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CREATING A VIRTUAL GEOGRAPHIC LEARNING ENVIRONMENT AND ITS USER ASSESSMENT

Diploma thesis

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ANOTATION

The warming of the ocean and the melting of land ice, such as glaciers and the ice sheets in Greenland and Antarctica, have a direct consequence: sea level rise. Raising public awareness is essential in combating this issue. Traditional media like films and brochures can visually represent climate change's effects, but virtual reality offers a more immersive experience, enhancing environmental consciousness. The objectives of the thesis were to create an immersive virtual learning environment (IVLE) by aligning with current trends in geographic education and its user assessment. To contribute to the achievement of Sustainable Development Goal 13 (SDG), the COPERNICUS MUSEUM IVLE was developed, focusing on the Copernicus Sentinel-6 mission and the topic of Sea Level Rise (SLR). The usability aspects of the developed IVLE were assessed as part of the research. To gain a better understanding of the IVLE, eye-tracking technology was utilized, and a strategy for analyzing eye-tracking data within a VR environment was outlined. The author also presented a comprehensive workflow for developing the IVLE, outlining specific steps and processes involved in its creation. Additionally, the thesis showcased the connection method between the virtual environment and a Virtual Reality headset using the Blueprint Visual Scripting system. By analyzing eye-tracking data and conducting subjective evaluations, the effectiveness of the design was assessed, and areas for improvement were identified.

KEYWORDS

Number of pages: 60
Number of appendixes: 4

DECLARATION

This thesis has been composed by *Guldariya KURBONOVA* for the Erasmus Mundus Joint Master's Degree Program in Copernicus Master in Digital Earth for the academic years 2021/2022 and 2022/2023 at the Department of Geoinformatics, Faculty of Natural Sciences, Paris Lodron University Salzburg, and Department of Geoinformatics, Faculty of Science, Palacký University Olomouc. The thesis was supported by the Czech Science Foundation project no. 23-06187S - Identification of barriers in the process of communication of spatial socio-demographic information.

Hereby, I declare that this piece of work is entirely my own, the references cited have been acknowledged and the thesis has not been previously submitted to the fulfilment of the higher degree.

16.07.2023, Olomouc, Czechia   Guldariya KURBONOVA

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All praise is due to Allah, the Lord of the Worlds!

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Sincerely,
Dariya

اقرأ

Quran.

Palacký University Olomouc
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ASSIGNMENT OF DIPLOMA THESIS
(project, art work, art performance)

Name and surname:	**Guldariya KURBONOVA**
Personal number:	**R210700**
Study programme:	**N0532A330010 Geoinformatics and Cartography**
Work topic:	**Creating a virtual geographic learning environment and its user assessment**
Assigning department:	**Department of Geoinformatics**

Theses guidelines

The aim of the thesis is to create a virtual learning environment with geographic content and perform its user assessment using eye-tracking. At the beginning of the thesis, the student will perform a thorough literature review and summarize the current use of virtual environments in geographic education. Based on the state of the art, she will select topics that will be visualized. In this selection, the focus will be placed on the possibilities of the use of Copernicus data. The core of the thesis will involve the creation of virtual learning environments compatible with the technology available at CO-LAB (Faculty of Arts). The resulting virtual learning environments will be tested with eye-tracking and subjective evaluation methods (interview, questionnaire). The insight obtained from the user testing will enhance the final product. The thesis outputs will be the final version of the virtual learning environments, general insights about these environments and the description of how to create virtual learning environments and analyze eye-tracking data from virtual reality.

The student will create a website about the thesis following the rules available on the department's website and a poster about the diploma thesis in A2 format. The student will submit the entire text (text, attachments, poster, outputs, input and output data) in digital form on a storage medium and the text of the thesis in two bound copies to the secretary of the department.

Extent of work report:	**max. 50 pages**
Extent of graphics content:	**as needed**
Form processing of diploma thesis:	**printed**
Language of elaboration:	**English**

Recommended resources:

Barnum, C. M. (2020). Usability testing essentials: ready, set... test!. Morgan Kaufmann.

Bojko, A. (2013). Eye tracking the user experience: A practical guide to research. Rosenfeld Media.

Bondarenko, O., Pakhomova, O., & Lewoniewski, W. (2020). The didactic potential of virtual information educational environment as a tool of geography students training. arXiv preprint arXiv:2002.07473.

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Supervisors of diploma thesis: **RNDr. Stanislav Popelka, Ph.D.**
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Date of assignment of diploma thesis: **December 5, 2022**
Submission deadline of diploma thesis: **May 5, 2023**

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Head of Department

Olomouc December 5, 2022

CONTENT

LIST OF ABBREVIATIONS

Abbreviation	Meaning
2D	Two-Dimensional
3D	Three-Dimensional
AI	Artificial Intelligence
AOI	Areas of Interest
ESTEC	European Space Research and Technology Centre
GIS	Geographic Information System
HMD	Head-Mounted Device
HMD	Head-Mounted Display
IK	Inverse Kinematics
IT	Information Technology
IVLE	Immersive Virtual Learning Environment
IVO	Interactive Virtual Objects
IVR	Immersive Virtual Reality
LiDAR	Light Detection and Ranging
NASA	National Aeronautics and Space Administration
OO	Object-Oriented
RGB	Red Green Blue (colour model)
SD	Standard Deviation
SDG	Sustainable Development Goal
SLR	Sea Level Rise
SPSS	Statistical Package for the Social Sciences
SRTM	Shuttle Radar Topography Mission
TDT	Total Dwell Time
UE	Unreal Engine
UI	User Interface
UNESCO	United Nations Educational, Scientific and Cultural Organization
VE	Virtual Environment
VFX	Visual Effects
VGE	Virtual Geographic Environments
VI	Visual Intake
VLE	Virtual Learning Environment
VM	Virtual Museum
VR	Virtual Reality
VRLE	Virtual Reality based Learning Environment

INTRODUCTION

Virtual Reality (VR) is an emerging computer interface that stands out for its immersive experience, reliability, and interactivity. This innovative technology is extensively discussed due to its diverse applications, usage, and various types, which offer significant real-world benefits. By utilizing advanced computer technologies, VR creates a fully immersive visual environment, revolutionizing learning experiences in multiple educational settings. Educators recognized the potential of VR several years ago as a powerful multimedia tool for education (Alqahtani et al., 2017). The key educational value of the VR was identified as its potential to offer a simplified representation of intricate concepts, allowing students to easily comprehend them, and providing them with the immersive experience of exploring various global locations (Jochecová et al., 2022). Geography education can be significantly enhanced through the integration of VR, which offers a multitude of possibilities. It can encompass diverse areas, such as the creation of VR ecosystems tailored for wind energy education (Abichandani et al., 2014), providing realistic simulations of tsunami disasters (Saitoh et al., 2018), and offering virtual experiences of earthquakes (Sinha et al., 2012). Moreover, VR enables users to explore different historical time periods and geographical locations throughout human history (Cecotti, 2022). Additionally, collaborative immersive virtual environments can be utilized in geography education (Jochecová et al., 2022) and for conducting virtual field trips (Han, 2019; Roelofsen & Carter-White, 2022). By incorporating VR, the geography curriculum can be enriched, raising awareness about climate change (Thoma et al., 2023; Renne et al., 2021).

In the realm of VR research, there exists a vast scope, and more recently, there has been a proliferation of virtual reality systems integrated with eye-tracking technology. A significant focus of VR research is to enhance the user experience and address issues related to usability. It is widely acknowledged that leveraging eye-tracking technology can be advantageous in accomplishing these objectives (Clay et al., 2019). Employing eye-tracking technology within VR presents a novel and intriguing avenue for investigating students' attention and motivation. Furthermore, it has the potential to accelerate and enhance teachers' effectiveness in teaching, while also serving as an assessment tool (Shadiev & Li, 2022).

The thesis aimed to develop an immersive virtual learning environment containing geographic content and evaluate its user assessment through the utilization of eye-tracking. The selection of geographic content for the study gave priority to the potential utilization of Copernicus data, considering the emerging trends in geographic education. As a result, to contribute to the achievement of SDG13, the COPERNICUS MUSEUM IVLE was developed and included the presentation of the Copernicus Sentinel-6 mission and the topic of SLR. The Sentinel-6 mission is specifically designed to meet the requirements of the European Copernicus program by providing precise measurements of sea surface height, significant wave height, and other tailored products in the areas of climate, oceanography, meteorology, and hydrology, all in near-real-time (Donlon et al., 2021). As a case study, the IVLE selected the city of Venice, Italy, due to its high vulnerability to variations in relative sea level, along with its surrounding lagoonal ecosystem (Zanchettin et al., 2021). The thesis utilized eye-tracking technology in order to uncover broader understandings about developed IVLE. The study outlined a strategy for analyzing data obtained from eye-tracking technology within a VR environment.

