Bachelor Thesis

The impact of visually realistic weather system on the effectiveness of virtual reality training

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Preface

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I hope you enjoy reading my thesis.

Admir Leka

Enschede, June 2019

Abstract

Strukton Rail wants to try new training methods for their employees by creating a virtual reality simulation where the workers can practice in a safe environment. Strukton employees have to do maintenance work in heights in the rail track. Besides the risks related to the actual job of working in heights, external factors like the weather changes play a big role in the increase of risks in the worksite. In the VR simulation that will be created to solve the client's problem, a weather system will be created to produce hazardous weather conditions, so the employees can practice in those conditions as well and learn about the conditions that they should stop working.

In this research literature review is conducted to better understand what makes the different weather components look real and how to achieve better visual realism for a weather system in VR. Afterwards different approaches are tried in Unity engine to create a multi-layered weather system for a VR simulation. The focus of the prototyping was to create a realistic transition from a clear sky to a thunderstorm. During the experimental design, besides the realistic looking weather system, two more scenes were created. One where the complexity of the weather system was reduced, and the illumination of the environment wasn't changing accordingly to the changes in the weather, and one where the weather system was rendered using cartoony shading and textures, rather than realistic looking ones.

The three scenes were tested out with the safety officer of Strukton Rail and 9 other participants. During the tests it was found out that an increase in visual realism of the weather system had a significant role on the feeling of presence of the participants. It was noticed that what had the biggest impact in the effectiveness of the weather system was the change of lighting and illumination of the environment depending on the weather changes, and the increase in complexity/detail of the weather components. The rendering technique didn't have a big impact as the cartoony rendered weather system was as clear as the realistic looking one, and according to the safety officer the thunderstorm felt hazardous in both scenarios.

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1 Introduction

Safety and training are important aspects in almost every working environment regardless the discipline. Traditional training methods, where workers have to read manuals, listen to lectures or watch certain videos have been used for many decades and have proven as dependable because these approaches are familiar for the employees and often affordable (Cornett, 2017). Everyone has watched a video or read a manual at a certain point in their life, therefore getting employees trained using these methods won't come as something new and not understandable to them.

Sometimes, however, these traditional training methods don't fully prepare the employees for real-life situations and risks and in some cases, they may be very costly and ineffective. An example would be on the field of healthcare. Surgeons must practice operations and procedures numerous times to boost their skills before going to a real patient. By just reading manuals and watching videos these surgeons cannot get fully prepared for the actual operation which may lead to a lack of confidence and mistakes during the operation (VRHealth, 2018). Another example where training in traditional ways is not very effective and, in this case, very costly, is in the aircraft pilot training. Flight stimulators are huge, weight tons and are very expensive (Ellis, 2018). And in case a new model of airplane gets launched, the old one has to be thrown away.

Strukton Rail, which is the organization who presented the problem to Saxion University of Applied Sciences, is having the same problem with ineffective traditional training methods in training their employees.

1.1 Client background and objectives

Strukton Rail is a company which provides cross-border solutions in the field of rail infrastructure, railway vehicles and mobility systems. They operate in an international basis and have long-term operations in the Netherlands, Sweden, Denmark, Belgium, Italy and Australia. They have been operating for almost a century and their goal is to make rail transport a more competitive, safe and reliable option.

Strukton employees have to do maintenance work in places where there is high voltage, or in a lot of cases working in heights, where a minor mistake can cost the life of the employees. Nowadays, most of the training is done through manuals and instructions, where employees get the information on what the risks are in their future working site, as well as what equipment they have to use to work in a safe way. But according to professionals who work in the safety department at Strukton Rail, it has been reported that a lot of incidents are happening due to the lack of training by the employees. To prevent this more training in field should be applied. There are cases where there is training in field done, but only a few times, if not at all, because it is not easily reachable. To train in field, Strukton has to take a particular place in the rail track, where there are no trains passing by for the whole training period, and they have to rent out all the appropriate equipment and machinery and bring them in that place.

Besides being costly and inefficient as there is no time for all the employees to take enough training in a day, training in this way still cannot fully prepare the employees for the different risks that there are in the real working site. That’s because, alongside the risks that the working site can present to workers health and safety, which can be tackled with the proper use of safety gear and working ethics, there are external factors as well which play a big role in the overall safety of the working environment. A major problem being the unpredictable changes in weather, which increase the chances of an accident or incident to occur (BFC group, n.d.). The most obvious weather conditions to pose danger are; strong winds, heavy rain, lightning, fog and temperature. For example, if it starts raining while working on an electrical component which has high voltage, the risks of electrocutions and explosions can increase. Another example would be in working in heights and heavy wind starts blowing, which can increase the chance of the worker being blown to the side or fall, or, increase the chance of materials and debris striking the worker. Fog as well can be particularly dangerous as it greatly reduces the visibility, making the task harder and increasing the chances for an accident to happen (BFC group, n.d.).

That's why it is very hard for employees to get a proper insight in the real work, and get fully prepared for the job, as these kinds of scenarios cannot get replicated using todays traditional training methods.

1.2 Graduation assignment

To solve the above-mentioned issue, Strukton Rail asked our group to explore new training methods, using virtual reality (VR). They presented two potential scenarios which could be implemented in the VR safety training. The 1st scenario is related with working in locations where high voltage is present. The employees have to perform certain maintenance tasks in a relay cabinet located next to the railway (Figure 2). The 2nd scenario is related with doing maintenance work in heights reaching to 8m in the railway catenary system (Figure 3).

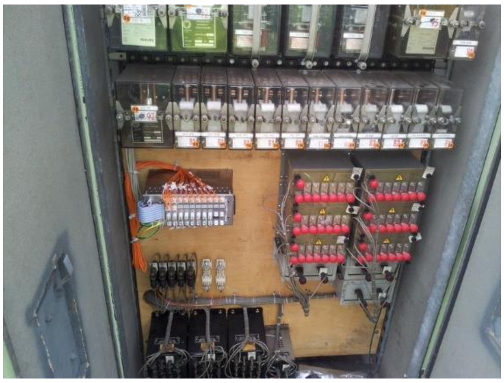

Figure 1 High voltage relay cabinet (Steentjes, n.d.)

Figure 2 Working in heights example (Working at heights ltd, n.d.)

After discussions with the group and the client, the 2nd scenario was chosen as the scenario that will be further developed. In this scenario the simulation will take place on the rail track. The worker will start the simulation on his construction shack, where he will be presented with all the safety equipment that he can use, and he will get a task that he has to perform. Depending on the task he has to gather the appropriate safety tools and proceed outside to the working site. A simple task that was decided to be implemented is the tightening of the bolts in the catenary system, which is a task commonly done by the employees in the real work. To perform such a task the worker has to use a mobile elevated work platform and move himself up to the bolts that need maintenance. While he is doing so, he will be evaluated based on how he uses safety equipment to keep working in a safe way while working at heights, and if he is not using any safety equipment he will be advised to do so.

As time progresses in the simulation, the weather conditions will change, getting from a clear sky to cloudy, and then to a stormy atmosphere. According to Strukton professionals, there are certain conditions when the worker should stop his job immediately. For example, when there is a lightening, or when the wind gets stronger than 6 on the Beaufort scale. And in the VR safety training, these weather conditions will be simulated and the reaction of the worker to the weather condition will be checked. In case he continues working even though the conditions are not suitable for working, he will be notified that he should stop and wait for the weather to get better.

By creating this kind of scenario, we believe that the employees will be more knowledgeable on the different procedures that they have to perform to work in a safe way, as well as on various harsh factors that can impact the safety of their work. The workers will at the same time be performing real life tasks, and working on a real-life looking environment, which will give them an insight on how the future job will be, therefore making them more prepared, thus solving our clients issue.

1.3 Problem definition

There are certain factors that have a big impact on the overall effectiveness of a VR simulation. Since a real world is simulated in a virtual space, making the users believe that they are somewhere else is very important. To address this, things like immersion and presence have to be considered (Ku, 2018). Immersion is the perception of being physically present in a nonphysical world (Rouse, 2016). Visual realism has been proven to have a significant impact in the feeling of immersion.

Several studies have been conducted in this topic. In a study conducted by Oak Ridge National Lab, realism has been proven to increase the trainee's performance in Virtual reality as opposed to a less realistic simulation (Eric D. Ragan, 2015). In another study about visual realism effect on height-related anxiety, published by Eindhoven University of Technology, visual realism had a big impact on the presence and immersion of the participants, where 67% of them chose the more realistic environment as the place they felt more height-related anxiety, meaning more immersed (Toczek, 2016). Therefore, creating a virtual reality simulation which is convincing and intuitive to our target audience and portrays real life well, will be an important aspect of the simulation.

According to the studies above, it is proven that having realistic equipment and surroundings helps with the effectiveness and immersion in virtual reality. But what about something that is more indirect to the actual simulation, and is not linked directly with the task that the player has to do? Such a thing in our project would be the weather system. The weather changes don't necessarily affect the players given task, but the way that the player reacts to the changes and if he decides to continue working on weather conditions which are not suitable for the task that he is doing. So, how important is having a realistic looking weather system in this virtual simulation? Will a realistic looking weather system make the trainees respond faster to the changes of weather and understand better if the current weather conditions are suitable for the given task? All these question lead to the formulation of the research question below.

2 Research question:

- Does an increase in visual realism of the weather system increase the overall effectiveness of training in a virtual reality simulation?

Sub question(s):

- How does weather function and how do weather conditions change from a state to another?
- What is the best way to create and optimize a weather system in Unity Engine for a smooth virtual reality experience?
- What is the impact to the player of a realistic weather system as opposed to an unrealistic weather system?

2.1 Research methodology

For the 1st sub question literature review and personal observation will be used as means of research. Websites, videos, time-lapses and other paper explaining how the weather functions and transitions from a state to another. Therefore, there will be a better understanding on the weather leading to a more realistic weather system in the virtual reality simulation.

For the 2nd sub question literature review and prototyping will be used as means of research. Websites, forums, videos and tutorials will be used to understand better how to create a multi-layered weather system in Unity Engine which also runs smooth in the virtual reality simulation.

For the 3rd sub question prototyping and questionnaires will be used as means of research. Three different scenarios will be created for the player to perform his training tasks.

The 1st scene will be the most realistic one. In this scene the weather system will be rendered with realistic textures. The lighting in the scene will change accordingly depending on the changes in weather and the complexity of the weather components will be higher. Meaning small things like water splashes forming when the rain hits the ground, atmospheric fog formed from heavy rain, clouds forming up, etc. will be rendered. The realistic weather will be based on the research of what makes weather components appear realistic.

The 2nd scene will be rendered with the same quality as the realistic scene, but in this case the visual complexity will be reduced. All the above-mentioned components like the lighting change and small details will not be rendered in this scene, resulting in a less realistic weather system.

The 3rd scene will be rendered using stylized cartoony textures. But the complexity of the scene will be the same as in the 1st scene (the realistic scene).

Several users will be asked to participate and try the simulation in the three different scenes and observations will be made to see how the users respond to the changes of weather depending on the increase in visual realism. Also, a short questionnaire at the end of each test will be handed in to the user to get their insight on the way the difference in visual realism affected their experience in the virtual world.

2.2 Scope

This project is part of the Minor Immersive Media semester in Saxion University of Applied Sciences. For this project I will be working along side with 4 other graduating students and 3 students from the Minor Immersive Media. The team is composed out of 5 programmers and 3 creatives. My part in this project is as an artist (VFX artist, 3D modeler). I will mostly focus on the creation of the visuals of the weather system, therefore modelling other aspects of the simulation will have a lower priority.

For this project, Unity Engine will be used as a platform to build the VR simulation.

Since the project is based on a short time frame, not every kind of weather type will be fully developed. For this thesis the focus will be in creating a smooth transition from a clear sky into a thunderstorm, with corresponding visuals and effects.

3 Theoretical framework

3.1 Virtual reality

Virtual reality is the use of computer technology to create simulated environment. Unlike traditional user interface where the user has to view a screen in front of him, VR places the user inside an experience (Bardi, 2019).

