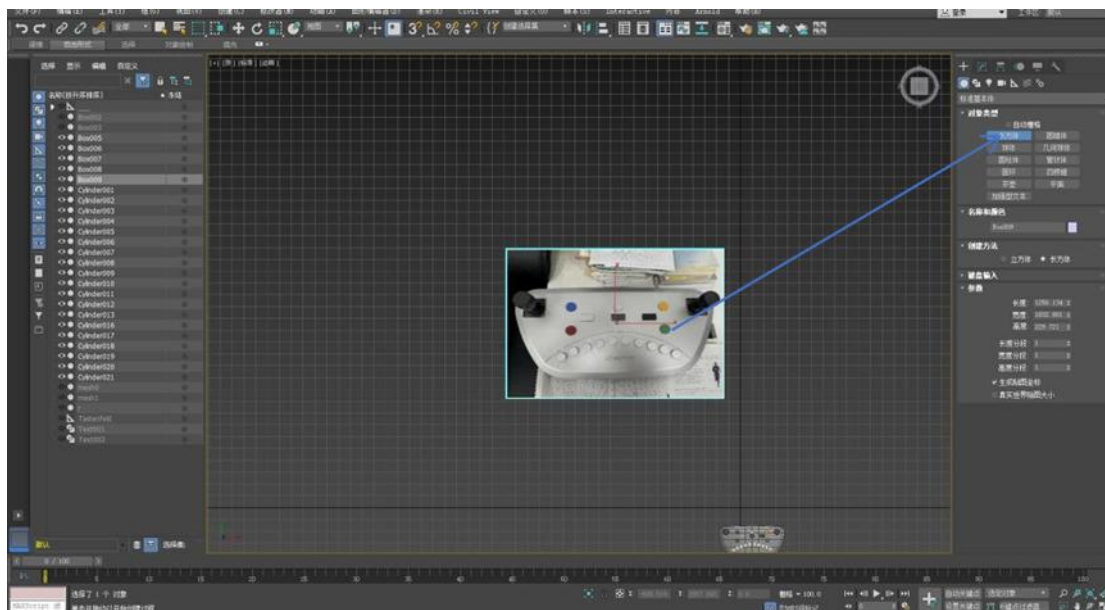
Finally, the layer of the object must be modified so that the corresponding event is triggered exclusively in the event of a collision with the specified object.



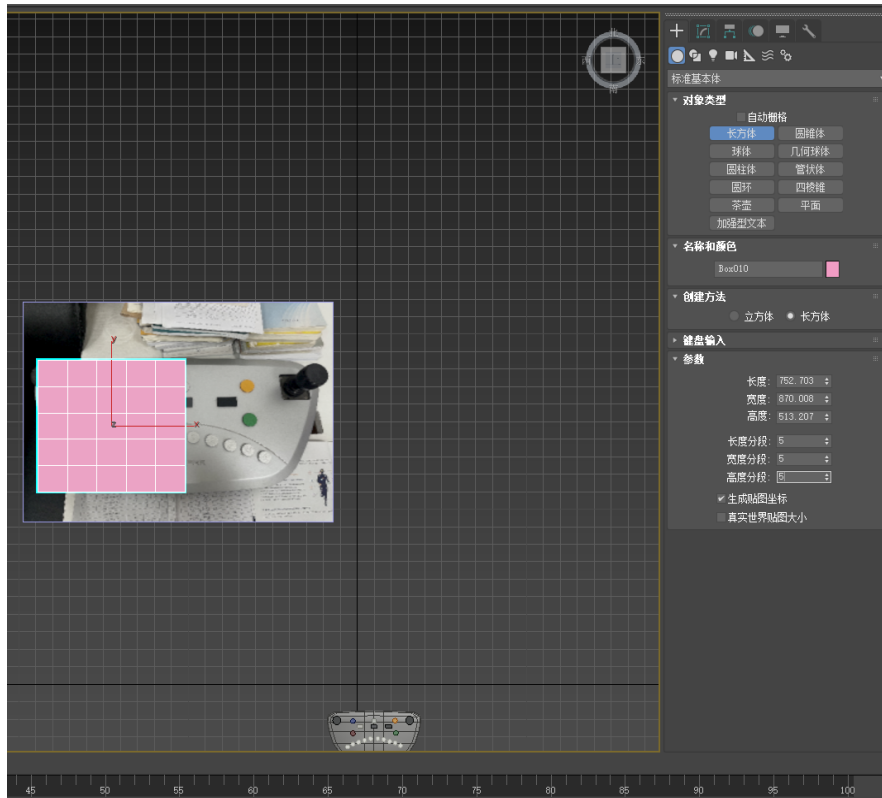
### A.5 Experimental operation station setup