1 OBJECTIVES

The aim of the thesis is to create a virtual learning environment (VLE) with geographic content and perform its user assessment using eye-tracking. To achieve this, the thesis outlines **two goals** which are defined and explained as follows.

The **primary objective** of this thesis is to create a VLE that incorporates geographic content. This includes a comprehensive literature review to examine the current utilization of immersive virtual environments in geographic education. Building upon the literature review, the thesis will focus on selecting specific topic to be visualized within the VLE. The selection process will prioritize the potential use of Copernicus data, taking into consideration the current state of the art and emerging trends in geographic education. This approach ensures that the chosen topics align with contemporary educational needs and leverage the wealth of geographic information available through Copernicus. Using the selected topic, the thesis will involve designing and developing a VLE that provides an immersive and interactive platform for geographic education. This will entail creating realistic three-dimensional (3D) visualizations, integrating accurate geographic data, and implementing interactive features to enhance the learning experience. The thesis outputs will be the final version of the VLE, and the description of how to create virtual geographic learning environment.

The second goal is to perform user assessment of created VLE using eye-tracking. The thesis will employ eye-tracking technology to reveal general insights about VLE. The thesis will analyze the collected eye-tracking data to understand the spatial experience of users in virtual geographic learning environment. This analysis will involve examining gaze patterns, initial daze dispersion and other relevant metrics to assess users' attention to specific geographic content. Based on the findings from the eye-tracking analysis and subjective evaluation methods, the thesis will determine the effectiveness of the design and identify any usability issues or challenges that may impact the learning experience. This evaluation will inform future enhancements and refinements to optimize the virtual learning environment's educational impact.

2 STATE OF ART

In the 1990s, the field of virtual reality witnessed a rapid and dynamic evolution, with the term "Virtual Reality" becoming incredibly popular. It found its way into various media platforms, and people frequently used the term, often incorrectly. This can be attributed to the fact that this revolutionary and captivating technology garnered more attention from the general public compared to computer graphics and other technological advancements (Mazuryk & Gervautz, 1999). Zheng et al. (1998) defined it as "VR is an advanced, human-computer interface that simulates a realistic environment. The participants can move around in the virtual world." In Mandal's (2013) perspective, VR is defined as a computer-generated Virtual Environment (VE) that users can actively explore and manipulate in real-time. This VE can be presented on different devices such as a head-mounted display (HMD), computer monitor, or large projection screen. To enhance the immersive experience, tracking systems for the head and hands are implemented, enabling users to observe, navigate, and interact with the virtual environment (Mandal, 2013). According to Basu (2019), immersion in virtual reality can be described as a mental state where users temporarily suspend their disbelief, enabling them to freely transition between the real and virtual environments.

Mazuryk & Gervautz (1999) highlighted the interchangeability of the terms VR and VE within the computer community. Bos et al. (2022) emphasized the utilization of various VR technologies as educational tools. According to a study by Mikropoulos & Natsis (2010) on educational virtual environments, a Virtual Reality based Learning Environment (VRLE) was described as "a virtual environment that is based on a certain pedagogical model, incorporates or implies one or more didactic objectives, provides users with experiences they would otherwise not be able to experience in the physical world and redounds specific learning outcomes."

Bondarenko (2020) emphasized that the current generation of students resides in a media-centric environment where the regular use of computers, internet resources, and mobile devices became an inherent aspect of their daily existence. Hruby et al. (2019) outlined a methodology process for translating Geographic Information System (GIS) data into an immersive VR application that accurately replicates real-world environments. The following sections explored the efficacy of VR in the realm of Geography Education and showcase the research conducted on the integration of Eye-Tracking technology with VR. These sections provided insights into how VR can facilitate a deeper understanding of human cognitive behaviors and the potential to enhance knowledge. Furthermore, the sections discussed various aspects such as eye-tracking technologies, methodologies, and related works, offering valuable perspectives on the intersection of Education and VR.

2.1 VR for Geography

VR is capturing growing interest as a highly promising educational technology, primarily due to its capacity to deliver authentic and immersive learning experiences by simulating realistic computer-generated environments (Luo et al. 2021). Wang et al. (2018) highlighted the advantages of utilizing VR in education, specifically emphasizing its ability to facilitate student interactions within virtual 3D environments and develop an intuitive understanding of learning subjects through interaction with objects, related messages, and signals.

The study, conducted by Predescu et al. (2023), assessed the impact of virtual reality in an academic context using a VR software named EduAssistant. The research

involved 117 students. Over 80% of the participants expressed satisfaction, rating the experience with a score of 4 or 5 out of 5. Predescu et al. (2023) demonstrated the potential of virtual reality as an effective approach to revolutionize conventional education. Their research, drawing from samples, simulations, and surveys, yielded positive results regarding the impact of VR and its gamification methods on students' cognitive performance, engagement, and overall learning experience. Shen et al. (2022) underscored the seamless integration of virtual reality into geography teaching, allowing for the creation of an immersive virtual geography learning environment that leverages the superior advantages of immersion and interaction. The study by Abichandani et al. (2014) exemplifies how VR can be utilized in geography. In their research, they developed a cloud-based VR ecosystem specifically designed for wind energy education. This ecosystem incorporated VR modules focused on STEM wind energy areas, allowing students to create virtual wind farms and optimize energy generation. By manipulating the parameters of the windmill within the VR environment, students could apply their independent thought processes and develop design and operational skills, as displayed in Figure 1. This study showcases how VR can provide immersive and interactive experiences in geography education, enabling students to explore and understand geospatial concepts dynamically and engagingly.

Figure 1 Left: Virtual reality system for a wind farm that allows users to adjust and customize the attributes of the wind turbines. Right: Example of a real-time adaptive question that the VR system poses to the student (Abichandani et al., 2014).

2.1.1 VR for Disaster Preparedness

VR can also play a crucial role in disaster preparedness by simulating evacuation scenarios and enhancing understanding of the geographic factors involved. The study conducted by Takeichi et al. (2020) demonstrates the applicability of VR systems, which can realistically simulate earthquakes, tsunamis, fires, and evacuation scenarios, as a valuable tool for enhancing learning experiences. Integrating such technology into the geography curriculum would allow students to learn about hazards and actively engage in virtual escape experiences, fostering practical knowledge and skills in disaster management, evacuation planning, and geographical understanding. Another example is the study conducted by Saitoh et al. (2018), which demonstrated the advantage of using a mobile-processed VR system in providing experiences that are typically inaccessible or unrealistic, particularly in the case of rare events such as tsunamis. Through developing a VR system aimed at creating a tsunami disaster experience, the researchers presented visual examples, including Figures 2(a) and 2(b), showcasing the capabilities of the VR simulation. In Figure 2(a), VR users were able to witness the approaching tsunami from behind a building, while Figure 2(b) depicted the VR user

being engulfed by the tsunami. These visual representations illustrate how individuals using the developed VR system with a smartphone can experience the velocity and height of the tsunami, which would be challenging to replicate in the real world. The findings underscore the potential of VR in geography education, enabling students to explore virtually and gain a deeper understanding of rare and high-risk natural phenomena.
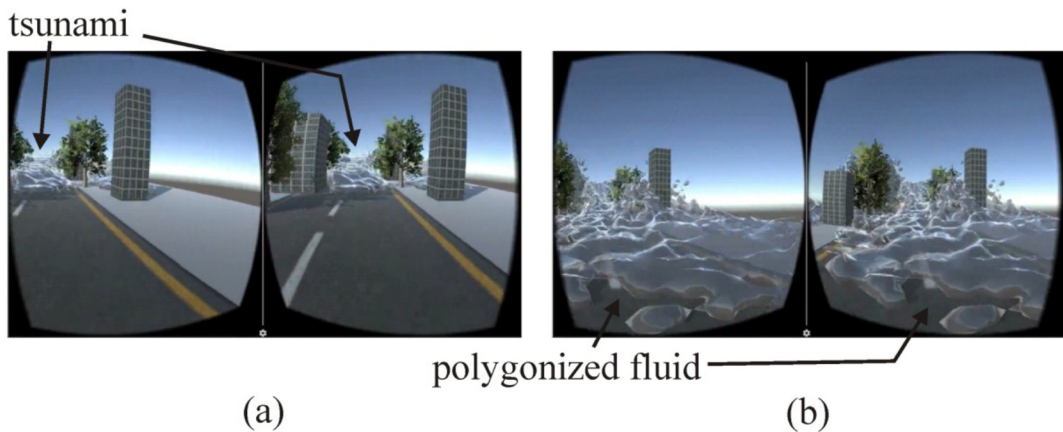

Figure 2 VR demonstration results at selected time steps: (a) a VR user can see the tsunami behind the building; (b) a VR user is swallowed by the tsunami (Saitoh et al., 2018).