VR has gained a lot of popularity since it got introduced to the market, and it has found use in various fields like entertainment, real estate, tourism, shopping, etc. (Gregoriadis, 2016).

Besides entertainment purposes by the average consumer, companies and organizations have turned to virtual reality as well as a means of training for their employees due to the low costs, low risks and its proven increase in training effectiveness (Donovan, 2018).

3.2 Visual realism in VR

As mentioned in the “Problem definition” section, visual realism is proven to increase the presence in a VR simulation, thus leading to an increase of effectiveness of a training simulation. However, the increase in visual realism should not be associated with a decrease in performance, as dropping the frame rate of the simulation will result in a reduction of presence instead of increase even though the visual realism is higher (Wallach, 2012).

According to Slater visual realism has two components: geometric realism (the virtual objects look like its real-world counterpart) and illumination realism (the fidelity of the lighting model) (Slater, 2009). Geometric realism can be achieved by taking in consideration two sub categories: object density, making the object shapes as close and smooth as the real-life object; and texture quality, using realistic colors and increasing texel density/pixel ratio (Hvass, 2017). Texel density is the amount of texture resolution on a 3D object and the higher the texel density the more detail can be added to a certain object, resulting to an increase in realism (Iezzi, 2016).

Illumination realism has to do with the way that the scene is illuminated, and the way the lights in the scene bounce to imitate real-life lighting. Global illumination is considered to achieve realistic lighting for VR rendering (Slater, 2009). Global illumination (GI) is a system that models how light is bounced off of surfaces onto other surfaces, leading to a more sense of belonging together between objects as they affect each other (Unity, n.d.). According to Unity documentation, setting the ambient mode to “Skybox”, meaning that the environment will be reflecting light based on the skybox color, changing the direction and color of a directional light and modifying the skybox along with the directional light makes it possible to create a realistic time-of-day effect which will illuminate the scene accordingly (Unity, n.d.).

Another thing which is proved to improve visual realism and is vastly used by game developers to drastically improve the visuals of the product, are the Post-processing (PP) effects (Unity, n.d.). PP effects are effects applied to the camera rendered on a layer on top of everything else. PP can be used to simulate effects and artefacts of real-world cameras, thus giving the scene a more filmic feeling as if it was rendered using real physical cameras. Also, a good use of the PP effects is the color grading effect which can adjust the colors and the feel of the scenery without having to readjust many different lights in the scene.

3.3 Clouds and thunderstorm

Among the many different cloud types, only three are responsible for creating precipitation that falls to the ground: stratus, cumulus and nimbus (Echolls, 2017). These clouds are capable of producing rain, hail and snow and the type of precipitation is only dependable on the temperature, humidity and air pressure on earth, rather than on the cloud type. While all the three types of clouds mentioned above are responsible of precipitation, only the cumulus cloud is exclusively responsible for the creation of thunderstorm.

A thunderstorm is a storm characterized by the presence of lightning and thunder, and they occur in a type of cloud called cumulonimbus. They are usually accompanied by heavy winds, heavy rain and sometimes hail or snow. And in some cases, a thunderstorm may not produce precipitation at all. A thunderstorm forms within three stages. The cumulus stage, when the clouds form, the mature stage when the storm is fully formed and the dissipating stage when the storm weakens and breaks apart (NCAR, n.d.). On the cumulus stage moist air moves upward forming cumulus clouds in the atmosphere. Cumulus clouds are puffy and have white or light grey colour. They look like cotton balls and have sharp outlines on the top and a flat base. Cumulus clouds usually form at a height of 1000m and they have a vertical growth.

Figure 3 Cumulus clouds (Pattern Pictures, n.d.) (NCAR, n.d.)

After the cumulus stage, during the mature stage clouds continue to grow. The clouds look darker as more water is added to them. The clouds grow vertically and get heavier forming now what is called a cumulonimbus cloud. Cumulonimbus clouds are also known as thunderstorm clouds and they are the only type of clouds that can produce thunder and lightning. The base of the clouds is mostly flat and very dark, almost looking like a dark wall of clouds which lies only a few hundred meters above the surface. This stage is usually associated with rain showers and thunders.

Figure 4 Cumulonimbus clouds seen from below(left) and from distance(right) (WW Forecast Team, 2013) (Flyineddy, 2018)

After the mature stage, during the dissipating stage the storm weakens and dies out with light rain as the clouds disappear from bottom to top.

3.4 Rain

Rain may not have an impact on the gameplay, but it has a huge impact on the visuals and mood of the scenery therefore achieving a realistic rainy mood is crucial. Lighting has a lot of influence in the rain, especially at night. Rain is usually very difficult to see, but it becomes very visible when reflecting light (Seymour, 2013). For example, under a street lamp, or when a car is passing, rain can be noticed way more. Raindrop sizes vary from 1-4mm in diameter. As opposed to the everyday belief that raindrops have the shape of a tear drop, raindrops look similar to a hamburger bun and the shape of the raindrop is constantly changing as it is falling down. Small raindrops (under 1 mm across) have a spherical shape. As they fall down they merge with other small particles of rain and form bigger raindrops. As the raindrop gets bigger it falls faster due to the increase in size, leading into an increase in pressure making the bottom of the raindrop flatter, while the top remains curved due to the lower airflow on the top, therefore giving it a hamburger bun shape (Oblack, 2018). While the rain is falling and getting even bigger the pressure on the bottom increases even more making the rain get the shape of a jellybean until it reaches a diameter of bigger than 4 mm, when the air flow presses deep enough to split the raindrop into 2 smaller raindrops. Figure 8 demonstrating the shape of the raindrop with the increase in size. Due to the fall speed the change in raindrop shape is barely noticeable with the naked human eye.

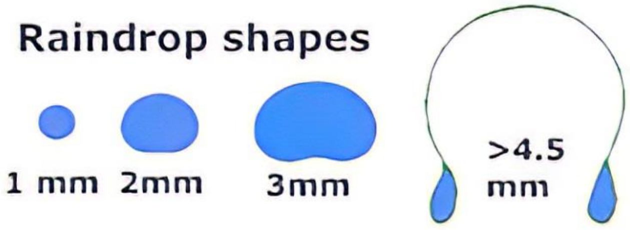

Figure 5 Raindrop shapes by size (USGS Science for a changing world, n.d.)

Although it is not generally discussed, rain also has an influence on the presence and formation of fog (Tardif, 2017). The heavier the rain gets; the more atmospheric fog gets formed leading into a misty look when there is a heavy rain. This is a small detail many AAA games use when creating their raining system, to add to realism. Another small detail which can make a big difference is the way the impact of the raindrop looks when it hits a surface, also called as rain splashes. Splashes can occur in two possible ways: corona splash, where a thin crow-shaped water sheet rises vertically above the surface before breaking into smaller droplets; and prompt splash where droplets are emitted directly from the base of the drop without the formation of a crown (Seymour, 2013). Usually a corona splash forms when the surface has a thin layer of water already, and it usually lasts for 10-20ms. The splash is usually associated with a ripple effect under it as well. Figure 9 demonstrates the corona splash effect, while in figure 10 the ripples formed by the impact of the rain on the surface can be seen.

Figure 6 Corona splash (left), Ripple effect(right) (Seymour, 2013) (Yashika, n.d.)

4 Implementation of the weather system

For creating the weather system multiple approaches were taken in consideration. The user can either choose a weather type in the main menu, before starting the simulation, and practice working in a particular weather type, or he can choose a random weather which will randomly change during the simulation and may produce unpredictable hazardous weather conditions which the player should be aware of and avoid working in such situations.

The weather conditions that will be able to choose in the menu are: clear sky, cloudy, raining, which can increase in intensity over time, snowing, which can increase in intensity over time, thunderstorm, and a separate option to add ground fog will be available as well.

For the random weather, a smooth transition will be made which will transition from one weather type to another, in a plausible way. Since all the above-mentioned weather conditions, besides clear sky, are linked with the formation of the cumulus clouds, creating a transition between a clear sky to a full cloudy sky will solve all the various transitions between weather types. And after having a smooth transition, different particles can be rendered depending on the type of precipitation.

The realistic scene will be created 1st with all the different weather components and details, and then the "less complicated" weather system scene and the "cartoony weather system" scene will be adjusted from the realistic scene.

4.1 Skybox

Before creating any weather-related assets like clouds or raindrops, having a good foundation of light and color in the sky depending on the time of day is very important in helping with the creation of the other assets. As well as adding to the illumination realism of the scene. There are different ways you can achieve a skybox in Unity.

The 1st approach that was tested was using a 6-sided cube map as a skybox. In this approach 6 images are used to create a cube map, an image for each side; front, back, left, right, top and down. The cube map then is mapped to the sky in a seamless way. The benefits of this approach are that you can use actual photos as an input leading to a photorealistic looking sky if done properly. Because to take such images you need to have 360 cameras, two different cube maps were downloaded from the Unity Asset Store instead, for testing purposes (Figure 7).

Figure 7 Cube map skyboxes in game mode

The results were looking realistic. Sun and the clouds were already part of the skybox meaning no extra work had to be put into creating that. While skyboxes representing a fully cloudy sky and a clear sky could be created for the various different weather conditions, achieving a smooth transition between them would be impossible using this technique, thus making it not suitable for the dynamic nature of our project. Things like changing the sky colors as time progresses or increasing the intensity of clouds depending on the precipitation level were not possible because the actual sky is composed of images. So that means that the sun and clouds would always be on the same position in the sky and have no movement.

After seeing the results, another approach for the skybox was using the Unity procedural skybox. This skybox is a built-in asset in Unity, and instead of images it functions based on colors. It is very similar to the default skybox, but you have more options on changing the sky tint and the ground color. Also, this skybox has an integrated feature of using a directional light in your scene to create a sun on the skybox, which is also adjustable. Figure 8 shows how the skybox dynamically changes if you rotate the directional light. This skybox is way simpler than the cube mapped skybox but at the same time it is more dynamic and adjustable. This skybox is a good example of creating a realistic time-of-day effect which illuminates the scene and changes the sky color accordingly to the position of the sun.

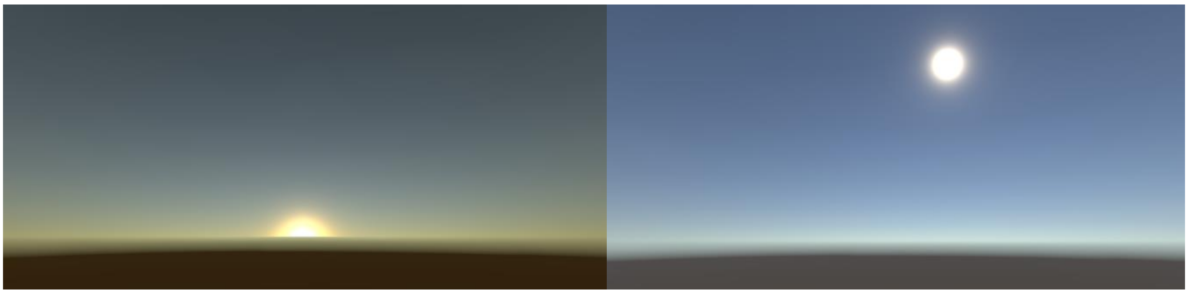

Figure 8 Unity procedural skybox

After working around with the exposed variables, I noticed that the procedural skybox didn't give much freedom to the sky color choice. While it still has a sky tint option, the way that it functioned wasn't very customizable. The sky color was blue by default and the tint color would just overlay a chosen color on top of the blue from the sky, which is not optimal for the sky in our project. Since the sky would have to transition from a clear sky to a cloudy sky when increasing the precipitation value, the color of the sky would have to change from a saturated blue in a clear sky to a grey color when the clouds would form. And while you could possibly fill the whole sky with clouds to block the color of the sky from reaching the players eye, the environment would still be illuminated by the blue color of the skybox, as ambient mode is set to Skybox in Unity, giving a non-realistic result. And in the procedural skybox, changing the color of the sky to grey was impossible due to the fact that you cannot overlay a color to blue and desaturate it.

