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The Use of Virtual Reality to Create an Immersive Nature Experience

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Abstract

This thesis explores the development and evaluation of "Serene Night", a Virtual Reality (VR) application designed to provide users with an immersive and calming camping experience. The main goal is to create an accessible way for people to enjoy the therapeutic benefits of nature, especially for those who cannot experience it firsthand. The application features a stylized forest environment enhanced with a dynamic sky and natural soundscapes to heighten the sense of realism and immersion.

This project addresses the growing disconnect from nature many people face today. Urbanization, long working hours, and constant use of digital devices contribute to what is known as "nature deficit disorder", leading to more stress, anxiety, and a decline in mental health. With the use of VR technology, "Serene Night" offers a potential solution to this problem, providing a virtual means to reconnect with nature. This approach not only enhances mental well-being but also fosters a greater appreciation for the natural environment, showing how innovative technologies can promote health and ecological awareness.

The development process involved using various tools like Unity for the game engine, Blender for 3D modeling, Adobe Audition for sound editing, and Adobe Photoshop for image processing. These elements came together to create a cohesive VR environment that simulates a peaceful night in the forest, complete with soothing nature sounds and a starry sky.

Key components of the VR environment include detailed models of trees, bushes, and rocks, all textured and optimized for performance. The soundscapes were carefully crafted to include natural elements like crickets, birds, and rustling leaves, providing an auditory experience that complements the visual immersion. Additionally, a sky system was implemented to simulate realistic transitions from dusk to dawn, enhancing the temporal aspect of the virtual environment.

The effectiveness of "Serene Night" in promoting relaxation and engagement was assessed through participant trials. The results indicated that while a level of relaxation was achieved, some negative emotions were also present. This suggests that VR can be a viable tool for providing nature experiences that contribute positively to mental well-being, although depending on the implementation, it may also evoke some mixed feelings.

This thesis adds to the growing research on the applications of VR in mental health and nature therapy. It shows the potential of VR technology to recreate natural environments that offer therapeutic benefits, providing an innovative solution for addressing the disconnection from nature experienced by many in today's urbanized world. The findings highlight the importance of integrating realistic soundscapes and visual elements to create immersive VR experiences that can effectively reduce stress and improve mental health.

Contents

Chapter 1

Introduction

In today's fast-paced, tech-driven world, many people feel increasingly disconnected from nature [37]. Urbanization, long work hours, and constant use of digital devices contribute to this growing separation. This disconnection which affects the mental and physical well-being, leads to conditions known as "nature deficit disorders" [10], which include increased stress, anxiety, and a decline in mental health.

Virtual Reality (VR) technology offers a promising solution to bridge this gap. By creating immersive and interactive virtual environments, VR can simulate the experience of being in nature, allowing users to enjoy the benefits of natural exposure without leaving their urban settings. This thesis explores the development and impact of "Serene Night", a VR game designed to provide a calming and engaging camping experience. The game aims to reconnect users with nature by simulating a peaceful forest environment with dynamic skies and natural soundscapes.

1.1 Background

VR technology is being used more and more to create immersive experiences in fields like education, training, simulation, and healthcare [29]. It gives users new ways to experience visual media by immersing them in a virtual world [29].

In education, VR has been applied to a variety of subjects like medical sciences, astronomy, engineering, history, physics, psychology, and more. VR offers advanced interaction with controllers, intuitive user experiences, and immersion, which makes it a standout teaching tool [53]. As VR technology has advanced, so have the concepts of immersion and presence, which rely on the system's technological features [53]. However, VR still has some drawbacks, such as user discomfort or sickness while using headsets, high hardware costs, lower resolution compared to the human eye and a lack of technical standardization [29][82]. Latency between head movements and the visual display updating can induce sickness, while lower resolution and refresh rates compared to the human eye's capabilities limit visual quality and contribute to discomfort [65][39].

Immersive Virtual Reality expands technical capabilities and encourages educators to transition from traditional Virtual Learning Environments (VLEs) to Virtual Reality Learning Environments (VRLEs) [28]. VRLEs offer immersive and interactive educational experiences, allowing for realistic simulations of real-world events like medical procedures or engineering projects, which are difficult to replicate in traditional settings. These advanced environments not only enhance student engagement but also improve learning outcomes by providing hands-on experiences and practical applications [28].

VR technology also provides immersive and interactive experiences that can have health benefits similar to real nature exposure [47][27]. Using VR in environmental education can make learning more engaging and effective by offering a new perspective on the importance of preserving natural environments [27].

1.2 Importance

The growing disconnect from nature in modern society is an increasing concern, with many individuals spending the majority of their time indoors, separated from the natural environment [10]. The Western disconnect from nature has been identified as a key contributor to convergent social-ecological crises [86]. This disconnect is a result of cultural norms and discourses that have led to a perception of humans as separate from nature, which is embedded in the Western discourse [86]. The drivers of this disconnect include social, psychological, historical, and physical factors that perpetuate or exacerbate the disconnect from nature [86].

The consequences of this disconnect include an inability to see oneself as part of nature, a denial of one's dependency on nature, and an excessive subject/object partitioning of the world that impedes people's ability to see or imagine connections between their doing and being [86]. This disconnect has also been linked to the perils of industrialization and scientific rationalization, which have been devastating to the human sense of belonging, mutualism, and connection with nature, earth, and the cosmos as a whole [86].

This disconnection has been linked to several negative health outcomes, including increased sedentary behavior, obesity, and cognitive deficits, collectively known as "nature deficit disorders" [10]. To combat these issues, a variety of interventions have been proposed and implemented.

VR has emerged as a powerful and innovative tool for reconnecting people with nature [49]. The VR's ability to simulate realistic natural environments can positively affect mental health. By creating multi-sensory VR experiences that combine both audio and visual elements, cognitive functions are shown to improve significantly [19]. The utilization of VR extends beyond mere simulation, as its use in clinical settings to treat a variety of conditions is rapidly increasing and proving to be highly effective [67].

Environmental education programs are one effective solution. Research indicates that even short-term programs can bolster an individual's connection to nature. For instance, a study in the Journal of Biological Education demonstrated that a single-day education program could enhance participants' connection with the natural world [7].

Another problem that plagues the modern man is stress. Beard, an American neurologist, coined the term "neurasthenia" to describe a condition characterized by fatigue, anxiety, and depression, which he attributed to the pressures of modern life [33]. This concept of stress as a response to the demands of modernity has persisted, with contemporary society facing various stressors such as global economic recession, job insecurity, marital breakdown, and political and religious extremism [33].

The already overwhelming stresses were also amplified by COVID-19, significantly impacting mental health, leading to an increase in stress, anxiety, depression, and post-traumatic stress disorder (PTSD) symptoms in various populations, especially among vulnerable groups [81][75][87]. The pandemic's prolonged nature and uncertainty exacerbated these issues, highlighting the urgent need for effective mental health interventions.

VR has been shown to effectively reduce stress levels through various mechanisms.

VR interventions can lead to a significant decrease in stress and anxiety levels. VR environments designed for stress reductions often incorporate relaxing settings, guided imagery, breathing exercises, and mindfulness techniques, all of which contribute to the reduction of stress [38][43].

The key aspect behind the effectiveness in stress reduction is the ability to immerse individuals in virtual environments that promote relaxation and mindfulness. By engaging the senses and creating a calming virtual space, individuals can escape from real-world stressors and focus on positive experiences, leading to significantly lower stress levels and improved overall well-being [43].

Light pollution has become a growing problem, surpassing the natural nocturnal lighting levels provided by starlight and moonlight [63]. This increase is primarily due to artificial lighting, such as streetlights and LEDs, which emit strong blue light that contributes significantly to skyglow. Skyglow obscures the visibility of stars, making it difficult for both amateur and professional astronomers to observe celestial objects [24][41].

Light pollution has significant implications for both environmental and human health. The presence of excess artificial light disrupts the natural day-night cycle, which is crucial for regulating circadian rhythms. Disruption of these rhythms can lead to various health issues, including sleep disorders, increased stress levels, and even chronic conditions such as obesity and cancer [16].

VR can create highly immersive educational experiences that help people understand the impact of light pollution. For instance, VR can simulate environments with varying levels of light pollution, making the differences between polluted and natural night skies more tangible and urgent for the public [40].

1.3 Aim, Objectives & Outcomes

The aim of this project is to *create a virtual escape, aiming to replicate the tranquility and aesthetic beauty of natural environments* within the constraints of current VR technology [48]. Recognizing the limitations inherent in realistically rendering complex scenes, the project strategically adopts an atmospheric approach to realism. This method not only facilitates a more feasible application of technology but also aims to alleviate stress and foster a deeper connection with nature for its users, enhancing their overall well-being and appreciation for natural settings.

One of the main goals is exploring *how the nature impacts human well-being and the potential of VR in reconnecting people with nature, psychology, and astronomy.* This involves looking at the benefits of nature for mental and physical health, how immersive simulations can recreate natural environments to help people reconnect with nature, and using VR in psychological treatments like exposure therapy. Additionally, it assesses how VR can improve astronomy education by making abstract concepts more tangible and engaging through simulations.

In this thesis, I developed an immersive VR application using high-resolution models and detailed textures, realistic and immersive soundscapes, and intuitive controls. The design focuses on maximizing user experience and immersion by carefully optimizing technical aspects such as latency and resolution.

To evaluate the impact, comprehensive user studies will be conducted to measure user satisfaction, immersion, and any potential discomforts. A psychologist will assess the application's effectiveness in achieving its goals of nature reconnection and educational enhancement. The findings will be documented to provide insights into the application's strengths and areas for improvement. The aim is to contribute valuable knowledge to the fields of Virtual Reality technology, mental health, nature reconnection, and astronomy education, ultimately enhancing the effectiveness and appeal of such applications.

The project was created for Oculus Quest 2, but through the Unity Engine version 2021.3.33f1, the game was made to work with other controller profiles:

- HTC Vive Controller Profile
- Microsoft Motion Controller Profile
- Oculus Touch Controller Profile
- Valve Index Controller Profile

The **intended audience** for this VR experience includes individuals of all ages, particularly those who have spent their lives in urban environments without substantial exposure to natural settings like forests. This project aims to reach nature-deprived adults as well as younger individuals, offering a virtual re-connection with the natural world to those who may have lost their connection to nature.

The game was designed to have an engaging environment with the help of sound. The sound space composed of a wide array of natural sounds that blend to form a lively yet realistic background. Intervals of quiet down time are strategically incorporated, aiming to give time of tranquility for reflecting.

Another key feature is the sky, originally developed by previous students of ICAM laboratory[26], was integrated to enhance the realism of the virtual setting. The sky itself progresses realistically over time, reflecting changes from dawn to dusk, creating a sense of the passage of time.

The surrounding forest is crafted in a way to create comfort but also having breathing room. The vision was a patch of space in a dense forest, showing the beauty of the sky to the fullest. This aspect of design aims to envelop the user in a cozy atmosphere, reinforcing the connection with nature.

The anticipated **outcomes** of this project include fostering a deep connection with the virtual setting for some users, while others might find the experience lacking in realism due to their previous experiences with nature. Ultimately, the project aims to **provide a brief respite** for individuals in need of a momentary escape, and **inspire** them to seek out real-world natural experiences more frequently. This, in turn, is expected to cultivate a **greater appreciation for the environment**.

1.4 Contributions

My main role in this project was foundational, focusing on the creation of the base environment and the implementation of the forest setting. This involved extensive work in designing and integrating natural elements such as trees, bushes, rocks, and dynamic sky systems, ensuring a cohesive and immersive virtual environment. This environment served as the basis for my thesis and was also integral to the Accessibility Features Experiment. I also provided support for the integration between these two projects. Mihai Tanasa, who worked on the Accessibility Features Experiment, handled the multiplayer features, accessibility options, and the welcome room. In contrast, I concentrated fully on the forest scene.

In the experimental phase, I was responsible for obtaining the necessary approvals from the university to conduct the experiments. This involved preparing detailed documentation on the procedures and contacting the university committee.

Once approval was granted, my responsibilities included overseeing the actions taken by participants during the trials and meticulously noting any significant occurrences throughout the sessions. This involved close monitoring to capture both expected and unexpected behaviors and responses from the participants, providing valuable insights into their interactions with the VR environment.

A critical part of my role was to record detailed physiological data from the tests, such as heart rates and blood pressure, to assess the physical impact of the VR experience. Additionally, I contributed significantly to the design and implementation of the experimental procedures, generating innovative ideas to maximize data collection. For instance, I proposed noting environmental variables such as temperature and time of day during the sessions to examine their potential effects on the results, ensuring a comprehensive and thorough analysis of all possible influences.

In the second experiment, where detailed data collection was paramount, I took it upon myself to document the results meticulously. This involved providing thorough descriptions of each session, capturing detailed observations to aid in both my understanding and the overall analysis of the final results. My efforts ensured that the data was robust and informative, contributing significantly to the project's insights and conclusions.

Throughout the project, my focus on creating a realistic and engaging forest environment and my dedication to detailed data collection and analysis were key factors in achieving the project's aims. By combining technical expertise in VR development with rigorous experimental oversight, I helped ensure the "Serene Night" application not only met its design goals but also provided meaningful data on its effectiveness in promoting relaxation and nature connection.

1.5 Chapters

This thesis is structured to provide a comprehensive exploration of the development and impact of the VR application. Each chapter focuses on different aspects of the project, from the current state of VR technology, and attitude of man towards nature, to the practical development, application, and evaluation of the VR experience. Below is a brief overview of the key chapters.

State of the Art This chapter reviews current VR technology, with a particular focus on its application in simulating natural environments. It delves into how VR is being used to create immersive experiences that allow users to engage with nature in ways that would otherwise be inaccessible, especially for those living in urban areas. It explores the role of VR in various fields such as education, healthcare, and its potential to simulate natural settings that can reduce stress, anxiety, and other symptoms associated with "nature deficit disorder". The chapter also discusses the benefits of VR in promoting mental well-being, enhancing cognitive functions, and providing therapeutic interventions.

Development This chapter details the technical creation of the VR application. This section describes the tools and processes used to build the application, including Unity for game development, Blender for 3D modeling, Adobe Audition for sound editing, and

Adobe Photoshop for image processing. It covers the selection of assets, copyright considerations, and the implementation of various components, such as the forest environment, dynamic sky system, and natural soundscapes. The chapter also discusses the integration of these elements to create a seamless and immersive VR experience.

Application This chapter focuses on the practical use and testing of "Serene Night". The chapter describes the setup and execution of user trials, detailing the methods used to assess the effectiveness of the VR experience in promoting relaxation and engagement. This section also highlights the ethical and legal considerations taken into account during the experimentation process.

Results The chapter presents the findings from the user trials and evaluates the impact of the "Serene Night" VR application on both physiological and psychological aspects of the participants.

Discussion This chapter goes over the broader implications of the findings for the fields of Virtual Reality technology, mental health, and nature therapy, offering suggestions for improving the application based on user feedback. The discussion also considers the potential for future research and development to further enhance the realism and effectiveness of VR nature simulations, aiming to create even more impactful and beneficial experiences for users.

Chapter 2

State of the Art

VR technology has opened new possibilities in fields like education, healthcare, and entertainment. It can create immersive and interactive environments, letting users experience scenarios that are hard or impossible to encounter in real life. This chapter reviews the current state of VR technology, focusing on its use in simulating natural environments and its potential benefits for mental and physical well-being, while also pointing out the struggles of the modern man and nature.

2.1 Simulating Nature in Virtual Reality

VR is a valuable tool for creating immersive virtual environments (IVEs) that can trigger real behavioral responses, even when participants know the environment is not real [59]. Another study found that VR can simulate the benefits of nature exposure on cognitive performance, offering potential for education and cognitive health [51]. Exposure to a virtual nature environment improved performance on tasks requiring sustained attention and working memory [51].

Nature environments in VR can also serve as an alternative for people with mobility issues [76]. Another article suggests that virtual nature could be considered when real interaction with nature isn't possible or practical [79].

Supporting the effectiveness of VR, a study found that students undergoing daily nature simulations can significantly improve their mental health, anxiety reduction being a main outcome [12]. Benefits include reduced physiological and psychological stress, increased relaxation, and improved happiness, mood, awareness, and emotions. Additionally, Virtual Reality can help reduce anxiety [52], distress, nervousness, and symptoms of depression [85].

Simulations of night skies are highly effective in astronomy education and public outreach. These simulations offer immersive and engaging experiences that help learners understand complex astronomical phenomena. For example, VR can vividly show the phases of the moon, the causes of seasons, and other celestial events, making them more tangible and memorable [36].

Another application of VR is replicating natural environments affected by global warming. These immersive experiences highlight the consequences of climate change, such as glacier melt, sea-level rise, and deforestation, allowing users to witness these impacts firsthand [71]. These simulations can raise awareness and promote environmental consciousness by making abstract concepts more concrete and emotionally impactful [71].

2.2 Virtual Reality in Education

VR has become a game-changer in education, offering immersive and interactive experiences that traditional methods cannot match. In fields like astronomy and psychology, its potential to enhance learning and research is particularly notable. By simulating real-world and abstract phenomena, VR makes complex concepts more accessible and engaging for students.

2.2.1 Virtual Reality in Astronomy Education

This technology brings the vastness of space closer to students. By creating immersive, three-dimensional environments, learners can explore celestial bodies, witness astronomical phenomena, and navigate through the depths of space.

Benefits

The immersive experiences provided by VR make abstract astronomical concepts more tangible and engaging. This immersion captures students' attention and enhances their sense of presence in the virtual environment [36].

Additionally, VR enables innovative visual representations that go beyond the limitations of reality. This is especially useful in astronomy, where many phenomena are far removed from everyday experiences and difficult to visualize [36].

Furthermore, it facilitates guided learning experiences, allowing educators and scientists to help students navigate complex concepts. It also promotes collaboration among learners, enabling social interaction within virtual spaces [36].

Applications

There are a variety of branches and subjects in astronomy that use Virtual Reality as a tool of learning:

- Astrophysics
- Planetary Geology
- Special Relativity Concepts

Visualizing Astrophysical Data Researchers have created custom VR tools to visualize and interact with complex astrophysical data in 3D environments. The iDaVIE suite, for example, lets users explore galaxy evolution, cosmic structures, and gas movements in detailed survey data. VR helps scientists understand intricate 3D structures significantly better than traditional 2D visualizations, providing deeper insights into astrophysical phenomena [34].

Simulating Planetary Surfaces Simulations and augmented reality are used to make virtual field trips to places like Mars and the Moon. High-resolution data from orbit and the ground is put into VR environments, allowing users to explore from a global scale down to specific locations [45][4]. This helps scientists and students visualize and analyze planetary geology in 3D.

Special Relativity Concepts A Virtual Reality system was created to teach concepts like special relativity and mass-energy equivalence. Users take a simulated spaceship trip at nearly the speed of light, experiencing effects like time dilation and length contraction firsthand. This simulation has been shown to improve learning, reduce cognitive load, and increase student satisfaction compared to traditional teaching methods [68].

Challenges

However, implementing VR in educational settings can be costly and requires significant infrastructure. There is also a need for teacher training to effectively integrate this technology into the curriculum [18].

2.2.2 Virtual Reality in Psychology Education

The field of psychology seeks to understand the complexities of human behavior, cognition, and emotions. Traditional research methods and educational approaches often struggle to replicate real-world scenarios or create controlled environments for study. VR can bridge these gaps, providing researchers and educators with a powerful tool to explore psychological phenomena in immersive and controlled settings, allowing for more accurate and realistic simulations. This advancement can lead to deeper insights and more effective interventions.

Benefits

VR technology offers researchers greater control over stimulus presentation and response options, which is especially useful in experimental psychology settings [80]. The immersive nature of VR can also create more ecologically valid environments, making experimental findings more applicable to real-world scenarios [80].

Applications

Various psychological domains can use VR to create tailored experiences that address specific needs. These domains include:

- Clinical
- Developmental
- Social Interactions

Clinical Psychology In clinical settings, this technology helps create scenarios for exposure therapy, aiding patients in confronting and managing phobias, anxiety disorders, and PTSD in a safe and controlled setting. It can simulate feared situations, allowing patients to experience and work through their anxieties without leaving the clinical environment [8][80]. This method has shown effectiveness across a range of mental health conditions, offering a novel approach to traditional therapeutic techniques [8].

Developmental Psychology In developmental psychology, this technology is used to study and enhance children's socialization, self-control, and learning. These environments can simulate real-life situations that help children develop social skills and manage behaviors in a controlled, engaging manner. Research shows that it can promote socialization and self-control in children, making it a valuable tool for developmental interventions [5][44]. Additionally, the immersive nature of these environments allows for interactive educational experiences that aid in the development of cognitive and motor skills [44].

Social Interaction Studies In social interaction studies, this technology offers unique opportunities to study human behavior in simulated social environments. It creates realistic social scenarios where researchers can manipulate variables and observe interactions in a controlled yet ecologically valid setting. This is particularly useful for studying implicit social behaviors, social pressure, and the effects of social mimicry [84][62]. Simulating social interactions with both real and virtual characters provides a unique platform for exploring complex social dynamics and testing psychological theories in a highly controlled environment [62].

Challenges

Higher levels of immersion and visual fidelity do not always guarantee a realistic psychological response. The effectiveness of these technologies can vary depending on the specific use case and the psychological constructs being studied [80].

Differences between actual and virtual reality could also pose problems, especially for tasks that rely on accurate space perception, such as physical reach tasks. These discrepancies can lead to difficulties in accurately judging distances and spatial relationships, potentially affecting the effectiveness of VR training and simulations. Ensuring precise calibration and realistic representations is crucial to minimize these issues and enhance the reliability of virtual reality applications [80].

2.2.3 Transition to Virtual Reality Learning Environments

The shift from traditional virtual learning environments to immersive learning settings is driven by the need to boost student engagement, provide more interactive experiences, and better replicate real-world scenarios.

Motivations

Immersive learning platforms offer a more engaging and interactive experience compared to traditional methods. Their immersive nature can significantly increase student motivation and participation in learning activities [53]. Studies have shown that these platforms can enhance student motivation by offering opportunities for active and experiential learning. For example, Cheng and Tsai [15] found that immersive field trips significantly increased student motivation [53].

These platforms also provide a more natural and intuitive learning approach, which is particularly beneficial for students with special educational needs. They help these students overcome learning challenges by offering tailored, interactive experiences that cater to their unique requirements and learning styles [53].

Furthermore, they can simulate real-world events and environments, giving students valuable hands-on experiences that are difficult to replicate in a traditional classroom setting. This is particularly useful in fields such as medicine and engineering, where practical experience is crucial [53]. By replicating real-world scenarios, these platforms can better prepare students for their future careers, allowing them to practice and refine their skills in a safe and controlled environment [53].

Benefits

Immersive learning environments can create highly realistic simulations of real-world events, enabling students to engage with the material in a more meaningful way. For example, they can be used to simulate medical procedures or engineering projects, providing students with hands-on experience that would be difficult to achieve in a traditional classroom [53]. These simulations help students develop practical skills and gain a deeper understanding of the subject matter, enhancing their overall learning outcomes [53].

Additionally, these platforms can provide access to learning experiences that might otherwise be inaccessible due to geographical or financial constraints. For example, students can take virtual field trips to distant locations or explore complex environments without leaving their classroom [30].

2.3 Health

Health encompasses physical, mental, and emotional well-being, forming an integral part of our overall quality of life. Advances in technology, particularly in immersive simulations, have opened new avenues for improving health outcomes. By simulating natural environments, these technologies offer innovative solutions for stress reduction, pain management, mental health treatment, rehabilitation, and cognitive enhancement. These experiences create the benefits of nature and controlled therapeutic environments to effectively improve various health conditions.

