Bachelor of Science Thesis

Virtual Exploration of the Ancient Port of Amathus: Creating Lifelike Underwater Environments with Procedural Generation and Artificial Intelligence

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May 2023

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A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Bachelor of Science at the University of Cyprus

May 2023

ACKNOWLEDGEMENTS

Throughout this research endeavor, I would like to express my profound gratitude to my adviser Andreas Aristidou for his helpful direction, wise counsel, and constant support. My research and academic development have been greatly influenced by his support and advice.

I also want to acknowledge Fotis Liarokapis for his contributions to this project. I am thankful for his cooperation because of his technical expertise, insightful feedback, intelligent criticism, and willingness to share his knowledge.

Moreover, I would like to express my deepest gratitude for the financing provided for the ANDIKAT project, which is the project that we took Amathus harbor 3D model from. ANDIKAT was co-funded by the European Union (EU) through the European Territorial Cooperation Program (ETCP), as well as by the national resources of Greece and Cyprus within the framework of the Interreg V-A Greece-Cyprus 2014-2020 Cooperation Program.

I'm also appreciative of my friends' encouragement and support, who have given me invaluable criticism, advice, and moral support during this difficult route.

Finally, I want to sincerely thank my family for their constant love, support, and encouragement throughout my academic career.

Abstract

Virtual reality (VR) is a powerful technology with the potential to revolutionize underwater exploration by providing immersive and realistic experiences without the limitations and risks associated with physical scuba diving. Given the lack of exploration of underwater environments and the limited use of virtual reality in this context, this project proposes a novel application of virtual reality to explore underwater environments, with a specific focus on the ancient port of Amathus. To create a more immersive and realistic virtual underwater environment, this research project employs procedural generation techniques to generate diverse and lifelike underwater vegetation. In addition, the project utilizes artificial intelligence algorithms to simulate fish movements, further enhancing the level of immersion and realism in the virtual environment. By exploring the potential of virtual reality in the uncharted domain of underwater environments, this research presents a simulated dive through Amathus harbor. The immersive and realistic experience offers users a chance to explore the underwater world without requiring physical scuba diving. Through the use of VR technology, this research aims to contribute to the development of new applications and experiences for underwater exploration in the field of virtual reality.

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Chapter 1

Introduction

1.1 Motivation

The exploration of the underwater world is a fascinating and important area of study, and it also plays a crucial role in the preservation and understanding of our cultural heritage [1]. The study of underwater cultural heritage provides valuable insights into the history, culture, and traditions of ancient civilizations and communities that once thrived along coastlines and riverbanks [1]. However, the exploration of underwater environments presents several challenges that limit its accessibility. Scuba diving and other underwater exploration activities require significant resources, making them expensive and inaccessible to many people. Moreover, individuals are required to possess swimming equipment and not only are expected to be proficient swimmers but also be capable of holding their breath for extended periods. Also, the vastness of the sea poses a challenge for swimmers to navigate and often leads to them becoming disoriented and lost at sea. Additionally, the destruction of coral reefs and the decline in fish populations due to pollution and overfishing have made it more challenging to experience the natural underwater world. [2]
Virtual reality technology presents a unique opportunity to overcome these limitations and allow users to explore underwater environments in an immersive and interactive way [3]. This opens up new opportunities for research, education, and entertainment, particularly in fields such as marine biology, oceanography, and archaeology [3].

Our project offers individuals the unique opportunity to experience, learn from, and interact with the rich cultural heritage of the sea, without the limitations and difficulties that were previously mentioned. By leveraging the immersive capabilities of virtual reality technology, our project provides an unparalleled level of engagement with underwater environments and cultural heritage that is both educational and entertaining. Although there is a lack of exploration of underwater environments in virtual reality applications, this thesis project aims to contribute to the development of new applications and experiences in virtual underwater environments by utilizing these advanced technologies. We will contribute to the development of new applications and experiences for VR in the field of underwater exploration, with potential applications in fields such as tourism, education, and marine conservation. Through this research, we hope to inspire and engage a broader audience in the exploration and conservation of our planet's underwater world.

1.2 Problems/Challenges

The creation of an underwater environment in virtual reality has not yet been fully explored due to several challenges. The main reason for this is the difficulty in creating highly realistic and detailed virtual environments that accurately reflect the complex and diverse nature of the ocean's underwater world [4]. Also, the simulation of a specific area in the sea presents a significant challenge in terms of collecting accurate data and creating the environment as it is in real life. Additionally, the complex nature of underwater environments, including the presence of marine life, coral reefs, and other features, makes it difficult to accurately simulate these environments using traditional modeling techniques [4].

Furthermore, the use of virtual reality in underwater cultural heritage preservation is a relatively new area of study that requires extensive research and development [4]. The lack of research and development in this area has made it challenging to create highly realistic and interactive virtual environments that accurately reflect the rich cultural heritage of the sea [4].

Another major challenge in creating underwater cultural heritage is the representation of the submerged monuments such as shipwrecks or in our case the ancient harbor. To be able to extract those monuments in detail, photogrammetry is one of the best but challenging techniques for creating 3D models [5]. This is because it can be difficult to achieve high-quality results underwater due to factors such as water turbidity and light diffusion. Moreover, the harbor's shallow waters present a significant challenge for obtaining high-quality photogrammetry results due to the presence of constant water movement and waves [5]. Furthermore, virtual reality navigation and exploration requires a high level of attention to the user experience, ensuring that user can safely and comfortably explore the virtual environment without any problems [4].

1.3 Innovation

A similar work about our case study is the "Amathus Harbour" app that is a digital tool that aims to enhance the visitor's experience by providing information and audio-visual material for a digital remote navigation in space [6]. The app's interactive map feature highlights points of interest that are within close distance to the visitor's geographical location. This allows users to explore the ancient harbor of Amathus at their own pace and learn about its history and environment. One of the app's key features is the audio touring function, which serves as a guide to tracking important remains along the coast. Users can listen to or read about the history and environment of this unique landscape, making their experience more interactive and engaging.

However, the app also has some limitations. It is not interactive in the sense that the user cannot physically interact with the points of interest, unlike in the virtual reality game. The app only provides information about the harbor and its surroundings, and users cannot experience it firsthand by swimming in the water and observing the marine life like in the VR game. Additionally, the app may not be suitable for those who prefer a more immersive experience. While it provides valuable information, some users may find the app to be limiting in terms of engagement and interactivity.

Our project presents a novel and advanced approach to digital cultural heritage, surpassing the capabilities of previously developed applications, such as the “Amathus Harbour” app. While the “Amathus Harbour” app provides visitors with information about the ancient port, it is limited in terms of its interactivity and engagement with the site. On the other hand, the virtual reality game developed in this project offers users a fully immersive experience, allowing them to explore and interact with the Amathus site in an unprecedented way.

1.4 Research Contribution

As part of this project, our aim was to showcase the development of a distinctive underwater environment by using the ancient harbor of Amathus as a case study. Amathus harbor is located in Limassol and dates to the beginning of the Hellenistic period around the 4^{th} century BCE. We chose this port due to its shallow sea water that is easily reachable by swimming. Moreover, the crystal-clear waters facilitated the photogrammetry process, allowing for the extraction of a highly detailed 3D model of the port [7] .

This project offers a novel solution to the challenges of underwater exploration by digitizing the port and creating a virtual reality environment that the users are able to explore without the need of any equipment or expenses. Moreover, we were able to create a guided tour that navigates the users to the points of interests which the users can learn about the history and the marine life of Amathus harbor. Procedural generation enabled us to automatically create large amounts of content like rocks and plants in the simulation, making it possible to offer a diverse and immersive experience for users. Additionally, artificial intelligence algorithms are used for the fish movements giving the underwater fauna a lifelike behavior. Furthermore, Photogrammetry was used to bring to life the port of Amathus that the users are able to explore and interact with. Generally, the project's focus on underwater environments and the use of virtual reality technology to offer an accessible and realistic experience of the underwater world represents an innovative approach to addressing the challenges of underwater exploration.

The "Amathus VR" project represents a groundbreaking innovation in the cultural heritage sector, as no similar application has been previously developed in Cyprus for any port or underwater museum. This unique and original project sets a new standard for virtual reality experiences, providing visitors with an unparalleled opportunity to explore and learn about the rich history and unique environment of Amathus.

Chapter 2

Related work

2.1 Cultural heritage

Many projects aim to bring attention to cultural heritage and preserve it for future generations. One approach of bringing up the cultural heritage was done by storytelling and projection mapping in the project called “Conveying Intangible Cultural Heritage in Museums with Interactive Storytelling and Projection Mapping: The Case of the Mastic Villages" by Tampakas et al. (2019) [8]. The project aimed to connect the architectural and intangible cultural heritage of the Mastic Villages in Southern Chios with engaging audiovisuals projected on a scale model of a historic settlement. The projection mapping installation displayed historical events and seasonal cultivation activities as part of the intangible cultural heritage of the place, providing visitors with a unique and immersive experience. This project has shown great potential in conveying cultural heritage in museums. The project of the Mastic Villages, in particular, provides a successful example of using these technologies to showcase the intangible cultural heritage of a place in an immersive and engaging way [8].

Figure 1: Screenshots from the formative evaluation at the Chios Mastic Museum’s supporting room (left) and the laboratory evaluation (right). [8]

2.2 Cultural heritage in underwater environments and VR

A similar work with our project, is the project "3d modelling and mapping for virtual exploration of underwater archaeology assets" of Mazotos shipwreck site in Cyprus which is located 44 meters underwater [9]. This study explores the use of photogrammetry and virtual reality to create an immersive experience of exploring an underwater archaeological site. Specifically, the project presents a photogrammetric solution for modelling archaeological assets in a VR visit to the Mazotos shipwreck site in Cyprus. The project aims to offer users an opportunity to visualize and learn about the site while exploring it virtually using VR headsets. To create the virtual environment, optical data was used for 3D modelling and mapping of the underwater archaeological site. The imagery captured by multiple underwater un-calibrated cameras was processed using a Structure-from-Motion (SfM) processing pipeline. The 3D models obtained were then incorporated into the VR application. [9]

The VR application not only allows users to experience an immersive virtual underwater visit but also provides them with textual descriptions, videos and sounds about the shipwreck and its cargo. This information is aimed at raising users' archaeological knowledge and cultural awareness while bringing up the cultural heritage of the underwater environment of Mazotos.

The findings of the study suggest that immersive technologies like photogrammetry and VR have great potential to enhance the exploration of underwater archaeological sites, both for researchers and scholars, as well as for the public. [9]

Figure 2: Underwater visualization of Mazotos shipwreck in immersive VR. [9]

Another project called "The VIRTUALDiver Project. Making Greece's Underwater Cultural Heritage Accessible to the Public" is another notable example of using virtual reality technology to bring awareness about the underwater cultural heritage [10]. This project aims to preserve and promote Greece's underwater sites by creating an immersive virtual reality experience that allows users to explore and learn about these sites. Through the use of advanced technology such as photogrammetry and 3D modeling, the VIRTUALDiver Project has created accurate digital representations of the underwater environments and artifacts. The project's virtual reality experience provides tourists with an opportunity to experience and learn about Greece's underwater cultural heritage by navigating through the virtual environment. The inclusion of educational materials and interactive features in the VIRTUALDiver Project provides users with valuable information about the history, significance, and conservation efforts related to these sites [10].

Figure 3: Diver Mode: User interacting with a 3D model of a shipwreck. (3D Model has been produced by Up2metric VIRTUALDriver partners) [10].

Overall, the VIRTUALDiver and Mazotos projects are an excellent example of the use of virtual reality technology to preserve and promote cultural heritage. The projects showcase how digital preservation and immersive experiences can make cultural heritage sites accessible to the public, even those that are difficult to access physically. Those projects' approach could serve as a model for similar initiatives aimed at preserving and promoting cultural heritage around the world [10].

Chapter 3

Implementation

3.1 Background

3.1.1 Unreal Engine 5

This project mainly uses Unreal Engine 5, a powerful and widely used game engine that is ideal for creating immersive virtual reality experiences [11]. Developed by Epic Games, it offers a wide range of features and tools that are designed to make game development more efficient and effective [11].

One of the key benefits of using Unreal Engine 5 for this project was its advanced graphics capabilities [12]. With its next-generation Nanite technology, Unreal Engine 5 allowed for highly detailed and realistic 3D environments and assets to be created with ease [12]. This was especially important for the creation of underwater vegetation and fish, which required a high level of detail to be both realistic and immersive.

In addition to its graphics capabilities, Unreal Engine 5 also offers a range of tools for procedural generation, which were used to automatically create the underwater environment [13]. This not only saved time and effort but also allowed for a more diverse and complex environment to be created.

Another advantage of using Unreal Engine 5 for this project was its support for virtual reality development [14]. The engine provides built-in support for VR devices, which enabled us to integrate the virtual reality component of the project into the overall experience.

Overall, Unreal Engine 5 proved to be an ideal choice for this project, providing the necessary tools and features to create an immersive and realistic virtual reality experience of underwater exploration. Its advanced graphics capabilities, support for procedural generation, and VR development tools were instrumental in the successful completion of the project.

3.1.2 Blender

Blender is a powerful open-source 3D creation software that we utilized in this project to create and edit 3D models. With Blender, we were able to easily import and export models, modify textures and edit assets that was later transferred to Unreal Engine [15].

3.1.3 Virtual reality

Virtual reality (VR) is a rapidly evolving technology that offers users with an immersive and interactive experience in a simulated environment [16]. VR has been demonstrated to be an effective tool for simulating and exploring these areas, which are frequently challenging to reach in the actual world, with regard to its prospective applications in aquatic situations. For recreational applications like diving simulations, VR can offer a safe and regulated environment for researchers and students to explore marine creatures and underwater ecosystems [17].

Overall, there are a wide range of possible applications for virtual reality in aquatic settings, and these applications are likely to grow in significance as marine research, teaching, and conservation initiatives move forward [17].