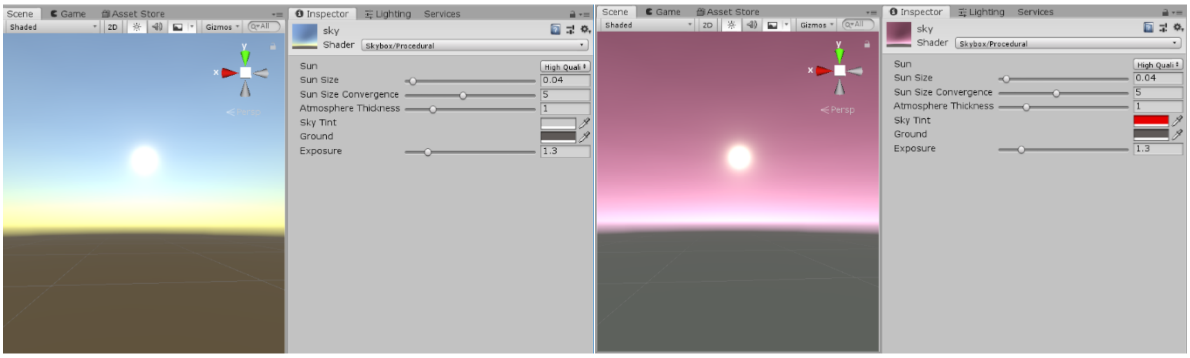

Figure 9 Changing Procedural skybox's sky tint

Figure 9 demonstrates how changing the sky tint into a desired colour, in this case a saturated red as an example, doesn't make the sky red, but overlays a red colour on top of the default blue, giving unwanted results.

The 3rd approach that was tested for creating a base sky was something very similar to the procedural skybox mentioned above. It was also a scriptable skybox, which works with colours instead of pictures. But in this case the skybox was way more suitable to the purpose of our project, because in this case the colour that you input to the sky changes the actual sky colour and doesn't overlay it on a blue default. This was the skybox featured in the Unity 3D Game Kit package, which gives a lot of freedom on the colour of the sky. And at the same time, the feature of using a directional light as the sun source still remains. Figure 10 demonstrates how you can adjust the skybox parameters to match different sky colours depending on the time of day.

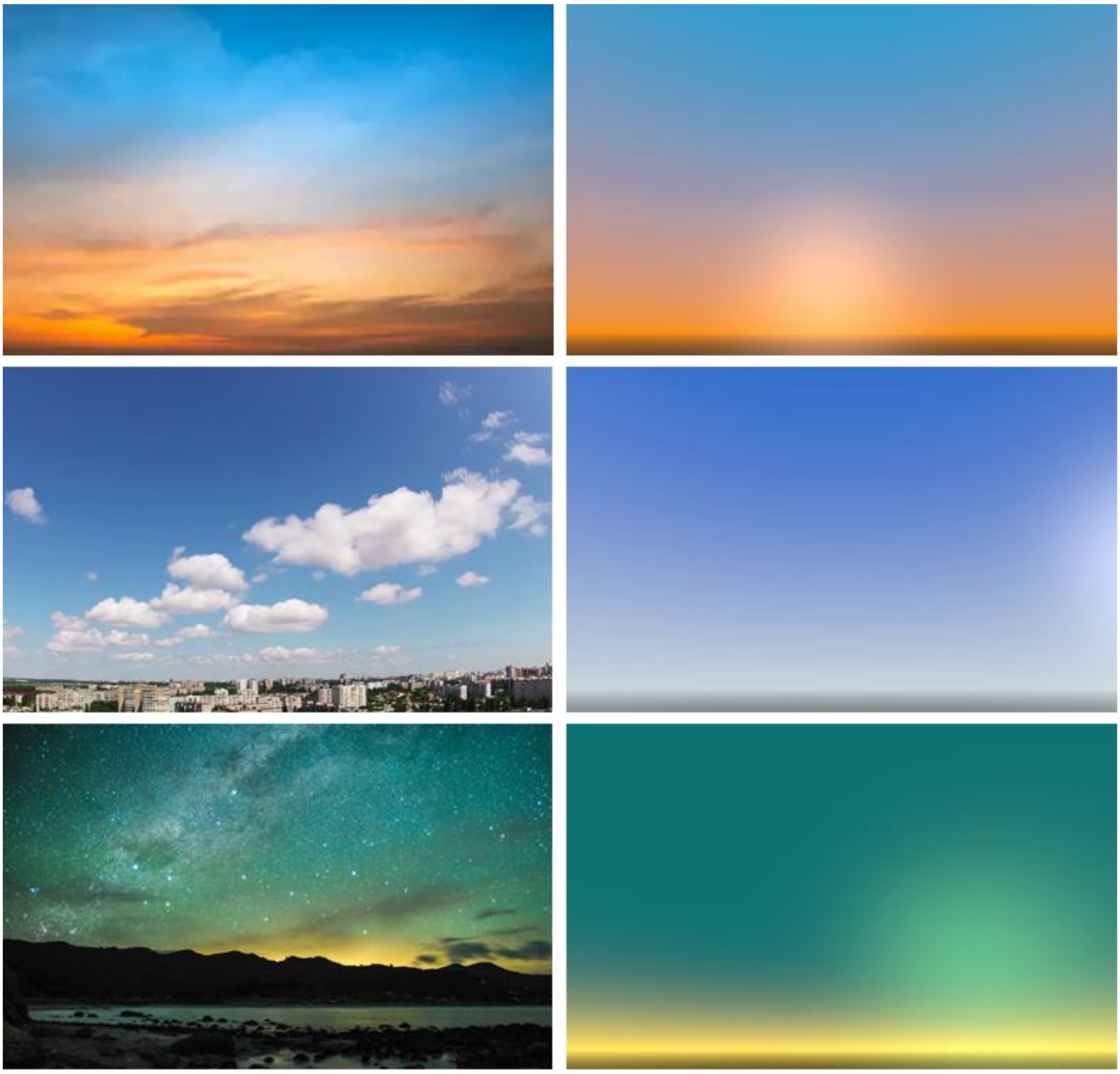

Figure 10 On the left real photos, on the right skyboxes in Unity

As seen in the pictures above, the skybox can take any colour and can match up to different scenarios, therefore it was decided that this approach will be used as a foundation for the skybox, and later on details like clouds, stars, the moon or any other detail would be added separately, as opposed to the cube map skybox where everything is already part of the image.

4.2 Clouds

Achieving realistic clouds in a game engine is a topic which is not really discussed in the gaming and VR industry. That's why for the creation of clouds many different approaches will be used to fundamentally end up with realistic looking clouds which are also not heavy on the memory. The clouds that will be created are cumulus clouds, as they are the only clouds which despite the ability to produce precipitation they also are responsible for the formation of thunderstorms. This way all the various weather types can be generated using the same clouds shapes.

The 1st approach that was tried was creating 3D models of the clouds (Figure 11), using a software like Houdini which can procedurally generate cloud volumes. The volume later on could be triangulated so it can be used in a game engine, and the number of triangles could be reduced by a sufficient amount, so it doesn't cause problems to the performance of the simulation. The cloud shapes rendered by Houdini are puffy on the top and flat on the bottom, similar to what cumulus clouds look. The benefit of using 3D clouds lays to the way that it interacts with the lights in the scene. Because it is a 3D object, it can interact with the main directional light (sun), resulting in getting lit on the top from the sun light and darker on the bottom as the light cannot penetrate there (Figure 11). Also, it gets part of the global illumination calculations, therefore getting a tint from the skybox, making them appear as they fade on the distance.

Figure 11 3D modelled clouds generated in Houdini

Even though the way that they interact with the light and the shapes are realistic, the way that it is rendered is not suitable for a realistic simulation. And at the same time, these clouds are static, meaning you cannot animate them so they gradually form up.

The 2nd approach that was tested was creating a particle system which would control the behaviour of the clouds. Real life photos of cumulus clouds with a transparent background were used to create a 4x4 sprite sheet which will later on feed on to the particle system as a texture. The particles were rendered on a cylindrical shape (Figure 15) placed above the play area and exceeding far in the distance. Because these clouds were actual photographs of real-life clouds, they had realistic shapes and seemed realistic inside the game engine. Also, using a particle system made it possible to control the movement, size and density of the clouds making it a good option for the dynamic nature that the weather system should have in the simulation.

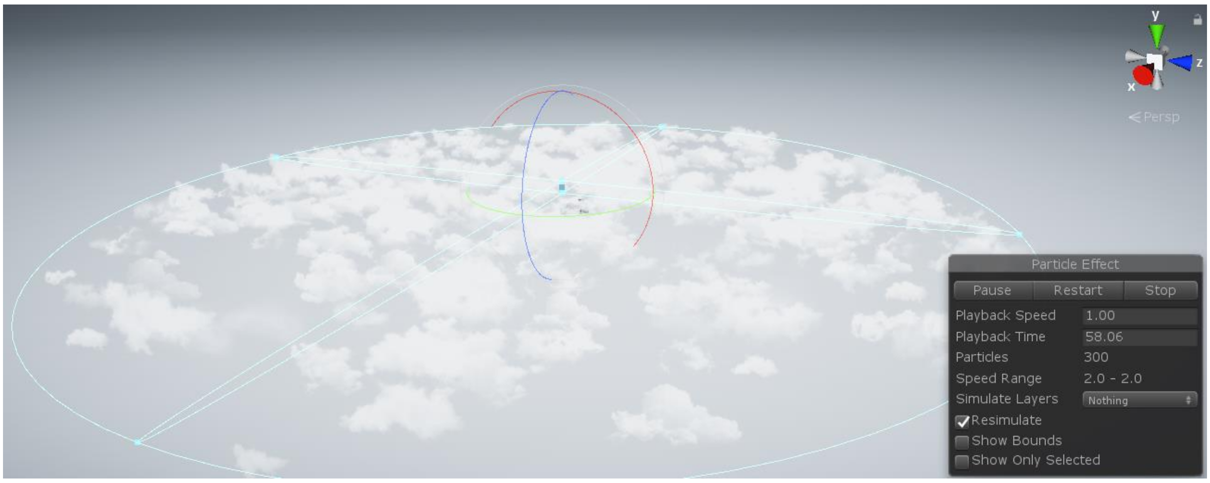

Figure 12 Clouds particle effect aerial view

On the other hand, the lighting of the clouds was not realistic because the clouds are just 2D sprites facing the camera, and not volumes that interact with the lighting on the scene. Another issue with this approach was the fact that the positioning of the clouds was random, meaning sometimes various sprites would render on top of each other giving unnatural shapes as seen in figure 13.

Figure 13 Cloud approach 2 seen from ground level

The 3rd approach for making clouds was using a particle system again. But in this case instead of using real photos of clouds to render the clouds in sprites, a sprite sheet of rendered cloud volumes in After effects (Figure 14) was used to create the shape of the clouds.

These sprites were blended together using the particle system to generate cloud shapes as seen in figure 14. Using this approach, it was possible to achieve realistic cloud shapes, which are dynamic at the same time, meaning the clouds can move and increase in intensity by tweaking the attributes of the particle system. Later, the tweaking can be targeted by a script and a variable can control the density of the clouds, without having to adjust the particle system attributes.

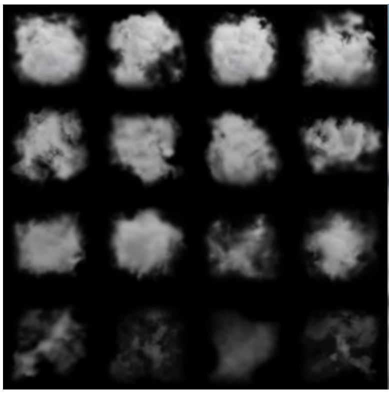

Figure 14 Cloud volumes sprite sheet

Figure 15 Aerial view of cloud approach 3

4.3 Rain

As opposed to clouds, rain in games has been researched thoroughly and many games and VR simulations have realistic rain effects on them. To create a rain effect in Unity engine, many particle systems were used. The main particle system of rain is rendered using a 2D texture of a stretched raindrop. Since raindrops are very small and travel at a fast speed for the human eye to see the shape of a raindrop, a stretched texture was created to fake the movement of the raindrop. The texture was created by taking the shape of a raindrop and applying motion blur to it (Figure 16). Note that the effect is very subtle, because rain is hard to notice in real life as well.