Brief exposure, around 6 to 15 minutes, to immersive 360-degree nature videos can reduce stress, improve mood, and increase connection to the environment, compared to urban control conditions [11][66]. These simulations can also decrease physiological markers of stress, such as heart rate and skin conductance, similar to the effects of real-world exposure [66][31].

Pain Management

Tests have shown that immersive simulations are effective in managing pain by providing a distraction from painful stimuli. This is particularly useful in clinical settings where patients undergo painful procedures or suffer from chronic pain conditions. These technologies can reduce the perception of pain and the need for pain medications, offering a non-pharmacological alternative for pain relief [35].

Mental Health

PTSD, anxiety, and depression are mental health conditions that show potential benefits from these immersive technologies. Exposure therapy allows patients to confront and process traumatic experiences in a controlled and safe environment. Studies have shown that these methods can lead to significant reductions in symptoms, with effects lasting beyond the treatment period. This innovative approach not only enhances traditional therapy methods but also provides new avenues for personalized and effective mental health treatment [35].

Rehabilitation

In physical rehabilitation, these technologies provide engaging and interactive exercises that can be tailored to individual needs. This is particularly beneficial for patients recovering from strokes, injuries, or surgeries, as it offers a customized approach to their recovery. They can also enhance motivation and adherence to rehabilitation programs, leading to better outcomes and faster recovery times [35].

Cognitive Enhancement

Cognitive functions, such as memory and attention, can be improved using immersive simulations. For instance, a study found that exposure to a green office in a virtual setting improved short-term memory by 14% compared to a neutral environment. This is useful for older adults and individuals with cognitive impairments, offering a novel way to enhance and mentain mental capabilities [57].

2.4 Environment

The term "environment" includes everything that surrounds us, both living and non-living. It is a complex system where various elements interact and influence one another, shaping the conditions in which organisms live and thrive. The natural environment includes all living and non-living things that occur naturally, while the man-made environment consists of elements created by humans, such as buildings, roads, and other infrastructure. These elements often interact with and impact the natural world. Simulated nature, akin to a man-made environment, aims to reconnect humans with nature and help mitigate the damages done by urbanization and technological advancement. By creating virtual experiences of natural settings, people can enjoy the benefits of nature even in highly urbanized areas.

2.4.1 Causes and Effects

The Modern Disconnect from Nature

Modern life has increasingly distanced people from nature, a phenomenon often referred to as "nature deficit". This disconnection is largely attributed to urbanization, technological advancements, and lifestyle changes that prioritize indoor and virtual activities over outdoor experiences. The consequences of this disconnect are profound, affecting both individual well-being and broader social-ecological systems. Research suggests that this disconnection contributes to a range of negative health outcomes, including increased stress and anxiety, and diminishes pro-environmental attitudes and behaviors, which are crucial for long-term sustainability efforts [32].

Nature Deficit Disorders

Nature deficit disorder, though not a clinically recognized condition, describes the physical and psychological impacts of reduced nature exposure. Studies have shown that a lack of contact with nature is associated with increased stress, anxiety, depression, and other mental health issues. For instance, adolescents experiencing nature deficit are found to have lower resilience and higher levels of anxiety and depression [20]. Similarly, urban residents with limited access to green spaces report higher levels of stress and poorer mental health outcomes [72].

Light Pollution

Light pollution, defined as the excessive or misdirected artificial light at night, is a rapidly growing and concerning environmental issue. It disrupts natural light cycles, which are crucial for the behavior, physiological functions, and biological rhythms of countless living organisms [46]. This disruption has far-reaching consequences, impacting ecosystems, human health, and our ability to observe the night sky.

This pollution reduces the visibility of stars, with the effect being so pronounced that in urban areas, the number of visible stars can be drastically reduced. For instance, a child born in a place where 250 stars are visible might only see 100 stars by their 18th birthday due to increasing light pollution [42][23]. On a global scale, light pollution is increasing at an alarming rate, with the night sky becoming around 10% brighter each year globally. This exponential growth means that sky brightness could double roughly every seven or eight years, severely impacting stargazing and astronomical research [42][23].

The starry sky has historically been a source of inspiration and cultural significance. Light pollution erases this experience, depriving future generations of the ability to connect with the night sky and its wonders [42][77]. Regarding health concerns, light pollution disrupts circadian rhythms and melatonin production, leading to issues such as insomnia and other conditions [42].

2.4.2 Re-connection

Several studies have demonstrated the effectiveness of Virtual Reality in stress reduction and mental health improvement. These interventions have shown a substantial reduction in heart rate and psychological stress, similar to the effects of real nature exposure [83][64][14]. For instance, short-term programs that simulate natural environments have been shown to improve mood, reduce anxiety, and increase feelings of connectedness to nature [47][57][85].

Experiences that allow users to explore virtual forests or oceans can evoke similar psychological and physiological benefits as real nature exposure, including enhanced cognitive performance and reduced stress levels. While real-world nature offers unmatched benefits, simulations provide a valuable and accessible alternative for those unable to experience outdoor environments, highlighting the significant potential of nature simulations to bridge this gap effectively [11][66].

Villani and Riva (2008) found that simulated VR environments depicting nature scenes significantly reduced stress and enhanced positive emotions among participants, outperforming traditional video and audio interventions [78][83].

McGarry et al. (2023) demonstrated that exposure to a virtual beach scene during a 15-minute VR session led to decreased heart rate and reduced psychological stress in young adults [54][64].

Chan et al. (2021) discovered that a virtual forest environment with waterfall sounds relieved anxiety and improved mood among university students [14][64].

The Enable, Reconnect, and Augment (ERA) Framework posits that immersive simulations can enable nature experiences for those who cannot access real nature, help reconnect individuals with the natural world, and augment human-nature interactions by providing enhanced, immersive experiences [49].

Nature at Night & Stargazing

Engaging in nighttime activities like stargazing has many benefits for both people and the environment. A study by Bell et al. (2014) found that people with more years of stargazing experience felt a stronger connection to nature. This demonstrates that spending time stargazing can help build a deeper emotional bond with the natural world. These activities also significantly improve mental and spiritual well-being by encouraging social connections, personal growth, and feelings of awe and wonder. Participants reported enjoying the sense of community, learning new things, and experiencing the profound beauty of the night sky [9][6].

Stargazing also boosts physical activity during usually inactive evening hours, leading to better physical health. Participants mentioned becoming more aware of nocturnal wildlife, which can make them appreciate and care more about these species. Many people reported emotional benefits like relaxation and a greater sense of life's preciousness, which improved their overall quality of life [9].

Importantly, spending time in nocturnal settings fosters environmental stewardship, as individuals become more concerned with conserving these environments and engage in protective behaviors [9]. Another study found similar results, showing a strong positive link between feeling connected to the night sky and better mental health and happiness. People in areas with more light pollution felt less connected and were less likely to want to protect the night sky [6].

2.5 Hypothesis

Based on the information gathered, I can *hypothesize that creating an immersive Virtual Reality application that simulates a serene night under the stars in nature could significantly reduce stress and anxiety, enhance mental well-being, and foster a stronger connection with nature, even for urban dwellers.* By integrating realistic forest settings, immersive natural soundscapes, and detailed night skies, users will feel deeply relaxed and present in the virtual environment. Experiencing the beauty of stars and nature in this way could give people a deeper appreciation for the natural world. Comprehensive user trials and psychological evaluations will be conducted to assess the application's effectiveness in promoting mental health and reconnecting people with nature.

Chapter 3

Development

Creating a functional Virtual Reality application is a complex task that involves expertise in various fields. This process becomes more manageable with the help of different tools, making each aspect more approachable. For development, I used several key software applications: an Integrated Development Environment (IDE), a development engine to build the basic structure and functionality, 3D modeling software to create and manipulate the objects, sound editing software to refine the audio and image editing software to edit the textures and images for the 3D models and environments. Using these tools, I managed to streamline the creation process.

3.1 Tool Selection & Process

3.1.1 Engine

Why Unity? Unity was chosen as the engine for this project primarily due to its strong community support [1]. The abundance of tutorials and videos available makes it easier to create and troubleshoot any issues that arise during production. Another key factor is Unity's robust support for VR development. It is compatible with a wide range of headsets and offers built-in frameworks, examples, and in-depth documentation. These features make Unity an ideal choice for developing a VR application, providing both the resources and support needed to streamline the development process.

What is Unity? Unity is a powerful development platform designed for creating interactive and high-performance applications. Originally built for game development, Unity has expanded to support a wide range of applications, including mobile apps, simulations, VR, augmented reality, and more. It offers a comprehensive Integrated Development Environment (IDE) with various tools for designing, coding, and debugging applications. The intuitive interface features a visual editor that allows for easy drag-and-drop functionality. Unity primarily uses C# for scripting, providing a rich set of APIs that help developers write efficient and maintainable code. The Unity Asset Store is a vast marketplace where developers can access a wide variety of assets, such as 3D models, textures, sounds, and scripts, significantly speeding up the development process [69].

3.1.2 Object Modelling

Why Blender? Blender was chosen for its free and open-source nature, which ensures that there are no features locked behind paywalls. Additionally, its extensive community support makes it an invaluable resource. Despite the availability of paid alternatives, Blender remains a top choice for professionals due to its high quality.

What is Blender? Blender is a powerful, open-source 3D creation suite widely used in various fields such as animation, visual effects, 3D modeling, game development, and more. It supports the entire 3D pipeline, including modeling, rigging, animation, simulation, rendering, compositing, and motion tracking, as well as video editing and 2D animation pipeline. Known for its robust features and flexibility, Blender is favored by both professionals and hobbyists. It includes a highly advanced rendering engine called Cycles, which provides ultra-realistic rendering capabilities. Blender's active community and extensive documentation contribute to its continuous development and broad adoption in creative industries [25].

3.1.3 Sound Editing

Why Adobe Audition? Compared to other software I've used, Adobe Audition is behind a paywall. Despite this, I chose Audition primarily because of my familiarity with Adobe products and the high quality they offer. Although it was my first time using Audition, I quickly became comfortable with its basic functions due to its similarities with other Adobe applications. The intuitive interface and consistent design language made the transition smooth and efficient.

What is Adobe Audition? Adobe Audition is a professional audio editing software developed by Adobe Systems. It provides a comprehensive set of tools for recording, editing, mixing, and mastering audio content. Widely used in the music, film, and broadcasting industries, Adobe Audition supports multi-track editing and includes features such as noise reduction, audio restoration, and powerful effects [2].

3.1.4 Image Editing

Why Adobe Photoshop? I chose Adobe Photoshop primarily due to my familiarity with the software, but also because of its extensive range of features. It offers a comprehensive suite of capabilities that can handle almost any task, from basic adjustments to complex graphic design projects.

What is Adobe Photoshop? Adobe Photoshop is a professional image editing software developed by Adobe Systems. It offers a comprehensive set of tools for creating, editing, and enhancing images and graphics. Widely used in the photography, graphic design, and digital art industries, Adobe Photoshop supports advanced layer management and includes features such as photo retouching, digital painting, and powerful effects [3].

3.1.5 Integrated Development Environment

Why Visual Studio Code? I chose Visual Studio Code (VS Code) because it is a highly versatile IDE that I was already familiar with. Its flexibility and extensive customization options make it suitable for any language or framework I use.

What is Visual Studio Code? Visual Studio Code is a free, open-source code editor developed by Microsoft. It provides comprehensive support for a wide range of programming languages and development tools, making it a versatile choice for developers. Key features include an integrated development environment with built-in Git control, syntax highlighting, intelligent code completion, snippets, and debugging support. Additionally, its vast extension marketplace allows for customization and enhancement of the editor to meet specific development needs [56].

3.2 Legal & Professional Issues

My project contains multiple resources that were not created by me. One of the most significant components is the Sky Package, which was developed by the ICAM lab [26]. This package provides a functioning system for simulating time passage, latitude and longitude modifications, and high-quality renditions of stars through Unity's particle system. It significantly contributed to achieving the desired visual appearance of my project. Since this is a project made for our university, it falls under the Creative Commons Zero (CC0) license, allowing for free use without any restrictions.

Another asset that I did not create is the hands asset, which is the Oculus hand model provided by the guide I followed when setting up the XR environment [74].

For the models, I used pre-existing add-ons from Blender to create them. The textures for these models were sourced from a CC0 domain of textures [70], ensuring they are free to use without attribution. However, for audio samples, I used multiple sites [13][22]. While some of these samples were under the CC0 license, others required attribution under the Attribution 4.0 International license.

All the assets used in this project are appropriately linked and credited in the project's README file, ensuring compliance with their respective licenses and ethical guidelines.

In terms of legal and professional issues, I have ensured that my project adheres to all applicable laws and regulations regarding the use of third-party resources. Specifically, I have followed the guidelines set forth in the Creative Commons licenses and have provided appropriate attribution where required. Additionally, the project complies with the University of Timisoara's Code of Student Rights and Obligations and the Regulations on Professional Activity for Students in Undergraduate and Master's Programs[58]. This includes adherence to the principles of academic integrity, proper citation of sources, and respect for intellectual property rights.

Furthermore, while developing the project using C# in Unity, I adhered to the coding conventions established by Microsoft, the creators of C# [55]. These conventions ensure consistency, readability, and maintainability of the code, which are crucial for collaborative development and long-term project success.

By following these guidelines, I ensure that my project maintains high ethical standards and aligns with the University's commitment to academic excellence and integrity. The project has been developed in a manner consistent with the legal and professional expectations of the University of Timisoara, as outlined in the official regulations and standards [58].

3.3 Implementation

3.3.1 Unity

Having no prior knowledge in creating VR games, the first step was to search the documentation and other sources for the initial setup requirements, including the connection with the VR headset. The editor version used for this project was Unity 2021.3.33f1, which is a long-term support (LTS) release. This version was chosen due to its stability and the abundance of available plugins, tutorials, and tools that facilitate development.

Instead of using the prebuilt Virtual Reality scene available in the editor, I chose to start with a basic 3D project using the Universal Render Pipeline (URP). This approach allowed me to better understand how the Unity XR Interaction Toolkit works. The URP was selected for its ability to provide enhanced visual improvements, while the High Definition Render Pipeline (HDRP) was not chosen due to the limitations of VR headsets. Additionally, it was necessary to configure the editor to support Android builds, as Android is one of the primary platforms for powering Virtual Reality experiences [69].

Once the project was created, one of the first steps was selecting the Plug-in Providers. I chose OpenXR version 1.9.1 because it simplifies development with its cross-platform compatibility. This choice future-proofs my project, reduces development effort, optimizes performance, and benefits from strong community and industry support. OpenXR also offers extensibility and provides a unified development experience across various XR devices [69][74].

To test the `XR Origin`, I started by placing a simple plane in the scene, which also serves as the area where users can teleport. I applied a specific material to this plane to indicate the teleportation zone. In the Main Camera, I added a `Tracked Pose Driver` to enable the camera to follow the user's head movements. This setup was essential to test the VR connection with Unity [74].

The next steps involved creating the Right and Left Controllers. These are initially empty GameObjects, to which I added the `XR Controller` component. Using the comprehensive starter assets from the XR Interaction Toolkit, I assigned the `XRI Default Input Actions` to these controllers. To complete the setup, I added an `Input Action Manager` to the scene and assigned the `XRI Default Input Actions` to it. This thorough configuration ensures that Unity recognizes and knows how to respond to the various actions performed by the user [74].

For the hands, I decided to use the high-quality hand models from Oculus to save significant time on hand animation and modeling. These models are clean and simple, fitting well with the game's aesthetic and setting. The next step entailed creating a robust script component to handle the hand animations based on user actions. The script effectively uses `Input Action References` to accurately track and respond to these actions [74].

The script's logic involves continuously checking for actions in the `Update` function. When an action occurs, a hand animator function is called to display the corresponding hand animation, such as a pinch. The same process is applied for the grip animation [74].

After adding hand animations, the next step was to implement continuous movement. First, I added the `Locomotion System` to the `XR Origin` to enable the game to recognize the player's movements from the headset. Then, I included a `Continuous Move Provider` component and a `Character Controller` [74].

The `Character Controller` sets how the player should react to movement inputs and collisions. For the `Continuous Move Provider`, I set the forward direction source to the Main Camera and assigned the left and right hand move actions, using the default input action references from the XR Interaction Toolkit [74].

For teleportation, I started by adding a teleportation system. The `Ray Interactor` consists of two essential components: the `XR Controller` and the `Ray Interactor` itself. For the controller, I added the default `XRI Action Input`, allowing the ray to follow the hand movements precisely. Next, I added a `Teleportation Provider` component, which references the `Locomotion System`, ensuring smooth and efficient teleportation mechanics [74].

I then added a `Teleportation Area` component to the plane, enabling teleportation within the designated area. To improve targeting, I modified the ray to use a *Bezier* curve for smoother and more precise aiming. At the end of the ray, I added a reticle by modifying a cylinder to mark the exact location where the player will teleport. I removed the collider from the cylinder and applied a transparent material to the reticle for better visibility [74].

Having created the basic setup for the VR application, I will now shift my focus towards the model creation and the tools used in this process. Later on, I will discuss the integration of the rest of the application.

3.3.2 Blender

There are three main tasks to be done in Blender: **Pine Tree**, **Bush** and **Rocks**

To expedite the modeling process, I have chosen to use the Sapling Tree Generator and the Rock Generator add-ons. These add-ons provide numerous options for customization, enabling the creation of models tailored to specific tastes and requirements. It was my first time working with them, so I needed reliable sources on how they work.

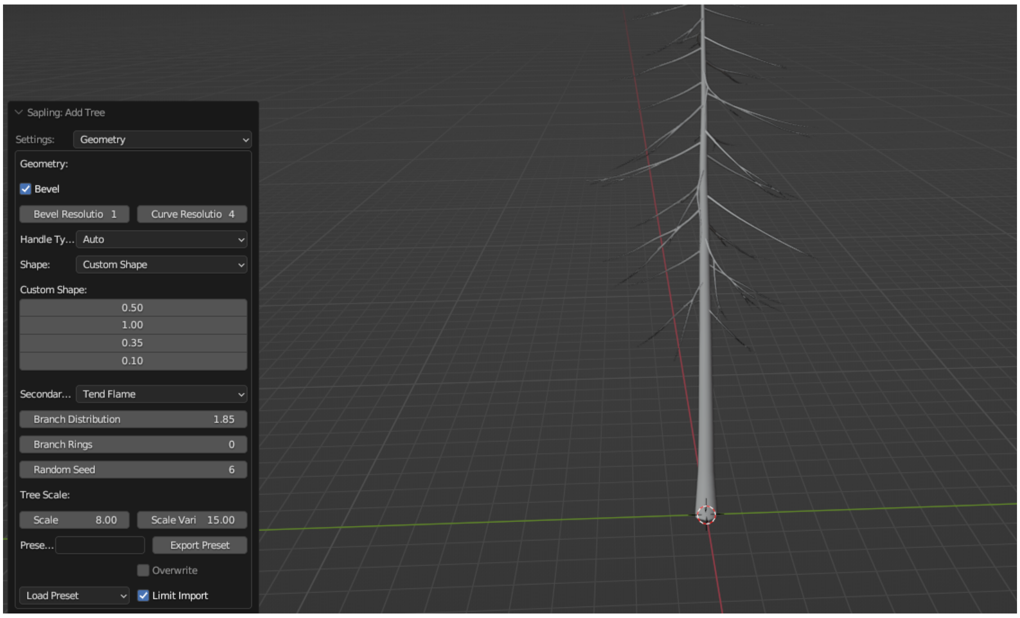


Figure 3.1: Geometry Settings for Pine Tree.

The default scale of the *Douglas Fir* is too large and obstructs the sky, making it difficult to achieve clear star viewing. I then play around with the random seed generator until I find one that aligns with my preferences. This step is particularly helpful for generating settings and combinations that I would not have considered otherwise, pushing me to try other settings variations.

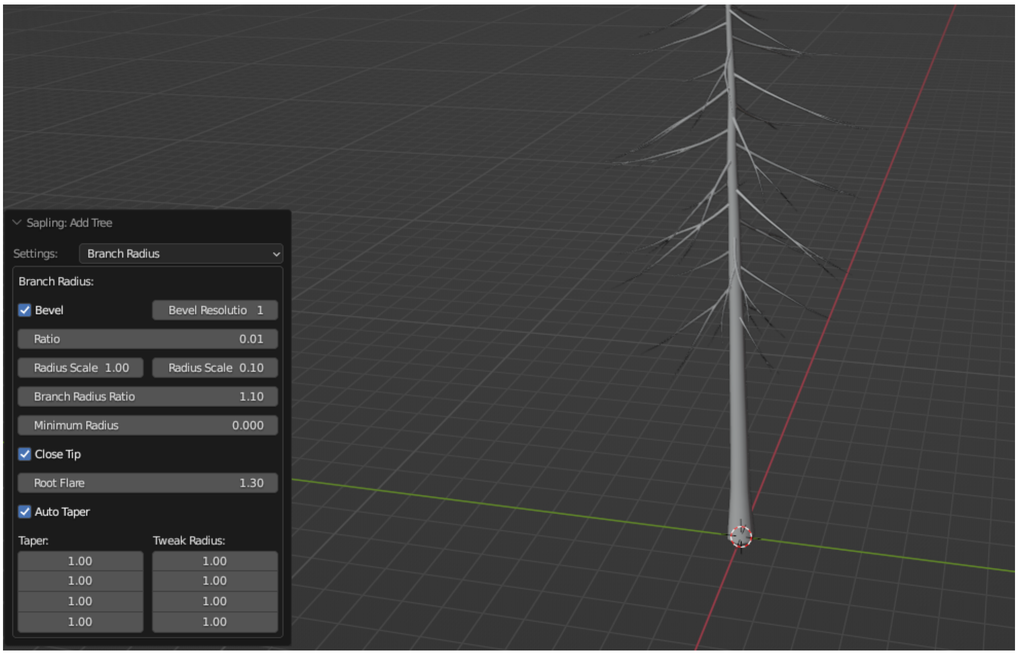


Figure 3.2: Radius Settings for Pine Tree.

Next, I'll modify the branch radius to make the tips slimmer for a more refined and realistic look while keeping the base sturdy. I'll also flare the root to avoid a straight, unnatural appearance. In the Branch Splitting tab, I set the levels to 3 for a balance of realism and performance. Additionally, I'll adjust the rotate angle and variation to make the branches point upwards, enhancing realism. The specific adjustments will vary with each trial based on the appearance of the leaves [17].