3.2 Modeling

3.2.1 Photogrammetry for 3D port

Photogrammetry is a method that involves taking a series of photographs of an item from different angles and positions [18]. When the pictures are collected, specialized software is used to stitch the images together and create a detailed 3D model [19]. The process for the underwater photogrammetry typically involves placing cameras in waterproof housings or using specially designed underwater cameras to take the pictures [19]. The photographer uses cameras that are mounted on tripods or other stabilizing devices to make sure the pictures are taken correctly, and the images are sharp, detailed, and well-aligned. After that the pictures are insured to software that identifies common points between the images and use these points to create a 3D model [19]. These models are often used to study the structure in detail, measure its dimensions, and create visualizations or animations for educational or promotional purposes. [18] [19] In our case Amathus port was scanned with 3D photogrammetry that means thousands of pictures were taken from different angles and positions to ensure that the resulting model was as accurate and detailed as possible [20]. The 3D mapping of the port of Amathus was done within the framework of the ANDIKAT project. [21]

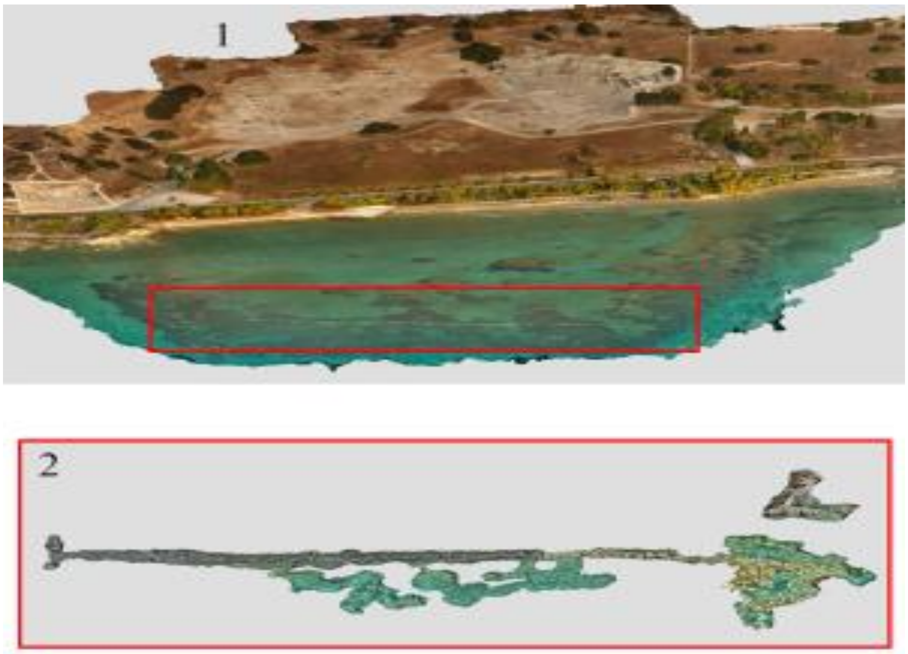


Figure 4: The location of the harbor structures visualized on the drone orthophoto (1); and (2) the underwater photogrammetry 3D model of the submerged structures [20].

The 3D model used in the Amathus VR project is a highly detailed representation of the south mole and entrance of the harbor. The model was edited using Blender software and was carefully modified to ensure accuracy in terms of scale, proportions, and colors. The model comprises approximately 5 million triangles and 14 million vertices.

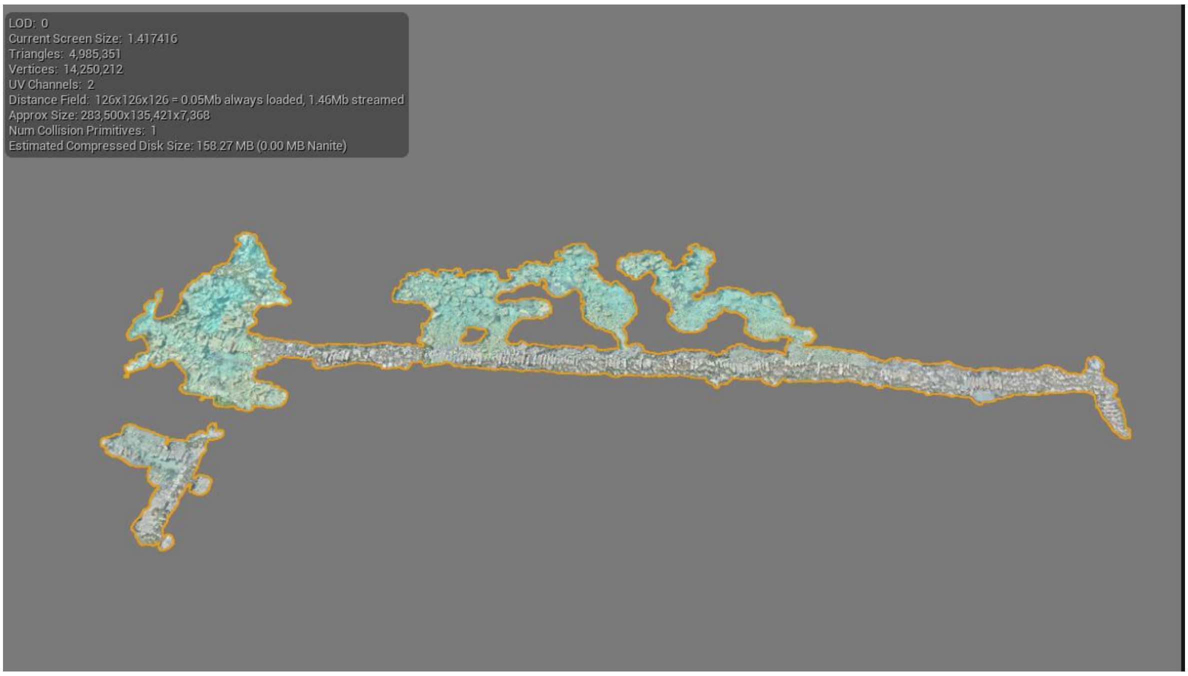


Figure 5: The 3D model of Amathus harbor in Unreal engine 5.

Although our team was able to capture most of the harbor, the constant water movement and waves caused some camera shake that resulted in imperfections in several parts of the resulting 3D model [6]. However, we were able to address these issues through several strategies. Firstly, we increased the density of foliage in the affected areas to effectively cover up the imperfections. Additionally, we applied more sand to the relevant areas to further conceal the imperfections and achieve a smoother appearance. These efforts allowed us to create a more accurate and visually appealing 3D model of the ancient harbor, despite the challenges posed by the underwater environment. Moreover, by employing these strategies, we were able to create more accurate and visually appealing 3D models of underwater structures, allowing us to better understand and preserve our shared cultural heritage.

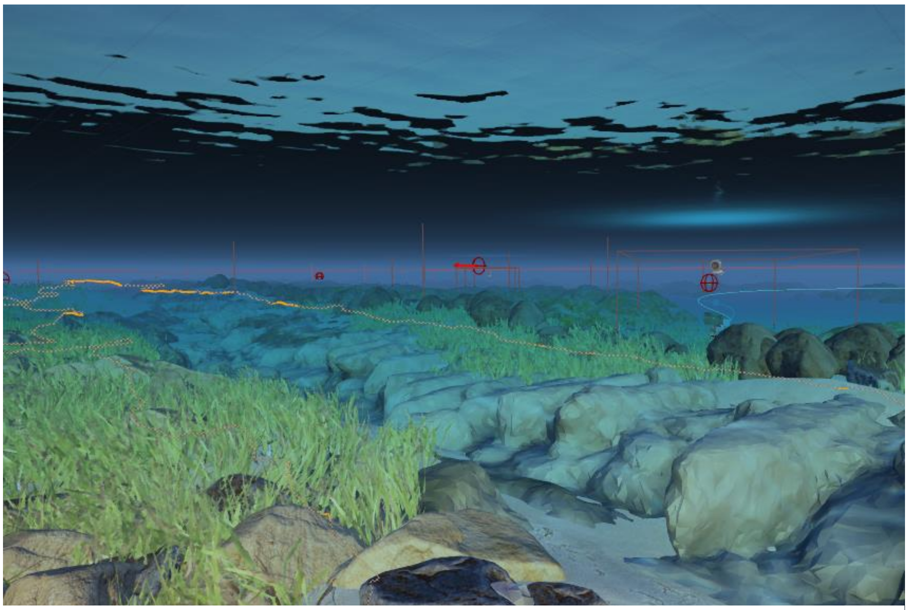


Figure 6: The port 3D model with use of foliage and sand to hide the imperfections.

3.2.2 Environment

3.2.2.1 Landscape

To create a realistic and immersive environment for our project we used the landscape mode of Unreal Engine 5 that is a powerful tool that allows game developers to create large, detailed outdoor environments [22] [23]. We began by sculpting the landscape of Amathus and carefully studied reference images and satellite maps from Google Earth to ensure that the landscape matched the real-world location as closely as possible. This involved creating the undulating contours of the coastline, the dimensions of the hole map, the depth and texture of the underwater sand, and the position and angle of the virtual sun to simulate the lighting conditions of the area. Furthermore, we added mountains to the background, which were carefully selected and placed to match the real-world topography of the area. We then procedurally generated trees, plants, and rocks onto the mountains to simulate the natural vegetation and terrain. By using procedural generation techniques, we were able to create a varied and complex environment that would have been difficult to achieve manually.
After the implementation of the landscape, we created the beach of Amathountas, which is the starting point of the Amathus virtual reality game. To create the beach, we used a combination of reference images and satellite maps to recreate the beach as accurately as possible. We modeled the beach using real-world measurements, and used high-quality textures to ensure that the sand, rocks, and water looked as realistic as possible. We also added the rocks of the beach in the correct place and also used procedural generation to place other rocks, foliage, and trees of the hole coastline to create a visually appealing and immersive environment. The map was then expanded to around 300 square meters to give the player a hole map to navigate and explore.

We also modeled the bridge that runs parallel to the coastline of Limassol. We found the asset by VictorSantos01 from Sketchfap that was then combined with other similar bridges to create the hole bridge. [23] We used reference images to ensure that the bridge matched its real-world counterpart and added appropriate textures and assets to achieve a high level of realism.

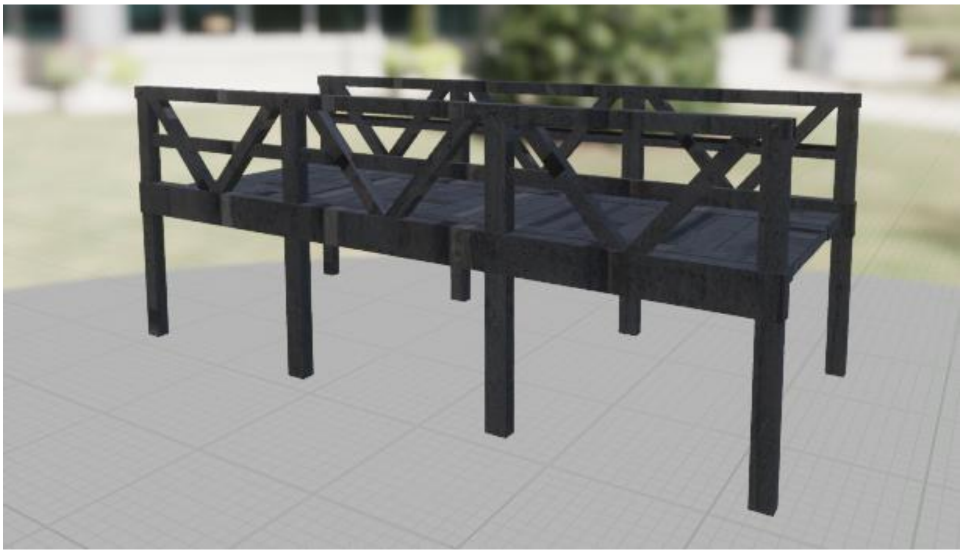


Figure 7: The asset that was used for the creation of the bridge.

Additionally, to further enhance the realism and authenticity of the landscape, we added more details such as electric poles, wires, and streetlamps. These assets were obtained from Sketchfab, and carefully selected to match our environment [24].

Figure 8: The electric pole (left) and the streetlamps (right) that were used for project.

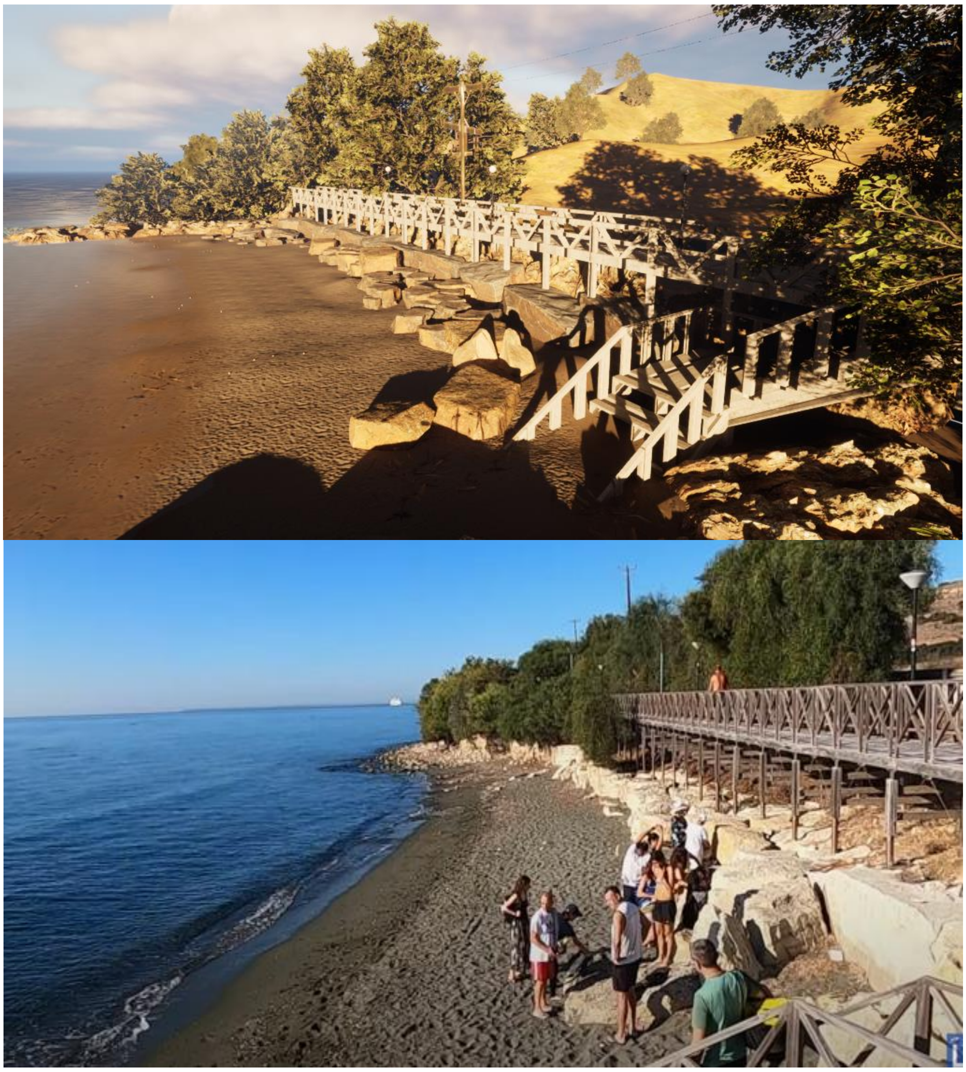


Figure 9: Amathuntas beach in our game in comparison with the google maps image.

3.2.2.2 Ocean and Underwater Environment

Water System

The role of water and the underwater world is crucial in this project, as it forms the core aspect of the game. To create a realistic and immersive experience, we utilized the Water System plugin from Unreal Engine [25]. This tool allows us to generate rivers, lakes, and oceans with a spline-based workflow that seamlessly integrated with our landscape terrain. The Water System unifies the shading and mesh rendering pipeline, enabling us to create surfaces that support physics interactions and fluid simulations. Furthermore, with the plugin the depth of the ocean, the colour of the water, the density and volume of the fog, and many more settings can be modified to the preferences of the user. [25]

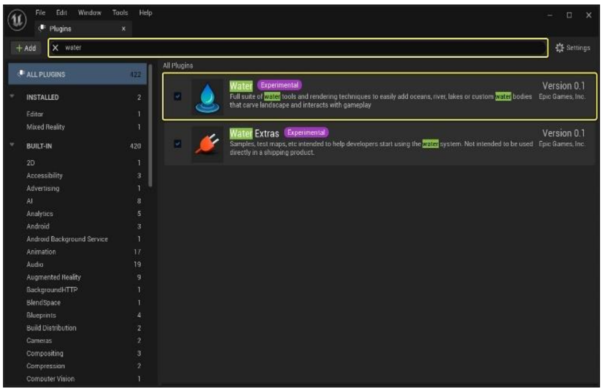


Figure 10: Water System Plugin installation [25].