Figure 16 Rain drop texture, to the right the texture applied in the particle system

The rain particle system seen in figure 16 is the main particle system, and the raindrops from this particle system will interact with surfaces, meaning creating splashes when they touch a surface. But as it can be noticed, there are very few raindrops, and increasing the number of raindrops that interact with surfaces will cause the memory to decrease as many calculations have to be made by the engine. To avoid that, two other particle systems were created, using this time a texture of many drops in one image, instead of a single raindrop (Figure 17). These particles were created just to add more volume to the rain and they are not using physics and interacting with surfaces. To add even more depth to the rain, as raindrops fall in different speeds and sizes, two textures were created for each particle system, where the motion blur amount is different, making the particles in game appear as if they are falling in different speeds. Once again, the effect is very subtle, and it is hard to notice it in an image, but it is

Figure 17 Rain textures, to the right the texture applied in the particle system

noticeable that there is more depth to the rain as opposed to figure 16.

After having the main rain volume done, to add more realism to the rain, the visuals for the splashes and other effects had to be added to the rain effect. For the splashes two instances of the splash particle effect were created. One of the particle effects is emitted from the main rain particle effect, which will be spawned when the rain hits a surface. This one is more important when the rain interacts with an object or an uneven surface. And the 2^{nd} splash particle effect is emitted straight from the ground. It is very hard to notice if a splash is being rendered when a raindrop hits the ground, therefore, to add more volume to the splashes and save memory the splashes are randomly emitted from the ground, without physics being applied. The same technique was used for creating the ripples as well, with two instances of the particle system.

Figure 18 Rain ripples and splashes spawning from the ground mesh

The last thing that was applied to the rain effect was the mist effect. Another particle system was created to create the mist effect. Similar to the clouds, a smoke sprite sheet was created in After effects to be used as a texture for the mist effect (Figure 19). In this case instead of having random shapes, the sprite sheet is animatable and loop-able, meaning the smoke has a smooth transition from the 1st to the last frame. This particle system was also combined with the Unity fog to generate both distance fog and mist around the player.

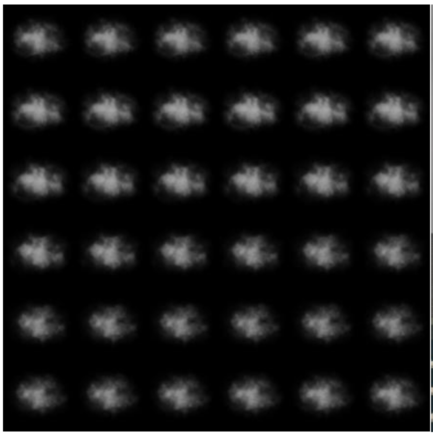

Figure 19 Smoke sprite sheet

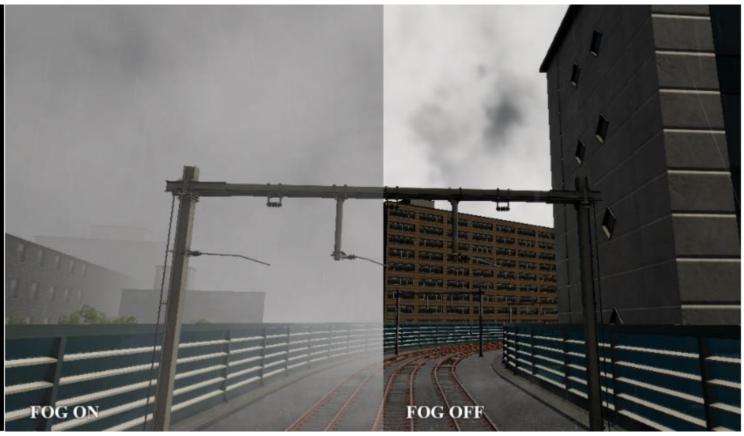

Figure 20 Fog effect On and Off

After creating the misty effect for the rain, everything was gathered together to create a stormy feel for the main scene. Only one last thing was left to implement, which was the lightning. For this a particle system combined with a directional light were created to create the lightning effect. The particle system was just a glowing light on the sky which turns on for a fraction of a second. And at the same time a directional light pointing 90 degrees down lights the whole scene, but with a small delay from the light from the sky. This way the whole scene gets lit for a fraction of a second similar to what would happen when a lightning in real life strikes.

4.4 Creating the thunderstorm

After creating each specific weather component on its own, a C# script was created to determine the behavior of these components as the weather transitions from a clear sky to a thunderstorm.

The created clouds were split into 3 groups, where each group had a few clouds and if all three groups were to be set to active then the whole sky would be covered. At the beginning of the simulation, during the clear sky, only one of these groups was set to active and the skybox color was set to a bluish tint. And the directional light had a slightly yellow tint, imitating the color from the sun.

The 1st stage that the thunderstorm goes through to form is the Cumulus stage, where the Cumulus clouds form in the sky. As time progressed slowly the 2nd group of clouds was set to active, making the 2nd group of clouds fade in and blend with the rest of the clouds and increasing the coverage of clouds in the sky. While this process was going on the skybox color was also changed to a light grey color, which changed the ambient color as the environment was reflecting the skybox. This made the environment get greyer, imitating the change in illumination in the real world when the sky gets covered. Besides the color change, using PP effects the exposure of the scene was reduced slightly, as well as the strength of the main directional light (sun), resulting in the scene getting a bit darker. As the clouds were just particles, they were not causing shadows on the ground as they were forming. To fake that the shadow strength of the main directional light was reducing slowly as more clouds were forming, making the hard shadows that the sun would normally create disappear as the clouds cover the sky. This whole process resulted to a covered sky which is light grey at this point, and this was the end of the Cumulus stage. During this phase also, light rain was set to active, giving the impression that maybe a storm is going to form.

Afterwards the thunderstorm goes through the Mature stage, where more water is added to the clouds, and they get heavier and darker. To imitate this effect the 3rd group of clouds was set to active as well, resulting in a fully cloud dense sky. The skybox color was changed once again, to a darker grey color, creating the illusion that the clouds are actually getting darker. The change in skybox color resulted in the change of the environment color as well, making the environment get darker. This effect was combined with lowering the exposure of the scene and the strength of the main directional light even more, resulting in a darker scene, which creates the illusion that the clouds got thicker and are blocking more sunlight. PP effects were used also to change the overall tint of the scene, making it slightly darker blue, giving it a cold feeling. At this stage, rain transitioned to a heavy rain shower, which is associated usually with thunderstorms. And while the rain formed, also the fog in the scene got set to active giving the scene a misty stormy look. At this point, a fully mature thunderstorm was achieved. To make the overall effect more realistic, the wind strength was increased after a while to create the effect of a worsening storm, and it was at this point when the lighting particle was set to active as well, creating lightning in a random time interval.

For the dissipating stage, all the above-mentioned changes were reverted resulting into a fading out of the storm. But this stage is not visible during the simulation as the simulation should be stopped during a thunderstorm and the player will have an option to "wait for a better weather", which will fast forward him to a better weather type.

5 Experimental design

5.1 Conditions

Three different scenes with different visual realism of the weather were created to test the impact of the visual realism of the weather system in the effectiveness of VR training (Figure 21). In all the scenes the environment and weather condition changes were the same.

The 1st scene was the realistic scene, where the weather is rendered using realistic textures, shapes and the world is illuminated in a realistic way depending on the changes of the weather (the weather created in the "Implementation of the weather system" section).

The weather in the 2nd scene was rendered using realistic shapes and textures, but in this scene the world illumination wasn't changing, and additional components of the weather which make the weather seem more complicated were removed. Things like the splashes on the ground and the ambient fog were not rendered in this scene.

The weather in the 3rd scene was rendered using cartoony shapes and textures. The raindrop size was exaggerated and was made bigger than the size of a real-life raindrop. Same principle was applied to the different rain components, like the splashes and ripples. The clouds were rendered using flat shading and sharp edges. Also, since this scene was cartoony the water color was changed to blue and the water was not reflective, making it look flatter. In this scene however, the illumination of the world and the complexity of the weather components was kept the same as in the realistic scene.

Figure 21 Storm progression in the 3 different scenes

10 participants were recruited for the experiment and a within-group design was used to test all three scenes, meaning that each participant experienced all three scenes with a randomized order of presentation. From these participants, one was the safety officer from Strukton Rail, one was the client who requested the project and the rest were students with prior knowledge in VR. The participants were informed about the procedures of the experiment and were explained that they have to enter the VR simulation 3 times, fill in a questionnaire after each exposure, and fill in a comparison questionnaire after experiencing all 3 scenarios. With the safety officer and the client, a short interview was made as well.

5.2 Procedures

In the virtual reality simulation, the participants were asked to look around and get comfortable with the environment and were told that they could move around freely in an area of 2 meters square, as well as explained that they could also teleport using the Vive controllers to move around. Afterward the participants were asked to perform a certain task in the simulation, such as tightening of bolts in the catenary system. While the participants were busy with working on the given task and operating the machinery that they needed to finish the work, gradually the weather was changing, getting cloudier, and transitioning from a clear sky to a light rain which later transformed into a storm. This transition happened in a time frame of approximately 2 minutes. After each exposure the participants were asked to remove the VR headset, fill in the questionnaire related to the current session, and were asked to take a short break if they wanted before getting in the new session.

5.3 Results

After collecting the information from the questionnaires, the interviews with the client and the safety officer, and general observation the results listed below were found. All the results of the questionnaire are from a scale from 1 to 7 and for each question a higher score means a higher reported feeling of presence in the simulation. The average of the results from all the participants was used to compare how each scene scored for each question.

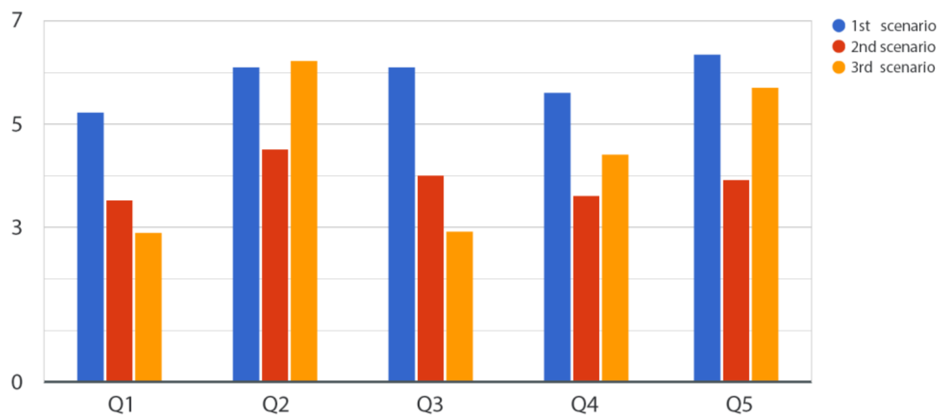

Figure 22 Comparison results chart for each individual question

There was a significant difference in perception of the overall simulation by changing the weather system visual realism. The 1st scene was the scene that was perceived as the most real looking scene, with an average of 5.2 out of 7 (Q1), as opposed to 3.5 on the 2nd scene and 2.9 on the 3rd scene. However, in all the three scenes the changes on the weather were noticeable and majority of the participants understood that the weather was getting worse (Q2). The only difference was on the 2nd scene which scored 4.5 as opposed to the 1st and 3rd scene which both scored approximately 6. The same differences were seen on the other questions (Q4, Q5) where the 1st and the 3rd scene scored similar results, and the 2nd scene scored slightly lower.

Out of 10 participants 90% reported that the scene where they felt more immersed with the world was the 1st scene. As well as 90% said that they would prefer the weather visuals of the 1st scene in a serious VR training platform.