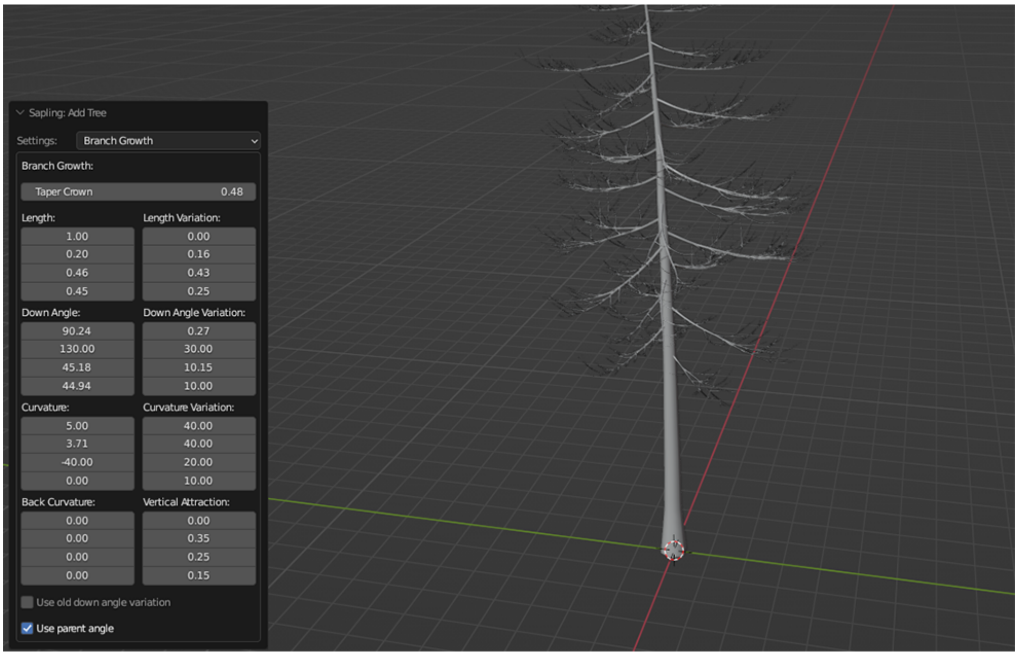
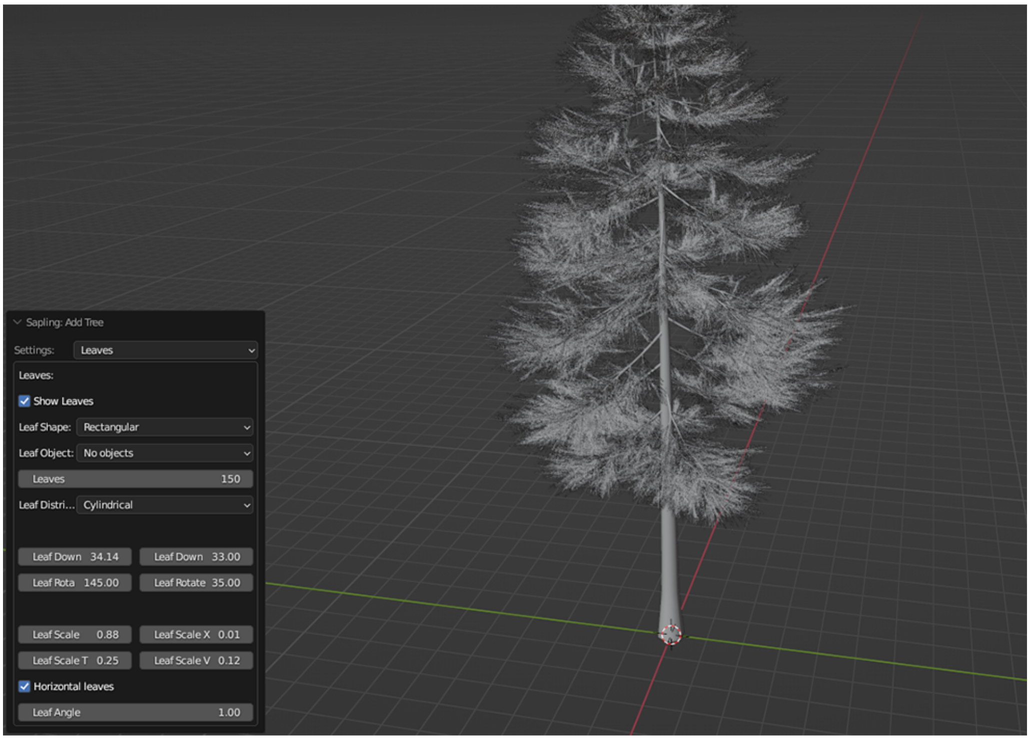
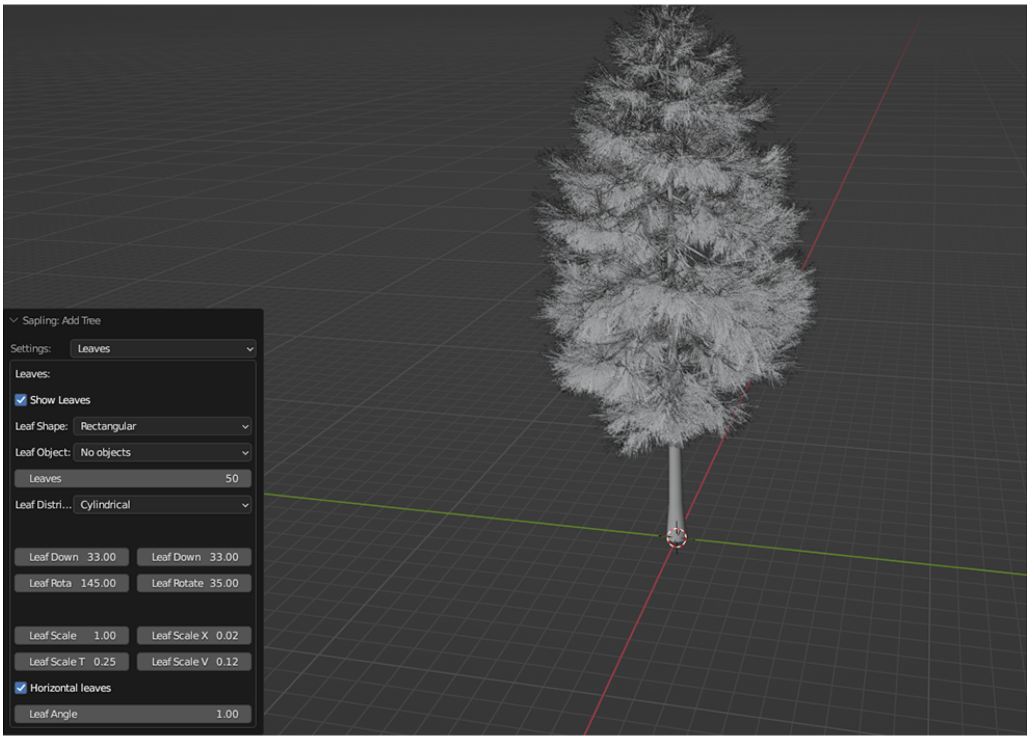


Figure 3.3: Growth Settings for Pine Tree.

In the Branch Growth section, I usually modify the curvature and the angles to give a more upward look to the tips of the branches. For the leaves, I select a rectangular shape to mimic needles, adjusting the leaf rotations and scale accordingly [17].



(a) Level 3



(b) Level 4

Figure 3.4: Comparison Level 3 and 4 Branches for Pine Tree.

To fill up the tree, I experimented with adding level 4 with fewer leaves and level 3 with more leaves, and I found that level 4 with low bevel and fewer leaves provided the best results. These are the most common changes I make to achieve the desired look.

After finalizing the tree, I would consider adding a bevel if the polygon count is not too high. However, I found that beveling can be too demanding for the VR headset, so I usually keep it at the default setting.

The next step in the process is transforming the tree into a mesh. This is necessary because Unity accepts only meshes, and it also enhances performance. Transforming the tree model ensures compatibility with Unity and allows for better optimization in real-time applications.I would also apply and name materials to the models to facilitate easier manipulation in Unity.

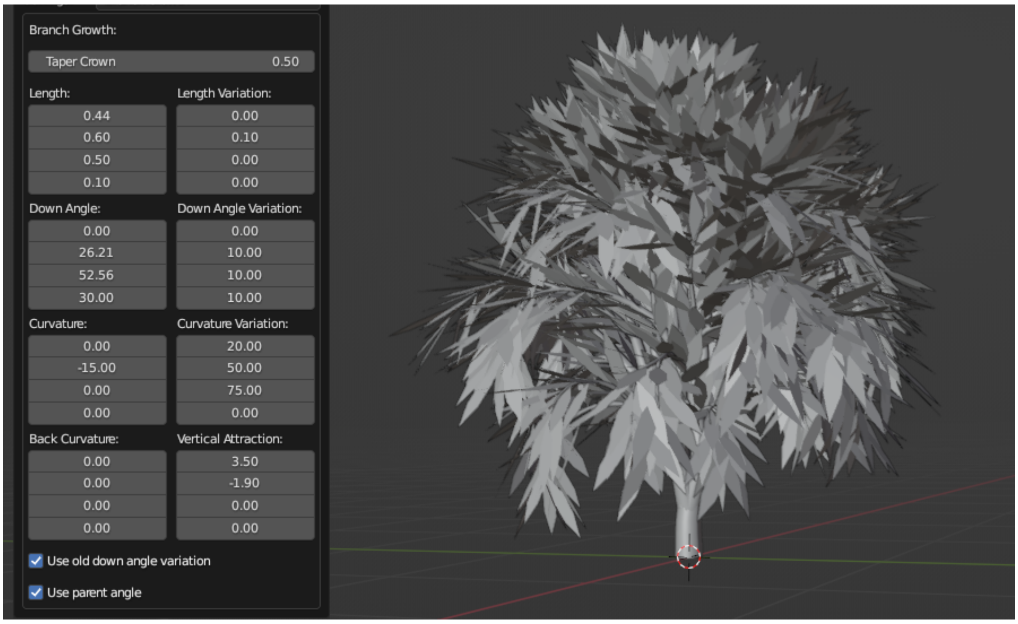


Figure 3.5: Growth Settings for Bush.

The same process applies for the bushes but with some important changes. This time, I am using the Callistemon because it is similar to a normal bush. I am scaling it down to create a small bush, keeping the other default settings except for branch growth. I will try to shorten the base of the tree as much as possible.

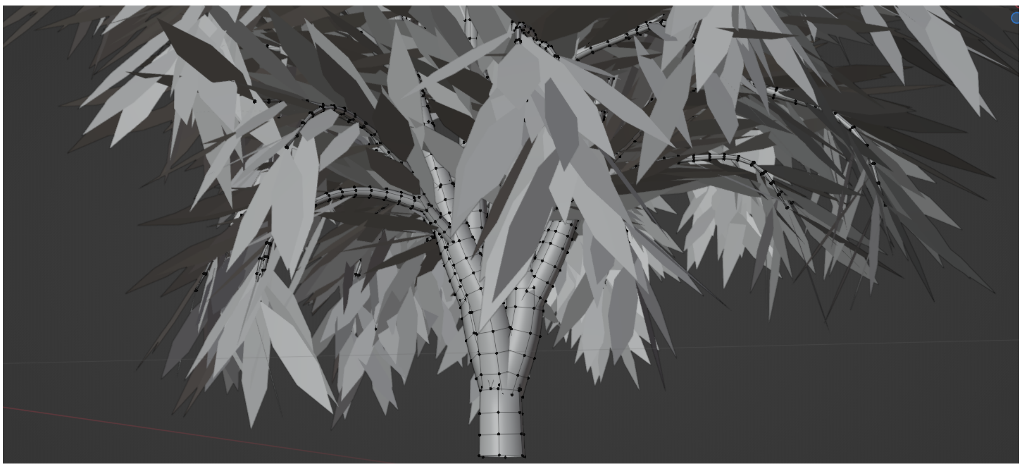


Figure 3.6: Growth Settings for Bush.

Apart from this, there are not any noteworthy changes in the Sapling menu. However, I still need to adjust the base length. After transforming the model into a mesh, I will enter edit mode. In node mode, I will select the entire base and shorten it. Finally, I will create the materials as mentioned above.

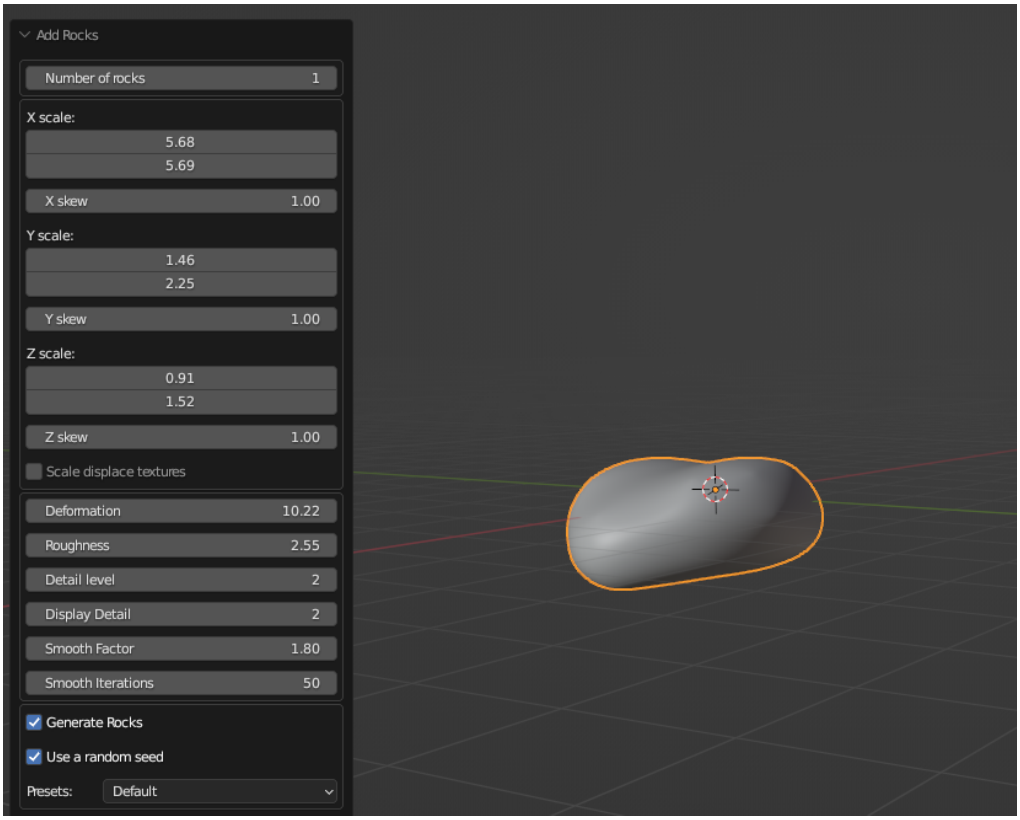


Figure 3.7: Rock Settings.

For the rocks, I used the Rock Generator add-on. My goal was to produce a variety of stones with two main attributes: pointy and smooth. Starting with this base, I experimented with the XYZ scale and skewness to generate rocks with different shapes. For added variety, I applied deformation, using roughness for the pointy rocks and adjusting the smooth factor and iteration for the smoother ones. To maintain performance, I kept the detail level moderate, ensuring that the number of polygons would not negatively impact the game.

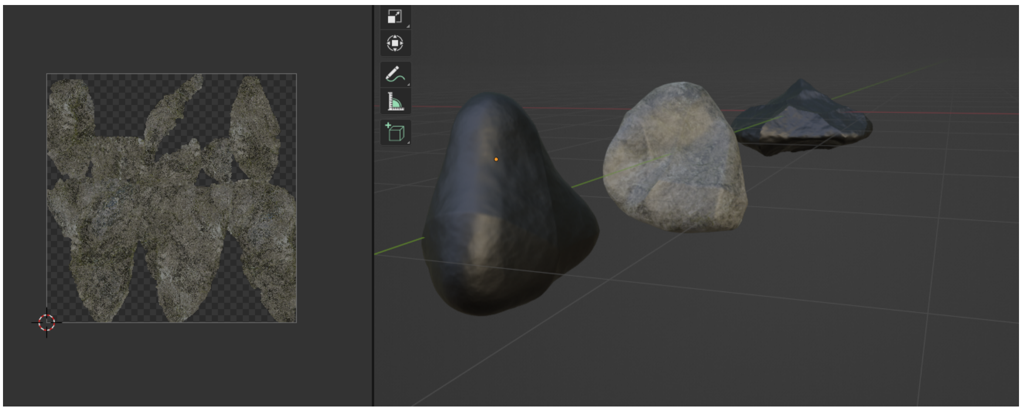


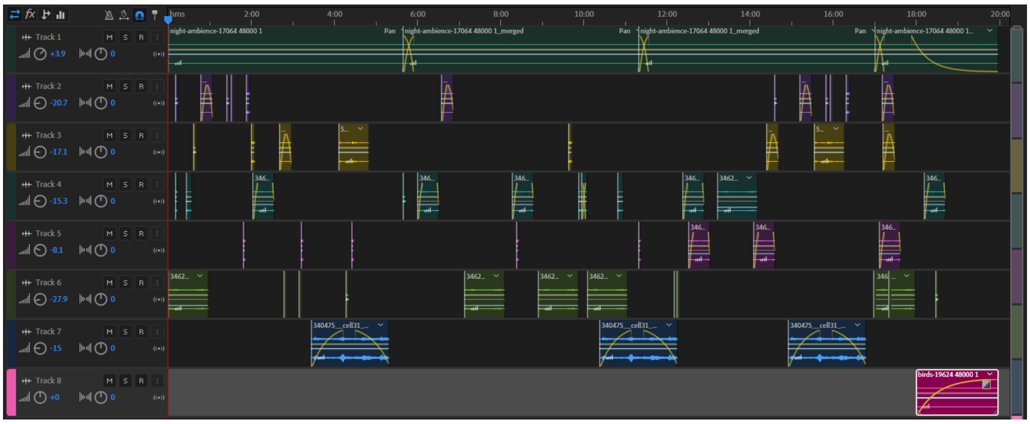
Figure 3.8: Rocks Texture.

Since the rocks are single objects, I can convert the texture-modified output in Blender into an image that can be used as the actual texture for the rocks inside Unity. First, I'll unwrap the model to ensure the texture maps correctly onto the rock surface. Then, I'll apply the desired textures and shading within Blender, bake the texture to generate a new image file, and export this image. This process allows the customized texture created in Blender to be used effectively within Unity, ensuring a consistent and high-quality appearance for the rocks in the game environment [73].

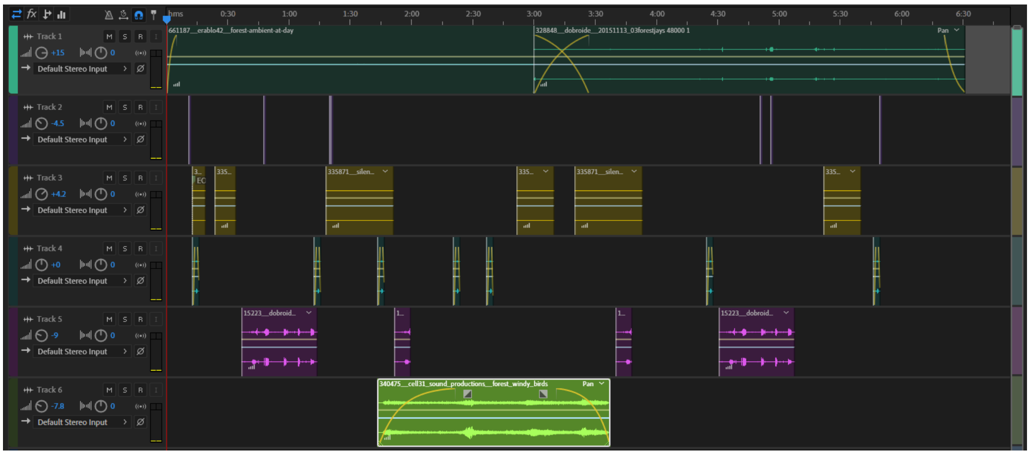
For the trees and bushes I'll apply the textures to the materials in Unity. All the models then are exported as FBX files fit for Unity use.

3.3.3 Adobe Audition

The process itself is not complicated, but it is time-consuming. The first step involves finding a base sound that fits either daytime or nighttime. For nighttime, I aimed to find a base filled with cicadas or crickets, which I consider the epitome of a relaxing summer night. For the daytime, I sought a base that captured the essence of midday, featuring the gentle sounds of birds, insects, and the soft rustling of the breeze.



(a) Night Sounds.



(b) Day Sounds.

Figure 3.9: Audition Multitracks.

Once I found suitable base sounds, I began searching for additional sounds to layer over them. This process involved a lot of trial and error—adding, removing, and adjusting sounds to see how they fit into the overall atmosphere. This was particularly time-consuming towards the end, as I would listen to large chunks of the soundscape to ensure cohesion and achieve the desired effect. In some parts, I aimed to add a narrative element, such as the build-up to strong winds causing wood to crack or birds communicating with each other, to enhance the immersive experience and create a more dynamic sound environment.

For the layered sound bites, I chose a variety of elements, including crickets, breaking tree branches, mockingbirds, wind, the rustling of bushes, wood cracking, owls, crows, and woodpeckers.

Ultimately, I created two soundscapes: a 20-minute main forest night scene and a 6-minute daytime scene used purely for the experiment.

In terms of actual editing, my primary focus was on noise reduction and sound level adjustments for each layer. I aimed to keep the recordings as sanitized as possible by cutting out unwanted noise. For each sound layer, I carefully modified the sound levels based on how intrusive the sound was and the distance I wanted to simulate. The contribution to the overall atmosphere was also a significant factor in these adjustments.

For the longer samples, I performed some cutting to introduce a wider variety of sounds without needing to use new versions. This approach allowed me to create a more dynamic and engaging soundscape while maintaining consistency in the audio elements. For the nighttime sound, I also added a transition towards the end to morning sounds, like birds chirping, since in-game it reached close to sunrise.

The resulting track is exported in MP3 format to compress and keep it to a lower size.

3.3.4 Adobe Photoshop

The process varied significantly depending on the specific requirements of each task. Some tasks involved modifying billboards used for backgrounds in the scenes to creating gradients that would be used alongside the billboards. Additionally, the process included converting texture formats to meet compatibility standards for different platforms and purposes, which is essential for maintaining image quality and performance. Simple editing of images was also a common task, involving adjustments such as cropping, resizing, color correction, and other modifications necessary for the experiments.

3.3.5 Visual Studio Code

Akin to any other IDE, VS Code was used for code editing. In my case, I utilized it mainly for scripting components to create functionalities for the XR model, developing the billboard forest that surrounds the scene, modifying the Sky Package to suit my specific needs, and implementing various other small quality-of-life scripts. The integration that Unity offers with VS Code sped up the editing process.

3.4 Integration

After completing the base setup of the XR scene, creating the models, mixing the background sounds, and getting the rest of the needed assets, the final step in the development process is to integrate all these elements to create the game.

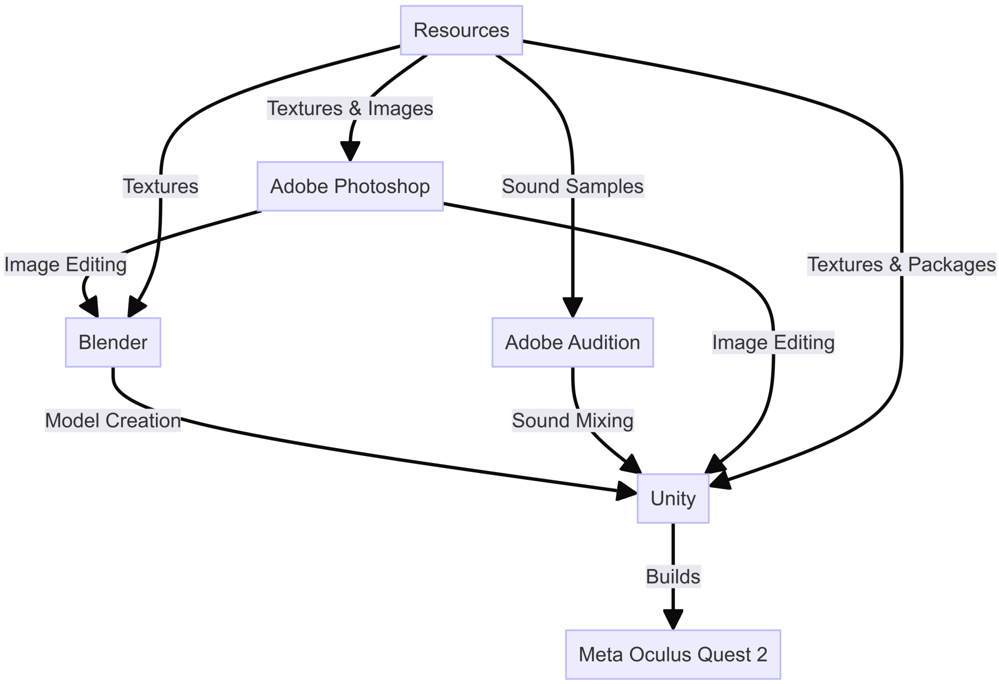


Figure 3.10: Workflow.