Sinha et al. (2012) conducted a study introducing a novel technique for simulating earthquakes to aid in disaster management. This method combines structural engineering, cinematography, and immersive 3D technology expertise. The approach involves analyzing the nonlinear time history of a building and its internal contents, capturing the building's response to an earthquake over a specific duration. The researchers can realistically depict the earthquake's consequences in a virtual 3D environment by converting the mathematical model into a physical model. Figure 3 illustrates simulations that demonstrate the movement of typical office furniture during an earthquake. Through VR platforms, visual animations offer a compelling sense of presence within the simulation, which Sinha et al. (2012) argue can have a lasting impact on memory and help train individuals to respond appropriately during an actual earthquake. To enhance the feeling of being on-site, audio cues can be employed.
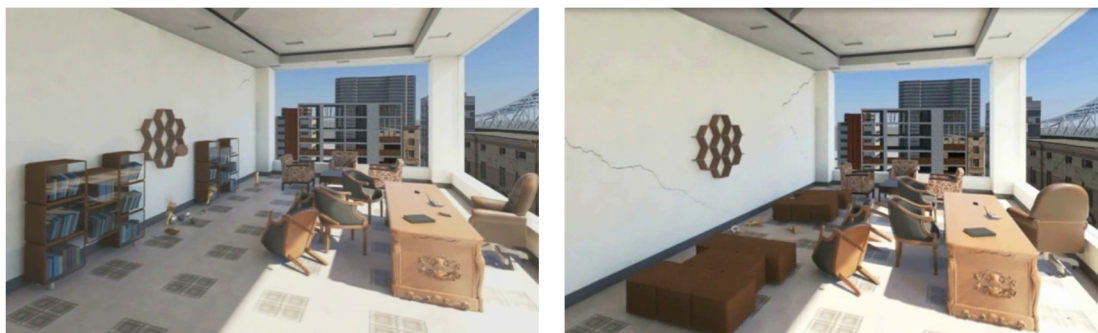

Figure 3 Capturing sequential snapshots of the motion of office furniture provides an authentic experience without the accompanying safety concerns during a real earthquake (Sinha et al., 2012).

A Virtual reality-based evaluation of indoor earthquake safety actions for occupants by Zhang et al. (2021) involved constructing an indoor seismic damage scene using the FEMA P-58 method and a physics engine to calculate the damage and movements of indoor nonstructural components accurately. A virtual body model and inverse kinematics (IK) algorithm were developed to track occupants' earthquake safety actions. Furthermore, a human safety model based on collision kinetic energy and fatal conditions was designed to evaluate the effectiveness of earthquake safety actions quantitatively. Using the developed inverse kinematics (IK) algorithm and the HTC Vive system, as depicted in Figure 4, occupants had the opportunity to immerse themselves in a virtual reality environment and view the 3D scene from a first-person perspective using the head-mounted display. This setup allowed for precise capturing of the occupants' earthquake safety actions. Furthermore, the drilling process could be observed from a third-person viewpoint, enabling external observers to witness the trainee's responses to survival. Figure 4 demonstrates that the virtual body models replicated the exact action of the occupants, specifically the "drop and cover" technique, illustrating the high level of accuracy achieved in motion tracking throughout the study.
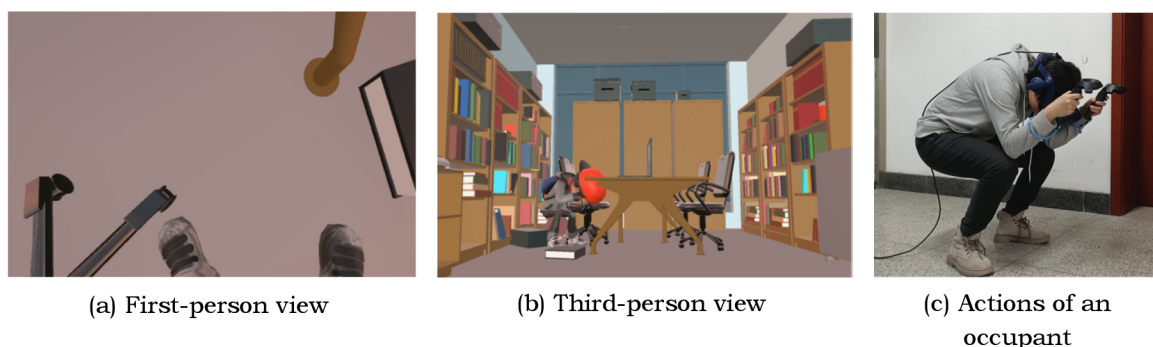

(a) First-person view   (b) Third-person view   (c) Actions of an occupant

Figure 4 Tracking earthquake safety actions of an occupant (Zhang et al., 2021).

2.1.2 VR for Discovering Historical Landscapes

VR also allows users to explore various time periods and geographical locations in human history. This includes prehistoric times, ancient Egypt, ancient Rome, and many more. Cecotti (2022) reviewed available software that focuses on cultural heritage in VR. Representative examples are shown in Figure 5. "The Dawn of Art" is a VR experience that enables users to visit the Chauvet-Pont-d'Arc Cave in southeastern France. This United Nations Educational, Scientific and Cultural Organization (UNESCO) World Heritage Site cave contains remarkably well-preserved figurative cave paintings from the Upper Paleolithic era. The VR experience includes an immersive film and a virtual cave tour, offering an opportunity to explore prehistoric times. It has received a high positive review rating of 94% out of 125 reviews and is available for free. "Nefertari: Journey to Eternity " is a 15-minute educational adventure in VR that takes users through the tomb of one of ancient Egypt's prominent queens. By using light-wielding controllers, players can explore the dark tomb as it would have appeared over 3000 years ago. The experience has received positive reviews, with 93% out of 199 reviews rating it positively. It is also available for free. "Baalbek Reborn: Temples" offers a VR tour of the Roman temples in Baalbek, a UNESCO World Heritage Site in Lebanon. Users can observe the ruins of the archaeological park and the reconstructed buildings as they existed in the third century AD. This VR experience has received a 79% positive review

rating out of 39 reviews and is available for free. The "Mannerheim Virtual Experience" focuses on a specific location and time period during World War II. It provides a virtual tour of the war-time office of Carl Gustaf Emil Mannerheim, the Field Marshal of Finland. The headquarters of the Finnish army operated in and around the city of Mikkeli during the wars in 1939–1940 and 1941–1944. Users can explore the Mikkeli Central Elementary School office, learn historical facts, and witness a 3D representation of Mannerheim reading a report from the front lines (Cecotti, 2022). This VR experience has received five positive reviews and is available for free. According to Cecotti (2022), despite the existence of educational applications that could potentially be used in classrooms, VR technology is not widely implemented in educational settings.

(a)   (b)

(c)   (d)

Figure 5 Historical landmarks (Cecotti, 2022). (a) The Dawn of Art (Atlas et al. 2020), (b) Nefertari: Journey to Eternity (Experius VR, 2018), (c) Baalbek Reborn: Temples (Flyover Zone, 2021), (d) Mannerheim Virtual Experience (CTRL Reality Oy, 2019).

2.1.3 VR for Climate Change Awareness

Increasing awareness of climate change with immersive virtual reality, by Thoma et al. (2023), can be an effective tool to enhance the geography curriculum by raising awareness about climate change. The study aimed to examine the potential of VR in raising awareness about climate change and shaping environmental attitudes, as compared to traditional media. The study focused on determining whether VR visualizations could significantly impact climate change awareness and attitudes by showcasing a time-lapse demonstration of the gradual melting of the Swiss Aletsch glacier over a span of 220 years. The researchers hypothesized that the immersive VR experience, which enables individuals to fully engage with the consequences of climate change and bridge the temporal gap, would have a stronger influence when compared to less immersive two-dimensional (2D) control conditions. The findings supported this hypothesis, as participants found the VR conditions to be more thrilling and enjoyable and reported a heightened sense of presence compared to the control conditions. This

outcome confirms the effectiveness of VR interventions in effectively conveying pro-environmental messages.