6 Analysis and discussion

The results suggest that the scene which contains the higher visual realism of the weather system yielded significantly higher scores in relation with the other two scenes. The participants reported after the exposure to the 1st scene that they felt like the weather system and the changes in weather were real and they perceived the simulation world as if it was a real place. In all the three scenes, the participants understood that the weather was getting worse over time. However, on the 2nd scene some of the participants didn't understand that there was a thunderstorm going on. After the exposure to the 2nd scene they reported a mismatch between the lighting in the surrounding environment and the fully covered sky, which resulted in confusion and a reduced feeling of "being there". On the 3rd scene, which was the scene with the weather system rendered in a cartoony style, after the exposure participants reported that they remember that scene more as images that they saw rather than as a real place, and they could immediately identify that the weather components were not real. On the other hand, even though they reported that the weather components on their own seemed cartoony, the experience of the thunderstorm was very clear, and they knew that the weather conditions were not suitable to continue with the work. According to the safety officer and the client the thunderstorm on the 3rd scene, felt the most hazardous, even though the water was blue, and the size of the raindrops was bigger than normal. This was due to the fact that the contrast between the rain and the rest of the environment was bigger resulting in a clearer visibility on the rain, as opposed to the realistic rain on the 1st scene which was slightly less visible. In addition, the safety officer was asked to stop his work in case he thinks that the current weather conditions are not suitable for continuing. And it was observed that on the 1st and 3rd scene, after being exposed to the thunderstorm for a few seconds, he stopped what he was doing on the catenary system and used the mobile elevating work platform to go down on the ground and stop the task. On the 2nd scene, it took him more time to understand that the weather was not suitable, and that was because of the lightening that happened later during the storm.

Based on the results and observations, it can be said that an increase in the visual realism of the weather system has an impact of the increase of presence in a VR simulation and majority of the participants would prefer a visually realistic weather system for a VR training simulation. As well as, if the weather is complex and close to the real-life weather, it can be easier for the workers to understand the changes in weather and better know if the current weather is or is not suitable to continue working which may lead to an increase of effectiveness of a VR safety training simulation where the understanding in changes in weather are important. What seems to have a bigger impact on the effectiveness of the weather system visuals is the change in the illumination of the scene, rather than the way the weather system is rendered. This was noticed, because the weather system in the 3rd scene even though it was rendered all in cartoony style, scored higher in most of the questions and was clearer than the 2nd scene which had realistic textures. So, maybe even a cartoony safety training simulation would work and portray that certain weather conditions are hazardous, as long as the lighting and illumination of the scene change accordingly to the weather events.

7 Conclusions

This research was conducted to help our client, Strukton Rail, with the development of a new safety training VR simulation, as the workers of Strukton Rail could not get fully prepared for the real-life situations with traditional training methods. These employees have to do maintenance work at heights reaching up to 8m in the catenary system of a rail track. Besides the risks involved with working in heights, external factors like the changes in weather have a big impact on the overall safety. In the VR simulation a weather system had to be implemented, where the worker can experience working in different weather conditions and create awareness about the risks involved with different weather types as well as understand when the weather conditions are too hazardous that they must stop work immediately.

In this research, the impact of the visual realism of the weather system were further discussed. A literature review was conducted to better understand what makes the different weather components appear real, and how to achieve that realism in a VR simulation. Further on, the knowledge gathered was applied to create a weather system in Unity, which behaves and looks like the weather in the real-life. During the experimental design phase, two additional scenes were created, besides the realistic weather scene. The 2nd scene that got created was rendered with realistic textures but had a reduced complexity on the weather components. Things like the splashes hitting the ground, the atmospheric fog and other details were not rendered in this scene. Also, the illumination of the scene wasn't changing as the weather was progressing, which resulted in a less realistic weather system. On the 3rd scene that got created, the weather system was rendered using cartoony shading and textures but keeping the complexity of the weather components the same as in the main realistic scene. These three scenes were created and tested out with 10 participants to get an understanding on the importance of the visual realism of the weather system in the effectiveness of a VR training platform. Of these 10 participants, one of them was the safety officer of Strukton Rail.

The test results showed that the increase in visual realism had a significant impact on the increase of presence in a VR simulation. It was reported that the scene where the participants felt more immersed and the weather system was understandable and easy to read, was the 1st scene which had the realistic weather system. Furthermore, it was noted that what had the biggest impact was the realistic change in illumination of the scene and the increase in complexity rather than the rendering technique used. This was noted because the 3rd scene which was rendered with cartoony textures was perceived as more immersive than the 2nd scene with realistic textures but reduced complexity. But nonetheless, the realistic scene was the scene which was more preferred by the participants.

Further on, the final product of the weather system needs more improvement and polishing. Right now, there is a smooth transition between a clear sky to a fully cloudy sky, which can be used as a transition to any weather condition like rain, snow, hail and thunderstorm. But on the other hand, only the rain system is implemented, and there is no weather controller which can determine how the weather will change. Even though the simulation was perceived as realistic from the participants, in my opinion more research has to be conducted regarding to the clouds rendering technique in order to create more realistic looking clouds. Also, it could be a good decision to make a longer test to determine if the weather visuals have an impact on the overall effectiveness of the VR training platform, where the weather takes a longer time to transition from a state to another, and the outcome of the weather is more random.

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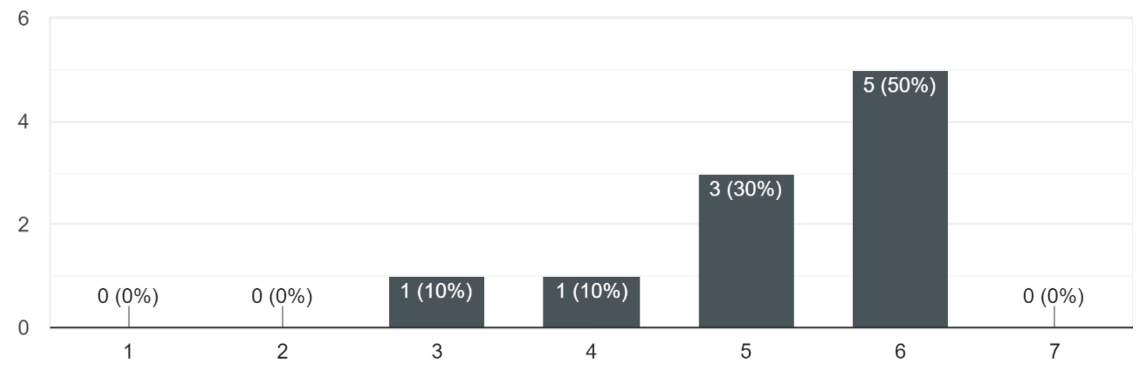
9 Appendices

Appendix A | Questionnaire results | Scene 1

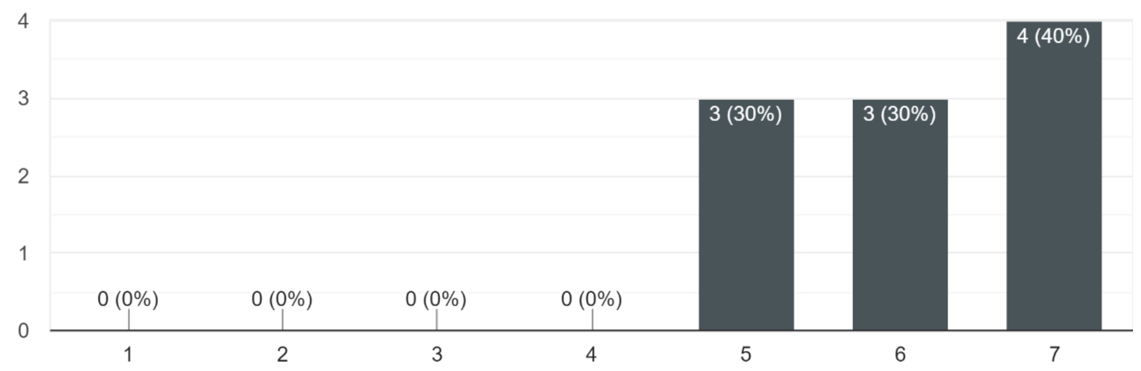
Q1. When I think about it now, I remember the working site more like a real place that I visited, rather than a computer generated world.

10 responses



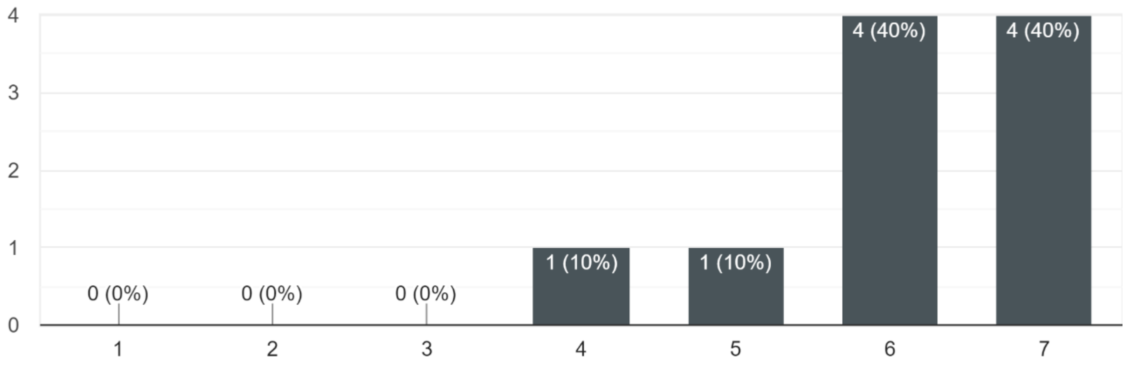
Q2. While I was doing my task I noticed that the weather was getting worse.

10 responses



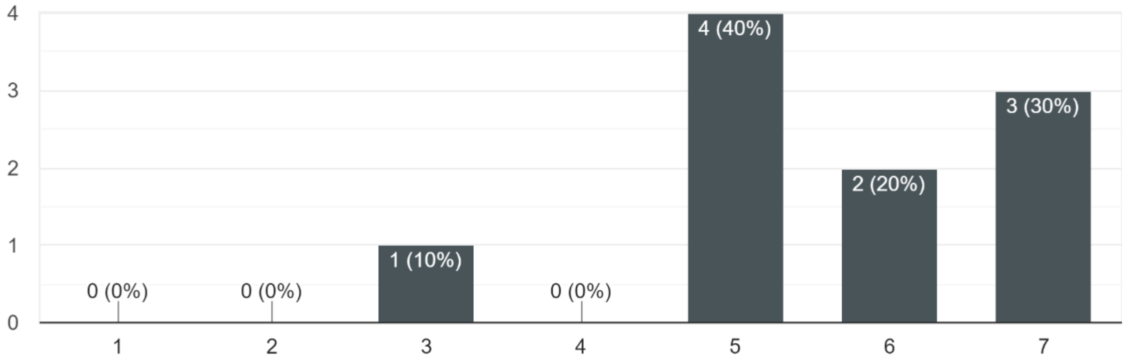
Q3. I perceived the weather components (rain, fog, lightning, wind, clouds, etc.) as if they were real.

10 responses



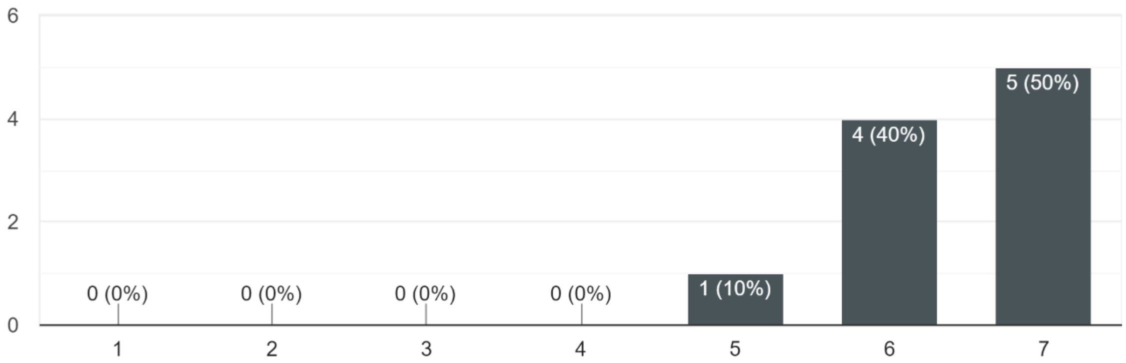
Q4. During the thunderstorm I felt like the environment around me was harsh, and I wanted to go somewhere safe, rather than continue working.