We utilized this plugin to construct our underwater world, carefully placing it within our landscape to ensure accuracy and realism. We adjusted the spine lines along the coast of our maps so that it matches the real environment. By carefully placing the water ocean within our landscape, we were able to adjust the curve of the terrain under the water to ensure it matched the real environment.

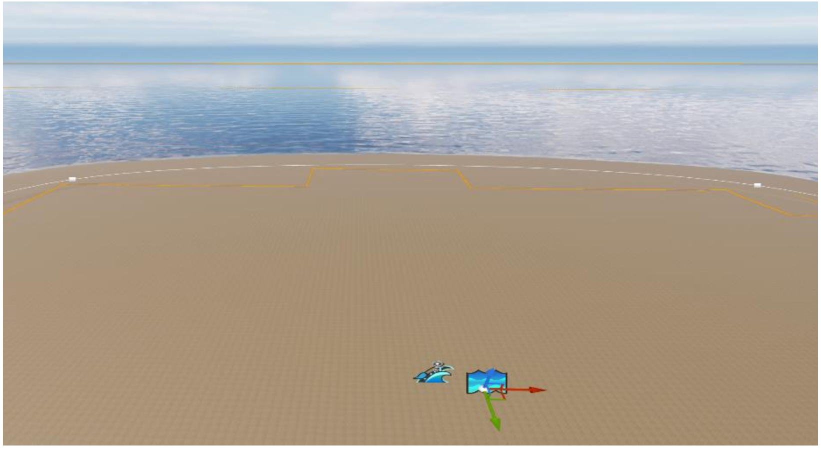


Figure 11:The use of water ocean asset from the water system plugin

The plugin we used also allowed us to adjust the waves to our liking. We chose to make the sea as calm as possible, opting for small and discreet waves that would give the impression of a peaceful and serene underwater environment.

Figure 12: The modification of the waves

To further enhance the realism of our underwater world, we modified the default water materials offered by the plugin. By adjusting the absorption and scattering of the water material, we were able to create a realistic appearance that closely mirrored the actual appearance of the sea at Amathus Beach. We also utilized the post-processing material for the underwater world, allowing us to adjust the fog and depth of the sea and automatically modify the post-processing effects accordingly. The color of the fog was also modified to accurately reflect the underwater environment at Amathus Beach.

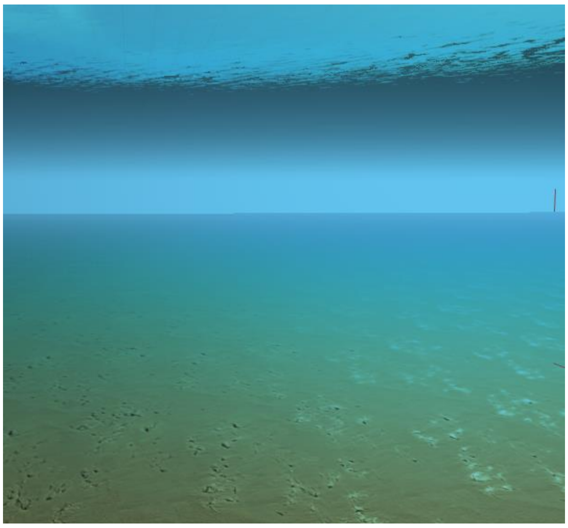


Figure 13: Water material results (left) and water post processing material result (right).

Overall, our use of this plugin allowed us to create a truly immersive and authentic underwater world, complete with accurate terrain, waves, and materials.

<u>Caustics</u>

The use of caustics in the Amathus sea environment adds to the overall realism and immersion of the underwater world. The shallow waters of the sea make the caustics particularly visible, making them an important visual element in the environment.
To create the caustics effect, we used a decal actor which allowed us to render material modifications on top of existing geometry. By applying the caustic material to the decal and placing it on top of the water area, the effect was achieved. The material itself was created using two textures that were combined and scrolled in different directions, to create the movement of the caustics. On top of that a third texture was used to create the trembling effect on each caustic. This careful attention to detail and use of textures created a realistic and dynamic caustics effect that enhances the visual quality of the underwater environment. Moreover, the implementation of the caustics effect allows for flexibility in adjusting the size and intensity of the effect, which can be important in ensuring the best visual experience for the player. The combination of the decal actor and caustics material results in a visually stunning underwater world in the Amathus sea.

Figure 14: Water Caustics results

Underwater environment

To truly immerse the player in the underwater world of our environment, we knew that we needed to add details that accurately reflect the real-life Amathus Beach experience. We decided to add rocks from Quixel Bridge that had green mold on them, as well as seaweed, to give the environment a more authentic feel [26]. Using procedural placement as mentioned in section 3.3.2, we carefully placed these assets in a way that looked natural and realistic.

In addition to these details, we also wanted to include important elements of the Amathus Beach ecosystem. To achieve this, we added Posidonia and other corals to the ocean floor. By randomly placing these elements, we were able to create a realistic underwater environment that mimics the natural beauty of Amathus Beach. Finally, we imported the 3D model of the Amathus harbor within the environment as mentioned in section 3.2.1, which helped to complete the underwater world of the project.

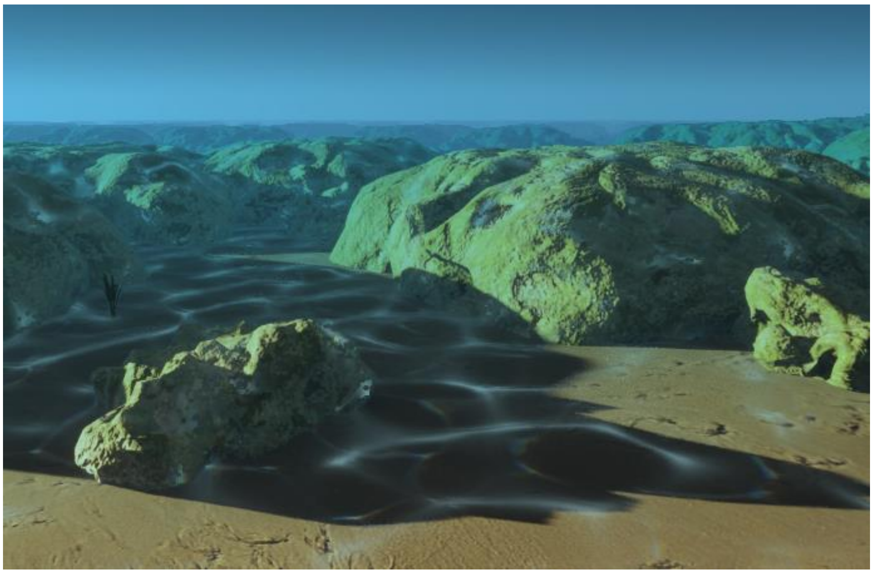


Figure 15: Underwater environment results.

3.3 Procedural Modeling

Procedural modeling played a crucial role in the development of our project, as it allowed us to create a vast and detailed environment while keeping the workload manageable. Almost all of the foliage, rocks, and plants were procedurally placed, giving us the flexibility to make adjustments quickly and easily. Additionally, we used procedural modeling to populate the ocean with fish, creating a dynamic and engaging underwater world. Overall, the use of procedural modeling helped us achieve a high level of realism and interactivity while maintaining efficiency in the development process.

3.3.1 Boids

The algorithm used for fish school simulation is based on the boid algorithm, which was originally developed by Craig Reynolds [27] for simulating flocking behaviour of birds and other living species, including fish. In this algorithm, each agent or boid has behaviour rules that govern its movement and interactions with other boids. The three basic rules of the algorithm are:

1.Separation: The boid steers away from nearby boids to avoid crowding or collisions.

2.Alignment: The boid steers towards the average heading of nearby boids to maintain a coherent group direction.

3.Cohesion: The boid steers towards the average position of nearby boids to stay close to the group.

In addition to these basic rules, the fish in the virtual visit have a specified area in which they consider the player as a threat and try to avoid him by changing their direction. This makes the interaction more realistic and engaging for the player.

The implementation of the boid algorithm in this project is based on Ghislain Girardot's implementation for creating boids using the Niagara effect [28]. Ghislain Girardot offers the project with the boids on his Patreon for free after becoming a member [29]. Niagara is a powerful visual effects system in Unreal Engine that allows for complex particle and fluid simulations. The boid algorithm is implemented using Niagara particle systems, which enable efficient and flexible particle simulation with advanced rendering and interaction capabilities.

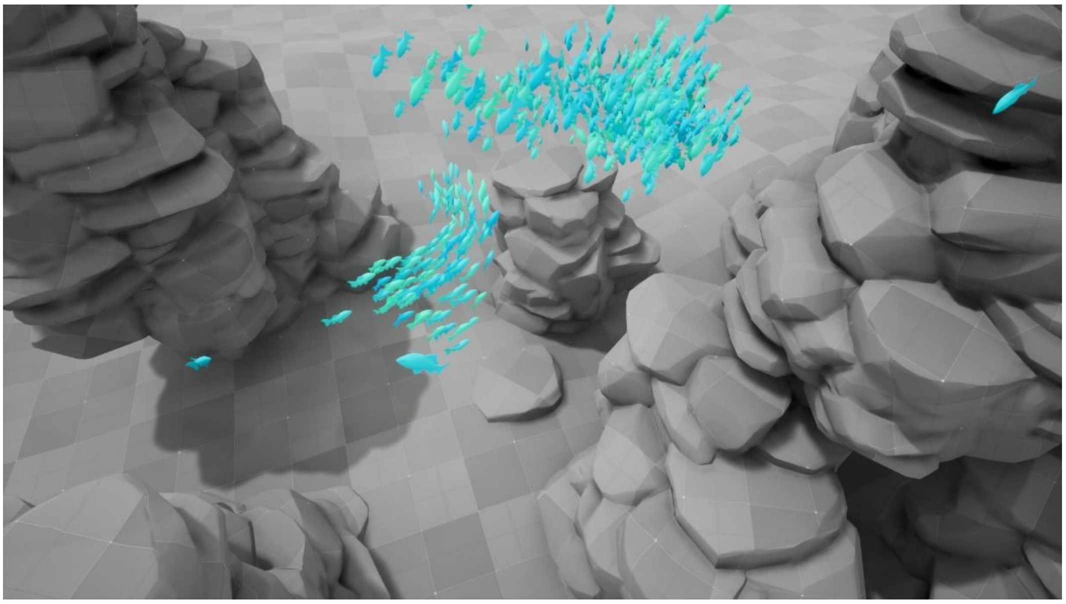


Figure 16: Implementation of the boids with the use of Unreal Engine 5 Niagara system

To implement the movement of the green turtle in our virtual environment, we utilized the ABK free birds project, which was created by Coqui Games and is available for free [30] .Although the project was initially intended for the movement of flying birds in the air, we found that the AI algorithm used for this project could be adapted to simulate the movement of a turtle in water. This project alowed the user to use the solo flight and the group flight of the birds. While the ABK free birds project allowed for both solo and group flight, we chose to utilize the solo flight function for the turtle's movement in our game.

The AI algorithm enabled the turtle to move in all directions and rotate when encountering an object or reaching the boundary of the designated area. To set up the turtle's movement, we first defined a bounding box in the area where we wanted the turtle to swim, with a scale of approximately 100 square meters and a height of 20 meters. We then assigned the turtle as the "flying animal" within this area, and set the awareness radius to 300 cm to detect nearby objects.

To ensure a realistic and natural movement, we set the turtle's speed to approximately 100 cm/s, allowing it to move smoothly through the water. This approach allowed us to create a lifelike simulation of a green turtle swimming through the virtual environment, enhancing the overall experience for the user.

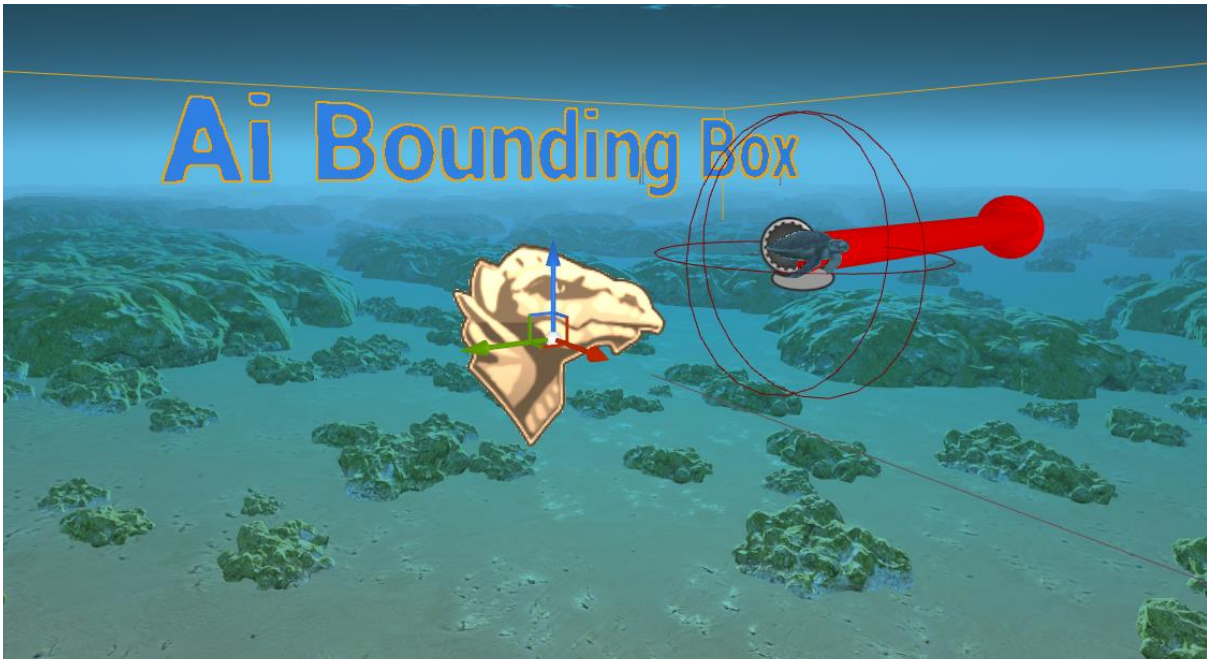


Figure 17: The turtle set up in the bounding box using the ABK free bird's project.

The virtual underwater environment in Amathus VR includes a diverse range of marine life, with 5 different species of fish and a green sea turtle that the player can interact with and learn information about. Each type of fish varies in size and speed, and spawns in groups of 4-10 instances at random locations throughout the map, providing a realistic and dynamic experience for the user.

The information about each fish species was obtained from the Amathus Harbour application, ensuring accuracy and relevance to the historical and ecological context of the location. The 3D models of the fish were sourced from the Sketchfab user baxterbaxter, who used photogrammetry to create detailed and lifelike meshes. [31]

The green sea turtle was also sourced from Sketchfab, specifically from the user DigitalLife3d [32]. This particular turtle was reconstructed from photos and measurements taken from a live individual by the Inwater Research Group, who are dedicated to studying and protecting marine life in the Mediterranean Sea. The turtle was in good health and released back into the wild after the assessment [32]. A skilled CG artist, Johnson Martin, used Blender software to reconstruct the green sea turtle in a realistic and detailed manner. The turtle also comes with a detailed animation, which enhances the immersive experience for the player.