Renne et al. (2021) conducted a study that highlights the reliance of local government officials, including transportation planners, on 2D visualizations like charts and maps to communicate potential scenarios of sea level rise to coastal communities. The researchers conducted a quasi-experiment comparing the effectiveness of 2D GIS representations with 3D VR models, as displayed in Figure 6, in educating stakeholders about the potential impacts of SLR on transportation infrastructure. The study's findings demonstrate the efficacy of VR technology in enhancing participants' understanding of SLR in the context of transportation planning. Over 90% of the participants agreed that their comprehension of the map data improved after experiencing the VR simulation. Interestingly, during Survey 2, 83.7% of participants reported gaining new information about SLR from the VR presentation, despite the data being the same as that presented in the 2D GIS maps. Additionally, 91.7% of participants believed that the VR presentation would be beneficial for other members of their community, and 80.3% expressed an increased interest in engaging with the topic of SLR. Furthermore, the number of respondents strongly agreed that "Sea level rise is a future threat" increased from 46 to 50 due to the VR intervention. According to recent studies by Thoma et al. (2023) and Renne et al. (2021), VR can be beneficial in geography education, particularly in promoting climate change awareness.
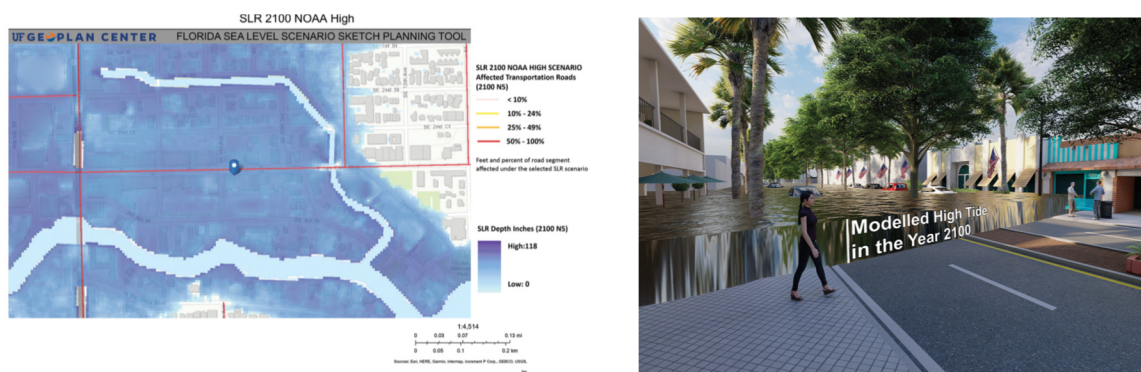

Figure 6 GIS Map (left) and depiction of virtual reality model (right) for study area in Florida (Renne et al., 2021).

2.1.4 3D Visualization in VR for geographical understanding

As Huang et al. (2010) pointed out, virtual reality technology can be utilized as an immersive human-computer interface for various purposes, including 3D visualization, collaborative work, group decision-making, and many more. As Fabrikant et al. (2014) noted, using 3D visualization expands the potential for representing virtual data. By creating a three-dimensional model of an object, more information can be integrated into the screen (Juřík & Šašinka, 2016). Hochmitz & Yuviler-Gavish (2011) further highlight how 3D visualizations enhance the visual accuracy of virtual representations, simulating characteristics present in the real environment. By integrating virtual reality with traditional GIS and 3D GIS, the development of Virtual Geographic Environments (VGE) represents a higher level of GIS. VGE combines elements such as traditional GIS, virtual reality, network technology, geo-models, human-computer interaction technology, and systematic methods (Huang et al., 2010).

Virtual reality as a spatial prompt in geography learning and teaching, by Roelofsen & Carter-White (2022), proposes a shift in perspective regarding the use of VR platforms. In their study, VR is seen as a spatial prompt to inspire and generate new questions for students already engaged in developing their geographical understanding and imagination. Rather than being viewed as a self-contained virtual dimension, VR challenges students' spatial perception, disrupting conventional notions of space and facilitating geographical thinking. The systematic literature review conducted by Asad et al. (2021) aimed to investigate the impact of virtual reality on experiential learning among students. By analyzing twenty-six selected articles, the review explored and comprehended the effects of virtual reality in diverse educational contexts. The selected studies employed various methodologies. Consequently, the review revealed that virtual reality is utilized as a pedagogical tool across multiple subject areas to foster student engagement. It enables learners to immerse themselves in virtual environments, experience a sense of presence, and enhance their experiential learning. Thus, the review establishes virtual reality as a crucial pedagogical tool for strengthening students' experiential learning.

2.1.5 VR for Virtual Museum

The virtual museum (VM) is formed by integrating the conventional museum concept with the multimedia computer and communication technology of the Internet (Djindjian, 2007). Today, a virtual museum is not limited to presenting collections online or offering virtual tours through panoramic photography. It now aims to enhance visitors' experiences by providing additional materials for deeper knowledge before or after a physical visit, as well as serving as a teaching tool for museum education (Kersten et al. 2017). Currently, virtual technology has emerged as a crucial tool through which the general population can explore and gain knowledge about cultural heritage. For instance, the Louvre Virtual Museum, the British Virtual Museum, and the Imperial Palace Museum have all embraced virtual technology to offer visitors a comprehensive and immersive visiting experience. This innovative approach gained immense adoration among the general public (Chen & Liu, 2023).

Perry et al. (2017) conducted a study that critiqued the existing state of VMs and emphasized the numerous possibilities for creating transformative and engaging cultural experiences in these virtual environments. The researchers aimed to go beyond conventional VMs by establishing meaningful connections with visitors in a measurable emotional, participatory, interactive, and social manner. To accomplish this, the authors proposed a conceptual framework for designing VMs that was firmly rooted in a user-centered design methodology (Perry et al., 2017).

In the study conducted by Mamur et al. (2020), they investigated the experiences of primary and secondary school visual arts teachers regarding VR museum visits. The research took place in various regions of Turkey and involved the participation of 508 teachers. The analysis of the study focused on how the teachers interpreted and reflected upon the objects and representations within the virtual museum. The study's findings indicated that the teachers' learning experiences were enhanced when they incorporated social and personal contexts into their interpretations. While the teachers recognized that VR museum visits might not offer the same level of richness as physical visits, they believed that it could be an effective tool in visual arts classes. According to the study, it is important to design virtual museum environments in a manner that facilitates effective learning and cultivates students' critical thinking skills, similar to the learning experiences in physical museums (Mamur et al., 2020).

The studies by Malinverni et al. (2019) and Varinlioglu et al. (2022) demonstrate the application of GIS in the development of VMs. Malinverni et al. (2019) collected data from various sources, including archaeology and geodetics, to create an orthophoto of a mosaic floor for their Virtual Museum. They utilized a dedicated GIS for data management and analysis to understand the changes in the iconography over time. Varinlioglu et al. (2022) proposed an innovative approach using a low-cost 360° virtual tour to create an educational game that allows users to explore and learn about Anatolian caravanserais through GIS integration.

The study by Anton et al. (2019) emphasized that even though the implementation of VR technology is costly and requires expertise in Information Technology (IT), virtual museums are regarded as the future and have the ability to attract larger audiences, especially among the younger generation. While virtual museums do face challenges that need to be overcome, a collaborative effort between museum curators and IT developers can achieve the desired outcomes. It is important to recognize that virtual museums cannot replace physical museums, but they can serve as an extension of physical exhibitions (Anton et al., 2019).
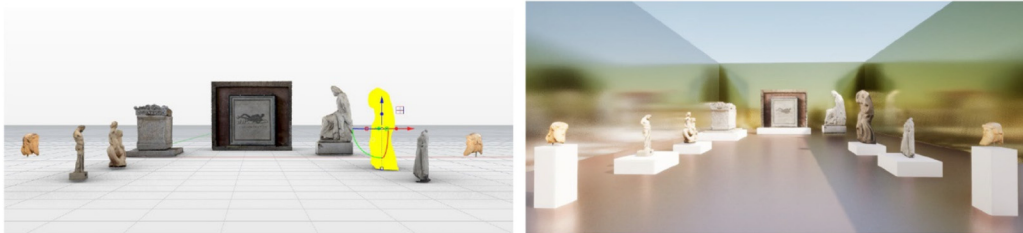
Development of VR Museum

A Geographical Presentation of Virtual Museum Exhibitions by Stawniak & Walczak (2006) introduced development of a system called GeoARCO, which allows virtual museum exhibitions to be presented in a geographical context. GeoARCO was built upon the technology developed by the ARCO project. Using the Google Earth platform, GeoARCO allows digital artifacts and complete cultural heritage exhibitions to be displayed on top of a 3D globe model. Users can browse and search available exhibitions, view the location of objects and access historical data. Detailed 3D models of artifacts, reconstructed sites, and entire virtual exhibitions can also be displayed. The system collaborates with multiple ARCO databases maintained by different museums (Stawniak & Walczak, 2006).