The objective of this study was to facilitate the execution of the 131, 342, and 51 behavioral ability tests in a virtual environment that emulates the flexibility observed in real-world settings. To this end, 3D Unity software was employed to engineer a virtual emergency scenario, incorporating an experimental operating console that was replicated in a 1:1 scale. The configuration of the console's buttons and layout is consistent with those of the real-world console. The virtual reality (VR) devices were adjusted to a semi-transparent state, thereby enabling the participants to complete the behavioral ability tests in the virtual environment without the need to remove their VR headsets. This specific design process is outlined as follows:

The initial step in the procedure is to create a new rectangular solid. Following this, the model image should be pasted onto the solid to serve as a reference.



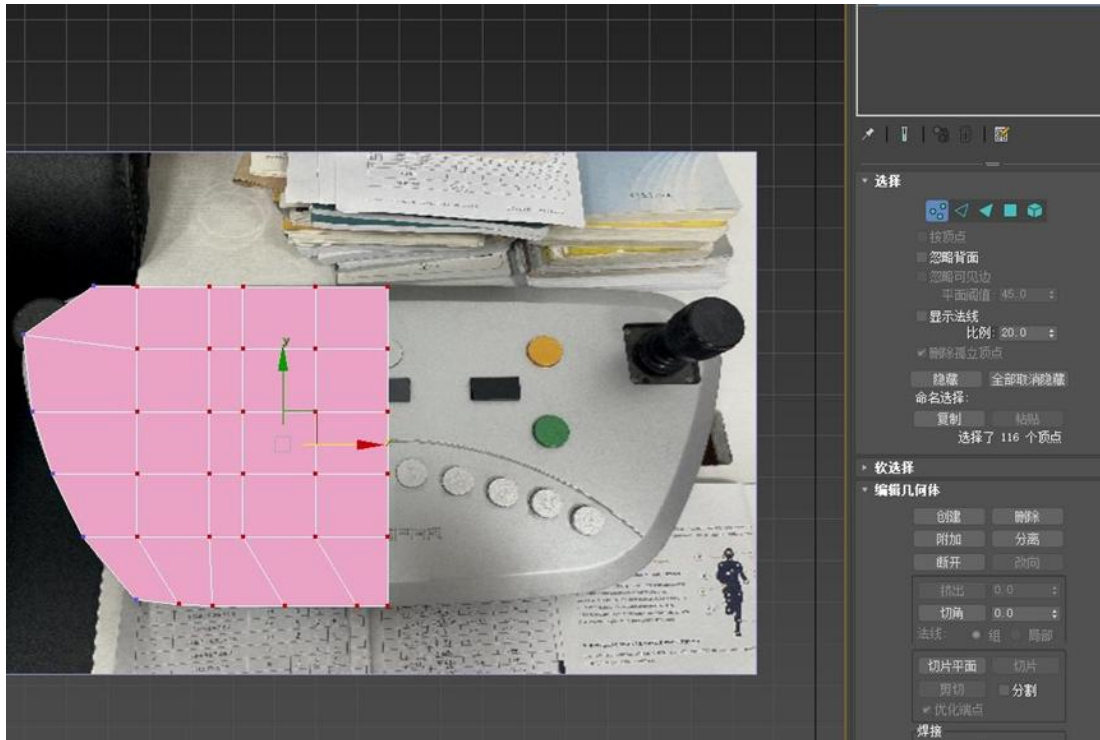
The second step in the process is to create an additional rectangular solid, which will serve as the primary structure of the model. This solid should then be divided into segments.