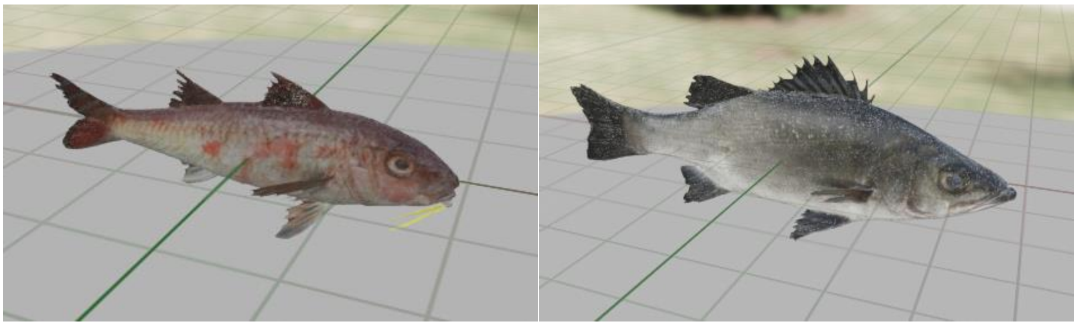


Figure 18: Red Sea goatfish (left) and European Seabass (right).

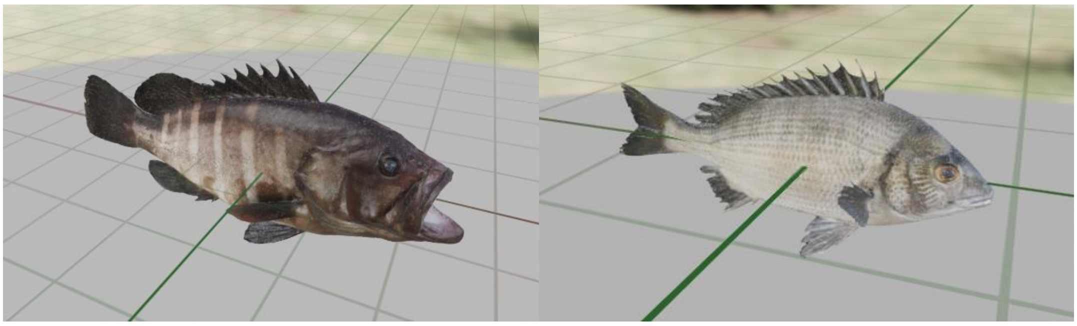


Figure 19:Grouper (left) and White Seabream (right)

Figure 20: Smaris (left) and green sea turtle (right)

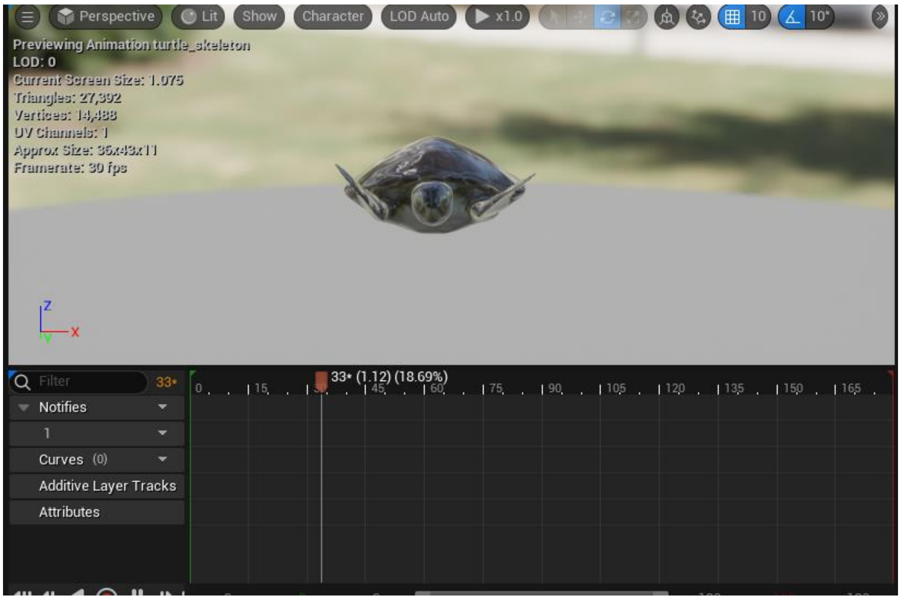


Figure 21: Swimming animation of the green sea turtle.

The spawning of fish in the sea is a critical aspect of creating a dynamic and unpredictable gaming experience. To achieve this, a procedural spawning approach was implemented, with fish locations randomized each time the game is played. The idea behind this was to create a bounding box where the fish could spawn in a specific area depending on the size of the box. To facilitate the procedural spawning of fish, an algorithm was developed that generates line traces based on the number of fish set to spawn. These line traces scan the ground to determine if it is safe to spawn a fish in a particular area. If the line trace finds no obstructions in the way, the fish will spawn in the specific area. One of the advantages of the procedural spawning approach is that the fish spawn in different areas each time the game is played. This is because, with every new game, the line traces will spawn in a different area within the bounding box. As a result, the fish spawning locations become unpredictable, enhancing the realism of the game.

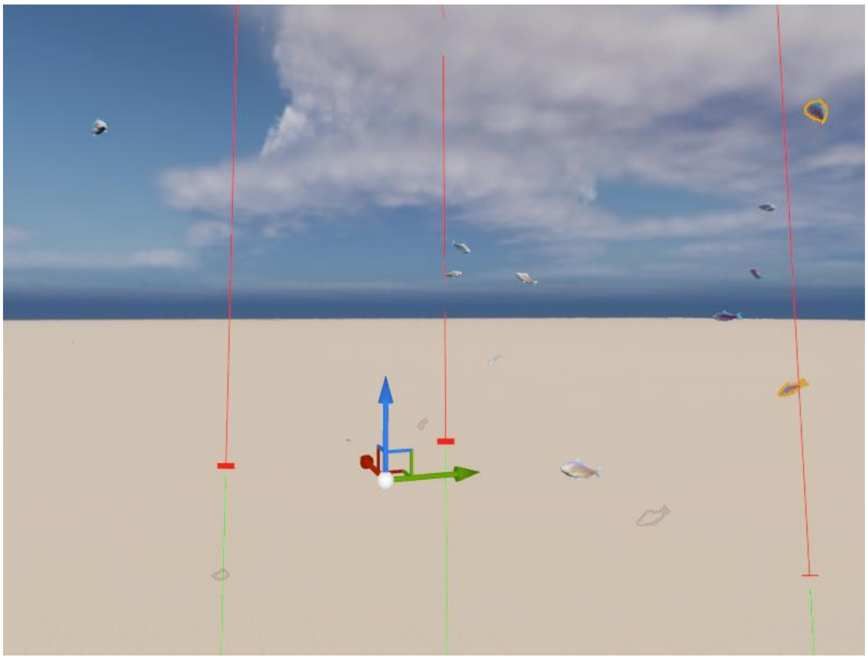


Figure 22: Procedural spawning of the fish in the map.

3.3.2 Foliage

For the creation of the foliage in our maps we used assets like the black alder tree from the Unreal Engine marketplace [33], Lemon grass that represents the seaweed and grass clumps asset that are representing the seaweed and the Posidonia and were taken from the Quixel Bridge [26].

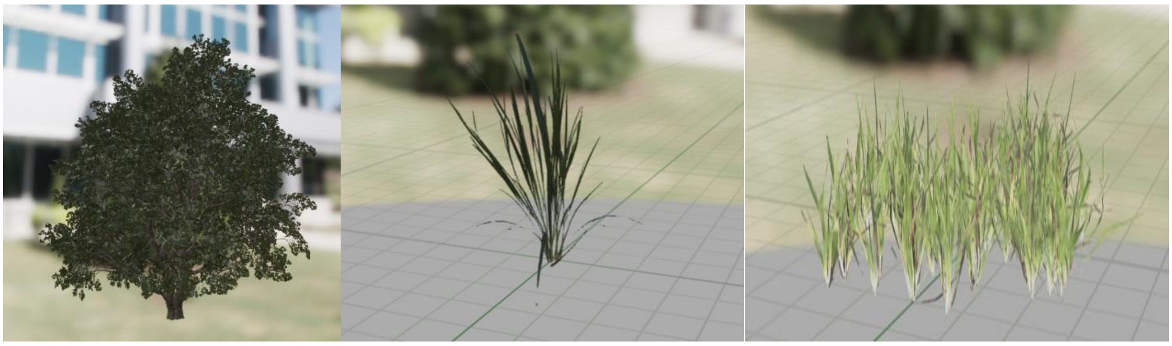


Figure 23: black alder (left), lemon grass (middle) and grass clumps (right), assets from Quixel Bridge

For the Posidonia we also modified the wind to make it look like the grass is swinging like is in the water. For this we set the simple grass wind on the world position offset of the material of the grass. To make the effect we utilized the parameter as shown in figure 24.

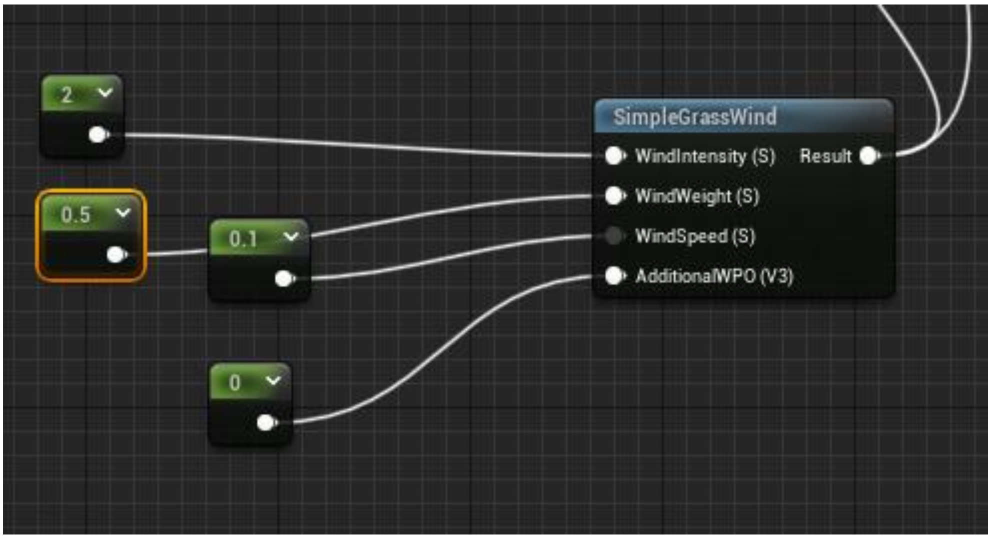


Figure 24: Grass wind parameters for the water effect on the Posidonia and seaweed.

The creation of a realistic and detailed environment is essential in any game or simulation. In our project, we utilized the Procedural Foliage Spawner tool offered by Unreal Engine 5 to procedurally place the foliage in our underwater world. This tool enabled us to automatically spawn rocks, plants, and seaweed in a volume and control the procedurality of the foliage with multiple options. [34]

The Procedural Foliage Spawner has three main sections that we used to customize the foliage in our environment. The first section is the Collision section, which determines which Foliage Type Objects should be removed when two objects are competing for the same spawn location. This feature helped us to avoid overcrowding and ensure that the foliage was spaced out realistically. [34]

The second section, Clustering, uses a variety of properties such as density, age, and proximity to help determine how the specified Foliage Type Object's mesh instances should be placed, grouped, and spread around inside of the Procedural Foliage Spawner. [15] This feature allowed us to adjust the distribution of the foliage and create more realistic clusters of rocks and plants.

Finally, The Growth section allowed us to adjust how a Foliage Type Object's mesh instances grew and got bigger over time. This feature added more detail to the environment and made the foliage appear more natural [34].

For Amathus harbor and its surrounding sea we noticed that certain areas of the sea had a higher density of rocks and seaweed than others. To replicate this in our virtual environment, we used multiple volumes with different settings for each to simulate the varying densities of rocks and seaweed in different areas of the underwater world.

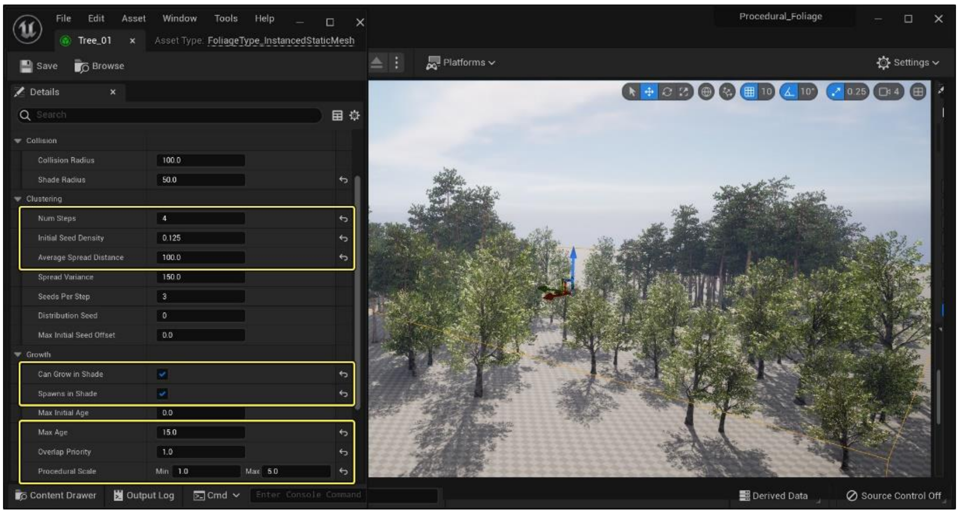


Figure 25: Procedural Foliage Spawner interface [34].

In addition to the Procedural Foliage Spawner, we also used the Foliage mode of Unreal Engine 5 to add more details in our world [35]. This mode enabled us to spawn foliage in specific areas that we designated with a brush, making the creation of the environment easier and faster. With this tool, we were able to semi-manually add foliage and rocks in specific areas to make the environment as realistic as possible with the use of procedural generation. This approach allowed us to create a more detailed and immersive environment for the user to explore and interact with.

Overall, the use of procedural modelling and generation allowed us to create a realistic and dynamic underwater world that accurately reflects the real-life location of the ancient Amathus harbor and its surrounding sea.