Banfi et al. (2023) conducted a study with the objective of developing interactive virtual environments using 3D models based on archaeological investigations in the south-eastern suburbs of Rome. The main aim was to enhance the storytelling, enjoyment, and dissemination of the discoveries by designing a virtual museum for artifacts from the Appia Antica Archaeological Park. The study employed techniques such as geometrical surveys, high-resolution 3D data, archival research, and interactive digital representation to manage historical and cultural artifacts. By digitizing these artifacts, new means of communication were made possible, enriching both virtual and on-site visits. The researchers utilized McNeel Rhinoceros for modeling and Unreal Engine 5 to create an interactive museum application. Open formats like FBX and OBJ were used to transfer complex geometry and high-resolution textures. Figure 7 demonstrates the correlation achieved between McNeel Rhinoceros software and VR. The process involved refining the model's geometry and integrating it into the VR environment. Within Unreal Engine, blueprints were employed to enable interactivity and immersion, allowing users to interact with the models and access relevant information, resulting in dynamic and immersive experiences. The study also focused on developing interactive virtual objects (IVO) that responded to user inputs, providing historical, cultural, and iconographic information through text, video, and audio formats. The implementation of specific collisions made the virtual objects tangible, while the design of the virtual environment prioritized user comfort and easy navigation (Banfi et al., 2023).
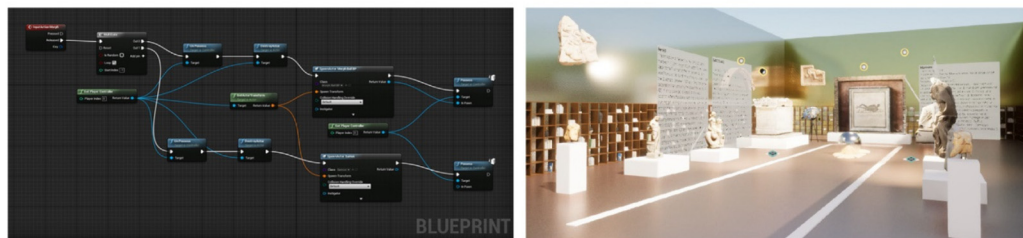
Import and design of virtual museum's digital base
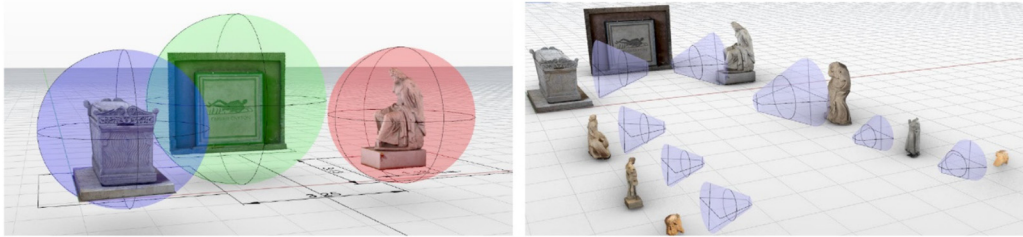
Direct one-click synchronization between modelling applications and VR environments

Blueprints development and Content placement

VR-based interactive experience

Digital outputs and devices

Figure 7 The development process applied to the digital interactive representation of the virtual museum: from textured models to the VR headset (Banfi et al., 2023).

Kersten et al. (2017) conducted a study that explored the development of a virtual museum for the "Alt-Segeberger Bürgerhaus," a historic townhouse in Bad Segeberg, Germany. The virtual museum provided two options for visitors: an interactive computer-based tour and a virtual reality experience using the HTC Vive system. The researchers created a comprehensive 3D model of the museum, including both its exterior and interior. The primary objective was to present the building's complex history through interactive visualizations of its construction phases spanning nearly 500 years. The project consisted of three main phases: concept creation and testing, modeling and texturing of the museum and its contents, and integration into a program with interactive features. For the development of the virtual museum, the researchers selected the Unreal game engine due to its functionality, visual programming language

(Blueprints). The virtual museum's implementation on Windows-based systems involved programming user movement, information queries, and animations using the Unreal Engine. Visitors could navigate the virtual space by interacting with the mouse, selecting positions within the building, or following predetermined camera paths. The virtual museum offered various notable features, including a graphical user interface that displayed and animated the building's history, menus, and information boards for exhibits. Comfort functions such as tooltips, an overview map, and a help menu were included to enhance the user experience. To provide an immersive experience, the researchers incorporated the HTC Vive virtual reality system (Kersten et al., 2017).

Design of VR Museum

When designing interactive systems such as a virtual museum, it is crucial to provide users with an enjoyable, user-friendly, and efficient experience. The user interface (UI) serves as the point of interaction between the user and the product, machine, or system. The primary objective of the UI is to facilitate easy, straightforward, and effective operation and control of the system or product. The UI plays a vital role in establishing a friendly visual environment for the user to engage with the technology. Designing the interface poses a significant challenge in the development of a virtual experience, especially considering that the VE itself serves as a form of human-computer interaction. In a VR system, users interact with various devices such as helmets, glasses, gloves, and controllers, among others (Besoain et al. 2021).

The attention span is a key factor that virtual museums need to address when it comes to designing exhibitions. There has been a clear decrease in attention spans recently. However, the way information is presented can influence the level of attention. In this scenario, digital technologies provide fresh and innovative avenues for storytelling and showcasing virtual museum collections (Banfi et al., 2023).

2.2 Eye-tracking for Educational VR

The emergence of compact, high-resolution cameras for devices such as smartphones has made it possible to create portable and lightweight eye-tracking systems. These systems can now be integrated into virtual reality headsets or portable glasses, offering convenient and unobtrusive eye-tracking capabilities. These advancements have revolutionized the monitoring of eye movements, providing rapid and precise data acquisition (Clay et al., 2019). Campanaro & Landeschi (2022) pointed out that virtual reality-based eye-tracking is a technology in its early stages of development and holds much potential. As highlighted by Clay et al. (2019), eye-tracking is a well-established technique widely used to investigate human cognition. Poole & Ball (2006) provided a definition of eye-tracking as a method that involves quantifying an individual's eye movements. This approach allows the researcher to determine the exact position at which a person is looking at any given time and the sequence in which their gaze transitions between different locations. Mikhailenko & Kurushkin (2021) stated that while there have been extensive studies and numerous review papers exploring the fundamental concepts and applications of eye-tracking technology across various fields, the application of eye-tracking in virtual reality, specifically for educational purposes is a relatively novel direction that has emerged only in recent years.

The study by Khokhar et al. (2019) presented an architecture for a VR pedagogical agent that utilizes eye-tracking to monitor and respond to shifts in user attention. The agent uses behavior-based Artificial Intelligence (AI), including low-level sensors, sensor

combiners, generalized hotspots, an annotation system, and a response selection system. The system's goal was to make the pedagogical agent in VR more responsive to student attention and distraction. By using eye-tracking, the agent can detect when a student's attention drifts away and adjust its behavior accordingly. For example, it can pause, replay, or provide additional assistance based on the student's gaze behavior. The system aims to create a more engaging and personalized educational experience by dynamically adapting the agent's behavior to the student's attentional state. The architecture was demonstrated in a VR oil rig training scenario where the agent controls the playback of teacher avatar clips to explain objects (Figure 8).
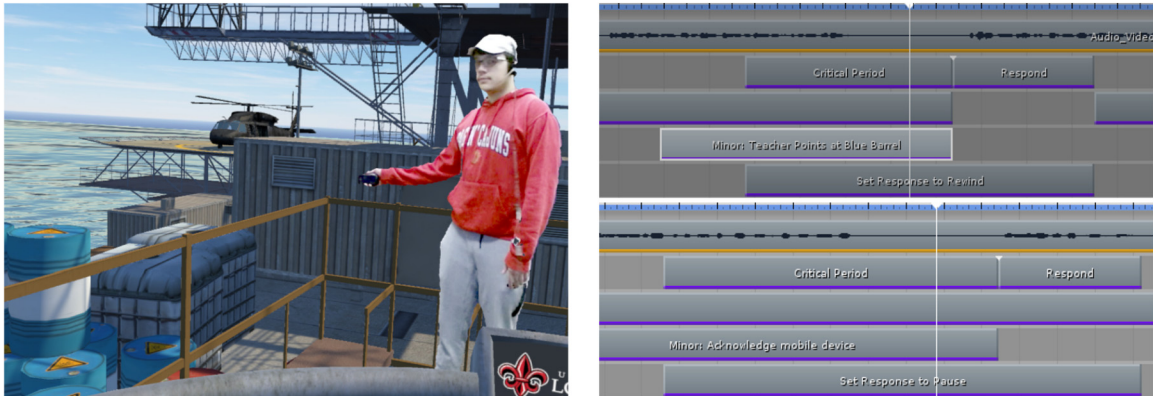
Figure 8 Left: Teacher agent points at a barrel. If the student does not look, the agent may pause or replay a phrase, depending on response ranks.
Right: Two timelines with different responses. The student is required to fulfill certain conditions in critical periods (Khokhar et al., 2019).