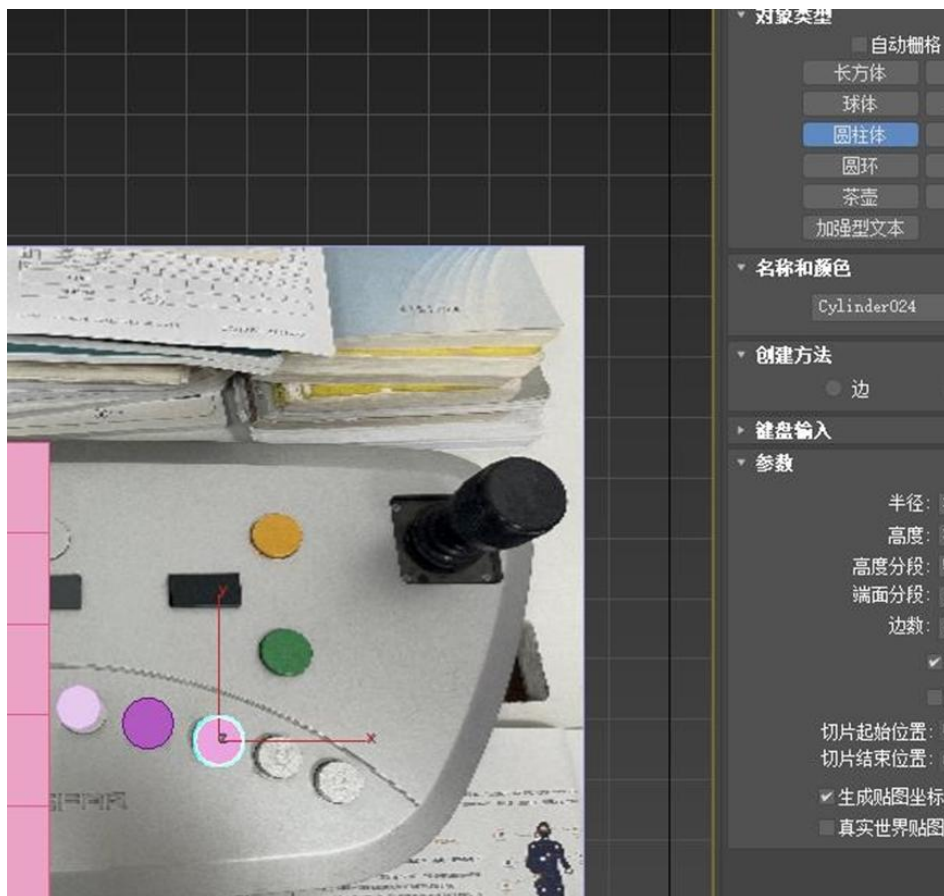
The third step in the process is to convert it to an editable grid.



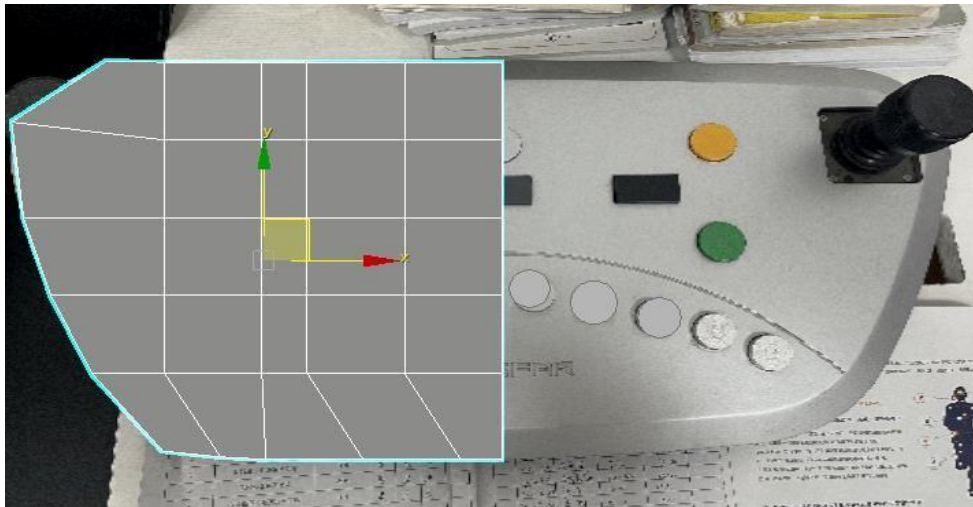
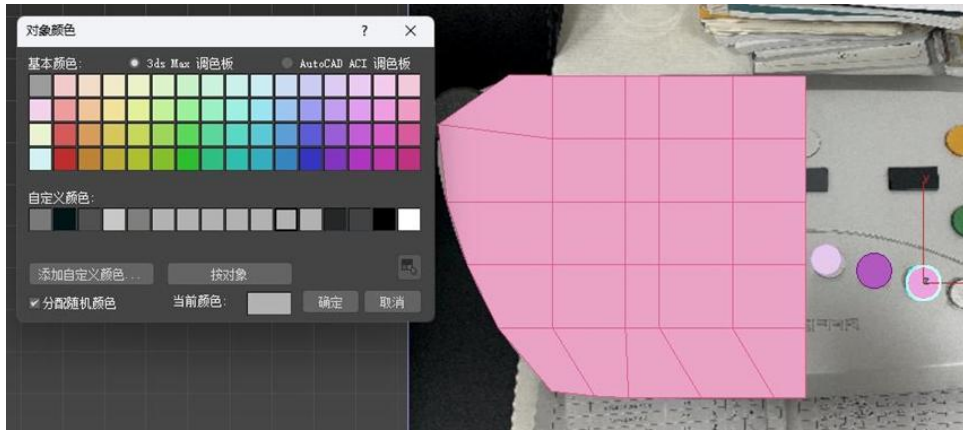
The fourth step in the process is to convert the rectangular prism into the required shape by manipulating the vertices.