3.4.1 Terrain & Models

Terrain In the Unity scene, I'm replacing the test plane with a terrain object, the terrain objects offers more options like raising and lowering of the terrain, placing of trees and addition of details. Initially, I experimented with different ground of textures that were made of leaves, but I ultimately chose a grassy terrain that has sparse grass patches, allowing the underlying dirt to show through.

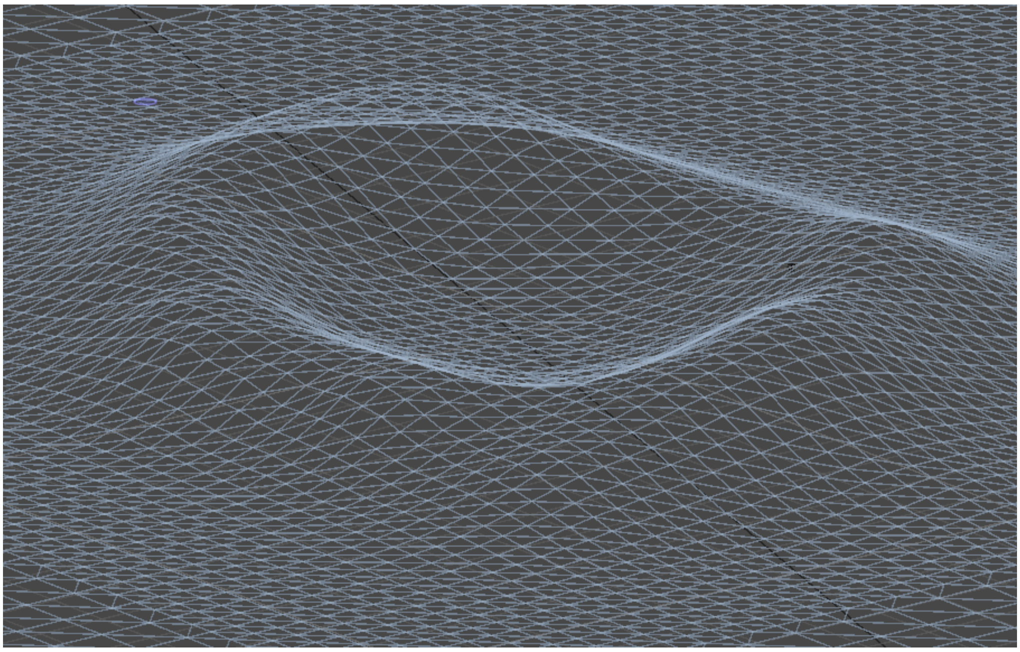


Figure 3.11: Wire-frame Hills.

After applying the texture, I sculpted hills around the forest area to create a natural boundary that conceals the limited world.

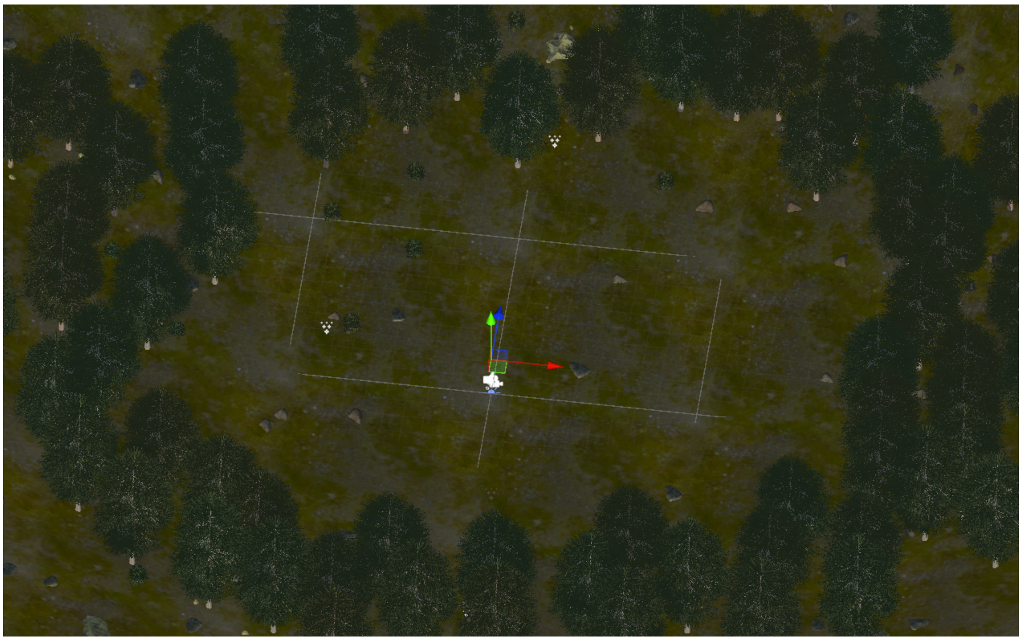


Figure 3.12: Trees, Rocks and Bushes.

Trees To create a realistic and immersive forest environment without compromising performance, I strategically placed tree models around the player using the terrain object's tree category. Initially, the tree models lacked textures, so I assigned two distinct materials to them: one for the bark and another for the leaves. I selected a whitish bark texture and dark green leaves to accurately represent the appearance of real-life pine trees.

For the shaders, I utilized the "SpeedTree8_PBR shader" from the Universal Render Pipeline (URP), which enabled me to apply the appropriate textures to each material effectively. This approach ensured that the trees not only looked authentic but also maintained optimal performance within the game environment.

Rocks The process of incorporating rocks into the terrain was more straightforward compared to the trees. I placed the rocks in the details section of the terrain editor and then used the painting tool to distribute them across the landscape.

To ensure consistency and visual harmony, I used the same "SpeedTree8_PBR shader" for the rocks as well. This shader proved to be versatile and well-suited for the rock material. Since the texture for the rocks was pre-mapped in Blender, I was able to seamlessly apply it within Unity, resulting in a natural and cohesive appearance that enhanced the overall aesthetic of the terrain.

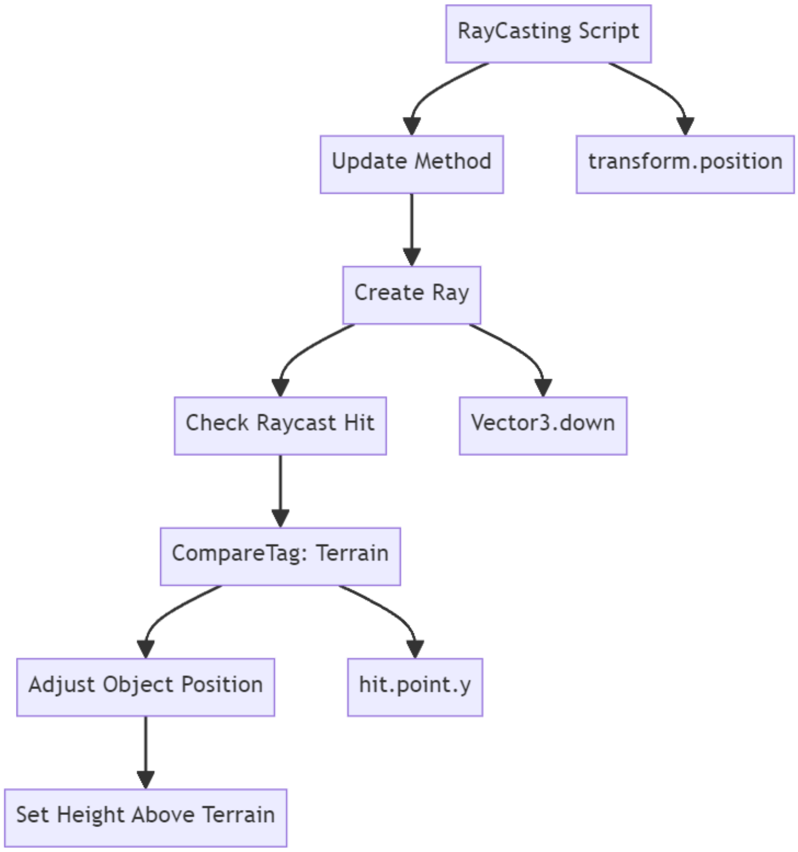


Figure 3.13: RayCasting Component.

Bushes For the bushes, I followed the same process as with the pine trees. Additionally, I wrote a ray casting script to enable accurate terrain-following during manual placement by checking the terrain collider. This RayCasting script ensures that an object remains at a consistent height above the terrain in Unity. Every frame, it casts a ray from a point 500 units above the object, straight downwards. If this ray hits an object tagged as "Terrain", the script adjusts the object's Y position so that it stays at the specified `heightAboveTerrain` above the point where the ray hit the terrain.

After placement, I grouped the bushes under an empty GameObject for better organization and management.

Boundaries To ensure the player stays within the forest zone, I manually placed invisible walls around the perimeter of the forest. These walls have colliders to prevent the player from passing through them. This was accomplished by creating Cube objects, editing them to form wall sections, and then applying a BoxCollider and a material that made them invisible. They were placed manually to give a unique shape to the perimeter.

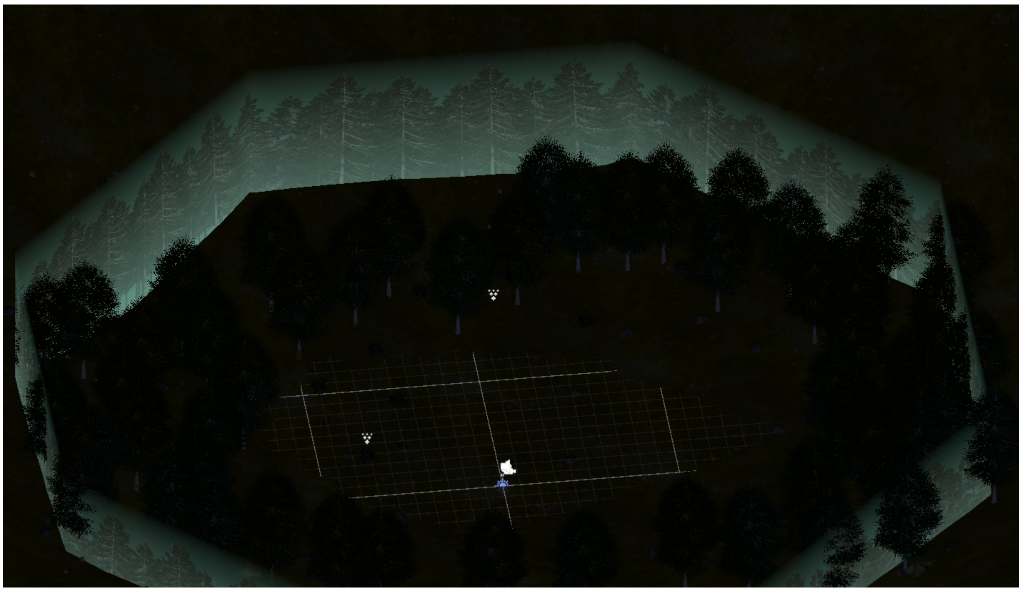


Figure 3.14: Billboard Octagon.

Billboards Next, I added billboards surrounding the forest to enhance performance. First, I created a scene in Blender with the tree models and rendered a side view of the scene. In Photoshop, I created a gradient matching the fog color—a white-blue inspired by how old games used to hide distant objects. Once in Unity, I combined the two images into a sprite, which I then turned into a prefab. A script was created to automatically size and resize the billboards around the center of the map based on input. This feature is only in the *Night Scene*.

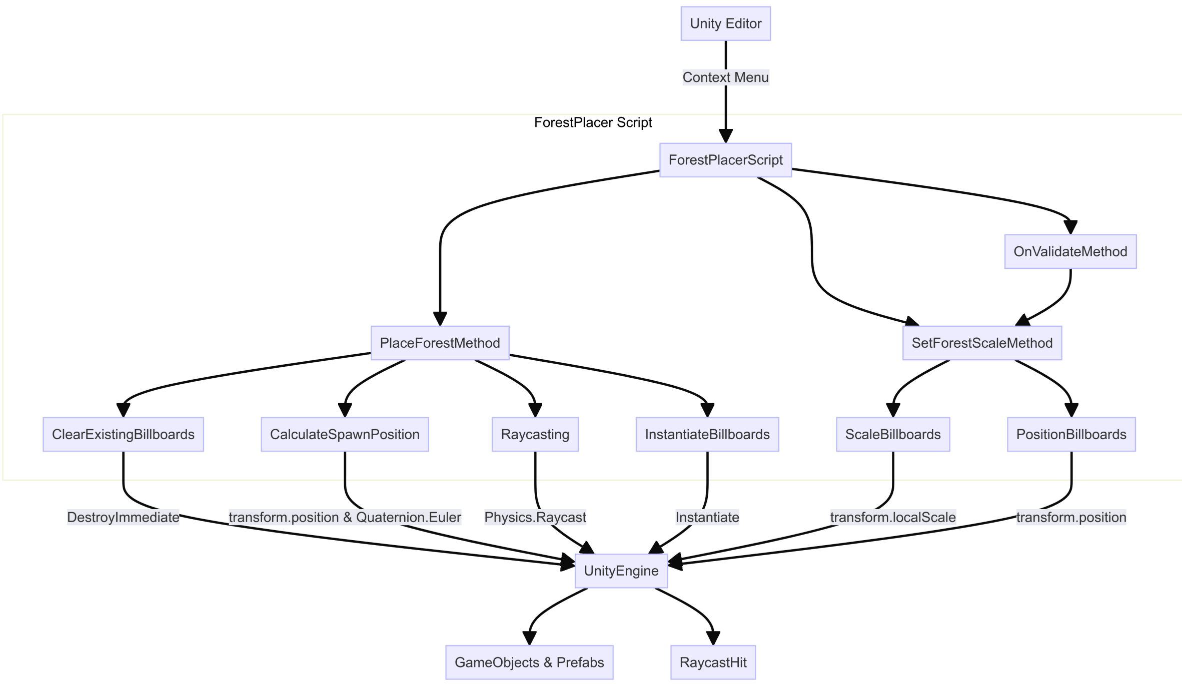


Figure 3.15: Forest Placer Component.

The `PlaceForest` method, triggered via the context menu, clears existing billboards, initializes placement variables, and uses a loop and raycasting to position eight billboards around a central point. The `SetForestScale` method, also context menu-triggered, iterates through the billboards to adjust their scale and position based on user-defined parameters. The `OnValidate` method automatically adjusts billboard scales when component values are modified in the Unity Inspector, ensuring correct placement if the forests list contains exactly eight billboards.

Grass Shader To enhance the scene's depth, I added grass to the terrain by creating a custom shader. I began by selecting the grass texture, and by that I mean foliage. Using Unity's Shader Graph I firstly manipulated the vertex positions to simulate swaying grass by incorporating sine functions and time variables, giving the grass a dynamic, wind-blown effect. I then applied the grass texture using UV coordinates, carefully adjusting the color and translucency to ensure a natural look. By combining these elements, the shader brought the grass to life, adding a vibrant, realistic layer to the scene.

3.4.2 Sky

The Sky package is an existing project developed in the ICAM [26] laboratory. It includes all the necessary functions for my use case, but some modifications are required to better suit my needs.

Currently, the package allows users to change the time of day, latitude, and longitude through input sliders. However, I need these parameters (hours, longitude, and latitude) to be editable only within the editor. Additionally, I want the night period to start at 00:00 and end at 06:00, and the day period to span from 14:00 to 20:00. Furthermore, I require the simulation time to progress in 20-minute intervals.

The simulation adjusts in-game time based on real-world elapsed time. Given that dayDurationInSeconds = 1200, representing a full day from dawn to dusk in the game, equivalent to 20 real minutes, we use a factor of 6 to simulate time, meaning one real-world day is equivalent to six hours of in-game time.

To calculate the number of in-game hours per second of real time:

$$\frac{x \text{ In-Game Hours}}{y \text{ Real Seconds}} = \frac{6 \text{ In-Game Hours}}{1200 \text{ Real Seconds}} = \frac{1 \text{ In-Game Hours}}{200 \text{ Real Seconds}}$$

Then, for 20 real minutes, which is $20 \times 60 = 1200$ Real Seconds:

$$1200 \text{ Real Seconds} \times \frac{1 \text{ In-Game Hours}}{200 \text{ Real Seconds}} = 6 \text{ In-Game Hours}$$

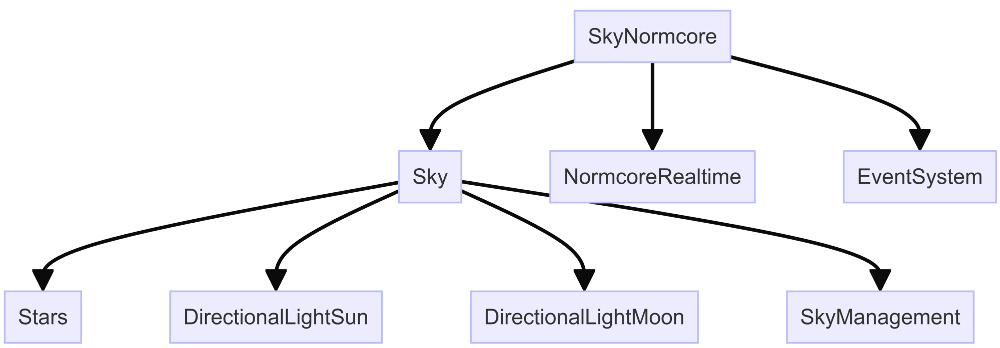


Figure 3.16: Sky Package High Level.

The `SkyNormcore` object is made out of 3 other objects: **Sky**, **NormcoreRealtime** Version 2.9.5, **EventSystem**

`NormcoreRealtime` is a component that manages connections to rooms and synchronizes data across clients in real-time. `EventSystem` is used to handle networked events, enabling real time interaction and communication between parts of the application.

Why Normcore? Normcore was used for its networking capabilities, enabling the application to connect to the internet to obtain accurate location data and time information. It also offers options for multiplayer development within the app.

What is Normcore? Normcore is a high-performance networking library designed to facilitate real-time, multiplayer experiences for various applications, particularly in gaming and virtual reality. It provides developers with the tools to synchronize states and messages across multiple clients efficiently, ensuring smooth and responsive interactions in a shared environment. Normcore achieves this through features like server authority, client prediction, and delta compression, enabling robust and scalable networked applications [60].

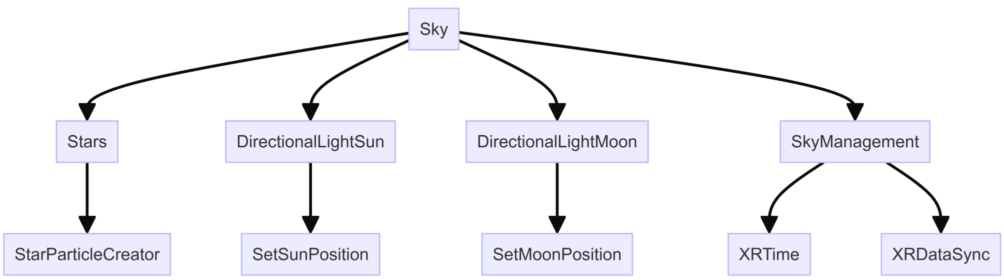


Figure 3.17: Sky GameObject.

Sky GameObject The `Sky` object contains all the objects and scripts that make the sky work this object itself goes in more depth: **Stars**, **Directional Light Sun**, **Directional Light Moon**, **Sky Management**.

The `Stars` GameOject contains a particle system that sets up the stars and `StarParticleCreator` which generates and updates the star field.

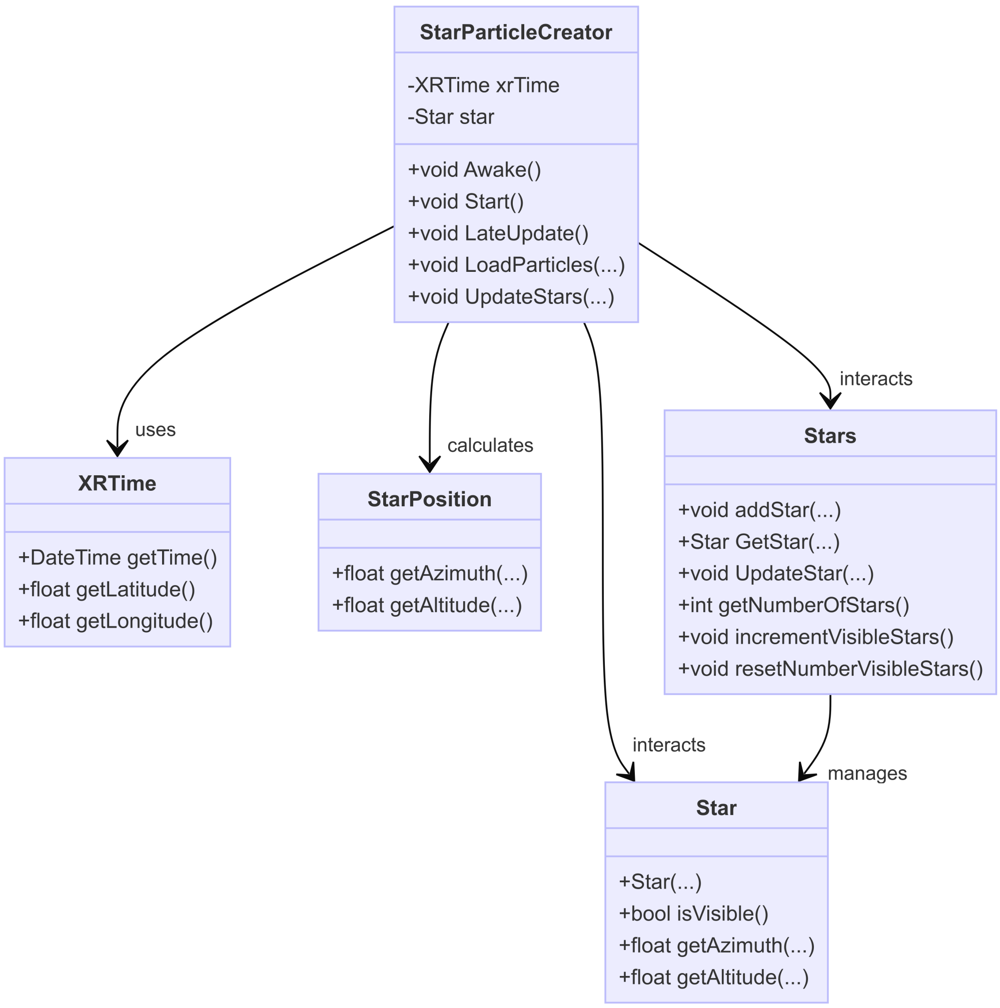


Figure 3.18: StarParticleCreator Class Diagram.

The `StarParticleCreator` class is designed to generate and update a star field as particles based on star data and the current time and location. It initializes the particle system with a specified maximum number of particles in the `Awake` method. The `Start` method reads star data from a resource file and sets up initial star positions using the current time, latitude, and longitude. The `LateUpdate` method continuously updates the star positions if the time or location changes. It uses the `StarPosition` class to calculate the altitude and azimuth of stars and assigns colors to stars based on their spectral classification.

The `StarPosition` class provides static methods to calculate the position of stars (azimuth and altitude) based on their celestial coordinates and the observer's location and time. The `getAzimuth` and `getAltitude` methods convert right ascension and declination to horizontal coordinates.

The `Star` class encapsulates properties of individual stars, such as position, magnitude, and color, with methods to get and set these properties. The `Stars` class manages a list of `Star` objects, providing methods to add, update, and retrieve stars, ensuring that the star field data is accurately maintained and updated.

The `XRTime` class is used to retrieve the current time, longitude, and latitude necessary for accurate star position calculations within the virtual environment.