2.2.1 Immersive Virtual Reality

In the review study conducted by Shadiev & Li (2022) regarding the utilization of eye-tracking technology in immersive virtual reality (IVR) learning environments, distinct findings emerged. Notably, Tobii and HTC Vive emerged as the prevailing tools of choice in research pertaining to the usage of eye-tracking technology within IVR learning settings. Furthermore, the analysis revealed that cognitive science and educational technology stood out as the most commonly explored domains in the research on eye-tracking technology implementation in IVR. Wang et al. (2018) stressed the importance of incorporating dedicated hardware, specifically the head-mounted device (HMD), in order to achieve a fully IVR experience. According to Al-Gindy et al. (2020), the HMD is characterized as a headset that directly delivers visual effects and multimedia content to the user's eyes. This unique design ensures that the display remains positioned in front of the user's eyes wherever they look, thereby accurately tracking the user's spatial location. In this study, IVR considered as the utilization of virtual reality technology through an HMD.

Renganayagalu et al. (2021) underscored that the recent focus on HMDs and their application is attributed to several factors. One key factor is the notable advancements in HMD hardware, which have become more sophisticated compared to the past. Another factor is the relative decrease in cost, making HMDs more accessible to a wider audience. Lastly, HMDs now offer the capability to create immersive simulations that were previously only achievable in high-end, expensive simulators, if they were possible at all. Lutz et al. (2017) emphasized that the incorporation of eye-tracking technology into HMDs shows great potential for VR. This approach presents the opportunity to

accurately evaluate attention in real-time. Bozkir et al. (2023) pointed out the rapid growth of eye-tracking and VR technology, noting that an increasing number of HMDs like the HTC Vive Pro Eye, Fove-0, and Varjo XR-3 now come with built-in eye tracking capabilities. The Varjo XR-3 is specifically highlighted as an example of an HMD device with an integrated eye-tracker, accompanied by eye images and a portion of raw data (Figure 9).
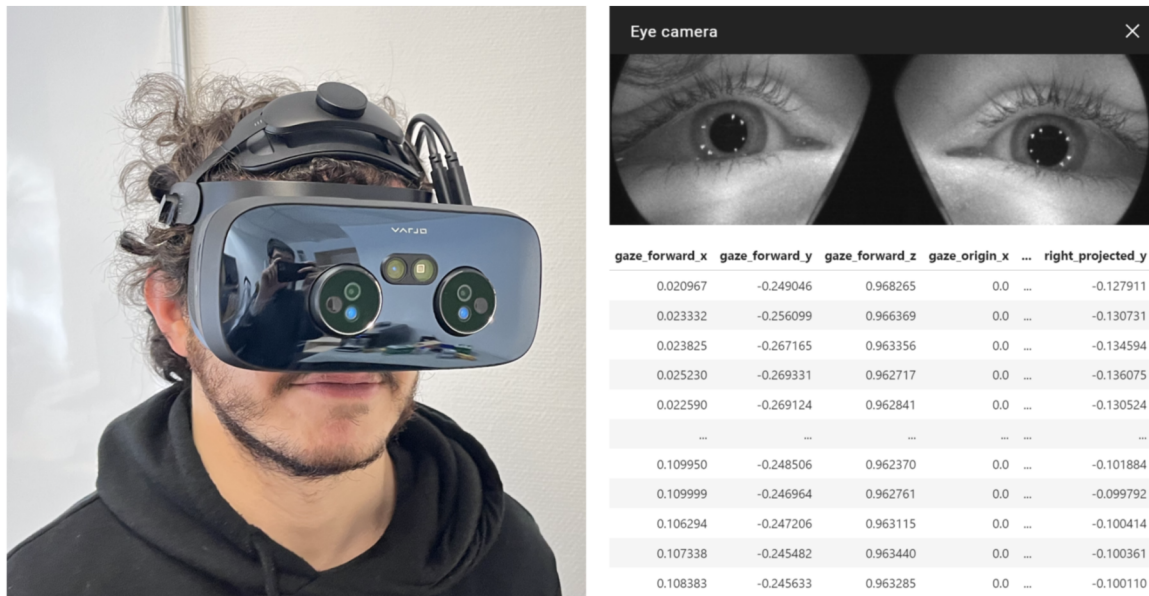

Figure 9 Left: Varjo XR-3, which is a high-end HMD device for both VR and AR.
Upper right: eye images taken by cameras inside Varjo XR-3.
Lower right: some eye features recorded by Varjo XR-3 (Bozkir et al., 2023).

2.2.2 Understanding the Role of Stimuli through Eye-Tracking

Palacký University in Olomouc, Czech Republic, has been actively employing eye-tracking technology to assess the effectiveness of 3D visualization in cartography, as emphasized in the study conducted by Herman et al. (2017). This research highlighted the extensive utilization of such technology in their practices. For instance, investigations have focused on 3D relief maps (Popelka & Brychtova, 2013), 3D maps of cities (Dolezalova & Popelka, 2016), a 3D model of an extinct village (Popelka & Dedkova, 2014), and tourist maps featuring hill-shading (Popelka, 2014). These studies have revealed that the effectiveness of 3D visualization cannot be generalized as superior or inferior to 2D visualization. Instead, the impact of visualization depends on the specific stimuli and task at hand (Herman et al., 2017). Gaining insights into how the distribution of visual attention varies based on a user's task provides evident advantages in advancing these techniques and enhancing the design of virtual environments (Hadnett-Hunter et al., 2019).

2.2.3 The Workflow for Virtual Reality-Based Eye-Tracking

A *Reviewing Pompeian Domestic Space through Combined Virtual Reality-Based Eye Tracking and 3D GIS* by Campanaro & Landeschi (2023) explores a novel approach to studying the domestic spaces of ancient Pompeii. The researchers combine VR technology, eye-tracking techniques, and 3D GIS to gain new insights into the layout and use of these spaces. The study presents a detailed workflow for integrating eye-

tracking data into a GIS environment. The workflow is displayed in Figure 10. First, participants are immersed in a virtual reconstruction of Pompeian houses using VR technology. While exploring the virtual environment, eye-tracking devices capture their gaze patterns and fixations, collecting data on their visual attention and interests. Next, this eye-tracking data is combined with the 3D GIS representation of the architectural elements and spatial relationships within the houses. By aligning the eye-tracking data with the spatial coordinates in the GIS environment, researchers can precisely map participants' visual focus points onto the virtual reconstruction (Campanaro & Landeschi, 2023).
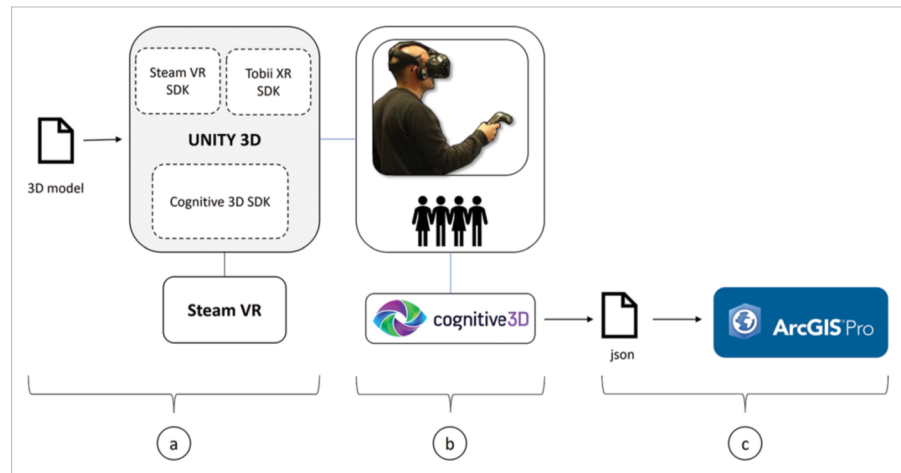
Figure 10 Workflow for the integration of eye-tracking data into a GIS environment (Campanaro & Landeschi, 2023).