The fifth step in the process entails the creation of cylindrical objects, utilizing the remaining components.



The fifth step of the process is to modify the color.



The sixth step in the process is to repeat the steps and refine the model until the final product is obtained.



## **Appendix B. Standardized behavioral competence test**

The present study developed a virtual reality-based miner behavior safety assessment system that uses a standardized test console (see figure above) to objectively evaluate emergency response capabilities in a multi-dimensional manner. The system was custom-developed using the Unity 2022.2.0 engine, integrating high-precision data collection modules and real-time visual feedback technology to comprehensively assess miners' cognitive behavior in simulated work environment. After entering the control console within the virtual scene, participants automatically trigger the system to activate the front-facing camera, which is then cropped to allow direct observation of the actual control console environment within the virtual scene. This enables the completion of the following behavioral capability tests in an immersive manner. The behavioral ability test is divided into three types, and they are respectively named according to the operation manual provided by the control console: 131 - Reaction competence test, 342 - Memory competence test, and 51 - Discrimination competence Test.

### **B.1 131 - Reaction competence test**

The purpose of this test module is to quantify the subject's basic reaction speed and hand-eye coordination. The control panel is equipped with 12 response buttons that utilize Cherry MX mechanical switches (with an activation force of 45g and a key travel of 3mm). These switches are controlled by an Arduino Mega 2560 controller, enabling millisecond-level response detection. During the test, LED indicator lights illuminate at random intervals and positions (500–1500 milliseconds apart), and the subject is required to accurately press the target button within 200 milliseconds. The system records the following parameters in real time: (1) initial reaction time (time from stimulus presentation to first button press); (2) average reaction time (mean of all correct responses); and (3) error rate (number of incorrect button presses/total number of stimuli). The test is administered for a duration of 60 seconds, at the conclusion of which an analysis report is automatically generated. This report contains reaction times and error rates. Following rigorous reliability and validity testing, the test demonstrated a test-retest reliability coefficient of 0.89 ( $p < 0.001$ ).

### **B.2 342 - Memory competence test**

The purpose of this module is to examine the short-term memory capacity and information processing efficiency of the test subjects. The test device consists of five sets of stimulus units employing RGB full-color LEDs (wavelength error  $\pm 2$  nm). Each test presents a spatial sequence consisting of three to five lights (e.g. 'left-right-center-left'). This stimulus presentation phase lasts 3000 milliseconds, followed by a 1000-hertz suggestion (duration 200 milliseconds, sound pressure level 65 decibels). Participants are required to reproduce the sequence with precision within a time frame of 15 seconds. The system utilizes an adaptive difficulty design, whereby the initial five trials employ a fixed mode with a sequence length of three, while the subsequent five trials employ a dynamic adjustment algorithm that adjusts the sequence length based on performance metrics. The evaluation metrics encompass the following: (1) Pattern memory accuracy rate; (2) Sequence reproduction time; (3) Maximum memory span. The study demonstrated a strong correlation ( $r = 0.78$ ,  $p < 0.01$ ) between the test results and the standard digit span test, indicating excellent criterion validity.

### **B.3 51 - Discrimination competence test**

The module in question simulates the multi-channel coordination requirements of underground operations, integrating visual stimulus discrimination and limb movement control. The test platform encompasses the following components: The first component is a set of three-color LED signal lights (red/green/yellow, diameter 5 cm, brightness 300 cd/m<sup>2</sup>). The second component is two industrial-grade foot switches (travel 8 mm, pressure threshold 1.5 kg). The third component is left and right hands response buttons (microswitches, life span 500,000 times). The test protocol stipulates that the subject is required to execute specific responses in accordance with the type of stimulus presented: red light → left hand button (index finger operation); green light → right hand button (thumb operation); yellow light → foot switch on the same side. Each stimulus is presented 10 times (in random order, with an interval of  $1500 \pm 300$  milliseconds), and the system synchronously collects three types of data: (1) reaction time (the time from stimulus presentation to correct response); (2) error type (wrong press, missed press, left-right confusion); and (3) hand-foot coordination index (hand-foot response time difference). The findings of the field

verification exercise demonstrated the efficacy of the test in differentiating between the operational levels of skilled miners and novices ( $t=4.32$ ,  $p<0.001$ ).

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