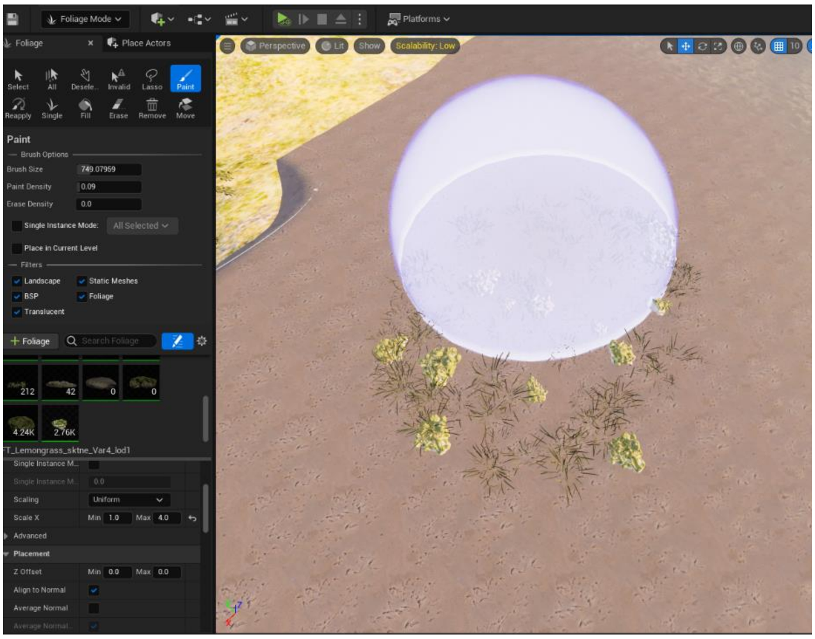


Figure 26: Procedural Foliage Spawner interface [35].

3.4 VR implementation

3.4.1 Character

The character was designed to allow the user to navigate in the environment and interact with various points of interest, fish, and other objects. To enhance the user's experience in the Amathus VR game, the VR pawn was modified and replaced with a Character pawn, allowing for more flexibility and control over the user's movements in the environment. The Character pawn enables the user to move, swim and teleport through the virtual world, providing multiple options for navigation and exploration.

To enable the character to move through the environment and avoid colliding with obstacles, a capsule was positioned on the player. This capsule served as a collision detection mechanism, preventing the character from passing through solid objects such as walls or trees.

The user's hands were also included as part of the character's design, as they were the only visible aspect of the character when the user plays the game. This allows the user to interact with various objects in the virtual environment, such as picking up and examining items.

The camera was also a critical aspect of the user's character, as it allowed the user to see the virtual environment from the character's perspective. To ensure that the camera moved with the user's movements as they wore the VR headset, the default pawn available with the VRTemplate of Unreal Engine 5 was utilized. This allowed for a seamless and intuitive user experience as the user explored the virtual environment of Amathus [36].

For the player to interact with the fish a line tracer was implemented. The line tracer checks for objects every 0.1 second and has the ability to spot fish's collision box in the range of 10 meters. Each fish has its own of variable that allows for differentiation between species. By utilizing a line trace, our program is able to determine which species of fish the line is colliding with, allowing for unique interactions with each type of fish. This gives the ability for the player to know when there is a fish in front of the player's camera to give the user the ability to interact with any fish.

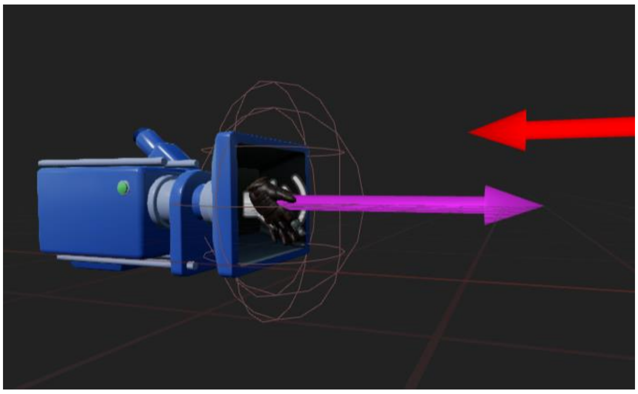


Figure 27: The character of the game.

3.4.2 Navigation

In order to provide the player with flexibility in exploring the underwater environment, two navigation options have been implemented in the Amathus VR experience: guided tour and free exploration. The option can be taken on the first objective when the player is in the game and can always go back to this marker point to change the option.

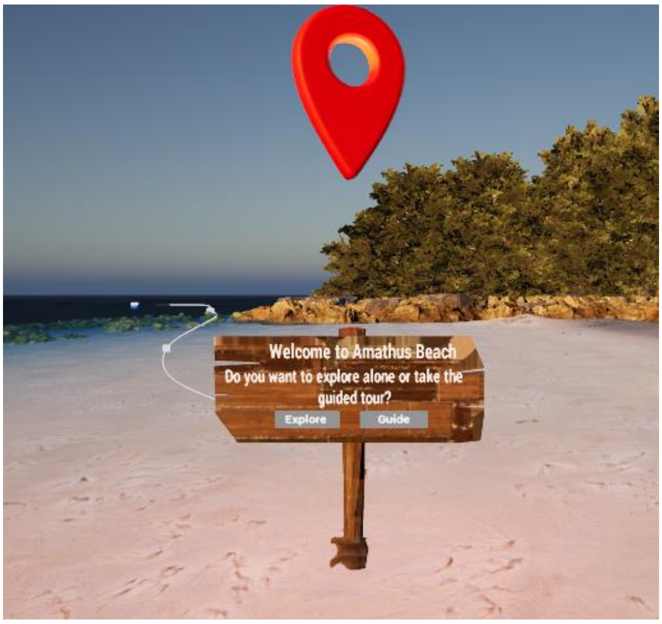


Figure 28: Starting point.

In the guided mode, the player is presented with a series of transparent arrows that direct him to each of the six points of interest in the game, including four related to the ancient port and two related to the fauna and flora of the sea. These arrows are designed to help the players navigate through the environment in a safe and efficient manner, ensuring that they do not become disoriented or lost. When the player reaches a point of interest, a wooden sign is presented with the name of the location. The players can press the 'A' button on their controller to hear an audio description of the point of interest, which provides additional information about the historical significance or ecological importance of the location. To enhance the overall experience and make the interaction with the virtual environment more realistic, we used LOVO AI to generate the audio [37]. This software was able to take the text input and convert it into a natural-sounding voice, giving the impression of an actual person speaking. This greatly contributed to the immersion of the player in the virtual environment, making the experience more lifelike and engaging. Once the audio description is complete, the next arrows reappear, guiding the player to the next point of interest.

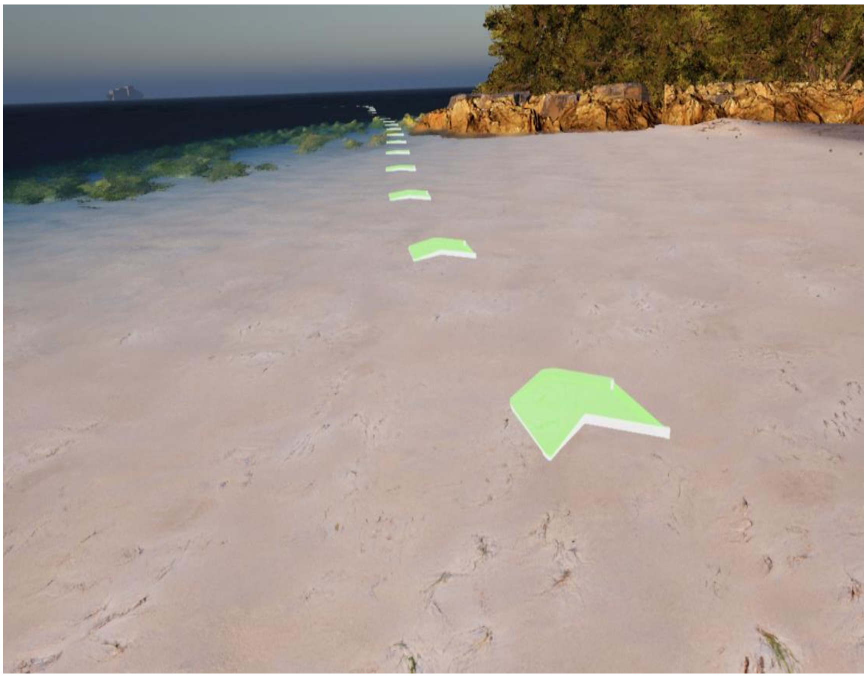


Figure 29: Transparent arrows to help the use to navigate through the game.

The second option is free exploration, where the player can move around the sea without any specific direction or path to follow. This option is more for the players who want to explore the underwater world at their own pace and discover the secrets of the sea by themselves. The objectives are still visible from a distance, but the players are free to choose which point of interest they want to explore first. The wooden signs are still present at the points of interest, and the player can visit them to hear information about them.

The system we implemented for the navigation is based on common VR navigation techniques, such as using arrows and waypoints to guide the user through the environment. This makes it easy for players to understand and use the system, even if they are not familiar with VR games. Furthermore, the use of wooden signs and sound effects to provide information about points of interest enhances the immersive experience for the player. Furthermore, the path that the player must follow to find all the points of interest was designed to be easy for the user to follow it without facing any issues with the controls. The path is also not that time consuming, as the user is able to finish the guided tour in around 5-10 minutes.

Overall, the two navigation options give the players the freedom to choose how they want to explore the environment, whether it be a guided tour or free exploration. It also adds to the replayability of the game, as the player can switch between the two options to experience the environment differently.

3.4.3 Menu

The menu is really simple and contains several options to help the user find information and execute functions.
It comprises 3 main options:
• Controls: gives an overview of the input of the left and right controller.
• Restart: The restart button restarts the game and brings the user to the start point again.
• Quit: exits the application.

The menu in our virtual underwater world consists of two widget interfaces: the Options menu and the Instructions menu. The widgets were designed to be easy to use and user-friendly, providing a seamless experience for the user. For the activation of the menu the player must press the settings button on the controller. The menu system in our project was designed to automatically appear in front of the players and follow their movement while allowing them to look around without obstructing their view. This was achieved by attaching the menu widget to a component that is always in front of the player and using blueprint logic to update the widget's position and rotation based on the player's movement and orientation. To navigate within the menu, we implemented a laser system that allows the user to interact with the widgets in 3D space. This laser system uses a Widget Interaction Component that is activated once the application starts. The component simulates a mouse button click by using a motion controller trigger press instead. Two functions are used to simulate the left mouse button press and release functionality and are later called when the respective key of the motion controller is fired.
In order to create the laser beam itself, we added a Spline Component and a Spline Mesh Component to the motion controller. The spline is activated once the menu is visible and only if the spline is hovered over the Widget. Once the spline hits a button, it can be clicked with the motion controller to execute the corresponding menu option. This laser system provides an intuitive and immersive way for the user to interact with the menu and navigate through the different options.

3.4.4 Controller input

By default, virtual hands are generated to represent the user's hands, providing a means of interaction with the virtual world through gestures such as pointing, touching, or grabbing objects. However, in our project, we went a step further by replacing the default Oculus 2 hand meshes with real hands.

These real hands were designed to be responsive to the user's actions, changing animations depending on the user's interactions with the virtual world. The user was able to point, grab objects, and even give a thumbs-up gesture, providing a more fun experience.
To achieve this, we imported the hand mesh and texture allocated by SteamVR into our project, which allowed us to customize and manipulate the appearance and behavior of the hands to match the requirements of our virtual environment [38]. This customization not only enhanced the overall experience but also added a level of realism that was appreciated by our users.
To provide an overview of the key bindings for the motion controllers, refer to Figure 30.

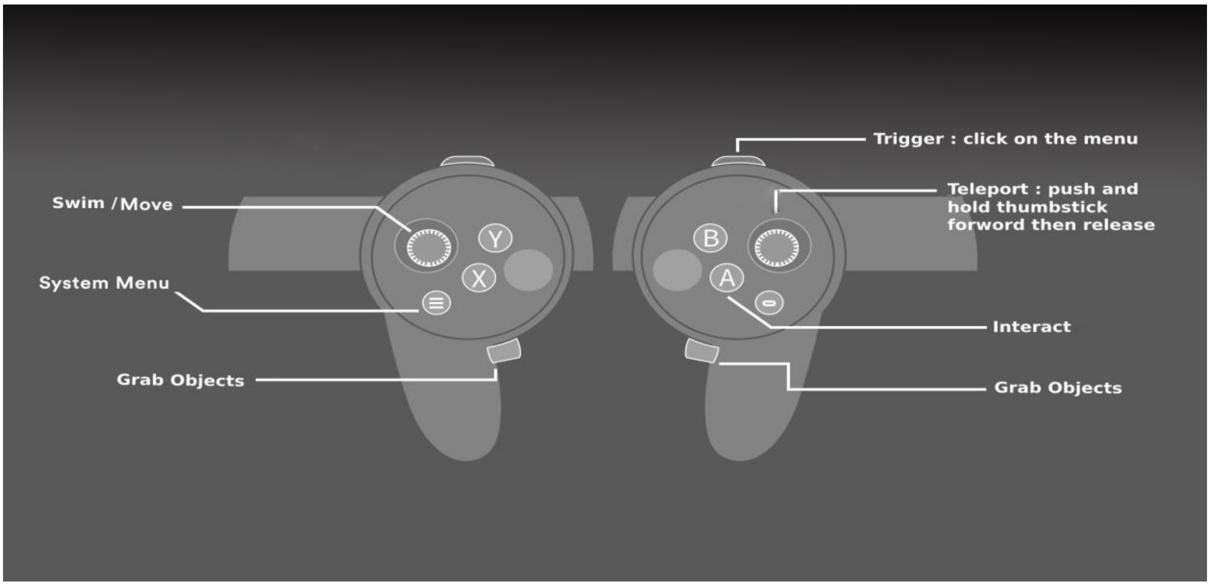


Figure 30: Key bindings for the left and right motion controller

In our VR application, we utilized the motion controllers for interaction with the virtual environment. The right motion controller was designated for main operations such as teleportation, triggering, interaction, and grabbing. The teleportation feature activates by pressing and releasing the right thumb stick button, allowing the user to teleport around the virtual space easily. The right trigger button also plays a key role in navigating menus and clicking on buttons within the interface. The 'A' button on the right controller is used to interact with the points of interest and the fish, while the right-hand trigger button is used to grab objects from the ground, such as a sponges or other items.
On the other hand, the left motion controller is primarily used for moving the player within the virtual environment and enabling or disabling the menu. The default locomotion allows the player to move in the direction the camera is facing, which is controlled by the left thumb stick. The player moves as long as the thumb stick is pushed, and eventually stops once released. To access the menu, the user must press the left menu button, which opens up a

menu interface. At the same time, a laser pointer appears on the right motion controller, which allows the user to interact with the menu options. Pressing the system menu button again would close the menu interface.

3.4.4 Transportation

Teleportation

In the Amathus project, two different teleportation systems have been implemented to allow users to navigate within the underwater world. The first system is the Motion Controller Teleportation, which is the default navigation system of the Blueprint Virtual Reality Template used in the project. This system allows the user to teleport forward by an arbitrary distance between 1 m and approximately 25 m. It involves the use of several static meshes, including an arrow, a beam, and a flat cylinder. When the user presses a button, an arced beam appears that traces the landscape. At the end of the beam, the arrow and cylinder show up and rotate according to the user's hand motion. On releasing the button, all the meshes disappear, and the user teleports to the arrow's last position. This teleportation system is designed to keep the user on the ground, preventing motion sickness, which can occur with other types of movement in VR. It also includes a valid location check to ensure that the user is allowed to navigate to the indicated position. This check prevents the user from teleporting to very steep terrain or jumping into deep chasms, ensuring a safe and comfortable experience.