The `Directional Light Sun` GameObject includes a Light component that provides sunlight. `setSunPosition` is used to update the sun's position.

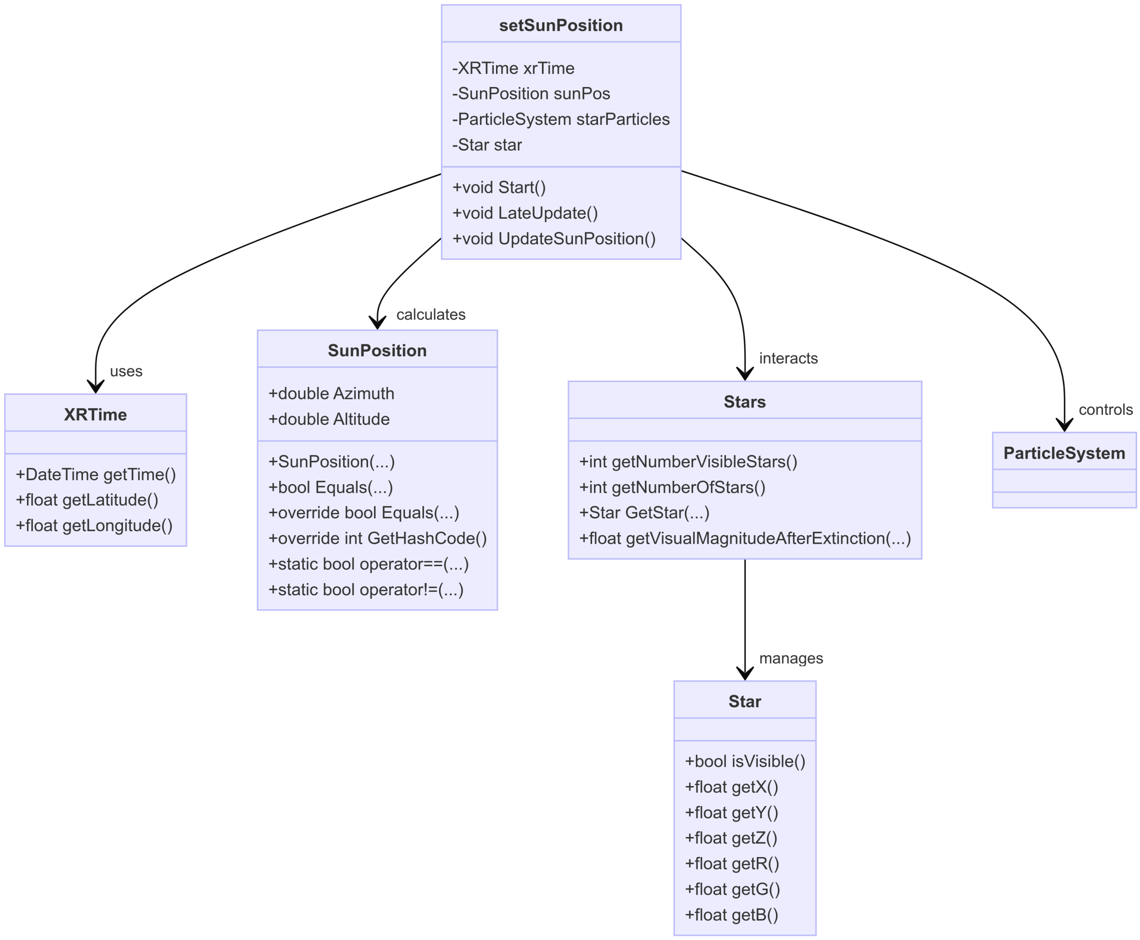


Figure 3.19: setSunPosition Class Diagram.

The `setSunPosition` class manages the sun's position in the Unity environment by leveraging real-time data to adjust environmental effects and star rendering.

It initializes references to the time management object, meteor, and star particle system in the `Start` method. The `LateUpdate` method periodically updates the sun's position based on the current time and location, using the `XRTime` class to get the necessary real-time data.

The `UpdateSunPosition` method calculates the sun's azimuth and altitude using the `SunPosition` struct from the `SunCalcNet.Model` namespace, adjusting the lighting effects and the rendering of stars based on the sun's altitude. It also controls a particle system that represents the stars, adjusting their visibility and fading to create a realistic sky environment.

The `Directional Moon Light` GameObject includes a child component called the Moon prefab. Within the GameObject, there is a Light source responsible for providing the moon's illumination. Additionally, the method `setMoonPosition` is used to update the moon's position.

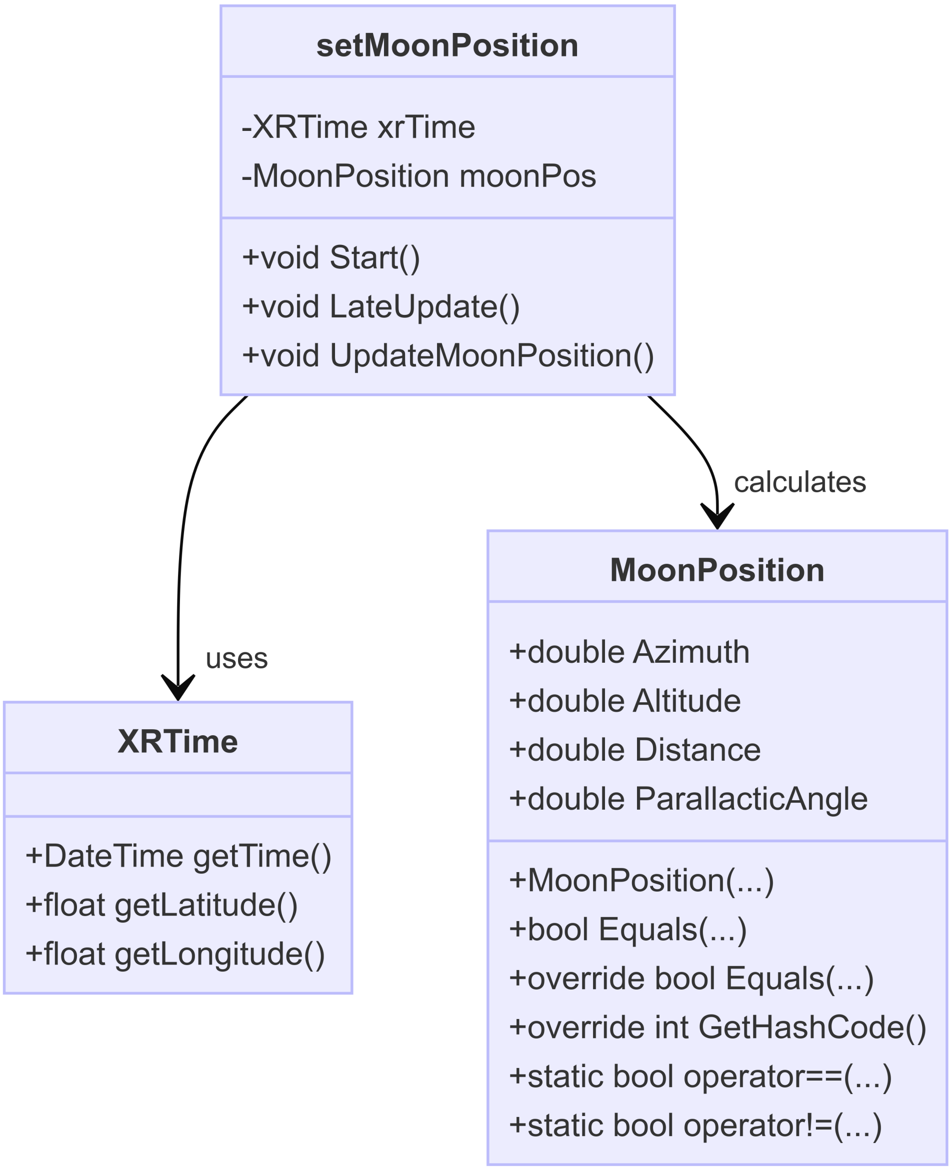


Figure 3.20: setMoonPosition Class Diagram.

The `setMoonPosition` class is designed to manage the moon's position in the Unity environment based on real-time data, similar to the `setSunPosition` class.

It initializes the `XRTime` component in the `Start` method to get the current time, latitude, and longitude. In the `LateUpdate` method, it periodically updates the moon's position if the time or location changes.

The `UpdateMoonPosition` method uses the `MoonPosition` struct from the `SunCalcNet.Model` namespace to calculate the moon's azimuth and altitude based on the current time and location.

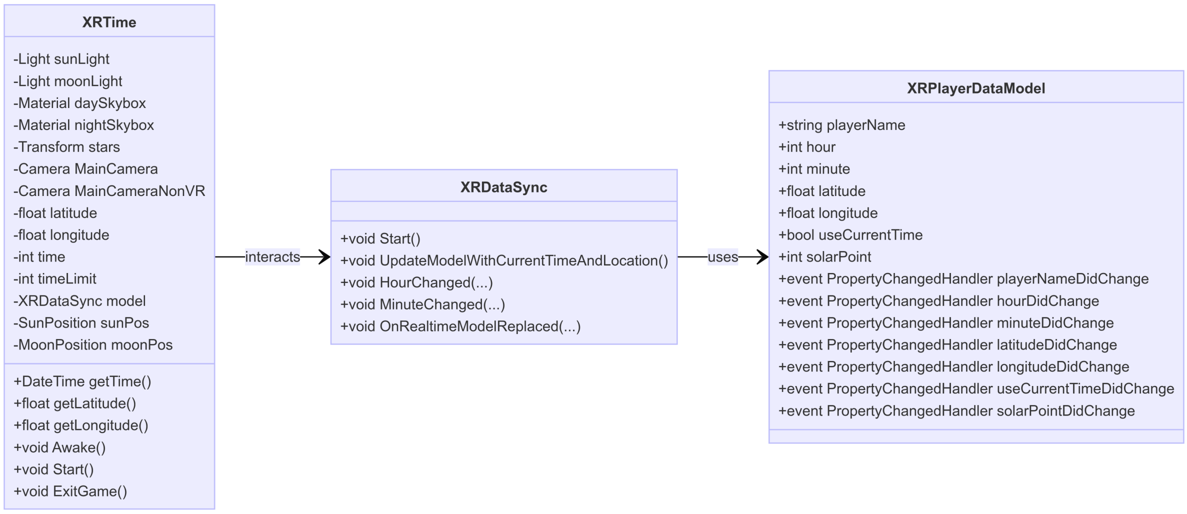


Figure 3.21: XRTime Class Diagram.

The `XRTime` class manages the simulation of time and geographical location within the Unity environment, providing real-time updates to various environmental elements. It initializes references to essential components such as the sun and moon lights, skyboxes for day and night, and camera transforms in the Awake method. The Start method sets the initial skybox. The primary method, `getTime`, calculates the current simulated time based on the elapsed real-time and a predefined day duration. This class also provides methods to retrieve the latitude and longitude, which are used to accurately position celestial objects in the scene.

The `XRDataSync` class synchronizes time and location data across networked environments using Normcore's real-time framework. It periodically updates the data model with the current system time and predefined geographical coordinates. The `Start` method sets up an invocation to regularly call `UpdateModelWithCurrentTimeAndLocation`, ensuring that the latest data is propagated. This class listens for changes in the data model properties, such as hour and minute, and handles these updates to ensure consistency across connected clients.

The `XRPlayerDataModel` class represents the data model for player-specific information, including time and geographical coordinates. It uses Normcore's real-time serialization to synchronize properties like hour, minute, latitude, and longitude across networked clients. The class includes events to handle changes in these properties, allowing other components to respond to updates. This model ensures that all connected clients have a consistent view of the player's time and location, facilitating synchronized environmental effects and interactions in a multiplayer setting.

Changes The main changes involved replacing the UI GameObject with the `SkyManagement` object, which contains `XRTime` and `XRDataSync`. `XRTime`, originally `XRGUI`, was modified to focus on the simulation of astronomical object positioning and the passage of time. This script now directly calculates the progression of time using a simulated day-night cycle, updates the positions of the sun and moon accordingly, manages skybox transitions, handles the main camera configuration based on VR status, and includes a game exit condition based on a predefined time limit.

In contrast, `XRGUI` primarily handled user interactions through UI elements and network synchronization, updating the scene based on inputs from sliders, dropdowns, and buttons. XRUIDataSync synchronized these UI changes across networked instances. Now, XRTime is dedicated to real-time simulation and positioning, while XRGUI managed interaction and synchronization.

The XRDataSync script was adjusted to focus on automatically updating the networked model with the current system time and predefined location values, simplifying synchronization. This script periodically invokes updates through the UpdateModelWithCurrentTimeAndLocation method, ensuring the model reflects the current time and fixed coordinates. This change eliminates the need for UI elements, contrasting with XRUIDataSync, which synchronized various UI sliders and text fields with the model, dynamically updating the UI. Consequently, XRDataSync offers a more automated approach to data synchronization, focusing on keeping the model up-to-date with real-time values without direct user input.

In setSunPosition, several unnecessary variables, such as multiple cameras and unused UI elements, were removed. This streamlined the initialization process. The code now directly initializes latitude, longitude, and the starParticles component from the XRTime component and stars transform. This change was made because user input was removed from the game, and the input now comes from the editor based on the time of day and location needed. To ensure the positions of the sun and stars are updated consistently at 30 FPS, an interval check was introduced, making sky updates smoother and better fitting with the sped-up time.

Similarly, in setMoonPosition and StarParticleCreator, redundant variables were removed due to the shift from in-game user input to editor-based input. The update check was also modified from minutes to seconds to match the sped-up passage of time in the new environment, reducing unnecessary dependencies and enhancing performance.

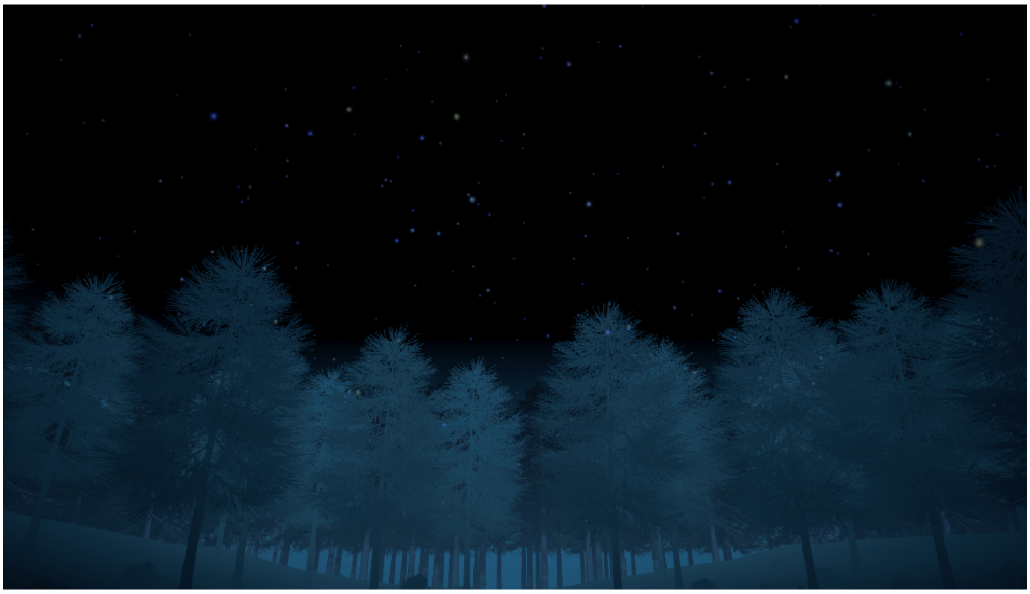
3.4.3 Day & Night

To enhance the auditory experience in both scenes, I added a GameObject with an Audio Source component to each environment to integrate the respective sounds. Initially, the audio output was insufficient to mask external noises, which could detract from the VR experience. To address this, I routed the audio source to an audio mixer and boosted it to its maximum level. This adjustment ensured that the VR audio effectively masked external sounds, maintaining immersion. Users could still adjust the volume through their headset settings for comfort.

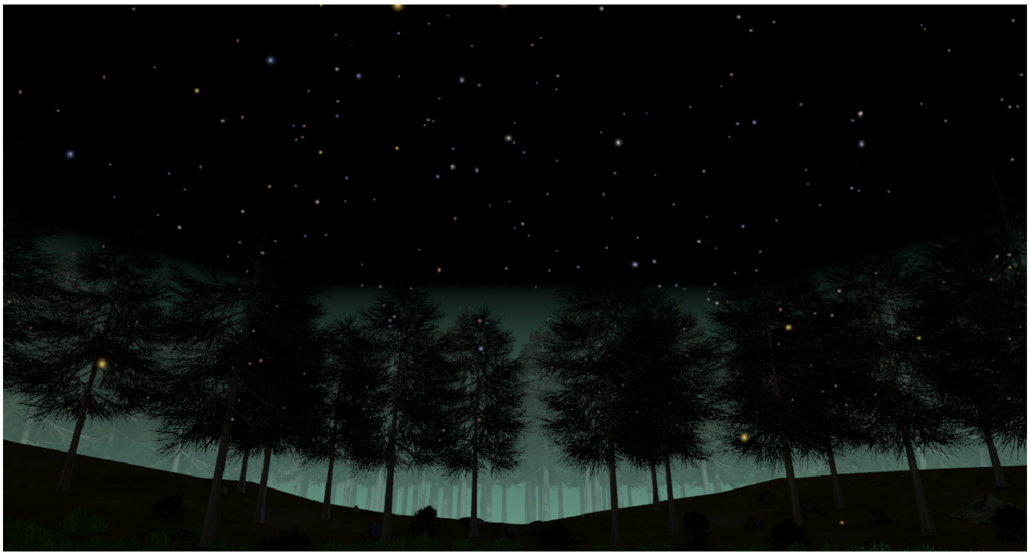
Night Scene

To enhance the scene's movement, I added fireflies using the Particle System. I increased the emission rate over time to produce more particles, downscaled their size since the default was too large, and set the system's shape to a sphere while also increasing its radius. Additionally, I changed the color over time to an orangish-yellow, made the size diminish over time to create a disappearing effect, and applied noise to generate movement [50].

In the lighting window of Unity, I customized several settings to create a more immersive and atmospheric scene. Firstly, I set the shadow color to a greenish-blue hue to give the shadows a unique tint that enhances the overall mood. The fog color was similarly adjusted to a greenish-blue and set to exponential mode, providing a natural falloff and blending seamlessly with the environment. The intensity of the lighting was lowered to create a more subdued and moody ambiance.



(a) With.



(b) Without.

Figure 3.22: Night With/Without Fog and Light Modifications.

For post-processing, I created a dedicated GameObject and added a Volume component to it. Within this Volume, I enabled several effects to refine the visual quality:

White Balance Decreased the temperature to introduce cooler tones, enhancing the scene's overall color temperature.

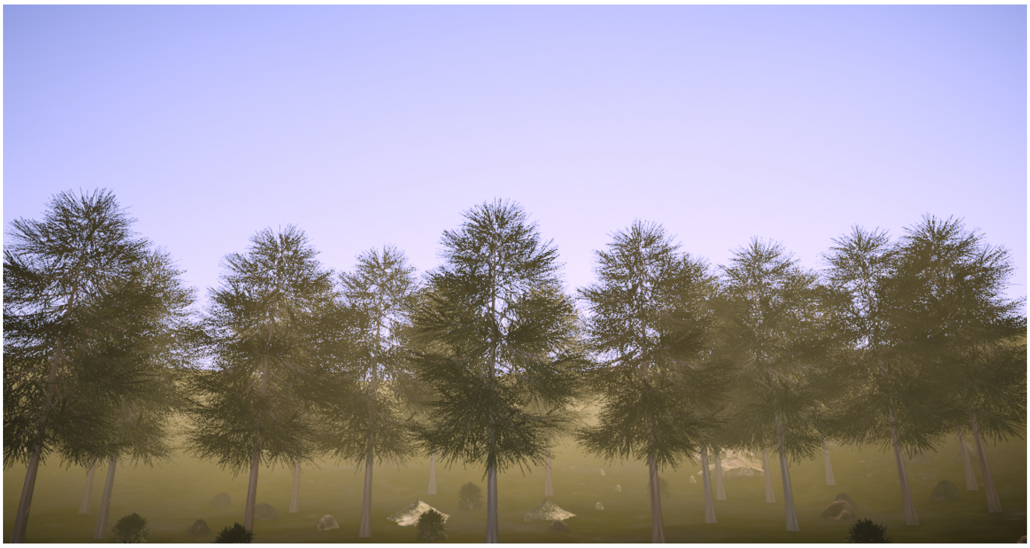
Shadows, Midtones, and Highlights Adjusted the shadows and midtones towards blue, creating a cooler and more cohesive color scheme.

Color Adjustments Increased the contrast to add depth and richness to the scene, making the colors stand out more vividly.

Vignette Enabled all options except for Rounded, and increased the Vignette and Smoothness values. This added a subtle darkening around the edges of the screen, focusing the viewer's attention towards the center and enhancing the overall visual experience.

Day Scene

In the lighting window of Unity, I customized the scene to enhance the visual experience by making several key modifications. I changed the shadow color to a green-yellowish hue to simulate the natural lighting and shadows one would see around noon, giving the scene a more realistic and warm feel. Additionally, I increased the intensity multiplier to slightly brighten the overall lighting, enhancing visibility and vibrancy.



(a) With.

(b) Without.

Figure 3.23: Day With/Without Fog and Light Modifications.

In the fog settings, I selected an exponential squared mode for the fog effect. This mode provides a more natural and gradual falloff in fog density with distance. I also adjusted the fog color to match the green-yellowish nuance of the shadows, creating a consistent atmosphere throughout the scene.

For post-processing, I created a dedicated GameObject and added a Volume component to it. Within this Volume, I enabled several effects to refine the visual quality:

Bloom Enabled all bloom options and set the threshold, intensity, and scatter to a value of 1. This adds a soft glow to bright areas, enhancing the overall luminance and making the scene appear more vibrant.

Vignette Enabled all options and increased the intensity. This effect darkens the edges of the screen slightly, focusing the viewer's attention towards the center.

Color Adjustments Enabled all options and made modifications, particularly increasing the post-exposure and contrast. This adjustment enhances the overall brightness and sharpness of the scene, making colors pop and adding depth to the visuals.

Tonemapping Set to ACES mode, which applies a filmic tonemapping curve, providing a more cinematic look by enhancing color grading and dynamic range.

White Balance Enabled all options and increased the tint values. This corrects the color temperature of the scene, adding warmth and balancing the overall color palette.

3.5 Challenges

There are two main challenges that plagued the development of this project: Performance and Software.

Performance

Making the game run efficiently on the VR headset was a significant struggle. Initially, the number of polygons in the models was a major issue. The original vision included multiple pine models of different sizes and features, but they were too demanding. I tried to scale them down without affecting the visuals too much, but it was too time-consuming to remake the other models. Eventually, I got them to a point I liked, but creating an entire forest with them was impossible. This is where the idea of billboarding came in, to create the illusion of a forest without actually making one.

When the sky package was added and had to be sped up for the faster passage of time, it took a toll on the framerate. I received an improved version and adapted it to my implementation, which helped improve the framerate. LODs were added to the grass, and it was decided to make the grass texture with a shader to reduce the demand of the game. Occlusion culling was also used, drastically improving the framerate.

Despite these changes, the framerate on Oculus Quest 2 is still not ideal and could induce sickness. Latency between head movements and the visual display updating can induce sickness, while lower resolution and refresh rates compared to the human eye's capabilities limit visual quality and contribute to discomfort. However, running it on a PC through Quest Link provides a good experience. Achieving a good framerate resolved most of these problems, ensuring a smoother and more comfortable experience for users.