Zhang et al. (2018) conducted an experimental study on attentiveness, combining VR and 3D eye-tracking. This research exemplifies another instance where VR and eye-tracking are employed together to explore the dynamics of attentiveness. Their study focused on integrating these tools to investigate how attention is influenced in the context of re-designing street spaces. The study adopts a protocol analysis methodology to capture and analyze the cognitive thinking and spatial cognition of individuals walking within the VR environment. Figure 11 demonstrates the spatial behavior patterns of individuals observed in this street space.
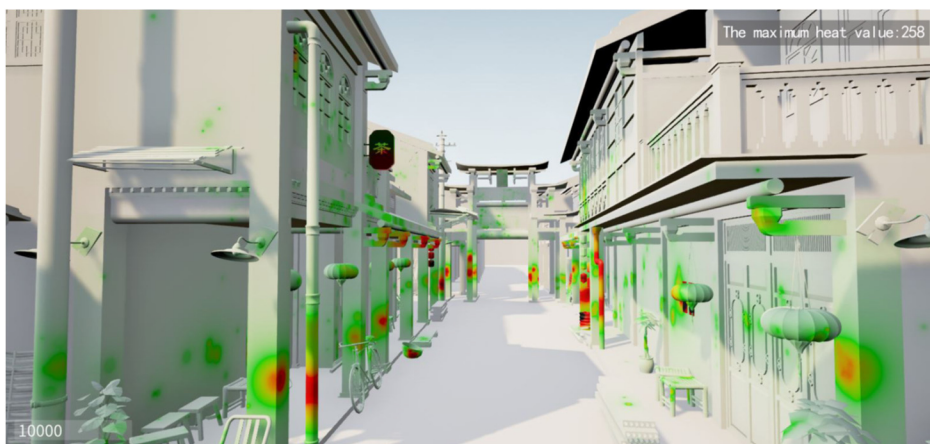
Figure 11 A three-dimensional eye-tracking spatial behavior composite thermal map (Zhang et al., 2018).

2.2.4 Visual Attention: Eye-Tracking Insights in VR and Education

According to a recent study by Mikhailenko & Kurushkin (2021), eye-tracking in VR enables the detection of the user's visual focus within the virtual environment. Additionally, VR can be utilized to shift attention towards specific elements if doing so enhances task performance. Various techniques exist to direct attention toward specific objects or areas within the VR environment, which can be employed as needed. The effectiveness of these techniques can be continuously monitored in real time by tracking the user's gaze. Incorporating eye-tracking into VR can prove valuable by enhancing the functionality of diverse applications and identifying shortcomings within VR experiences. Furthermore, VR allows full-body motion tracking, enabling the virtual environment to respond to the user's movements, actions, and gaze (Mikhailenko & Kurushkin, 2021). Shadiev & Li (2022) point out that scholars are actively exploring innovative applications of IVR and gathering data to understand its impact on learning outcomes. For instance, recent studies have utilized eye-tracking technology (Wang et al., 2021) to measure learners' visual attention in IVR. Furthermore, researchers have even measured learners' stress levels (Tawa, 2022) and cognitive load (Abdurrahman et al., 2021; Shi et al., 2020) within the IVR environment. These findings contribute to a deeper understanding of how humans learn in IVR settings and help uncover the essential aspects of this learning approach (Shadiev & Li, 2022).

The field of visual attention has witnessed significant advancements, with researchers exploring various methods to understand how individuals allocate their attention to visual stimuli. Several noteworthy studies have focused on measuring visual attention in different contexts, shedding light on the intricacies of this cognitive process. One such study, titled "*Measuring Visual Attention Processing of Virtual Environment Using Eye-Fixation Information,*" by Kim & Kim (2020), focuses on VR. By utilizing eye-tracking technology, researchers collected eye-fixation data to analyze participants' attentional focus within virtual environments. This research adds to the existing knowledge on visual attention in VR and has implications for fields such as human-computer interaction, user experience design, and cognitive psychology.

Similarly, the study "Employing Eye Tracking to Study Visual Attention to Live Streaming: A Case Study of Facebook Live" by Chen et al. (2022) investigates visual attention patterns in the context of live streaming platforms. Through eye-tracking techniques, researchers examined how individuals allocate their attention when engaging with content on Facebook Live. This study demonstrates the applicability of eye-tracking technology in understanding visual attention dynamics in real-time environments, offering valuable insights for content creators and platform designers. Additionally, the study by Alghofaili et al. (2019) explores the optimization of visual element placement based on visual attention analysis. Researchers used eye-tracking data to study how different visual elements attract and sustain attention, aiming to enhance the effectiveness of visual designs. This research holds practical implications for domains such as advertising, graphic design, and user interface development, emphasizing the importance of visual attention analysis in these areas.

The present study by Hasenbein et al. (2022) investigated the effects of different configurations in an IVR classroom on students' visual attention and learning experiences. The study included 274 sixth-grade students who were exposed to various IVR classroom setups. The configurations included students' positions in the classroom, the visualization style of virtual avatars, and the performance-related behavior of virtual

classmates (Figure 12). The researchers used eye-tracking data to analyze students' visual attention patterns and employed network analysis to examine gaze-based attention networks. The results showed that the IVR configurations influenced students' visual attention on classmates and instructional content, as well as their overall gaze distribution in the IVR classroom. The study also explored the relationship between gaze-based attention networks and students' learning experiences, including their interest in the IVR lesson, situational self-concept, and performance on a posttest. The findings provide insights into the effects of different IVR configurations on students' attention and learning experiences, with implications for future research and the use of IVR classrooms in education.
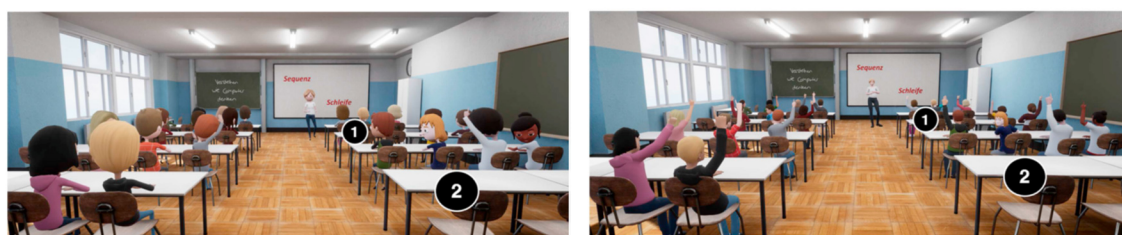
Figure 12 IVR configuration conditions. Left: The avatar visualization in cartoon style. Right: The more stylized (i.e., more realistic) avatar visualization (Hasenbein et al., 2022).

Visual attention in education plays a crucial role in optimizing the learning process. It encompasses how individuals allocate their attention to visual stimuli and maintain focus on educational materials. Researchers have explored various approaches to understanding and enhancing visual attention in educational settings, particularly within the realm of VR. One notable study, titled "*Eye-gaze-triggered Visual Cues to Restore Attention in Educational VR,*" by Yoshimura et al. (2019), investigates the use of eye-gaze-triggered visual cues to restore and sustain attention in educational VR environments. By utilizing eye-tracking technology, the researchers aimed to address the challenge of maintaining learners' attention during immersive educational experiences. The findings of this study shed light on the effectiveness of eye-gaze-triggered visual cues in restoring and maintaining attention in educational VR. These cues serve as attentional anchors, redirecting learners' gaze and reinforcing engagement with the educational content. By leveraging real-time eye-gaze information, educators and designers can tailor interventions that effectively guide learners' attention and enhance knowledge acquisition (Yoshimura et al., 2019).

The research conducted by Shadiev & Li (2022) indicates that employing eye movements in VR represents an innovative and advanced approach. Based on their analysis of existing studies, numerous scholars concur that this technique shows promise. Incorporating eye-tracking technology into VR opens a fresh and fascinating avenue for investigating students' attention and motivation. Furthermore, it has the potential to accelerate and enhance teachers' effectiveness while also serving as an assessment tool. Shadiev & Li (2022) underline that the capacity to utilize VR with a variety of environments, models, and precise control establishes it as an essential and irreplaceable educational asset.

3 METHODOLOGY

This chapter outlines the methodology for creating a VLE and presents the approach of user assessment through eye-tracking technology. In addition, the workflow of this diploma thesis is provided to highlight the final visualization of the VLE and the data analysis.