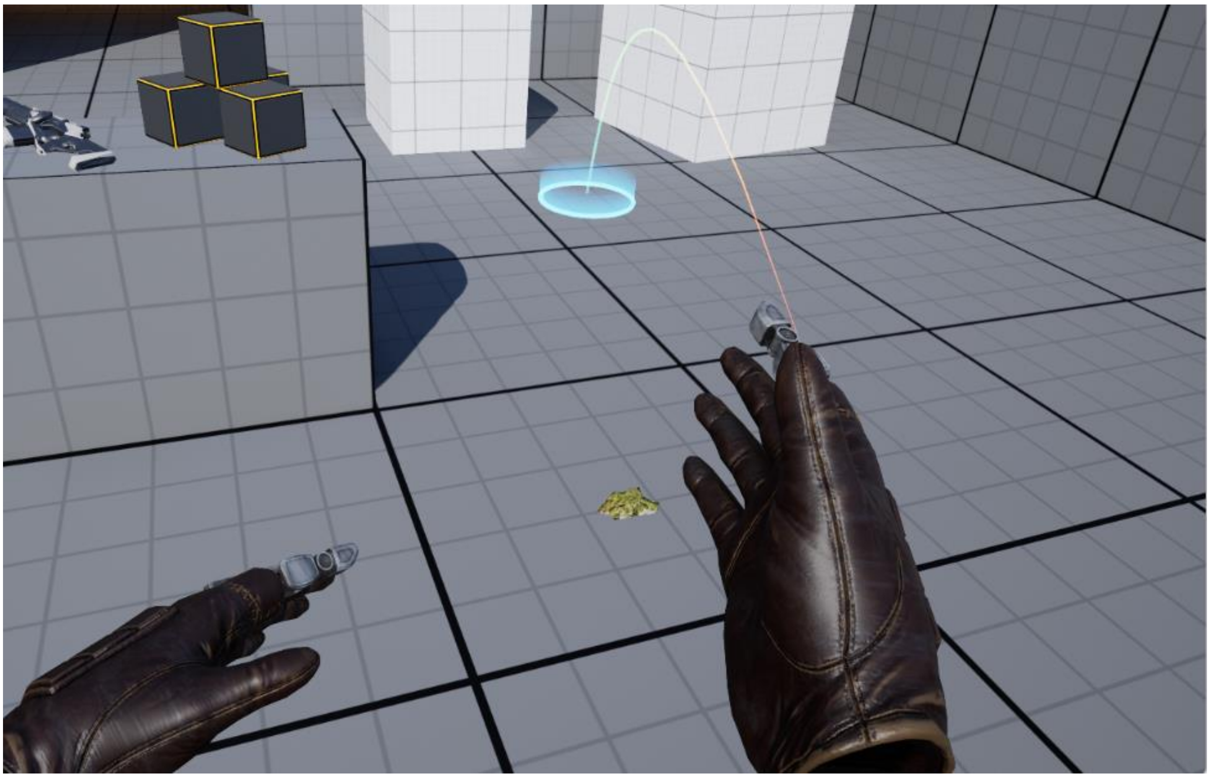


Figure 31: Teleportation using the default navigation system of the Virtual Reality template.

Thumb stick Locomotion

The second method of transportation is the thumb stick locomotion. The thumb stick direction movement in VR allows for a more natural and intuitive way of movement in a virtual environment. It provides a smooth and seamless experience for the user, making it easier for them to navigate and explore their surroundings. This is particularly useful in underwater environments where the player is in a swimming mode and needs to move freely in all directions.

Using the thumb stick, the player can move on both the x and y axis, allowing them to move in any direction they choose. Additionally, the same thumb stick can be used to move on the z axis by looking up or down. Basically, the players are moving in the direction they are looking by using the thumb stick and their camera, which makes it easier for them to focus on their exploration and interactions with the virtual environment.

The player's locomotion in the virtual environment was carefully designed to ensure an enjoyable experience. The player is able to move on the surface with a speed of 600 cm/s, which is faster than normal walking speed, allowing for efficient navigation without inducing boredom during transportation. When swimming, the player's speed is reduced to 300 cm/s, reflecting the slower pace of actual swimming. Additionally, the physics of the environment was adjusted to create a realistic illusion of swimming.

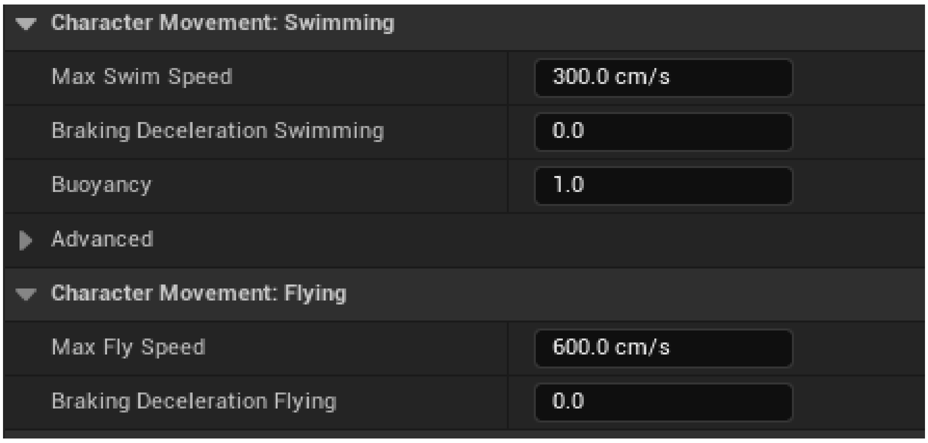


Figure 32: Character's swimming and moving movement speeds.

Chapter 4

Results

4.1 Video Snapshots

This chapter presents the outcomes of the Amathus virtual reality game, showcasing various video snapshots that highlight the game's features and gameplay mechanics. These snapshots demonstrate how users can navigate through the virtual world, interact with various objects, and engage with the game's immersive elements. The video snapshots offer an in-depth view of the game's capabilities, such as the user's ability to teleport to different locations, interact with points of interest, and explore the underwater world.

4.1.1 Terrain and Environment

Figure 33 provides a comprehensive view of the coast of the beach of Amathuntas, as seen from the user's perspective within the virtual reality game. This image is a visual representation of the detailed assets that were combined to create a realistic and immersive experience. As highlighted in section 3.2.2.1, the beach is composed of various elements, such as the bridge that runs along the coastline, the mountains, and the trees in the background. Additionally, to enhance the overall realism of the environment, smaller details, such as electric wires and lamps, were included.

Figure 33: The Landscape of the beach of Amathuntas.

Figure 34 illustrates the beach of Amathuntas as seen from the player's perspective in the VR game. As discussed in section 3.2.2.2, the water system plugin used in the game provides a realistic representation of the sea by accurately reflecting the sunlight and creating a shimmering effect on the water surface. In the distance, the player can observe container ships on the horizon, adding to the immersive experience of being in a coastal environment.

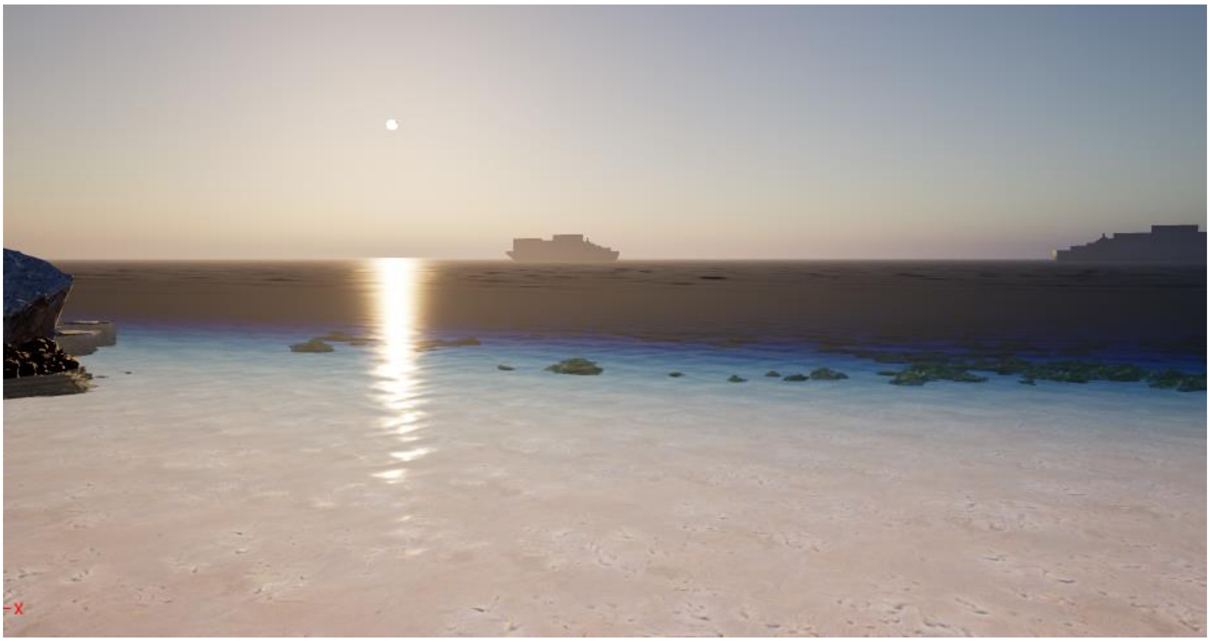


Figure 34: The beach of Amathuntas

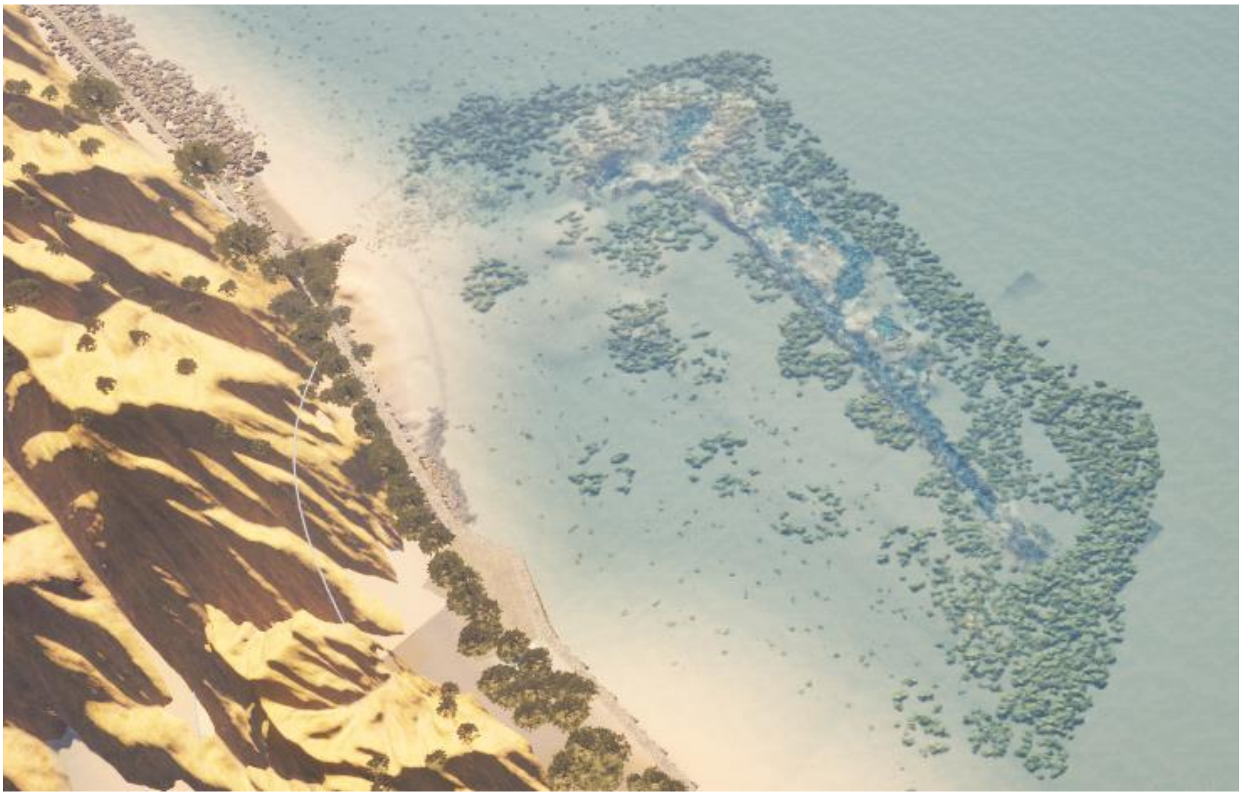


Figure 35: Amathus top view.

Furthermore Figure 36 as mentioned in section 3.2.1 shows the underwater world of the game, that the user can swim along the 3D model of Amathus ancient harbor.

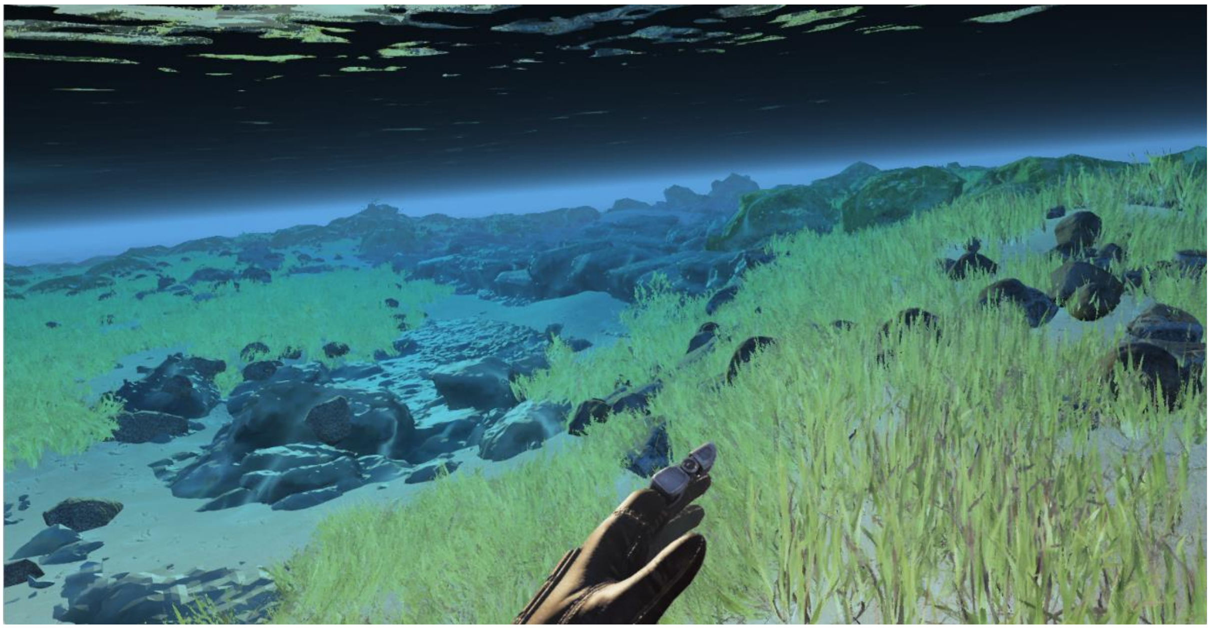


Figure 36: The 3D Model of Amathus Ancient Harbor covered with sand and foliage.

4.1.2 Fish

In Figure 37, the player's interaction with the fish is demonstrated. As the player approaches the fish, a widget appears, providing options for the player to interact with the fish and learn information about it. This interaction adds an educational element to the game, allowing players to learn about marine life in an immersive and engaging way.