Software

Software issues, particularly with Unity and Meta, were another time-consuming problem, in Unity, there were bugs and problems without apparent fixes. For example, the terrain's automatic resizing of bushes to tree sizes was an issue, and it also happened with complex grass elements that could not be added as details. Layer management was another problem, such as not preventing stars from appearing over the billboards. Transitioning to URP required changing the Sky package shaders of the materials, but the URP's particle system shaders did not work for the `Stars` materials. I had to use flares, which make stars appear through some objects if viewed attentively but visually the setting was the best choice. These issues might be due to my lack of knowledge or improper handling of features.

On the Meta side, putting a build on the VR headset was cumbersome, requiring multiple applications just to enable development mode. At least three applications were needed, two on the PC and one on the phone. Even with these applications, problems with Airlink or QuestLink were often sometimes only resolved by factory resetting the headset, these being suggestions from the official forums. Multiple accounts on a headset also created problems when trying to connect the devices.

QuestLink and Airlink are both features provided by Meta to connect the VR headset to a PC. QuestLink uses a USB-C cable to establish a stable connection between the headset and the computer, allowing users to run PC VR content on the headset. Airlink, on the other hand, is a wireless solution that leverages a Wi-Fi connection to stream PC VR content to the headset, offering greater freedom of movement but often requiring a strong and stable network.

Chapter 4

Application

“Serene Night“ is the name I chose for the application. It’s designed to give a peaceful experience, all in just a couple of words. The application was created using a modular architecture with a component-based design.

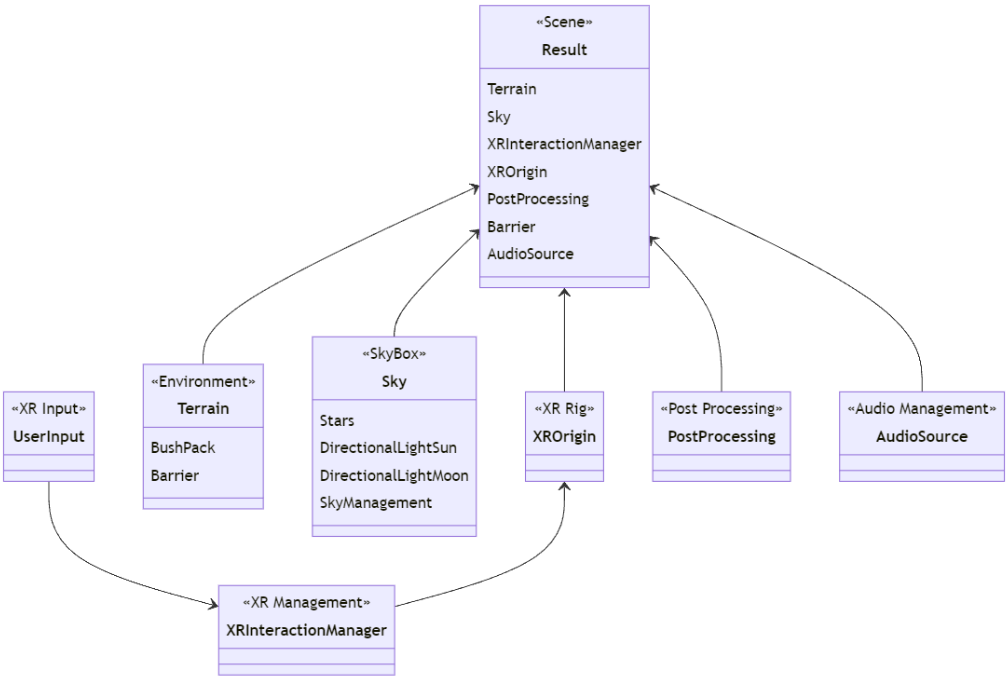
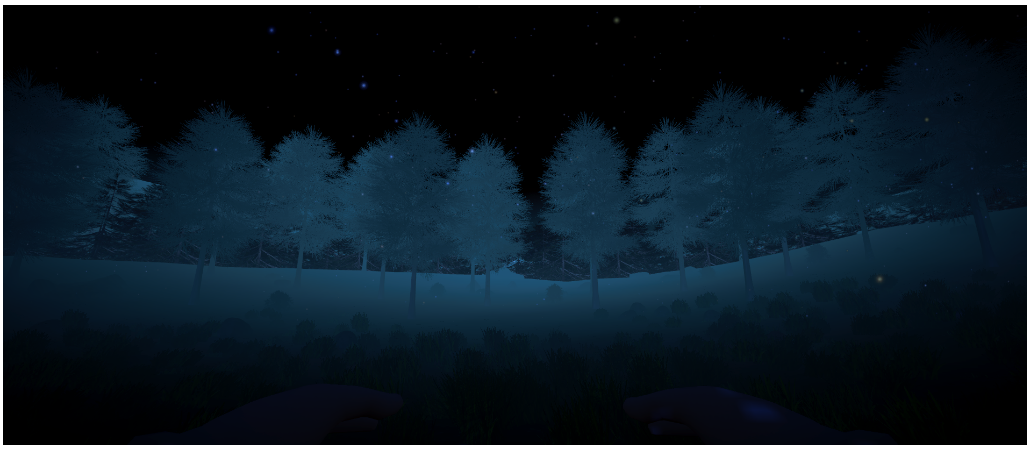
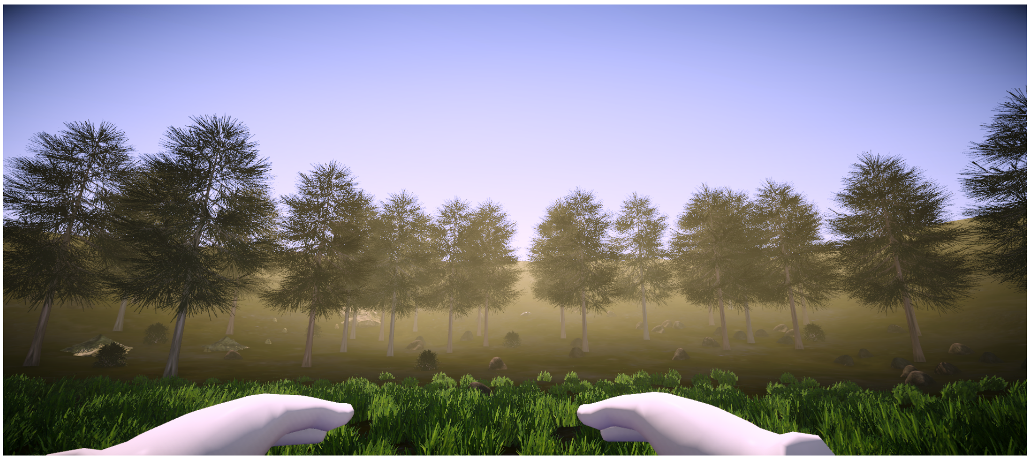


Figure 4.1: Scene Arhitecture.

This component-based design is highly beneficial for reusing scripts, models, and other assets. Thanks to this architecture, I was able to create two distinct scenes with ease by modifying only small details and resources to suit the specific needs of the day scene compared to the night scene. This approach allowed me to efficiently create two experiences—one during the day and one at night.



(a) Night Scene.



(b) Day Scene.

Figure 4.2: Results.

The night scene was the main focus of the application. Most of the time was spent working on and improving it to make the experience as relaxing and entertaining as possible. The main goal of the day scene is in the experiment, to highlight the differences in relaxation and mental well-being compared to the night scene. Despite these differences, both scenes are designed to evoke a sense of relaxation, with the aim of reducing stress and anxiety.

4.1 Use Case

The result is a 20-minute session featuring a starlit sky and a surrounding pine forest, complete with soothing nature sounds. This setup aims to transport you from your current space into a peaceful forest.

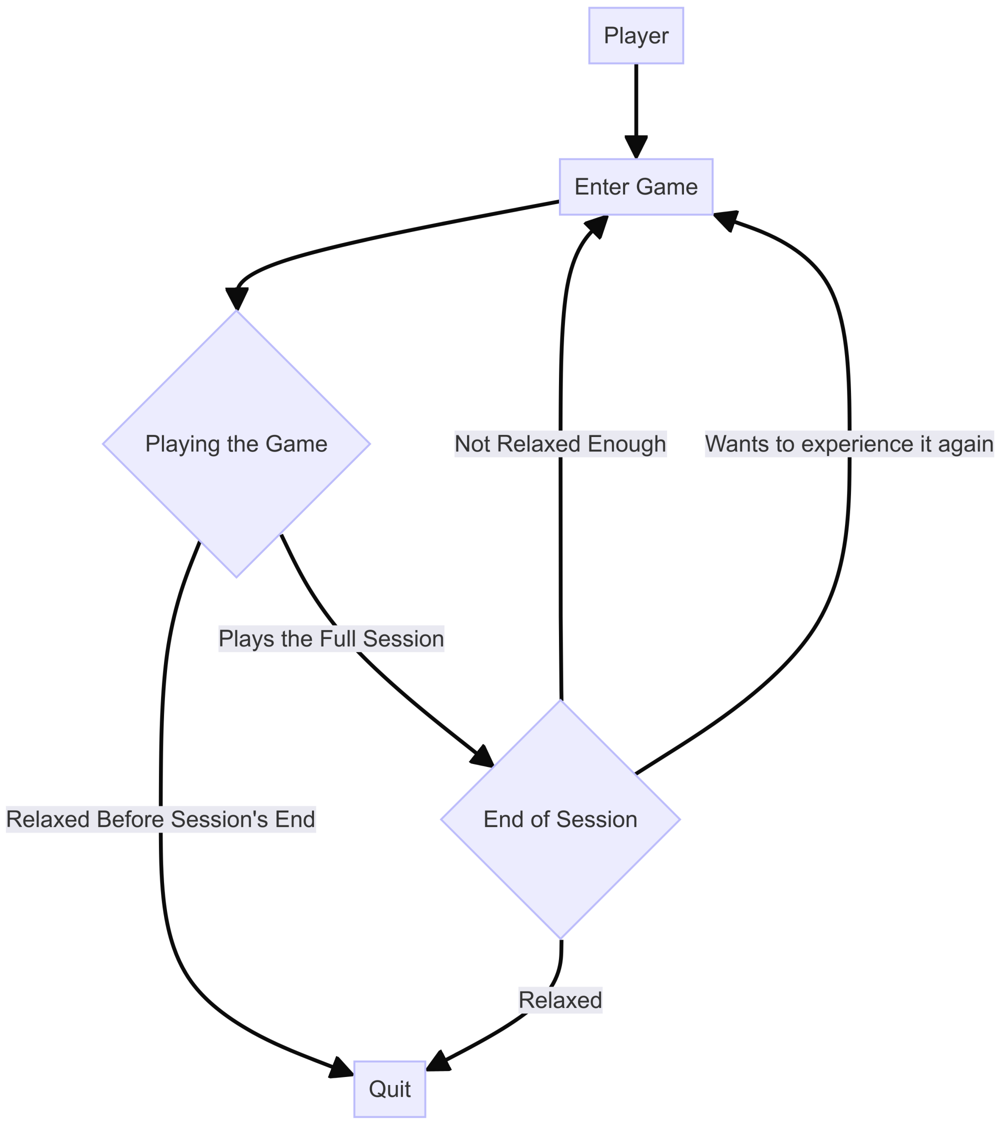


Figure 4.3: “Serene Night“ Use Case.

The app is designed for mental well-being. If the player is stressed or just want to enjoy the night sky and disconnect from modern life, they can open the application and immerse themselves in the experience. The 20-minute session might be too long or too short for some people. Those who prefer short sessions can leave whenever they feel relaxed, while others might stay until morning birds start chirping. Some might find that even a full session is not enough because they are so immersed and want to continue experiencing the simulated nature or that they did not have enough time to fully relax.

In the end, the aim of “Serene Night“ is to become a refuge from daily stress and perhaps inspire people to explore and preserve nature.

4.2 Experiments

To test the actual effects of the application, we conducted two experiments. The first experiment involved volunteers, specifically targeting the age group represented by university students. The second experiment included children, divided into two groups:

one typical and one atypical. Typical children are those who develop along expected lines in terms of physical, cognitive, and social milestones. Atypical children, on the other hand, may have developmental differences or disorders such as autism spectrum disorder, ADHD, or other conditions that affect their development.

The primary goal of the first experiment was to assess the capabilities of my application. The second experiment, conducted by Mihai Tanasa, provided additional insights into the application's effectiveness across different age groups by utilizing my application as a component of their thesis.

The team behind the experiments comprised Professor Marc Frincu, who served as the coordinator, and the following members: Student Paul Alexandru Ungur, Student Mihai Tanasa, Doctor Alin Semenescu, and Ph.D. Student Alexandru Vlasiu.

Professor Marc Frincu, organized and coordinated the team and the experiment. Mihai Tanasa worked on a separate project, which was integrated with mine for the second experiment, and we collaborated on organizing both experiments. Doctor Alin Semenescu assisted in interpreting the results from the completed forms and the received data. Ph.D. Student Alexandru Vlasiu contributed by graphing the outputted data to provide insights into player behavior.

4.2.1 Legal, Ethical & Social Matters

To ensure compliance with all relevant regulations and ethical guidelines, we submitted a request to our university for approval of our experiments. Our coordinator, Professor Marc Frincu, assumed responsibility for all necessary documentation and authorizations. In the application, we specified that the experiments would be conducted at our ICAM [26] laboratory and included detailed descriptions of the experiments. All previously mentioned members provided their signatures for this submission. We have strictly adhered to the ethical guidelines outlined in the official guide of our university [61], as well as the General Data Protection Regulation (GDPR) [21]. This adherence ensures the protection of participants' rights and well-being.

We obtained informed consent from all participants, ensuring they were fully aware of the nature of the experiment and their involvement. For any minors or individuals with disabilities participating in the experiments, we secured consent from their parents or guardians. Measures were implemented to maintain the confidentiality and anonymity of participant data, in accordance with GDPR. Personal data was processed lawfully, fairly, and transparently, collected for specified, explicit, and legitimate purposes, and was adequate, relevant, and limited to what is necessary.

The consent form provided to participants included detailed information about the study's purpose, which is to evaluate the impact of virtual reality on participants' well-being. It described the virtual environments they would encounter and the use of the Meta Oculus 2 VR headset for a maximum of 10 minutes. Participants were informed that their blood pressure and pulse would be measured and they would complete a short questionnaire. The form emphasized that participation does not involve any foreseeable risks and that participants could withdraw at any time without cost or inconvenience. It also clarified that there are no right or wrong answers, only honest opinions.

The form also stated that participants' consent was required for the collection, storage, and processing of their data, which would be handled confidentially and processed in aggregate form. Specific conditions included understanding that the virtual reality application would record their movements, and project members might take images of them. Participants could refuse to be photographed and request the deletion of any photos. They were also informed that they could withdraw at any time, and any requests to delete data afterward would be impossible as the form did not retain personal data.

A thorough risk assessment was conducted to identify and mitigate any potential risks to participants, particularly considering the potential effects of the VR headset. Preliminary tests with team members ensured there were no risks to the volunteers. If any signs of sickness caused by the VR headset were observed, the experiment was immediately stopped. After the experiments, participants received feedback and were debriefed to ensure transparency and address any questions or concerns.

We also considered the broader social impact of our research, ensuring that our experiments contribute positively to society and align with the principles of proportionality, non-discrimination, and the protection of human dignity, as emphasized in the ethical guidelines.

4.2.2 Serene Night Experiment

The experiments were conducted over two days at the ICAM [26] laboratory. The first session ran from 10 AM to 3 PM, and the second session from 10 AM to 6 PM. Participants were informed via university email and through word of mouth. They were required to reserve a specific time slot, with each session lasting approximately 15 minutes. Upon arrival, participants completed and signed a form to confirm their understanding of the experiment's nature and their involvement.

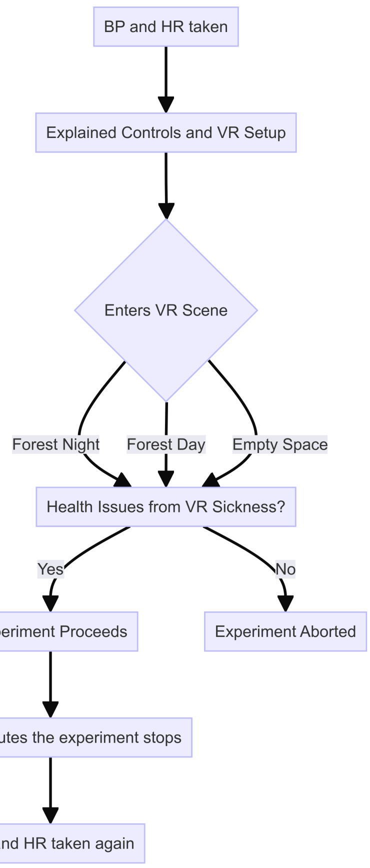


Figure 4.4: “Serene Night“ Experiment Workflow.

After signing the consent forms, volunteers entered the room with the VR setup. To maintain the experiment's integrity and avoid influencing the results, we informed them that we would not provide details on what they should feel, which scene they would experience, what we expected of them, or engage with them during the experiment. During this explanation, we measured their blood pressure and heart rate using a WITHINGS BPM Connect, recording the data in an Excel spreadsheet. Alongside this, information of the hour they arrived and the temperature was also recorded. The reasoning behind this was the influence temperature might have had on their results.

Once the experiment began, my colleague and I supervised the volunteers closely, monitoring their actions both in the VR environment and in real life. By running the application on my laptop and streaming it through QuestLink, we were able to monitor each experiment. If any signs of VR sickness appeared, or if the volunteer requested it, we would abort the experiment immediately. Each participant experienced a different scene to ensure fairness and to create a diverse data set for comparison. The scenes included the Night Forest Scene, Day Forest Scene, and Empty Space Scene. The Empty Space Scene, created using assets from Mihai Tanasa's experiment, featured a room with two exits in a calming space surrounded by the sky.

The experiment lasted three minutes, ensuring a consistent duration across scenes and preventing prolonged exposure to the Empty Space Scene. While inside the session, a component added to all scenes which retrieved movement data each 10 seconds, this script was created by Mihai Tanasa. After the session, we measured the participants' blood pressure and heart rate again. Participants then completed an anonymous feedback form and received a comprehensive explanation of the experiment from Professor Marc Frincu.

The **aim** of the experiment was to demonstrate that the Night Forest Scene had better results in lowering blood pressure and heart rate, while also eliciting a more positive overall reaction from users.

The form, created by Doctor Alin Semenescu, covered the following topics and questions:

- **Section 1: Current Feelings Post-VR Session** Questions about the participants' current feelings included: Worried, Cheerful, Agitated, Irritated, Strong, Relaxed, Hostile, Upset, Anxious, Inspired, Calm, Enthusiastic, Sad, Nervous, Lively, Free, Energetic, Disappointed, Stressed, Tense, and Satisfied with themselves. Each feeling was rated on a scale from 1 to 10.

- **Section 2: Relaxation and Stress Levels** Questions focused on whether participants felt relaxed, stressed, tense, or if the experience was pleasant. Each feeling was rated on a scale from 1 to 10.

- **Section 3: Attitude Towards Nature** Questions about their attitude towards nature used adjectives and scales to choose between pairs such as good or bad, useless or useful, harmful or beneficial, pleasant or unpleasant, and positive or negative.

- **Section 4: VR Scene Feedback** Participants were asked which VR scene they experienced, how quickly time seemed to pass, from “did not feel it at all“ to “a lot“, how many minutes they thought had passed, whether they lost patience, and if they would re-enter the scene. They were also asked which elements they appreciated the most, including nature representation, sound design, night sky simulation, immersion, realism, and an option for their input. A question about potential improvements was also included, with options such as clarity, introduction of 4D stimuli, or their own suggestions.

- **Section 5: Demographic Information** Participants were asked about their age, gender, education level, and medium of origin.

The results from this experiment were analyzed by Doctor Alin Semenescu and Ph.D. Student Alexandru Vlasiu for their own research but summaries of data were also shared with us.

4.2.3 Accessibility Features in Virtual Reality Experiment

The experiment was conducted over one day at the ICAM [26] laboratory, from 10 AM to 6 PM, following a similar format to previous experiments. For the typical group, children from a school were invited along with their teacher. For the atypical group, children from a community of families with children who have disabilities were invited.

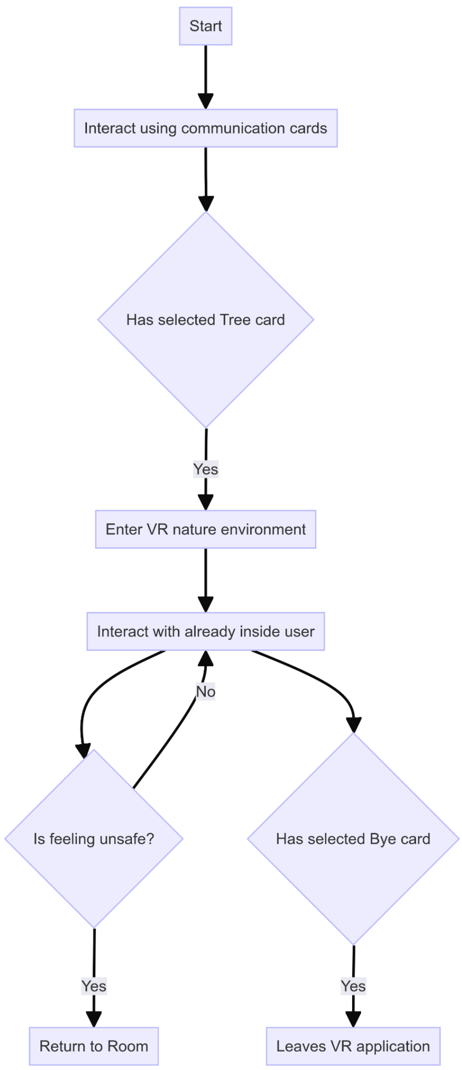


Figure 4.5: Accessibility Features Experiment Workflow.

This experiment is designed to engage with atypical children in a virtual environment to assess and enhance their verbal and non-verbal communication skills, as well as information retention. The approach focuses on eliciting general feelings from the children before and after the session, simplifying the process and making it child-friendly.

The subject is verbally instructed to pick a card or cards from the deck depicting their current feelings or state of mind. They are informed that picking the Tree card will transition them into a virtual forest scene, and to leave the environment and return to the friendly room, they can select the Room card. Reentry is possible by selecting the Tree card and to exit the VR session, the Bye card can be selected.

The subject initially enters an autism-friendly room, a safe space for retreat if needed. Adequate time is given to acclimate to the headset and environment, with movements monitored automatically. In the virtual forest, the subject can see and communicate with other participants.

The session involves the subject picking cards like Hello and Moon to facilitate interaction. Post-session, subjects pick cards depicting what they saw and heard in VR, such as Tree, Moon, Sun, Star, Firefly, and Bird, and describe their experience in a short text if they wish. This method, differing from previous experiments with complex forms, aims to capture the children's general feelings before and after the session.

While inside the session, I observed and took detailed notes of any events that took place both inside and outside the VR environment, aiming to capture a comprehensive overview of each session. I also ensured that the VR application ran smoothly without any technical issues.

This approach offers the opportunity to observe the children's reactions to the forest environment, evaluate their post-session responses, and assess the success of conveying the beauty of nature. The children's reflections and chosen cards provide insight into their emotional engagement with the scene.

Data movement was recorded once again, and will be analyzed alongside the texts by our team members.

Chapter 5

Results

The first experiment had 35 participants, while the second experiment had 12 participants, split evenly between typical and atypical individuals. On the first day of the first experiment, all 20 volunteers attended, resulting in 100% attendance. On the second day, out of 28 possible volunteers, only 16 attended, resulting in approximately 57% attendance. Since 2 slots were not booked, the attendance rate for the booked slots was 61%. The second experiment included an hour break during the eight hour session. For the second experiment there was a full attendance, all scheduled volunteers attending.