10 responses



Q5. It was clear to me that the weather at the end of the simulation was not suitable for working.

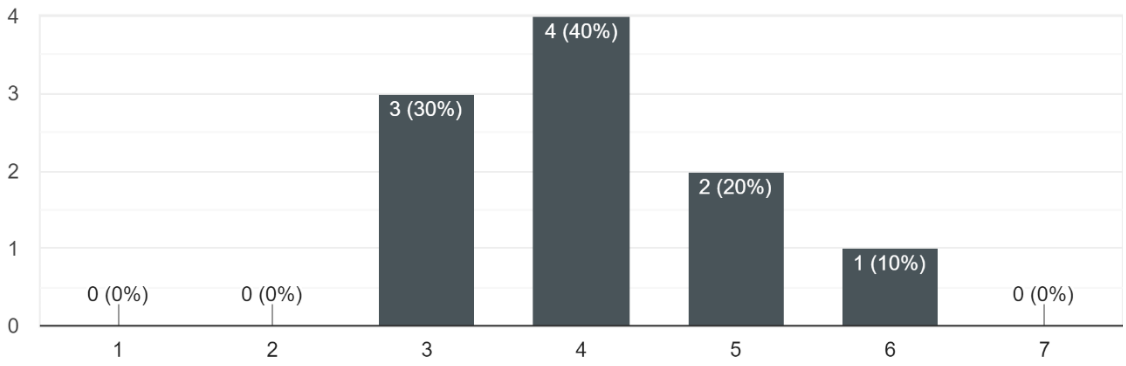
10 responses



Appendix A | Questionnaire results | Scene 2

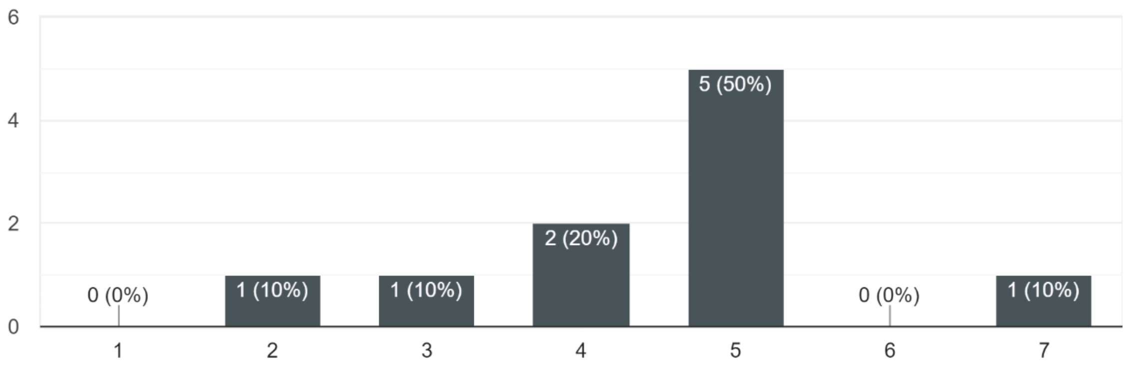
Q1. When I think about it now, I remember the working site more like a real place that I visited, rather than a computer generated world.

10 responses



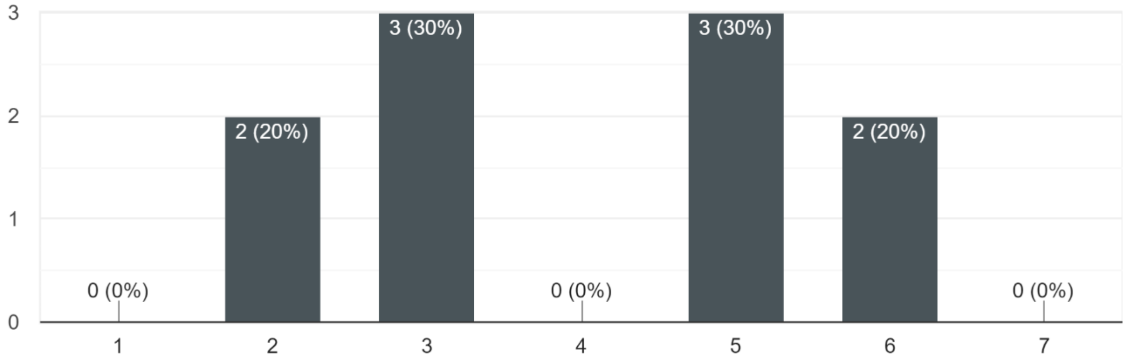
Q2. While I was doing my task I noticed that the weather was getting worse.

10 responses



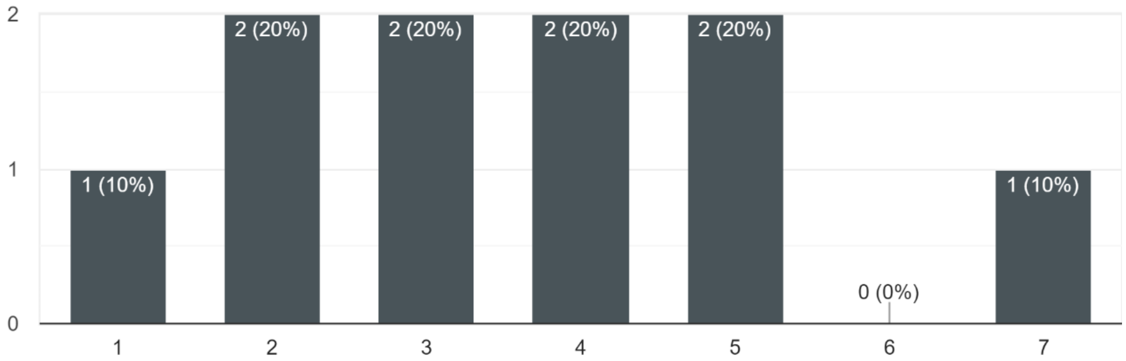
Q3. I perceived the weather components (rain, fog, lightning, wind, clouds, etc.) as if they were real.

10 responses



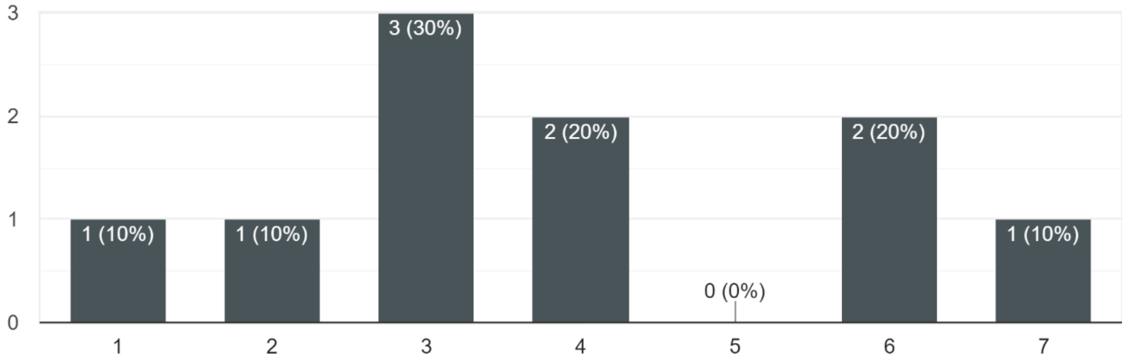
Q4. During the thunderstorm I felt like the environment around me was harsh, and I wanted to go somewhere safe, rather than continue working.

10 responses



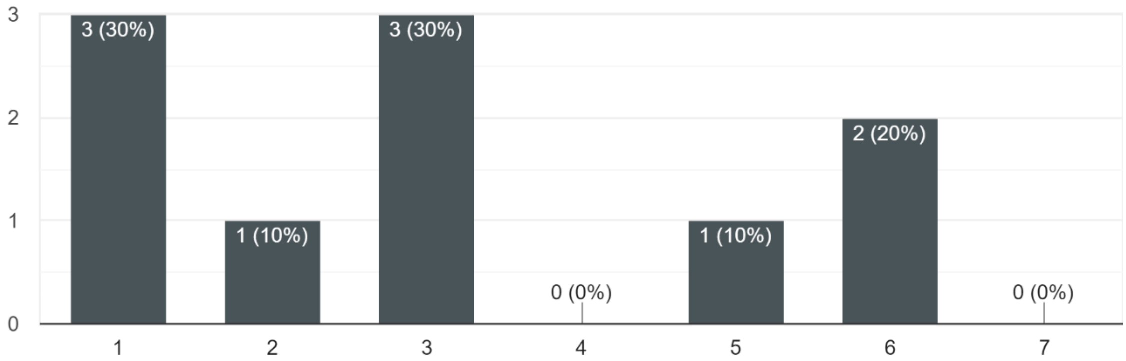
Q5. It was clear to me that the weather at the end of the simulation was not suitable for working.

10 responses



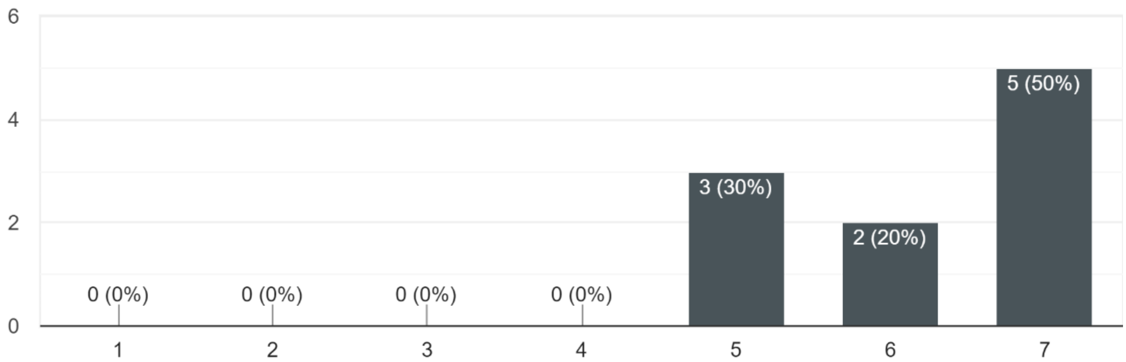
Q1. When I think about it now, I remember the working site more like a real place that I visited, rather than a computer generated world.

10 responses



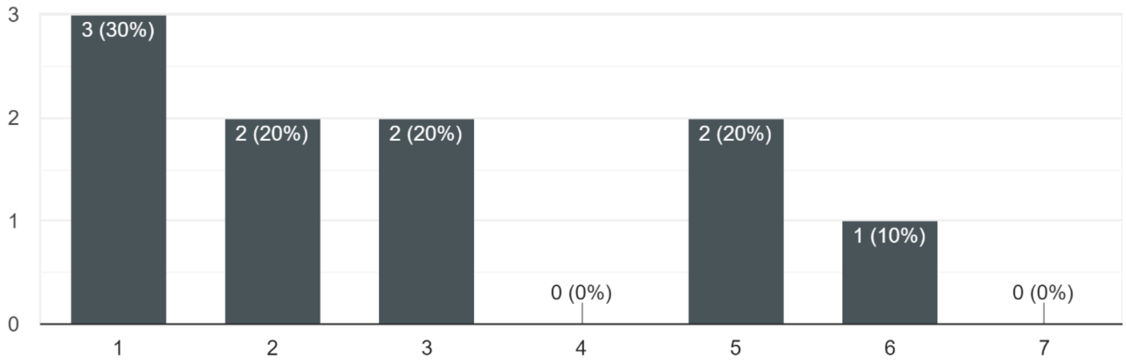
Q2. While I was doing my task I noticed that the weather was getting worse.