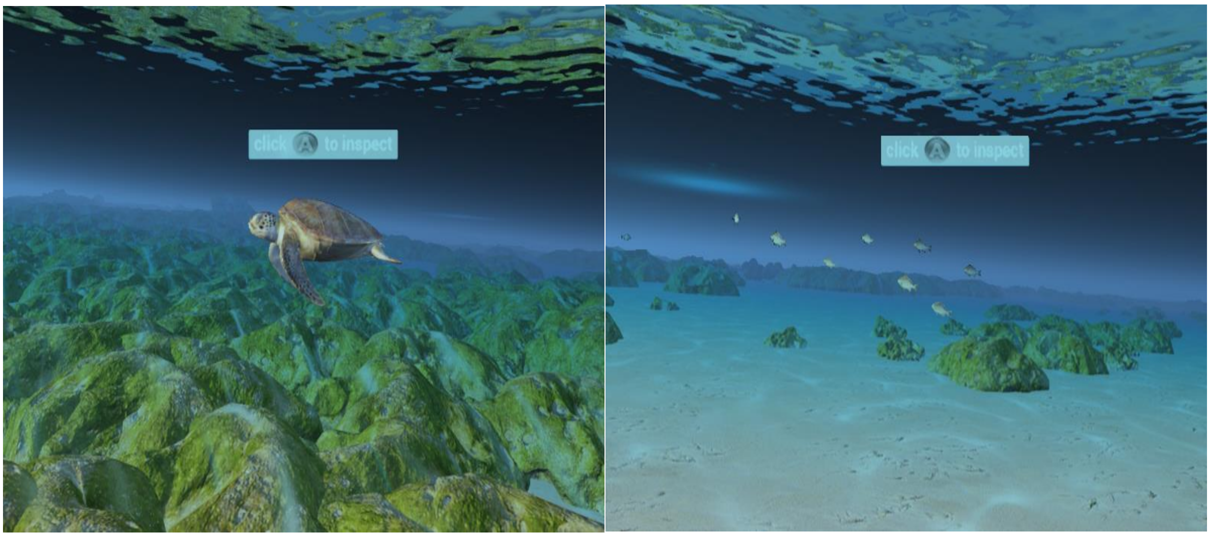


Figure 37: Player-Fish Interaction

4.1.3 Navigation

In Figure 38, transparent arrows can be seen indicating the path towards the first marker point. The player can then interact with the point of interest and gain information about it, as demonstrated in Figure 39. The information is conveyed through voiceovers, providing the user with an immersive learning experience.

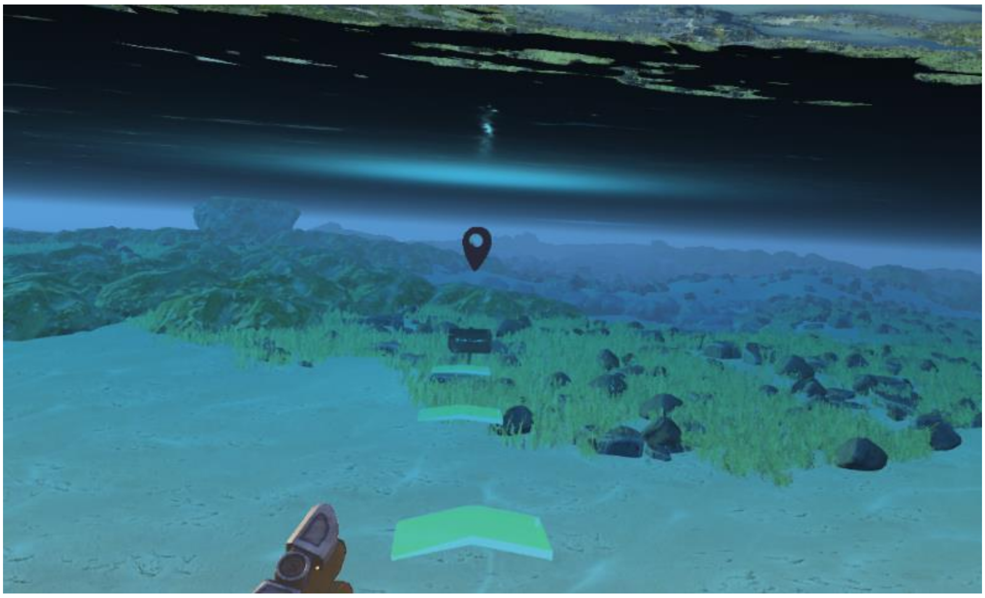


Figure 38: Player navigation to the first point of interest with the help of the navigation arrows

Figure 39: Player-Point of interest Interaction

4.1.4 Motion Controller and Transportation

Figure 40 shows both hands in VR as it is in real life. The hand meshes are default meshes with animations that were installed in the game to show the idea of the hand movement. Those meshes are going to be replaced with real hand meshes in the future. With the hand meshes the player has the options to point, grab and thumbs up with them.

Figure 40: (right) Pointing animation. (middle) Thumbs up. (Right) Grab objects.

The player transports through the map with the left thumb stick and the use of teleportation. Teleportation display specifies the distance to the proposed location. An arc to the indicated location is formed while the right trigger is pushed. After the trigger is released the user jumps to the location of the arc endpoint. (Figure 41)

Figure 41: Teleportation

4.1.5 Menu

The menu is activated from the left motion controller and the right controller is used to navigate within the menu. As the menu is opened, the user can use the menu options to restart, quit and see the controller’s input (Figure 42). Moreover, the pink laser is enabled on the right controller to allow the user-menu interaction.

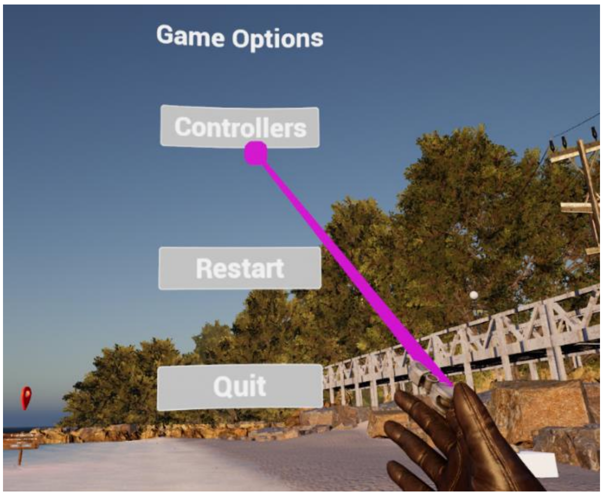


Figure 43: Main menu page “Game Options” providing the game options.

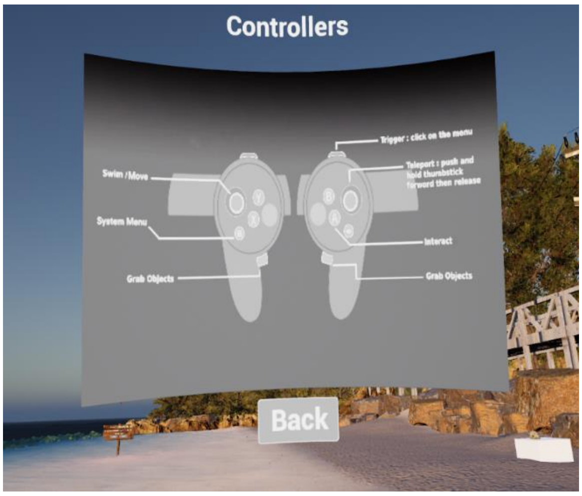


Figure 42: Menu page "Controllers" provides information about the controller inputs.

4.2 User Evaluation

In the user evaluation section, we conducted an expert evaluation with a group of experienced VR users who possess a strong background in graphics and VR technologies. These individuals were selected from CYENS Research and Innovation center based on their expertise and involvement in VR-related projects. The evaluation process commenced by providing the experts with an overview of the project's objectives and concept. They were then given the opportunity to explore the VR dive navigation application without any prior knowledge of the controls or specific tasks. This approach aimed to elicit their natural interaction and initial impressions. After the guided tour, the experts were encouraged to freely navigate and explore the virtual environment. After completing the assigned tasks, we engaged in structured conversations to gain deeper insights into their experiences, opinions, and observations regarding various aspects of the project. These discussions provided valuable feedback and fostered meaningful exchanges.

To capture more specific data, a questionnaire was administered to the experts. The questionnaire encompassed key aspects of the VR dive navigation experience, including usability, immersion, graphics quality, educational value, and overall user experience. The questionnaire utilized a mix of rating scales, multiple-choice questions, and open-ended responses to gather both quantitative and qualitative feedback. The expert user evaluation was conducted with the intent of gathering valuable insights and recommendations from individuals with expertise in VR technology. The feedback obtained from these evaluations will be used to refine the VR dive navigation project, address any identified issues, and enhance the overall user experience. By engaging experts in the evaluation process, we were able to tap into their wealth of knowledge and experience to validate our design choices and identify areas for improvement. The evaluation results will guide future iterations, ensuring that the VR dive navigation experience meets the highest standards of usability, immersion, and educational value.

4.2.1 Demographics

The expert evaluation panel comprised four individuals representing a similar range of age groups, specifically between 26 to 34 years old. Additionally, the evaluators hailed from two different countries (Cyprus and Croatia), contributing to a broader perspective and cultural diversity in the assessment process. The chosen experts brought similar professional backgrounds to the evaluation, mostly in research and graphics. One of the evaluators possessed a background in psychology, adding valuable insights into the user experience from a psychological perspective. While all participants were well-versed in virtual reality, it is noteworthy that they had limited experience specifically related to diving.

For the evaluation the experts match our requirements as we aimed to obtain a comprehensive and well-rounded evaluation of the VR dive navigation application. The diverse range of expertise and perspectives among the evaluators allowed for a more comprehensive analysis of the user experience, taking into account factors such as age, cultural influences, professional backgrounds, and prior VR knowledge.

The inclusion of researchers in graphics and a psychologist provided a unique blend of technical knowledge and insights into human behavior and perception. This combination of expertise enabled us to delve into both the technical aspects of the application and the psychological impact it may have on users. Also, the selection of experts with limited diving experience ensured a fresh perspective, allowing us to gauge how effectively the VR dive navigation application could bridge the knowledge gap and provide an engaging and educational experience even for those unfamiliar with diving. Their unbiased viewpoint provided valuable feedback on the accessibility and clarity of information presented within the application.

4.2.2 Questionnaire

The questionnaire was divided into two sections, with the first section focusing on the virtual reality (VR) experience in our game. This section consisted of 19 questions and was designed by professionals to assess the user's experience and performance within the virtual environment. The questions encompassed various aspects of the VR experience, aiming to gather insights into the impact of control devices on task performance, levels of concentration, proficiency in interacting with the virtual environment, perceived delays, ability to examine objects from different viewpoints. Moreover, we were able to get information about the sense of immersion and movement within the environment, naturalness of movement controls, responsiveness of the environment to user actions, and overall perceived control over events. By including questions related to these aspects, we aimed to gain a comprehensive understanding of the user's subjective experience and perception of the VR environment in our game. This feedback helped us assess the effectiveness of the control devices, the level of engagement and immersion provided by the environment, and the overall sense of control and agency felt by the users.

The second section of our questionnaire delved into more specific aspects of our project, including education, navigation, transportation, and interaction. The questions in this section aimed to gather feedback on the users' perceptions and experiences related to these areas. For example, we asked about the level of learning achieved regarding the history and culture of Amathus through the VR dive navigation. We also inquired about the potential contribution of VR dive navigation to the tourism industry in promoting cultural heritage sites. Additionally, we sought to understand whether users found the VR dive navigation experience more engaging than traditional methods of learning history.

In this section, we also explored users' perceptions of the completeness of information available about the ancient harbor and marine life. We asked about the clarity and user-friendliness of the navigation method, ensuring that users found it well-defined and easy to understand. Moreover, we sought feedback on users' ability to navigate and explore the map using the transportation methods provided in the game.

For researchers, we collected additional metrics, such as time-to-completion, success percentage, and identification of the main difficulties encountered by users. These metrics provided valuable insights into user performance, overall completion time, and any challenges they faced during the VR dive navigation experience. By including these questions in our questionnaire, we aimed to gather comprehensive feedback on the VR experience, educational aspects, navigation, and interaction in our game.

4.2.3 Questionnaire Results

In the first section of our questionnaire, the feedback from users regarding the VR experience in our game was generally positive. Users reported that they were able to control events and interact with the environment without facing significant difficulties. They found the responsiveness of the environment to their actions to be satisfactory, and the interactions felt natural and intuitive. The movement of the player within the virtual environment was described as almost completely natural, providing a compelling sense of navigating through the surroundings.

Regarding the visual aspect, users had no trouble viewing the environment clearly and were able to examine objects from multiple viewpoints with ease. This indicates that the visual display was effective in providing a clear and immersive experience. Additionally, the consistency of the environment, although not matching the real world perfectly, was deemed acceptable by users. They found the results of their actions to be predictable, contributing to a more engaging and interactive experience.

While most users were able to adjust to the virtual environment quickly, there was one user who initially struggled but eventually adapted throughout the guided tour. This highlights the importance of providing a sufficient learning curve and guidance for users who may be less familiar with VR technology. Overall, users reported minimal distractions from the visual display, allowing them to focus on completing the tour and exploring the virtual environment.

In conclusion, the results of the first section of our questionnaire indicate that the VR experience in our game was well-received by users. The majority of users found the interactions and movement within the environment to be natural and engaging. The visual display was effective in providing a clear view and allowing users to examine objects from different perspectives. While some users required a short adjustment period, they were able to adapt and navigate the virtual environment smoothly. These positive findings contribute to the overall success and effectiveness of our VR dive navigation experience.