5.1 Serene Night Experiment Results

Out of the 35 sessions, only one problem occurred during the 3rd session, where data was not collected, requiring an additional session to make up for the missing data. Since the number of volunteers was not a multiple of 3, one scene had fewer tests: 12 sessions took place in the Empty Space Scene (Room), 12 in the Night Forest Scene (Night), and only 11 in the Day Forest Scene (Day).

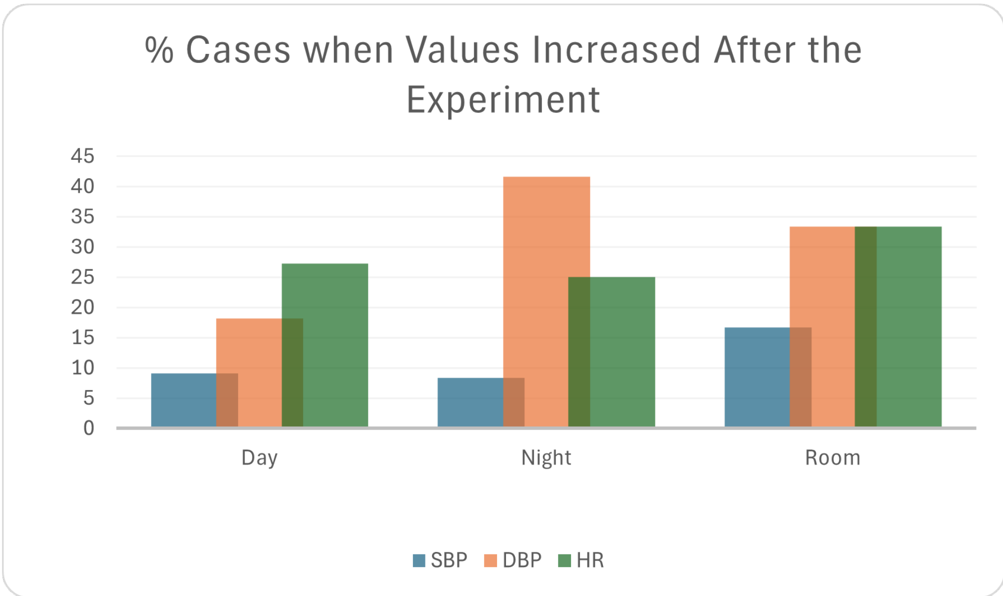


Figure 5.1: Health Related Values.

Figure 5.1, which shows the increased percentage change in SBP (systolic blood pressure), DBP (diastolic blood pressure), and HR (heart rate) after VR exposure for each scenario. The night and room scenarios resulted in the highest increases in DBP and HR, with both metrics rising in around 40% of the cases. SBP increases were more modest, with a maximum of 30% during the room scenario. From this we can conclude that the Night and Room VR scenarios are more likely to cause increases in DBP and HR compared to the Day scenario.

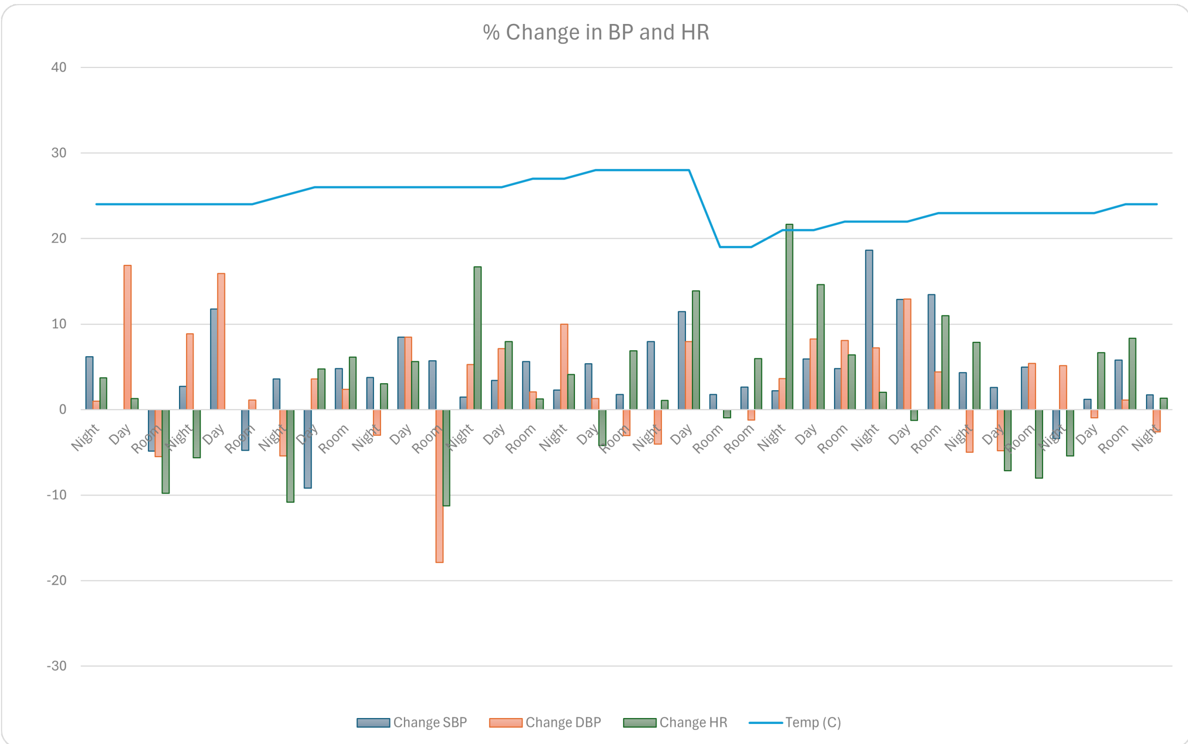


Figure 5.2: Health Related Values per Room.

Figure 5.2, illustrates the percentage changes in SBP, DBP, and HR across the scenes, compared with the temperature experienced outside from the volunteers. Notably, SBP exhibited minor fluctuations around the zero line, indicating marginal changes, with slight increases more frequent than decreases. DBP showed a broader range of changes, particularly with significant positive changes during the Day and Room scenarios. HR changes were the most variable, with notable increases and decreases, especially pronounced in the Night and Room scenarios. The temperature curve remained largely stable, suggesting it had little impact on the changes observed in BP (blood pressure) and HR.

Observations from the 8th-Day and 9th-Room sessions indicate that both arrived at the laboratory on bicycles, leading to a noticeable decrease in SBP in the Day session. On the 22nd-Room session, they reported consuming coffee beforehand, but no significant changes were observed. Similarly, during the 29th-Night session, although the volunteer mentioned having hypertension, there were no apparent fluctuations in their readings.

Sessions on the 7th-Night, 8th-Day, 11th-Day, and 32nd-Night showed participants moving beyond the boundary to explore the surroundings. Some attempted to re-enter but were unable to do so, possibly causing panic that might have influenced their results. The 25th session reported that their Room scene was relaxing, whereas the 35th session found the Night scene creepy, indicating varying preferences among participants.

Table 5.1: SBP, DBP, HR and Temp Correlation Matrix

	Change SBP	Change DBP	Change HR	Temp
Change SBP	1	0.2492633	0.149513	-0.0222051
Change DBP	0.2492633	1	0.3174388	-0.112556
Change HR	0.149513	0.3174388	1	-0.058368
Temp	-0.0222051	-0.112556	-0.058368	1

The correlation matrix indicates the relationships between the percentage changes in SBP, DBP, HR, and temperature. The analysis reveals a weak positive correlation (0.249) between changes in SBP and DBP, suggesting that as SBP changes, DBP tends to change in the same direction, albeit not strongly. Similarly, a very weak positive correlation (0.150) exists between changes in SBP and HR, indicating a slight tendency for HR to increase as SBP increases, but this relationship is minimal. The correlation between changes in SBP and temperature is almost negligible (-0.022), suggesting that temperature has virtually no effect on SBP changes.

The matrix also shows a moderate positive correlation (0.317) between changes in DBP and HR, implying that increases in DBP are somewhat associated with increases in HR. However, the correlation between changes in DBP and temperature is weakly negative (-0.113), indicating a slight tendency for higher temperatures to decrease DBP, though the effect is minimal. Lastly, there is a very weak negative correlation (-0.058) between changes in HR and temperature, suggesting that temperature has a minimal negative impact on HR changes.

Table 5.2: Before and After SBP, DBP, HRA, Hour and Temperature Correlation Matrix.

	SBPB	DBPB	HRB	SBPA	DBPA	HRA	Hour	Temp
SBPB	1	0.7624	0.1496	0.8896	0.7424	-0.0693	-0.0400	-0.2883
DBPB	0.7624	1	0.1199	0.7523	0.8710	-0.0548	-0.0818	-0.2101
HRB	0.1496	0.1199	1	0.1522	0.0859	0.8546	-0.2632	-0.0539
SBPA	0.8896	0.7523	0.1522	1	0.8085	-0.0076	-0.1389	-0.2564
DBPA	0.7424	0.8710	0.0859	0.8085	1	0.0007	-0.0008	-0.1702
HRA	-0.0693	-0.0548	0.8546	-0.0076	0.0007	1	-0.3219	-0.0539
Hour	-0.0400	-0.0818	-0.2632	-0.1389	-0.0008	-0.3219	1	0.1352
Temp	-0.2883	-0.2101	-0.0539	-0.2564	-0.1702	-0.0539	0.1352	1

Legend:

- SBPB/SBPA - Systolic Blood Pressure Before/After Session
- DBPB/DBPA - Diastolic Blood Pressure Before/After Session
- HRB/HRA - Heart Rate Before/Affter Session

The correlation matrix provides valuable insights into the relationships between blood pressure, heart rate before and after the experiment, as well as the impact of time and temperature. A strong positive correlation (0.7624) between SBP and DBP before the experiment indicates that individuals with higher systolic blood pressure also tend to have higher diastolic blood pressure. There is a weak positive correlation (0.1496) between SBP and HR before the experiment, suggesting a slight tendency for individuals with higher SBP to have higher HR, though the relationship is not strong. A very strong positive correlation (0.8896) between SBP before and after the experiment shows that individuals with higher SBP before the experiment tend to maintain higher SBP afterwards. Similarly, a strong positive correlation (0.7424) between SBP before and DBP after the experiment suggests a consistent relationship between systolic and diastolic blood pressures across the experiment.

In contrast, the correlation between SBP before and HR after the experiment is very weak and negative (-0.0693), indicating almost no relationship. Likewise, there is a very weak negative correlation (-0.0400) between SBP before and the hour of the experiment, suggesting no significant relationship between the time of day and initial SBP. However, there is a weak negative correlation (-0.2883) between SBP before the experiment and temperature, indicating that higher temperatures might be associated with slightly lower initial SBP.

Other notable correlations include a strong positive correlation (0.8546) between HR before and after the experiment, indicating consistency in heart rate measurements, and a strong positive correlation (0.8710) between DBP before and after the experiment, showing consistency in diastolic blood pressure. There is also a moderate negative correlation (-0.3219) between the hour of the experiment and HR after, suggesting that heart rates tended to be lower later in the day. Additionally, a weak positive correlation (0.1352) between temperature and the hour of the experiment indicates a slight increase in temperature as the day progressed. This suggests that individual physiological characteristics are the primary determinants of blood pressure and heart rate changes, rather than external factors like time and temperature.

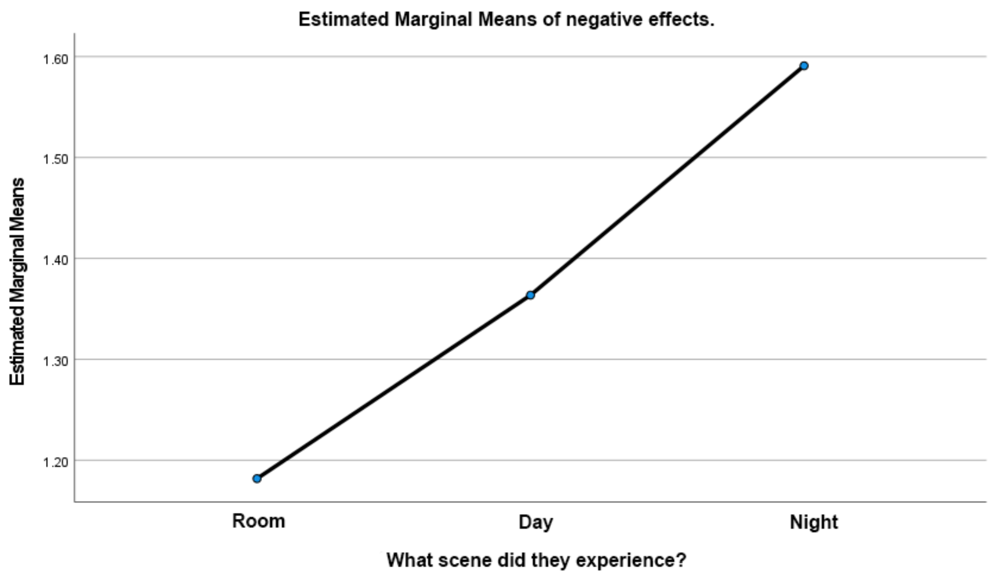


Figure 5.3: Negative effects.

Figure 5.3 presents the estimated marginal means of negative affect across the three virtual environments. The Room setting shows the lowest mean of negative affect, indicating minimal negative emotions. In contrast, the Day environment exhibits a slight uptick, suggesting more negative emotions in the forest during daylight compared to the Room. The Night scene displays a significant surge, with the highest negative affect, revealing that the forest at night greatly intensifies negative emotions among participants.

This trend indicates that daytime natural environments might slightly elevate negative affect, while nighttime settings can substantially heighten it.

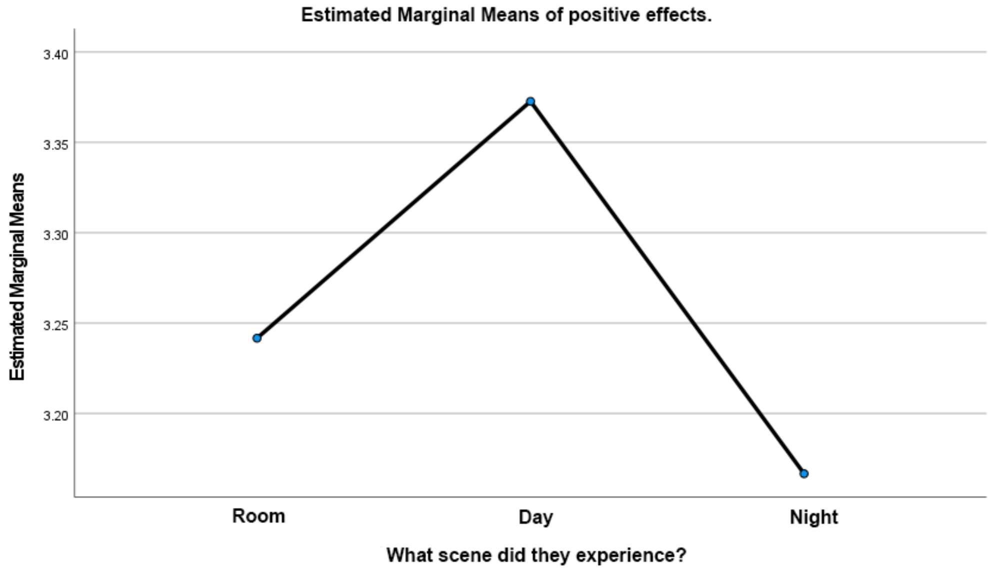


Figure 5.4: Positive effects.

Figure 5.4 illustrates the estimated marginal means of positive affect. The Room setting registers the lowest positive affect, signifying the least positive emotions. The Day environment shows a notable rise, suggesting that the forest during the day elicits the most positive emotions. Conversely, the Night environment reveals a significant drop in positive affect, even lower than the Room, indicating that the forest at night is the least conducive to positive emotional experiences. This pattern implies that daytime natural environments enhance positive affect, whereas nighttime settings diminish it.

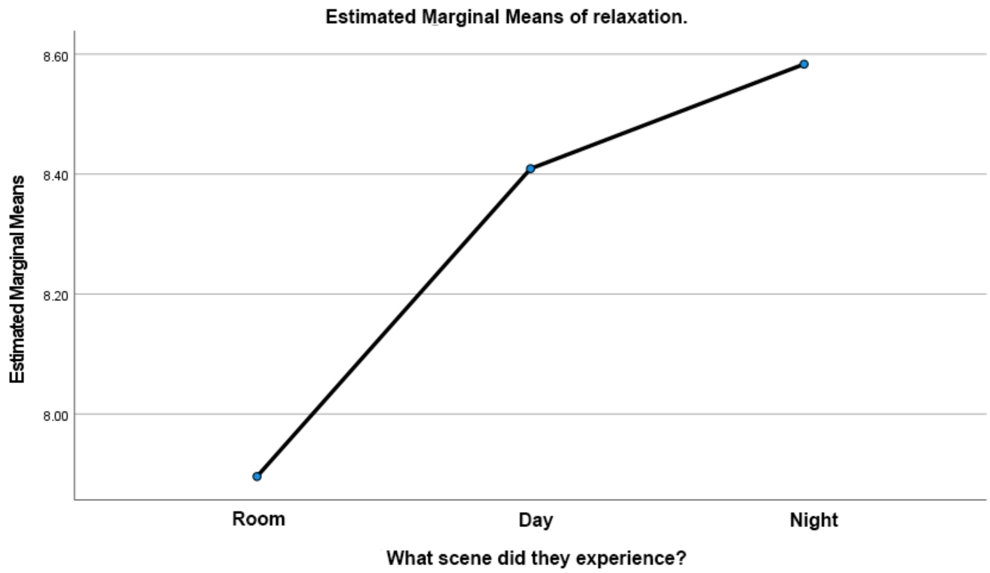


Figure 5.5: Relaxation.

Figure 5.5 showcases the estimated marginal means of relaxation levels. Participants felt the least relaxed in the Room setting. The Day environment indicates a substantial increase in relaxation, suggesting that the forest during the day fosters relaxation. Interestingly, the Night environment displays the highest relaxation levels, implying that participants felt most at ease in the forest at night, possibly due to the calming effect of nighttime.

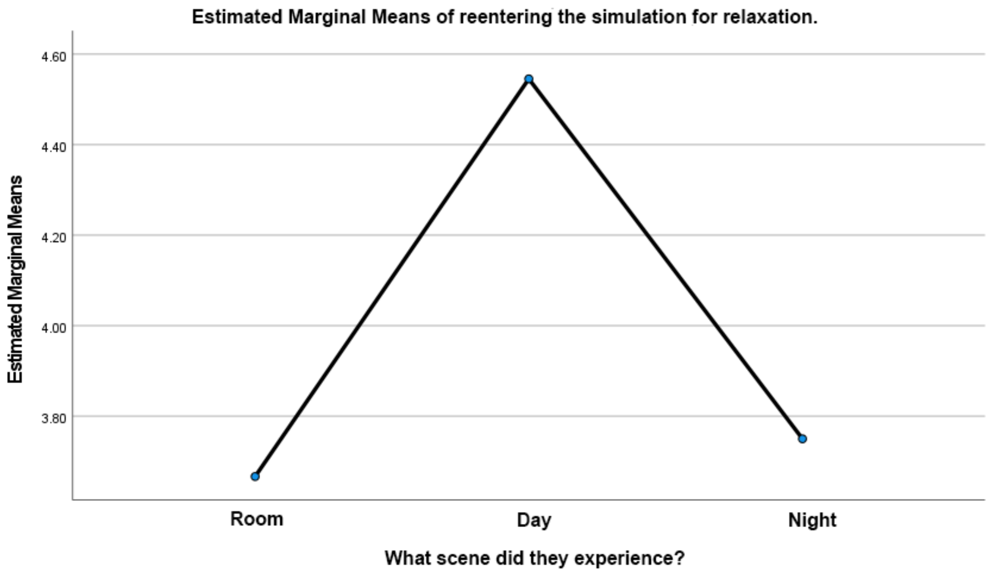


Figure 5.6: Reentering.

Figure 5.8 demonstrates the estimated marginal means of participants' willingness to re-enter the virtual environment for relaxation. The Room environment shows the lowest willingness to re-enter. The Day setting displays the highest willingness, indicating it is the most appealing for relaxation. The Night environment reveals a decline in willingness, just slightly above the Room, indicating the forest at night is perceived as less suitable for relaxation due to potential unease or fear.

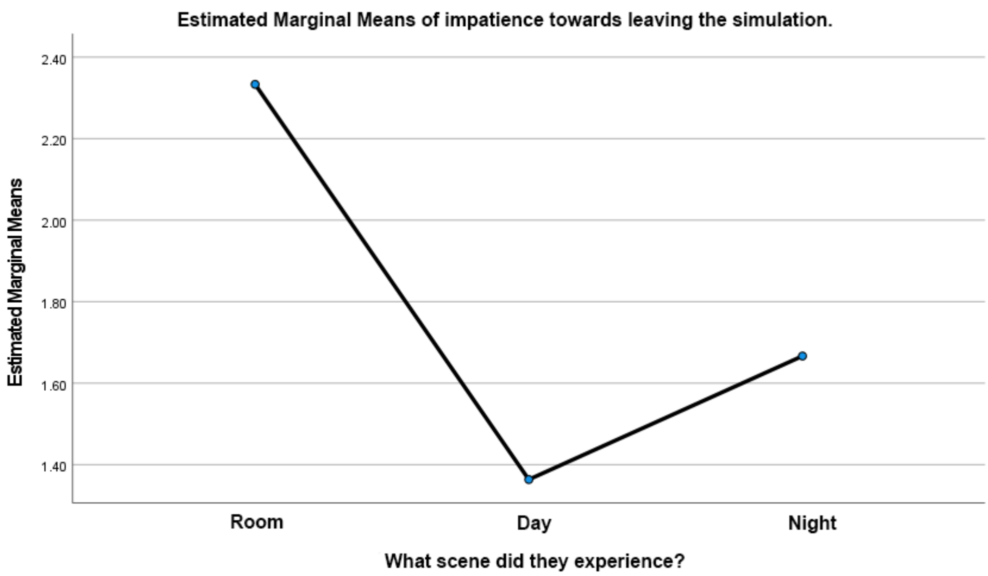


Figure 5.7: Impatience.

Figure 5.7 displays the estimated marginal means of impatience to leave the virtual application. The Room environment exhibits the highest impatience, indicating participants were most eager to exit. The Day setting reveals the lowest impatience, suggesting participants were most comfortable. The Night environment shows increased impatience compared to the Day but remains lower than the Room, indicating that the night forest is more tolerable than the Room but less comfortable than the forest during the day.

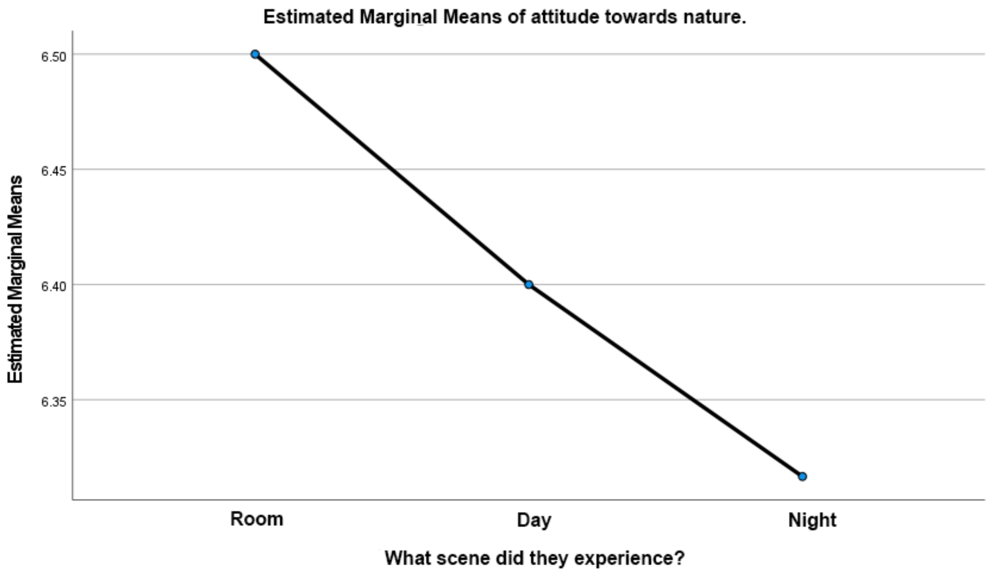


Figure 5.8: Attitude Towards Nature.