10 responses



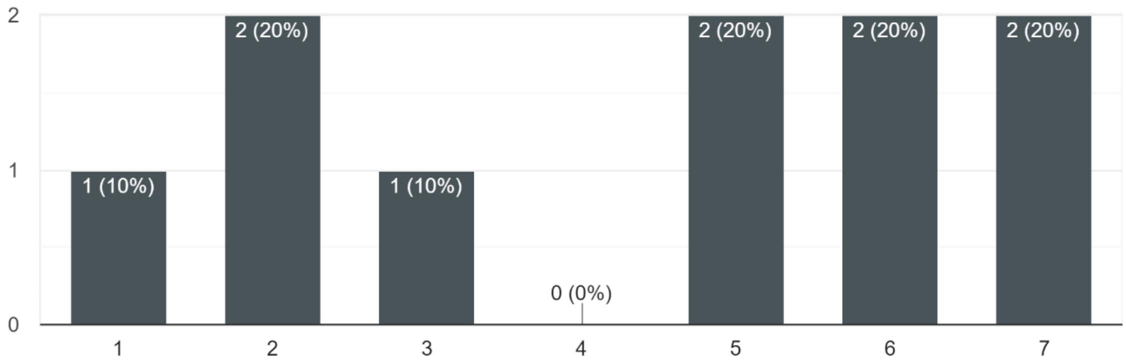
Q3. I perceived the weather components (rain, fog, lightning, wind, clouds, etc.) as if they were real.

10 responses



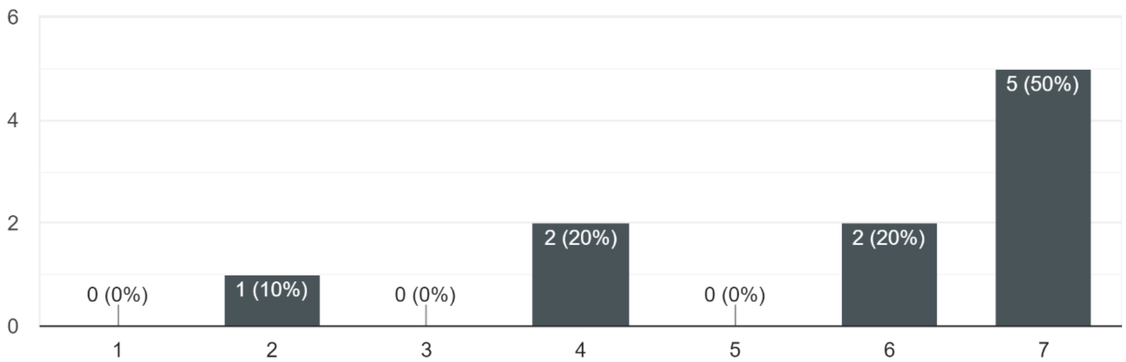
Q4. During the thunderstorm I felt like the environment around me was harsh, and I wanted to go somewhere safe, rather than continue working.

10 responses



Q5. It was clear to me that the weather at the end of the simulation was not suitable for working.

10 responses



Appendix A | Questionnaire results | Scene comparison

Did you see any difference between the weather system in the 1st and the 2nd scenario? If yes, could you please mention some of the differences below.

6 responses

The 1st had a clear different between rain and sunshine. The 2nd the rain was visualy better.

Scenario 1 felt more realistic. In the second scenario I perceived a mismatch between the shades (indicating a sunny day) and the worsening conditions.

scenario one was more intense

The 1st scenario had a clear progression from clear sky and dry weather to a thunderstorm. The 2nd scenario didn't progress, it was just a bit of rain and a cloudy sky.

Lighting on the environment

Less fog. Less the feeling it is raining and the ground didn't change or I didn't had the feeling so I did not even notice the rain.

Did you see any difference between the weather system in the 1st and the 3rd scenario? If yes, could you please mention some of the differences below.

6 responses

the 3rd had a good thunderstorm, the 1st had better clouds and the sunshine after the rain.

The sky and clouds in the 3rd scenario felt really unrealistic, similar to a nintendo-game. However, the other conditions were sort of similar and the wind/rain in the 3rd scenario seemed more present. However, the puddles on the ground in the 3rd scenario also felt unrealistic.

scenario two was cartoonie + blue water -.-

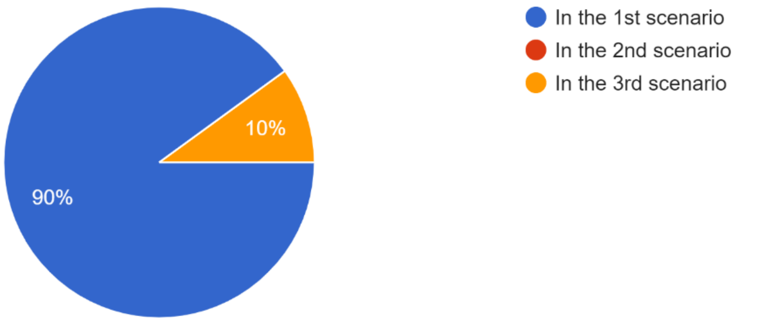
The clouds in the 1st scenario looked realistic, the clouds in the 3rd scenario looked cartoony. The rain in the 1st scenario looked real, the rain in the 3rd scenario was blue and unnatural.

The style was different

3rd were cartonish

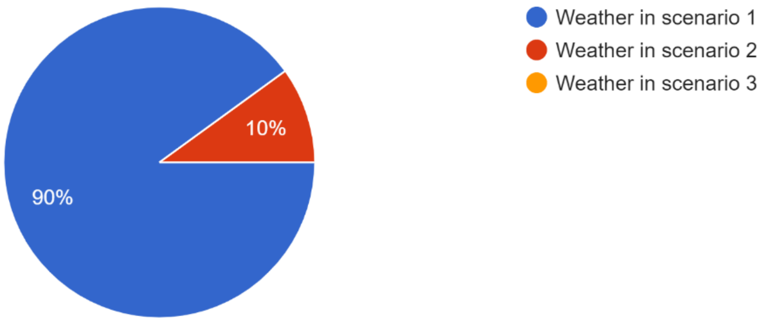
In which scenario you felt more immersed with the world.

10 responses



Which weather type would you prefer in a serious VR training platform.

10 responses



Appendix B | Additional work | Gravel material

Created a gravel material which was used in the rail track of the simulation. The gravel material was created based on real life pictures taken at the Enschede train station. Then the pictures were adjusted to create a seamless texture in Adobe Photoshop which later was used in Substance Alchemist to create a material with all the required texture maps like Height map, Normal map and Occlusion map.

Figure 23 Gravel material applied to a plane in Unity

Appendix B | Additional work | Catenary system

Modeled, UV-mapped and textured the catenary system used in the simulation. The catenary system was based on real-life pictures taken at the Enschede train station.

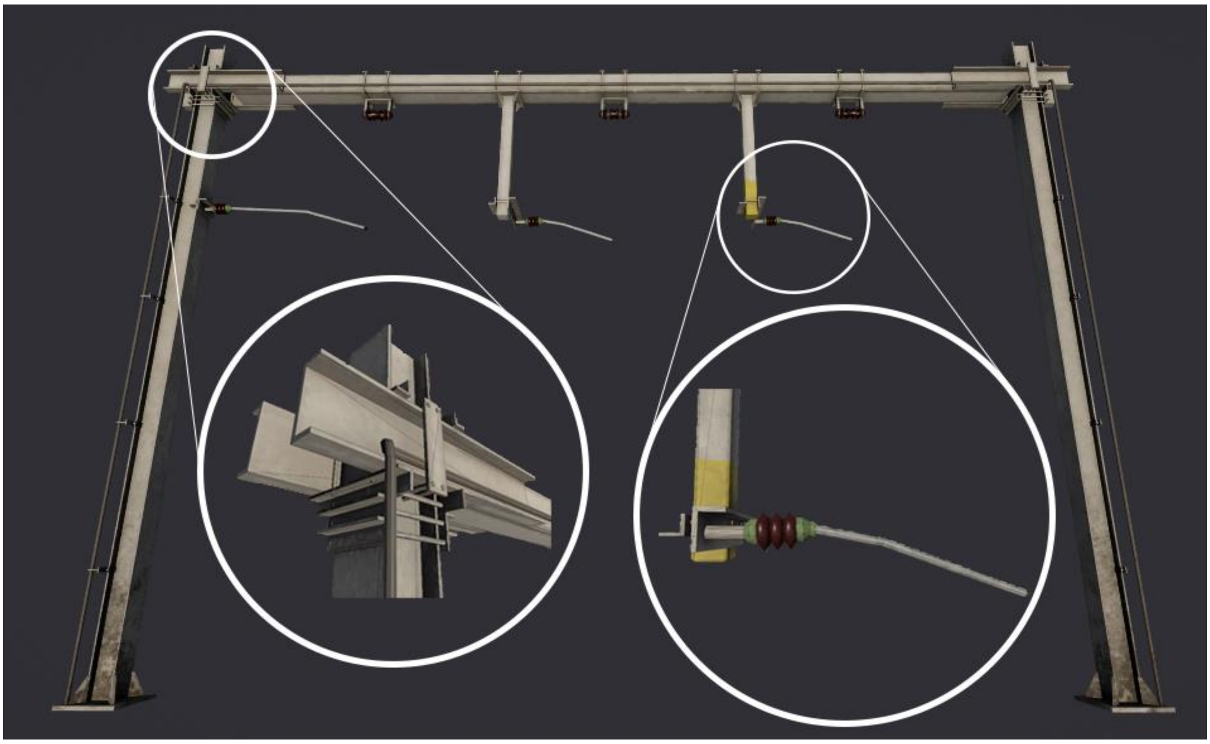


Figure 24 Catenary system rendered in Unity

Appendix B | Additional work | The rail track

Modeled and UV-mapped the rail track. After experimenting with different approaches, the rail track was modeled using pieces which can merge with each other in a seamless way. This approach was chosen so just a small piece from the rail track could be UV-mapped (Figure 25, which will give more space for detail for the texture, as the texture will start repeating for each piece, rather then UV-mapping the whole rail track and using bigger texture sizes to fit the necessary detail. After modeling and UV-mapping, the rail-track was imported in Unity, and Mesh deformer tool from Unity asset store was used to duplicate the rail track piece and deform it to create smooth shapes in order to create the designed shape of the rail track used in the simulation (Figure 26).