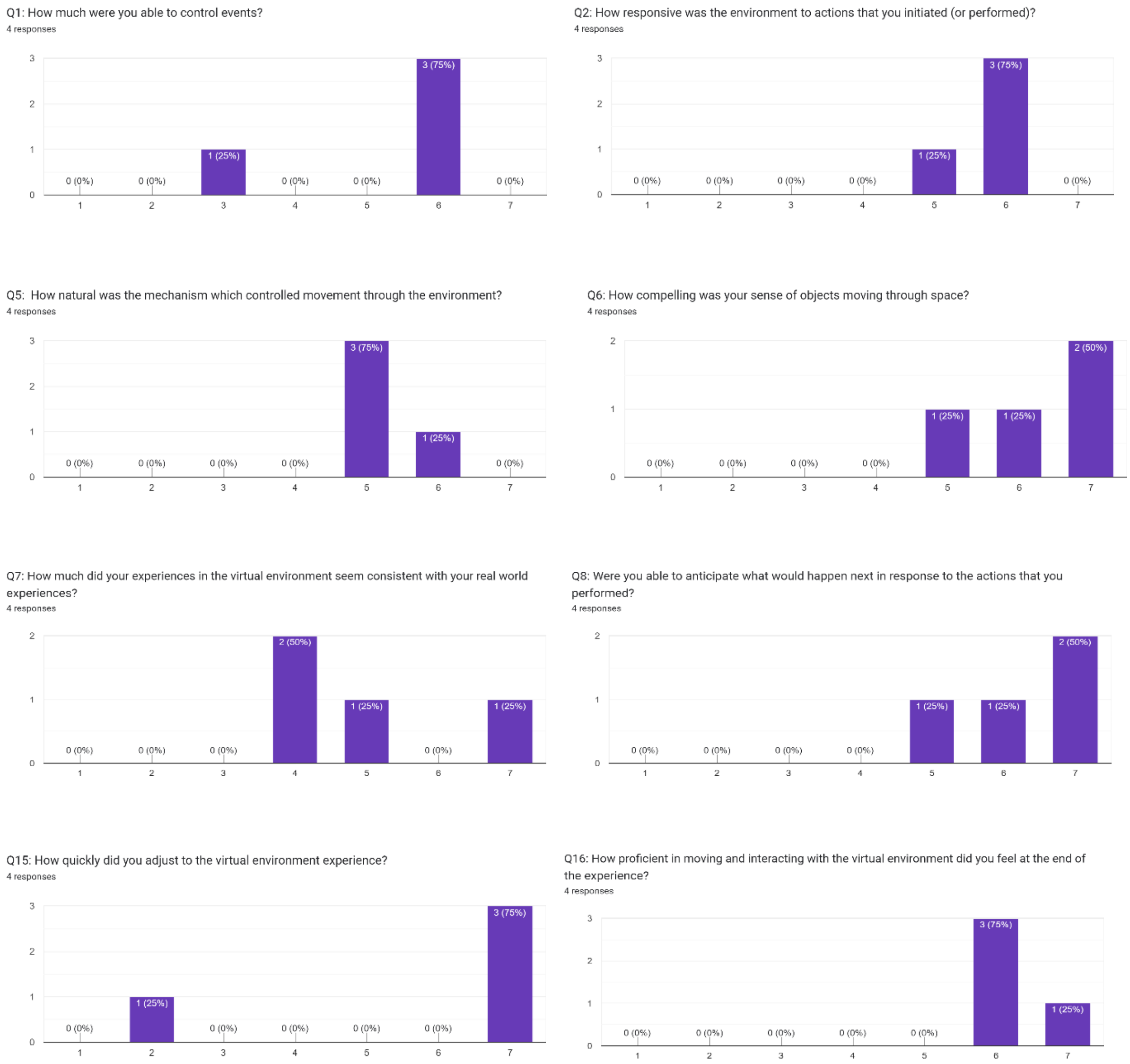


Figure 44: Virtual Reality Survey Results.

In the second part of our questionnaire, focused on the educational aspects of the VR dive navigation experience, we aimed to evaluate the users' understanding of the project topic and their ability to learn about the history of the Amathus harbor. The hypothesis was formulated to assess the effectiveness of the educational resources available in the virtual environment.

The results indicated that the users were able to understand the topic of the project and gain knowledge about the history of the Amathus harbor. The learning resources provided within the VR experience were found to be helpful in facilitating this understanding. However, it was observed that approximately half of the users felt that the amount of information available in the VR environment was incomplete. This suggests that there may be room for expanding the content and providing more comprehensive information to enhance the educational experience.

Furthermore, it was noted that some of the expert users had difficulty understanding the information presented within the VR environment. This highlights the importance of ensuring clarity and accessibility in conveying educational content, especially for users with a background in VR and graphics. This feedback can be valuable in refining and improving the presentation of information to cater to the diverse knowledge levels and backgrounds of the users.

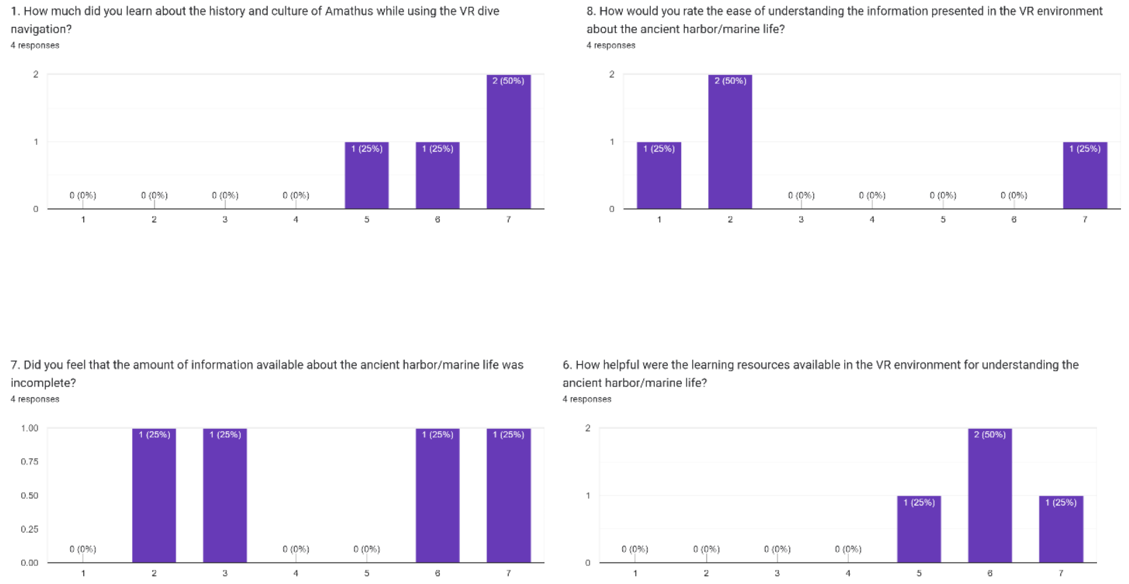


Figure 45: Questionnaire results about the education factor of the game.

The expert users' feedback regarding the potential of VR navigation to increase the accessibility of ancient heritage sites and contribute to the tourism industry was largely positive. The majority of the experts agreed that a VR navigation experience like the one provided in our project has the potential to enhance the accessibility of ancient heritage sites that are often difficult to access physically. By virtually recreating these sites, VR can offer a unique opportunity for individuals to explore and learn about cultural landmarks from the comfort of their own homes or through immersive experiences. Furthermore, the experts noted that the VR method used in our project was more engaging compared to traditional methods of learning history. They acknowledged the immersive nature of VR and its ability to create a sense of presence and interaction, which enhances the overall learning experience. The experts expressed that VR navigation can be an effective tool for teaching others about historical events or subjects.

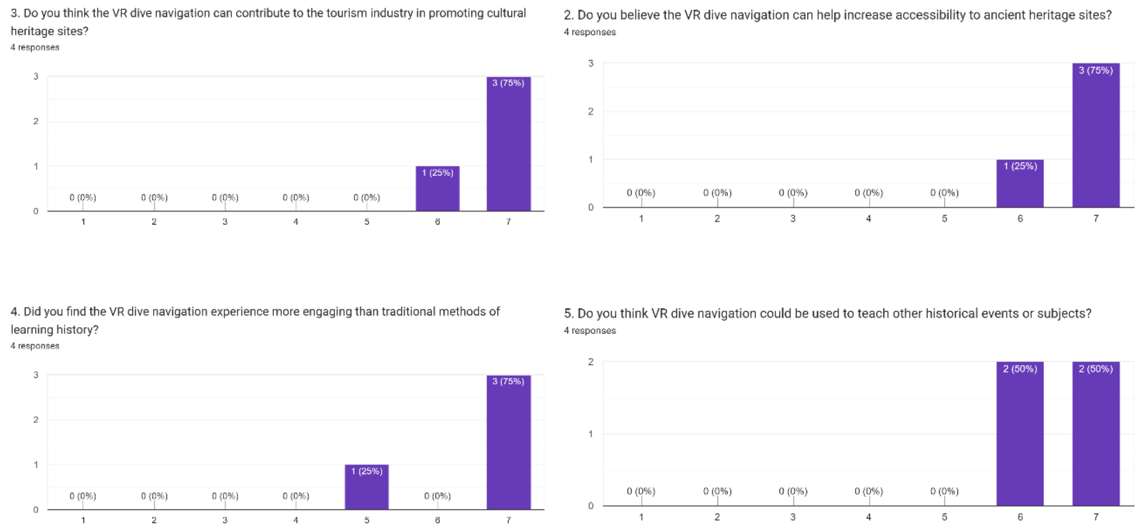


Figure 46: Questionnaire results about the importance the game in the society, tourism, and education.

The feedback from the users indicates that the existing navigation method, although effective, may have room for improvement to enhance user satisfaction. The suggestion for an up-head arrow highlights the importance of providing clear visual cues and guidance to aid users in navigating the virtual environment. This alternative navigation suggestion may serve as valuable input for future iterations or improvements to the VR dive navigation experience.

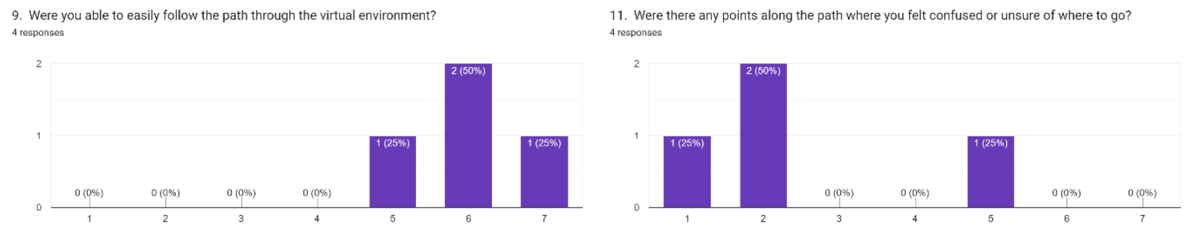
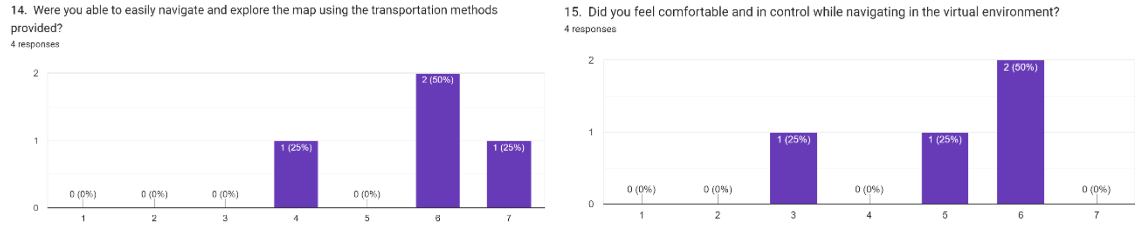


Figure 47: Questionnaire result about the navigation system.

One of the key areas of feedback from the questionnaire was related to the transportation options within the VR dive navigation experience. The responses from the experts varied, with some expressing satisfaction with the provided transportation methods, while others felt uncomfortable, particularly with the underwater locomotion. The experts provided valuable insights and suggestions for alternative locomotion methods. One suggestion was to incorporate the use of a virtual propeller that users could hold and manipulate to navigate through the underwater environment. This alternative approach aims to provide a more immersive and intuitive locomotion experience. Additionally, there was a mention of incorporating hand movements as a means of transportation. This suggestion implies utilizing hand gestures or gestures with virtual objects to control movement within the virtual environment. This alternative locomotion method aims to enhance the sense of agency and physical engagement for the users. It is worth noting that one of the experts experienced discomfort or motion/cyber sickness during the transportation phase.



16. Would you have preferred any additional or alternative transportation methods in the game? If so, what would they be?

4 responses

The locomotion under the water (allowing users to go in all directions) is always a bit tricky. Not sure what would be better than what was implemented in this application. Maybe incorporating some active hand movement to go through the environment (like simulated swimming) could be more compelling for some users (less auto-generated movement).

Holding some sort of propeller in one hand and using the trigger to move in the direction of the propeller.

None

Figure 48: Questionnaire results and comment on the transportation methods.

Chapter 5

Discussions and Conclusions

5.1 General discussion on our observations

In conclusion, this project achieved its main goals of creating a realistic representation of the Amathus environment in a virtual reality world, with a focus on underwater exploration. We were able to address the challenges that arose during the development process and implemented solutions that contributed to a more accurate and immersive user experience. The use of Unreal Engine 5 and other third-party tools allowed for a more efficient workflow and a more polished final product. The placement of assets was done procedurally, resulting in a diverse and natural-looking underwater world.
In terms of user experience, user found the VR experience to be immersive, engaging, and conducive to learning about the history and culture of the Amathus harbor. The ability to control events in the virtual environment, examine objects from multiple viewpoints, and navigate the designated path successfully were notable strengths of the application. However, there were some areas of improvement identified through user feedback. Although the expert user evaluation helps us understand our main weaknesses and strengths, it is difficult to make a definitive conclusion without a proper user evaluation. However, the overall design and functionality of the controllers and user interface suggest that the experience should be easy and intuitive for most users.

5.2 Limitations and open challenges

One of the major limitations of our VR project was related to performance. In order to create a truly immersive and convincing VR experience, it is crucial that the application runs smoothly and with minimal lag. Unfortunately, we encountered performance issues that affected the user experience. A VR application ideally should run at a frame rate that matches the refresh rate of the HMD, which is 90 Hz for the Oculus Quest 2 [39]. A frame rate exceeding 60 FPS is required for stereoscopic images to create a continuous flow. In our project, we were only able to achieve a frame rate of 35 FPS (30 ms) while navigating through the world [40]. This resulted in motion tracking lag and dropped frames, which impacted the overall quality of the VR experience. Although, by reducing the quality of the graphics the gameplay is smooth when the player is not making sharp movements with the VR headset.

Another challenge we faced was related to the rendering of the trees in our virtual environment. We observed that the leaves on the trees flickered and were jittery, which negatively impacted the user experience. It was difficult to find suitable trees that matched the VR environment, and this issue was compounded by the performance limitations that we encountered. The problem partially solved by switching the anti-aliasing method from multi sample anti-aliasing (MSAA) to Temporal anti-aliasing (TAA) in the project settings. This option reduced the jagged edges and flickering of the trees but caused a slightly blurred image quality to our game.

Moreover, while many users found the transportation system easy to use, there were suggestions for alternative methods. Also, a user experienced discomfort and motion sickness, particularly during underwater transportation, which can make the experience unpleasant.

Finally, as mentioned in the 3.2.1 section we also encountered challenges related to the 3D model of the underwater archaeological site that we were depicting in our VR application. The model had a number of imperfections, making it hard to hide from the user. This detracted from the realism of the experience and impacted the overall quality of the VR application.

5.3 Future work

In the future, there are several plans to enhance the overall experience of the Amathus underwater world simulation. Firstly, the underwater environment will be enriched with the addition of more species of fish, sponges, and plants that are found in the sea surrounding the Amathus harbor. This will increase the diversity of the underwater world and provide the user with a more immersive experience.

Moreover, the points of interest in the simulation will be increased, offering the user more opportunities to learn about the cultural heritage and underwater life of the Amathus sea. By providing more detailed information about the historical significance of the site and the ecosystem, the simulation will not only serve as an entertainment tool but also as an educational resource.

To improve the performance of the game, optimizations will be implemented to increase the frames per second (FPS) and make the user experience smoother. This will enhance the overall visual quality and gameplay experience, making it more enjoyable and engaging for the user.

Furthermore, the user evaluation with over 30 users will happen to learn more about the limitations of the project and how a normal user will be interacting with our project.

In addition, efforts will be made to improve the user experience by providing clearer information about the game controls and updating the menu to offer more settings and information. This will help the user navigate the simulation with ease and make it more user-friendly.

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