Figure 5.6 reveals the estimated marginal means of participants' attitudes towards nature. The Room environment garners the highest positive attitudes. The Day setting experiences a decline, indicating the forest during the day is less favorable but still positive. The Night environment registers the lowest positive attitudes, suggesting that the forest at night significantly diminishes positive attitudes towards nature. This trend indicates that controlled environments like the Room may better support positive attitudes towards nature compared to more dynamic environments like the forest at night.

Based on the feedback from the forms, several strong features of the application were highlighted. Notably, 77% of participants appreciated the nature sounds, and 45% valued the visual representation of nature. Both immersivity and realism were tied at 28% as significant traits, while 25% of volunteers specifically noted the night sky or starry night as a notable feature. Additionally, the teleportation system received positive feedback from a small number of testers. In terms of improvements, the most critical suggestion was the introduction of 4D stimuli, with 78% of participants advocating for it, followed by 50% who emphasized the need for greater clarity in the simulation. Other minor suggestions included calls for increased realism, a more interactive environment, and greater opportunities for exploration.

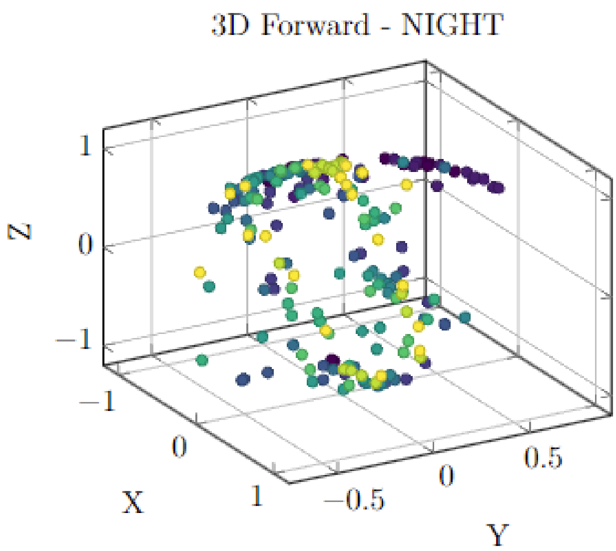


Figure 5.9: 3D Graph of Positions Night Scene.

In Figure 5.9, we can derive several observations about the viewing behavior of the users. The high concentration of data points in the upper region of the graph indicates that many users directed their gaze towards the sky. This trend suggests that the sky, captured more attention from users compared to other areas within the mapped environment. Additionally, there is a noticeable concentration of points near the terrain, specifically towards the bottom of the graph. The distribution along the Y-axis shows that user attention was not limited to a single area but was spread across various locations, suggesting that the environment captured their attention. This spread indicates that users were actively scanning their surroundings, leading to a diverse range of viewing angles. From the Z-axis perspective, the data points are dispersed across the positive and negative values, showing that users' gaze varied in depth. Points above zero likely represent gazes directed above the horizon, reinforcing the earlier observation of interest in the sky.

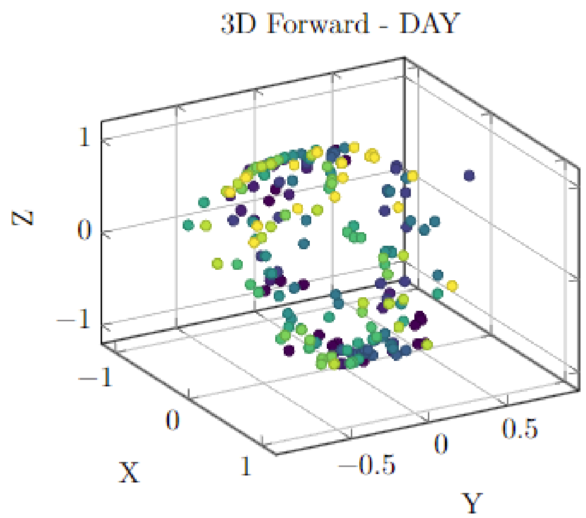


Figure 5.10: 3D Graph of Positions Day Scene.

In Figure 5.10, we can observe a distinct pattern in the viewing behavior of users compared to the nighttime data. During the day, there is a lower concentration of data points in the upper region of the graph, suggesting that users are less likely to direct their gaze towards the sky. This indicates that the sky is less captivating or has fewer points of interest during the daytime. Instead, there is a higher spread of data points towards the terrain, specifically in the lower region of the graph. The terrain may be more visually engaging in daylight. The distribution of points along the Y-axis remains spread across various locations, which indicates that users are still actively scanning their surroundings. The dispersion of data points along the Z-axis, both above and below zero, shows that users' gaze varies in depth. However, the reduced number of points above zero compared to the nighttime data reinforces the observation that the sky is less frequently a focal point during the day.

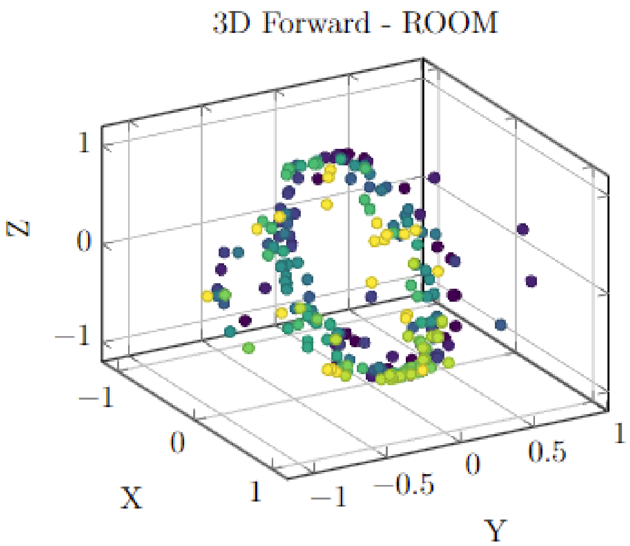


Figure 5.11: 3D Graph of Positions Room Scene.

In Figure 5.11, we observe a more uniform distribution of data points compared to the previously analyzed graphs. This pattern highlights the simplicity of the environment within the room, suggesting that users did not find any major points of interest. The data indicates that users generally looked around initially to see if there was anything noteworthy, but after realizing there was nothing particularly spectacular, their gaze patterns became more centralized and less varied. The clustering of points along a relatively straight line suggests that users' attention was focused at a consistent level, without significant deviations to the sides or extremes of the environment. This uniform reaction underscores the lack of dynamic elements or engaging features within the room, leading users to maintain a straightforward viewing pattern.

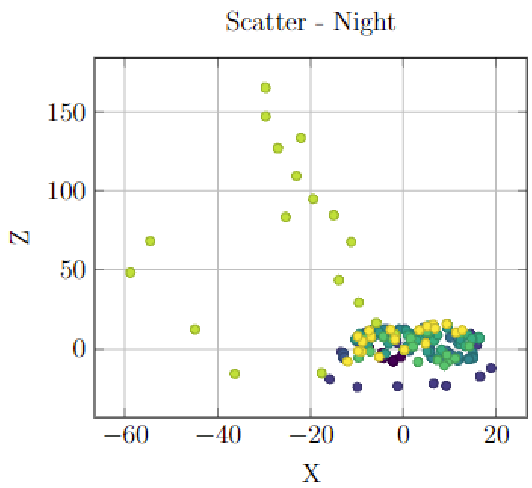


Figure 5.12: 2D Graph of Positions Night Scene.

In Figure 5.12, we can observe two main patterns in the data. Firstly, there are a number of data points extending significantly above the main cluster, indicating that some participants ventured far out of the central boundaries of the night scene, exploring the periphery before eventually returning. This behavior suggests a degree of curiosity or perhaps an attempt to navigate the environment beyond its typical limits. Secondly, the majority of the participants' presence is concentrated near the border of the scene, with their positions spread around this area. This spread indicates that many participants attempted to leave the forest. The overall pattern highlights a tendency among users to test the limits of the environment, suggesting that the forest area might not have been sufficiently engaging, prompting participants to explore the scene's edges in search of more interesting features or simply to understand the extent of their navigable space.

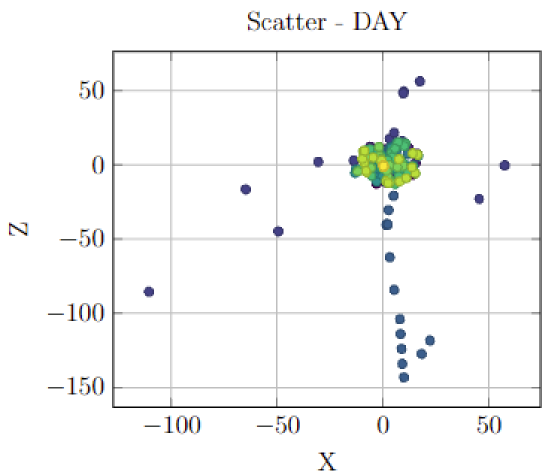


Figure 5.13: 2D Graph of Positions Day Scene.

In Figure 5.13, we can analyze two distinct patterns in the users' movements. The first pattern shows that some participants ventured out of the forest scene, as indicated by the spread of data points far from the central cluster. These users explored the periphery, moving significantly away from the central area before eventually returning, similar to the behavior observed in the nighttime scatter plot. The second pattern, however, reveals a more centered movement among the majority of participants, who remained closer to the core of the forest scene. Unlike the night scene where many users attempted to leave the area, during the day, users' movements were more concentrated around the center. This suggests that the central part of the forest scene was more engaging or visually stimulating during the day, retaining users' attention and reducing the inclination to explore the boundaries. The presence of some outliers indicates occasional exploratory behavior, but overall, the tighter clustering around the center highlights a stronger focus on the central features of the forest during the daytime.

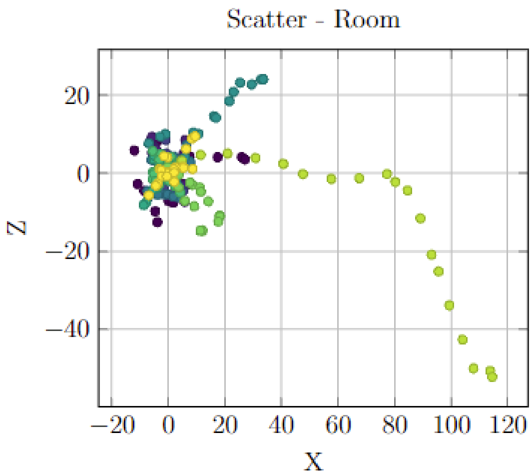


Figure 5.14: 2D Graph of Positions Room Scene.

In Figure 5.14, we observe patterns similar to those seen in the forest scenes. Some participants explored the boundaries of the room scene, as evidenced by the data points extending far from the central cluster. This behavior indicates that, like in the forest scenes, users were inclined to test the limits of the environment. Additionally, there is a more uniform spread of data points from the center into various parts of the map. This random pattern of movement suggests that the simplicity of the room scene might have contributed to users' exploratory behavior. With fewer engaging features or focal points, participants likely moved around in a more arbitrary manner, seeking out potential points of interest throughout the space. This lack of a strong central attraction led to a dispersed pattern, as users did not find specific elements that captured their attention for prolonged periods.

5.2 Accessibility Features Experiment Results

From the group, three participants did not enter the forest scene and therefore could not provide any useful feedback. From the atypical group, we had the following conditions: the first participant had Autism Spectrum Disorder (ASD); the eighth had Down Syndrome; the ninth had both ASD and ADHD; the tenth and eleventh had Asperger Syndrome; and the twelfth had ASD.

The first and second sessions had neutral feedback. The first session participants reported feeling a "different emotion" than those listed on the cards, while the second session participants felt "happy" but did not provide a concrete feeling afterward. The third session yielded negative feedback. Participant initially felt “happy“ but were startled by the sounds in the scene and did not give a clear response afterward. The fourth and sixth sessions did not enter the forest scene, remaining in the starting room.

The fifth participant entered feeling “happy“ but felt “unsure“ afterward. The seventh session involved a participant who initially felt “something else“ but reported feeling “really good“, “pleased“, and “impatient“ afterward. The eighth participant, initially “disappointed“ due to external reasons, found the session “cool“ afterward. The ninth participant showed little interest in the VR experience, barely tried the headset, and quickly lost interest. The tenth participant remained “happy“ before and after the session. The eleventh session participants felt “unsure“ and “happy“ initially, and afterward, they described the experience as “cool“, similar to previous feedback. The twelfth participant entered feeling “happy“ and reported feeling “joyful“ afterward.

In terms of elements that caught participants’ attention in the scene, 41% noticed the Moon, 75% observed the stars, 83% noticed the fireflies, 66% saw the forest, and 16% remarked on the bird sounds. Breaking it down by typical and atypical participants: among the 6 typical participants, 16% observed the Moon, 66% noticed the stars, 66% noticed the fireflies, 50% saw the forest, and 16% heard the bird sounds. Among the 6 atypical participants, 66% noticed the Moon, 83% observed the stars, 100% noticed the fireflies, 50% saw the forest, and 16% remarked on the bird sounds. For each session, participants were asked what they saw or heard. To help with identification, they used communication cards if needed.

From the short texts the children wrote, the first participant described the trees, explained what a firefly was, and also described the stars, stating, “I liked staying there“ and “I liked everything“. The second participant mentioned the fireflies and stars. The third participant wrote, “I got scared, did not know what was that sound“, “It was really dark“, and “I saw a lot of stars“. The fifth participant described the stars, fireflies, and forest, also mentioning “a lot, a lot of grass“.

The seventh participant said, “I really liked the experience“, and described seeing fireflies and stars, as well as hearing birds. The eighth participant noted seeing fireflies, stars, the moon, and the forest, and included words like “beautiful“, “happy“, and “proud“ in their text. The eleventh participant mentioned seeing fireflies, the moon, stars, grass, and flowers.

The fourth, sixth, ninth, tenth, and twelfth participants either didn’t enter the forest or didn’t talk about the forest. Notably, the sixth participant lied about entering the forest and described what they imagined the scene to be. The ninth participant wrote colors on a random paper instead of writing on the one provided. The tenth participant only described the welcoming room and interaction in the multiplayer setting, while the twelfth participant chose to draw on the paper instead.

From the observation notes I took, noteworthy information includes the following: The second participant, at the end of the session, paid more attention to the scene than to us. The third session’s participant entered the forest but left instantly due to being scared by the noise. The fifth participant showed a desire to interact with the forest. The seventh participant left earlier than the allocated time in the forest. The mother of the eighth participant claimed that, towards the end, he seemed to be having a lot of fun. The ninth participant removed the VR headset after only a few seconds in the forest and started playing with a pen. The eleventh participant expressed a desire to try the forest experience again.

Chapter 6

Discussion

The study aimed to create an immersive VR application that simulates a serene night under the stars, with the goal of reducing stress and anxiety and enhancing mental well-being by reinforcing users' connection with nature. The experiments, which varied in participant numbers and conditions, provided significant insights into physiological responses, emotional states, and participant feedback, highlighting both the potential and the challenges of the application.

Physiologically, the VR scenes had distinct impacts on BP and HR. The Night and Room environments notably increased DBP and HR, with less pronounced changes in SBP. This suggests that the Night scene evoked feelings of stress and anxiety, as evidenced by the physiological data. This is problematic, indicating that the VR approach may inadvertently increase user stress post-session. In contrast, the Day scene exhibited more stable physiological responses, suggesting that a day setting leaves people more at ease compared to the Night scene, which appears more stimulating or stressful.

Correlational analyses revealed weak to moderate relationships between changes in BP and HR, with temperature having minimal influence. This allows us to discount external factors such as higher BP due to external heat or time of day, including peak stress times. Strong correlations between pre- and post-experiment BP and HR suggest that individual physiological characteristics remain consistent across different VR experiences. In other words, if a participant had high BP or HR before the VR session, they were likely to have similarly high BP or HR after the session. This consistency implies that an individual's physiological characteristics, such as their tendency to have higher or lower BP and HR, do not change drastically due to the VR experience alone.

Despite this consistency, the pattern of worse results in the Night scene compared to the Day scene is concerning. It suggests a need for a more thorough review of existing literature and a reassessment of the current approach to VR environment design to mitigate stress-inducing effects.

Psychologically, the VR environments elicited varied emotional and relaxation responses. The Night scene significantly increased negative emotions, reinforcing the physiological data that indicated higher stress and anxiety levels. This was contrary to expectations, as it was anticipated that the Night scene would elicit a more positive response compared to the Room and Day scenes. Instead, the Room setting showed the lowest levels of negative affect, suggesting that it was the least stressful environment. The Day environment was associated with moderate negative emotions, which may point to issues with the implementation rather than the concept itself.

Conversely, the Day environment induced the highest positive emotions, while the

Night environment showed the lowest positive affect, even lower than the Room setting. This further indicates potential problems with night settings, as participants might have felt uneasy being placed in a forest in the middle of the night without knowledge of what was inside. The combination of the unknown and darkness, tapping into primordial fears, likely created a scenario in which users felt vulnerable.

Unexpectedly, relaxation levels were highest in the Night environment and lowest in the Room, with the Day environment also promoting significant relaxation. Despite the negative emotional response, the Night scene managed to relax the majority of users, which presents an interesting paradox. Restlessness was most pronounced in the Room environment, with the Day environment being the most comfortable and the Night environment falling in between. This reinforces the idea that the Night scene, while relaxing, also created uneasiness due to the sense of unknown and darkness.

In terms of user movement data, the Night scene scatter plot reveals a stronger tendency for participants to leave the forest, which supports the theory of uneasiness created by darkness and the unknown. The 3D graph of positions for the Night scene highlights the significant attention given to the sky, indicating that the starry night sky retained user attention. Conversely, the Day scene showed more centered user data, with less inclination to leave the forest and a greater focus on the terrain and surroundings rather than the sky. The Room scene provided very sterile feedback, with users attempting to find entertainment, reflecting a lack of engaging features within the environment. This suggests that while the Day scene was more comfortable, the Night scene's combination of relaxation and stress highlights the need for a balance in VR environment design to create engaging yet comfortable experiences.

The second experiment yielded mixed feedback from participants, who reported a range of emotional responses influenced by their interactions within the VR scene. These responses varied from happiness to other emotions, providing a simplified but insightful overview of the results. While the Night scene generated positive reactions in some instances, it also elicited negative responses from many users, altering their moods for the worse due to various elements such as unexpected sounds. Despite these negative reactions, the positive feedback suggests that there is potential in the concept of using simulated forest nature for mental well-being and relaxation.

In terms of connectedness with nature and increasing users' awareness of it, the results suggest that the Room environment fostered the best attitudes towards nature. This is an intriguing finding, as it indicates that the more active environments, such as the Day and Night scenes, may not have deepened the connection with nature as intended. Instead, these active environments might have had the opposite effect. One possible explanation is that the immersive and stimulating aspects of the Day and Night scenes could have overwhelmed participants, preventing them from fully appreciating the natural elements presented to them.

Alternatively, the Room environment, which was a stark and empty space, may have created feelings of yearning towards nature. The absence of natural elements in the Room setting might have highlighted the importance and beauty of nature, leading users to develop a greater appreciation for it. This suggests that humans may not fully appreciate nature until they experience its absence, highlighting a psychological aspect where the lack of nature amplifies its perceived value.

In conclusion, the varied emotional responses indicate that while the Night scene can evoke stress and anxiety, it also has the capacity to produce positive experiences for some users. This duality underscores the complexity of designing VR environments that cater to diverse emotional and psychological needs. The mixed feedback highlights the necessity of a more nuanced approach to environment design, particularly in addressing elements that might trigger negative emotions. Refining the VR environment by incorporating user feedback and adjusting elements that contribute to negative reactions can enhance the overall user experience. This study emphasizes the importance of balancing stimulating and calming elements to create VR environments that are both engaging and comfortable, ultimately achieving the intended goal of reducing stress and enhancing mental well-being.

6.1 Future Work

Based on the feedback and user actions, several improvements can be made to enhance the VR experience. Firstly, there is a clear need for more space within the VR environment. Many users attempted to leave the forest upon first entering it, which could indicate a desire to escape due to feelings of anxiety or a natural curiosity for exploration. This latter trait was suggested in the feedback as a potential feature to be added.

The lack of direction within the VR environment may have contributed to feelings of anxiety. Changing the mode of testing to include more detailed instructions or an introduction could alleviate these feelings by providing users with a clearer idea of what to expect and what to do. In the second experiment, where a multiplayer feature was enabled, participants were able to appreciate the scene more fully. The presence of another person in the scene who suggested various elements to explore significantly enhanced the experience. This indicates that social interaction and guidance can play a crucial role in how users perceive and engage with the VR environment.

To improve the environment, making the scene wider and providing more breathing space for the user could be beneficial. The current closeness of the trees seems to contribute to negative feelings. Additionally, incorporating interactive elements, such as picking up rocks or interacting with grass, could offer users more engaging activities while they relax. These interactive elements could make the environment feel more immersive and provide users with additional ways to connect with the scene.

Introducing a guided introduction for first-time users could further enhance the experience. This introduction could explain the purpose of the environment, suggest activities, and set expectations, helping to reduce anxiety and improve overall user satisfaction.

In addition to the new features, several existing aspects of the VR environment also need improvements. One broad area that requires attention is clarity. This encompasses a variety of elements, including performance optimization, quality of models, and textures. Ensuring that the VR environment runs smoothly and looks visually appealing is crucial for creating an immersive and engaging experience. High-quality models and textures can significantly enhance the realism of the scene, making it more believable and enjoyable for users.

One area that received positive feedback and can be expanded is the use of sound. Incorporating more varied and dynamic sounds can deepen the sense of realism. Randomizing sounds or triggering them based on user actions can make the environment feel more alive and responsive. However, it is essential to carefully select and balance these sounds to avoid startling users, as noted in the second experiment. Sounds that are too abrupt or unexpected can increase anxiety rather than reduce it, undermining the primary goal of the VR application.

Another feature worth exploring is the inclusion of 4D stimuli. Adding elements such as wind, scents, or slight vibrations can further enhance immersion, making the VR experience more engaging and multi-sensory. For instance, a gentle breeze synchronized with the visual movement of trees can create a more convincing outdoor environment. Similarly, subtle scents that match the environment, such as the smell of pine in a forest scene, can enhance the feeling of being in nature. These additional stimuli can make the virtual experience more immersive and help users feel more connected to the environment.

In terms of fostering nature connectedness and raising awareness about light pollution, the current approach needs to be tweaked. Our findings suggest that a single session may not be sufficient for users to develop a deep connection with nature or a comprehensive understanding of light pollution.

After implementing the suggested improvements, another round of testing should be conducted. The ultimate goal of the application is to be used for relaxation, stress reduction, and enhancing connectedness with nature. Following further testing and refinement, the application could be integrated with Mihai Tanasa's application. The combined applications would then undergo additional testing to evaluate their effectiveness. The hope is that this integrated solution can be used in centers around the city to help enhance verbal and non-verbal skills and improve information retention while providing a relaxing and immersive space.

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