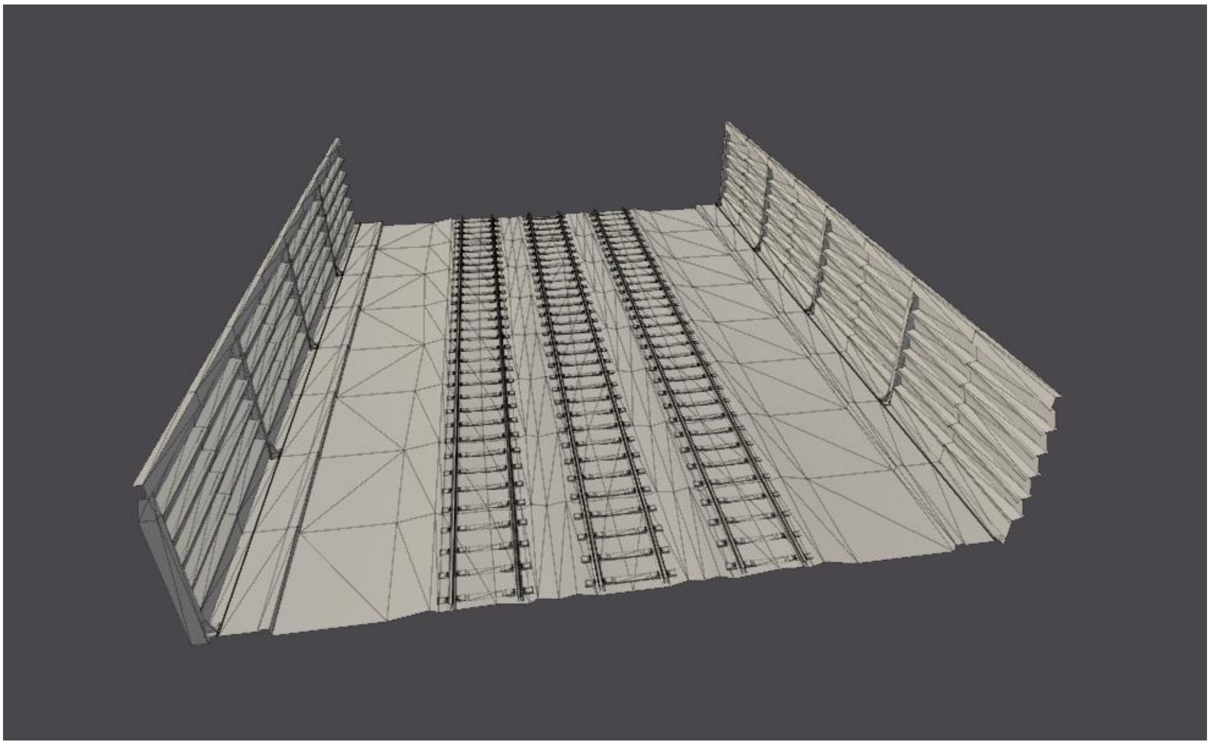


Figure 25 Rail track piece

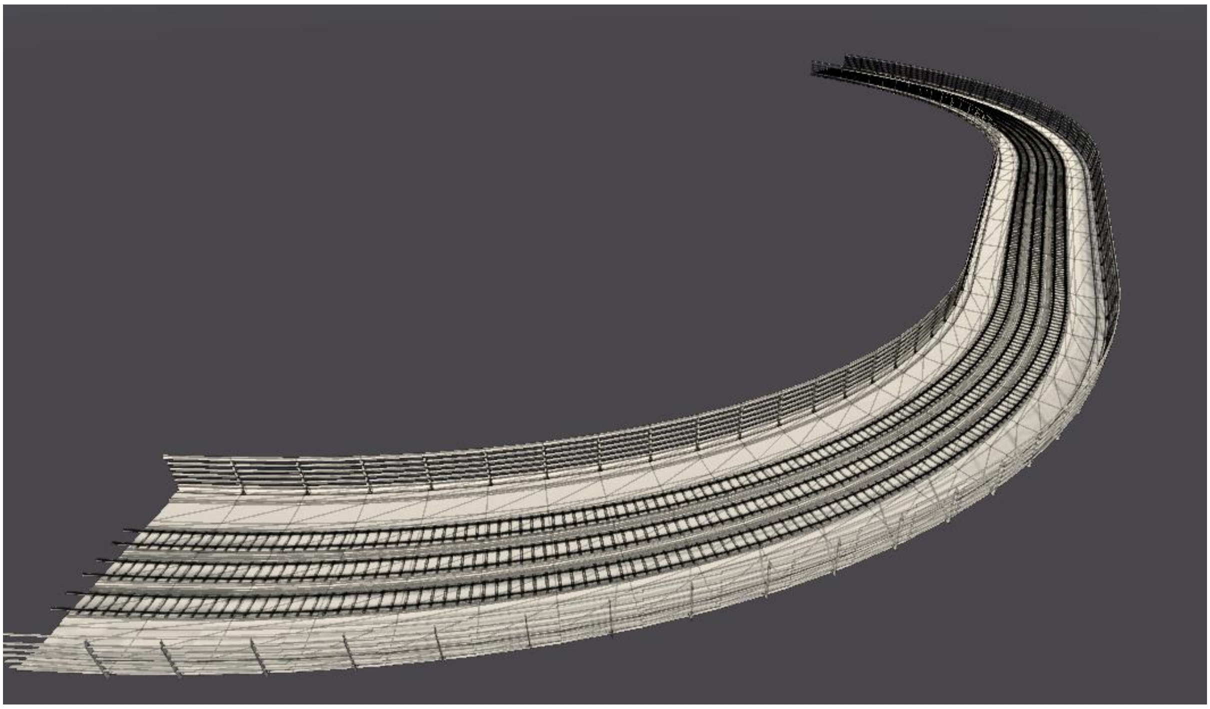


Figure 26 Rail track created using Mesh deformer in Unity

Appendix C | Reflection on the 12 competences | 1. Technical research and analysis

Together with the team we created an interactive virtual reality safety training simulation. To create the simulation various aspects of development had to be considered to create a smooth experience for the users. We had to create a realistic scenery where the workers could perform their training with all the equipment and machinery that the workers needed. And since we had to use VR we had to do the whole process in a more refined way and more optimized to avoid any performance issues which would have negative effects on the users.

I was responsible for creating the weather system which is something that I had never done in a game or simulation before and prior to this graduation I had very little knowledge about visual effects in games. Because of this, during the graduation I had to experiment a lot and try out different approaches therefore I gained new insights in the creation of visual effects for games and VR and managed to create a complex weather system, which was optimized for VR and didn't affect the performance of the simulation. Also, I gained more knowledge on achieving realistic lighting of a scene in Unity depending on the time of the day or weather condition.

Appendix C | Reflection on the 12 competences | 2. Designing, prototyping and realizing

The client wanted a virtual reality safety training platform, where the workers could train in a safe virtual environment. One of the requests from the client was to have a weather system on the simulation where the weather can replicate real life hazardous weather conditions, like heavy rain, thunderstorm and heavy fog. During this project I was responsible for creating the weather system and I iteratively designed each weather component, trying different approaches until ending up with a suitable approach. Also, I prototyped three different versions of the visual realism of the weather system to test out if the weather realism changes have a different outcome in the effectiveness of the simulation.

Appendix C | Reflection on the 12 competences | 3. Testing and rolling out

The simulation that we created was tested out multiple times during the development. We tested the simulation with the safety officer and a maintenance worker from Strukton Rail halfway through the project, where we got a lot of insights in the effectiveness of the simulation. These are the people for whom the VR simulation will be created for, so testing with them was very important to help us further guide the project in the right direction. Also, at the end of the graduation, we had tests with the safety officer again, as well as the company supervisor. During this test, besides testing the overall simulation, a specific test was done just to see the impact of the visual realism of the weather system which was important for this thesis.

Appendix C | Reflection on the 12 competences | 4. Investigating and analyzing

I conducted a literature review to understand if the visual realism has an impact on the presence of a VR simulation. After finding out that the visual realism was proven to have an impact of the immersion and presence of a VR simulation, I conducted a literature review to gain more knowledge on how to achieve a higher visual realism for VR. And combining this with the literature review on what makes weather in real life look realistic and how does the weather function, I created a realistic weather system for VR. Later prototyping was used to determine if the visual realism of the weather system also has an impact of the effectiveness of a VR safety training tool, where three different scenes were tested out with 10 participants, of which one was a safety officer at Strukton Rail. Questionnaires were handed in to the participants to get their insights and observations on their behavior were made during the tests to finally get an answer on the research question.

Appendix C | Reflection on the 12 competences | 5. Conceptualizing

Besides solving the client's problem of having a weather system in the virtual simulation, during this thesis I tried to focus on creating something which has a broader use and is of value to other people who might read this report. I created a realistic weather system which is optimized and runs smooth in a VR simulation. And I tried to create the whole thing without or with very little use of coding. Mostly faking physics and finding a way to make the transitions from a weather type to another more animation related rather than coding related. This could be useful to other 3D artists without a knowledge in programming in case they want to achieve something similar. Also, I explored different approaches for achieving the same weather components, which even though for this project they may not be useful, for another project one of the different approaches could be used.

Appendix C | Reflection on the 12 competences | 6. Designing

Besides my previous knowledge, I learned how to work with particle systems in Unity and learned how to achieve better lighting and atmosphere for the environment. Also, with the help of my brother I managed to learn a bit of coding which I used to create some simple transitions from a weather type to another.

The concept is by no means ready to market and a few more adjustments are needed to get to that stage. Nonetheless, it serves as a very solid foundation which can be further developed until it is ready for market.

Appendix C | Reflection on the 12 competences | 7. Enterprising attitude & 8. Enterprising skills

The product was created for training the employees within the company rather than to be shipped to the market. However, the knowledge gathered in this thesis has a wide market potential. More and more companies are turning to VR as a means of training for their employees, and there are various other scenarios where creating a realistic weather system in VR can be helpful. Think of construction workers, pilot simulations, driving simulations. Basically, any kind of work which is outdoors and the weather can have an impact on. And in this thesis, it was concluded that having an increased visual realism on the weather system had an impact on the feeling of presence and immersion. Besides this, in the field of gaming and entertainment (not necessarily VR), a good-looking realistic weather system will help to increase immersion.

So technically, with the knowledge that was gained during this thesis a fully functional realistic weather system can be created which can then be shipped as a package of assets which can then be used by other developers which need a weather system for their creation.

Appendix C | Reflection on the 12 competences | 9. Working in a project-based way

During this project we worked by employing Scrum methods. This was one of the projects where most of the team members were familiar with the Scrum methodology which resulted in a good execution of the Scrum principles. We worked with 2-week sprints where at the end of each sprint we had a meeting with the client where we presented our progress, showed recommendations of what we could include in the other sprint, and asked for a more detailed list of priorities. We also tried to make each sprint “ready to ship”, meaning that each sprint would have a fixed number of features that we can implement, which are easily presentable and showable. However, the overall process was far from a perfect Scrum-based project, but in my opinion, we did a good job as a team in regard to that.

During this project, we were only three artists where each had his specific graduation focus. Therefore, we decided not to have a lead-artist as it was not necessary, but instead we had meetings and discussion on what each one will be working, besides the focus of the graduation, and we were evaluating each other’s work all along the project.

However, during my study years I have had multiple occasions where I had to direct team members (ranging from 3-8) in other projects we had to do. And in fact, I was chosen as the lead artist in most of the other project that we had to do prior to now. As a result, I had the chance to understand what it means to direct other artists and was able to gain a lot of useful knowledge on how to manage the art department of a product and how to make the work more efficient for all the team members.

Appendix C | Reflection on the 12 competences | 10. Communication

As a team we had several meetings with the client where we discussed the progress of the product that we were developing and talked about the decisions that were made and what had to be prioritized. Also, within the team we had daily stand-ups every day where we discussed what everyone was working on and we discussed any issues that there could be.

The final product is not finished yet, and it is still in prototype phase. However, the things that we managed to achieve during this short period are worth using as portfolio material. Personally, I will further develop the weather system that I created during this thesis and will use it in my portfolio. Also, a link to the general product that we created as a team, where the weather system was used, will be referenced in my portfolio.

Appendix C | Reflection on the 12 competences | 11. Learning ability and reflectivity

Reflecting on my work and using others feedback to further improve it, it's a recurring theme when working on a project during my CMGT years. It is something that we are taught to do a lot and I can see that it has a big value. During the graduation progress I have received a lot of feedback from my graduation coach, which helped me to shape my thesis the way it is now. I didn't get to write a lot of research papers before and it is something that I wasn't very confident of doing. But with the constant feedback received from my coach I had a clearer understanding of the certain steps that need to be taken in order to conduct a research which helped me tremendously in making the report better.

In addition, as a team we were constantly working with the feedback from the client as we had meeting every two weeks. And based on the meeting and the discussions we had with the client we were adjusting our goals and sub products that needed adjustment. Besides this, within the group we were giving feedback to each other on various stages of development. Within the artists of the group we were constantly checking each other's progress and giving feedback and suggestions to each other in order to create a coherent product.

Appendix C | Reflection on the 12 competences | 12. Responsibility

During my research I have acquired a lot of new knowledge about the way that the weather functions which helped me create a more realistic virtual weather during the prototyping phase.

Appendix D | Proof of product

In the link below, you can see the current state of the product that was developed during the graduation period. On minute 3:16 a demonstration of the dynamic weather system created by me can be seen.

https://www.youtube.com/watch?v=UgUEcimkOAE&feature=youtu.be