3.1 Selection of Geographic Content

During the content selection process, the author placed a high importance on current geographical events and specifically highlighted the role of the Copernicus program in addressing climate change. With guidance from supervisor, the author ultimately decided to establish the COPERNICUS MUSEUM environment, which aims to educate and create awareness about Sea Level Rise and the significance of the Sentinel-6 mission. To achieve this goal, the museum's geographic content was carefully chosen and includes European Space Research and Technology Centre (ESTEC), Falcon 9 rocket, Sentinel-6 satellite, Ocean, Globe, and Venice city. Moreover, each of these geographic exhibits accompanied by corresponding video materials. These exhibits chosen as Areas of Interest (AOIs) in COPERNICUS MUSEUM environment.

3.2 Hardware

Varjo XR-3 eye-tracking headset and the **HTC Vive controllers** were used to present the COPERNICUS MUSEUM environment to participants.

Varjo XR-3 is specifically engineered to provide optimal comfort for users of all head sizes and shapes, even during extended immersive experiences, thanks to its 3-point precision fit headband. With features such as automatic IPD adjustment, active cooling, a smooth 90 Hz frame rate, and advanced non-Fresnel lenses that offer a wide field of view and exceptional clarity, users can work without experiencing any discomfort or motion sickness. Additionally, Varjo XR-3 headsets are compatible with a wide selection of Windows 10 and 11 computers.

The content (COPERNICUS MUSEUM environment) was displayed through a desktop computer with an Intel Core i7-8700 CPU, 64GB RAM, an NVIDIA GeForce RTX 2080 GPU, and a 64-bit **Windows 10 operating system.**

HTC Vive controllers were employed to enable users to actively engage with the virtual realm. It incorporates various sensors like motion trackers, a gyroscope, and an accelerometer, which allow accurate monitoring of the controller's location and orientation within the virtual reality space. This precise tracking enhances the overall experience by ensuring smooth and immersive interaction for users.

3.3 Software

The virtual geographic learning environment was primarily developed using **Unreal Engine 4.27.** This software was utilized to build COPERNICUS MUSEUM environment and establish a connection to Varjo software by employing Blueprints and Varjo OpenXR plugin.

Blender 3.5 was employed to create the 3D model of ESTEC and Globe. Blender offers powerful 3D modeling capabilities, allowing for the creation of detailed and realistic models. The visual appearance of the models was enhanced by applying textures within Blender.

SketchUp Pro 2022 was utilized to generate the 3D models of the Falcon 9 rocket and Sentinel-6 satellite. SketchUp Pro is known for its intuitive interface and ease of use, making it suitable for creating accurate and visually appealing models. Textures were applied to these models to achieve a realistic view.

CityEngine was used to import 3D model of Venice city developed by Esri. CityEngine specializes in procedural modeling and urban planning, enabling the efficient generation of complex cityscapes.

Datasmith plugin in Unreal Engine 4.27 were enabled to facilitate the import of models from SketchUp Pro 2022.

Quixel Bridge plugin was enabled to access Quixel Bridge's assets, which provide a library of high-quality textures and materials for enhancing the visual quality of the virtual environment.

Once the Copernicus Museum was prepared, the subsequent task involved utilizing the VARJO XR-3 VR Headset to collect eye-tracking data. To accomplish this, the **Varjo Lab Tools** software was employed for masking purposes, while the eye-tracking data from the VR environment was gathered using the **Varjo Base** software. The calibration process for eye-tracking was conducted within Varjo Base by wearing the VR Headset.

Microsoft Visual Studio 2022 was utilized as the primary tool to analyze the eye-tracking data stored in a CSV file, employing the Python scripting language.

Statistical Package for the Social Sciences (SPSS) used to conduct in-depth analysis.

3.4 Data

3.4.1 Blueprint Visual Scripting System

In this thesis, the hardware and project called "Church" developed in Unreal Engine 4.27 by the Faculty of Arts at Palacký University Olomouc in Czechia were used. The LogOpenXRUpol_BP Blueprint was sourced from the "Church" project. This blueprint is responsible for collecting data related to eye-tracking. Additionally, the blueprint for Teleportation and VRPawn were obtained from the same source, and modifications were implemented to each of the blueprints.

3.4.2 Assets in the Virtual Environment

The majority of assets used in the Virtual Environment were sourced from the Bank Building/Interior (Modular) collection developed by Leartes Studios, available on the Unreal Engine Marketplace. The assets for the Ocean Model were obtained from the Underwater World/70 Assets collection developed by Pack Dev and accessible on the Unreal Engine Marketplace. Arctic assets were sourced from Quixel Bridge.

3.4.3 Sources for 3D Models

To create 3D model of ESTEC in Blender, the "BlenderGIS" add-on was used to get elevation data. "BlenderGIS" add-on was obtained from the GitHub repository[1] developed by domlysz. The model used the Blender-OSM add-on to obtain OSM building

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[1] https://github.com/domlysz/BlenderGIS

data, which was sourced from an external website[2] (*Prochitecture*).

The 3D model of the Venice city was obtained from Esri's online platform[3] (*esri*).

3.4.4 Texture data for 3D Models

To achieve a realistic visualization of the 3D models, various textures were applied to each content. For the 3D model of ESTEC, textures were sourced from Textures.com[4] (*textures.com*) to give the buildings a lifelike appearance. The Falcon 9 rocket model incorporated the official logos of Sentinel-6 Michael Freilich and SpaceX Falcon 9. The logo for Sentinel-6 Michael Freilich was obtained from the National Aeronautics and Space Administration's[5] (*NASA*) website, whereas the logo for SpaceX Falcon 9 was sourced from an external website[6] (*logodix.com*). The texture for Sentinel-6 satellite model was obtained from an external website[7] (*freepik*). Additionally, textures from an Architecture Services Portal[8] (*Archweb*) were used to accurately depict the spacecraft's solar panels. Image sourced from news website was utilized as texture to enhance the visual representation of the Ocean Model (Figure 22). The Global Ocean Sea Surface Temperature trend map was applied as a texture for 3D model of Globe, which was accessed from website of Copernicus Marine Environment Monitoring Service[9] (*Copernicus Marine Service*).

3.4.5 Video Materials

Table 1 displays the sources of video materials that were utilized in the COPERNICUS MUSEUM to enhance participants' understanding of the museum's geographic contents. These videos provided additional information on ESTEC, Falcon 9 rocket, Sentinel-6 satellite, Globe, and the city of Venice.

Table 1 Sources of Video Materials

Videos	Sources
ESTEC	European Space Agency, ESA, 2018
	European Space Agency, ESA, 2022
Falcon 9 rocket	Space Curiosity, 2021
Sentinel-6 satellite	NASA 360, 2021
Globe	NASA, 2023
Venice city	Atlas Pro, 2020
	Insider, 2019

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[2] https://prochitecture.gumroad.com/l/blender-osm

[3] https://www.arcgis.com/home/item.html?id=51d3f2f1f14f43fdb6386a47d8fd86b8

[4] https://www.textures.com/category/buildings/1926

[5] https://blogs.nasa.gov/sentinel-6/2020/11/20/tune-in-tomorrow-for-sentinel-6-michael-freilich-launch-coverage/

[6] https://logodix.com/spacex-falcon

[7] https://www.freepik.com/premium-photo/crumpled-golden-foil-as-background_15263051.htm

[8] https://www.archweb.com/en/photogallery/solar-panels-textures/

[9] https://data.marine.copernicus.eu/product/GLOBAL_OMI_TEMPSAL_sst_trend/description

3.5 Workflow

The study's workflow presented in Figure 13, providing a visual representation of the various stages involved. Section A focuses on the Development of the Virtual Geographic Environment, outlining the specific steps and processes involved in creating it. Development of Virtual Reality Environments methodologies adopted from the studies of Govea & Medellín-Castillo (2015) and Lucas (2020). This environment was then connected to a VR headset using Blueprint Visual Scripting system. The Blueprint Visual Scripting system within Unreal Engine presents a comprehensive gameplay scripting approach, relying on a node-based interface within Unreal Editor to construct various gameplay components. Much like conventional scripting languages, it serves the purpose of defining object-oriented (OO) classes or objects in the engine (Unreal Engine, n.d., Introduction to Blueprints). Section B encompasses the sequential steps involved in the workflow, which begins with the calibration of the eye-tracking and extends to participants experiencing the COPERNICUS MUSEUM environment while concurrently collecting eye-tracking data. The workflow in Section B was modified differently from the gaze-based interaction scheme for VR environments proposed by Piotrowski & Nowosielski (2020). Section C details the workflow for analyzing the data obtained from the Virtual Environment. The SPSS analysis was conducted following the methodology outlined by Kim & Lee (2021). This analysis aims to uncover general insights about the environment, possibly related to user behavior, preferences, and patterns observed during the participants' virtual experiences.
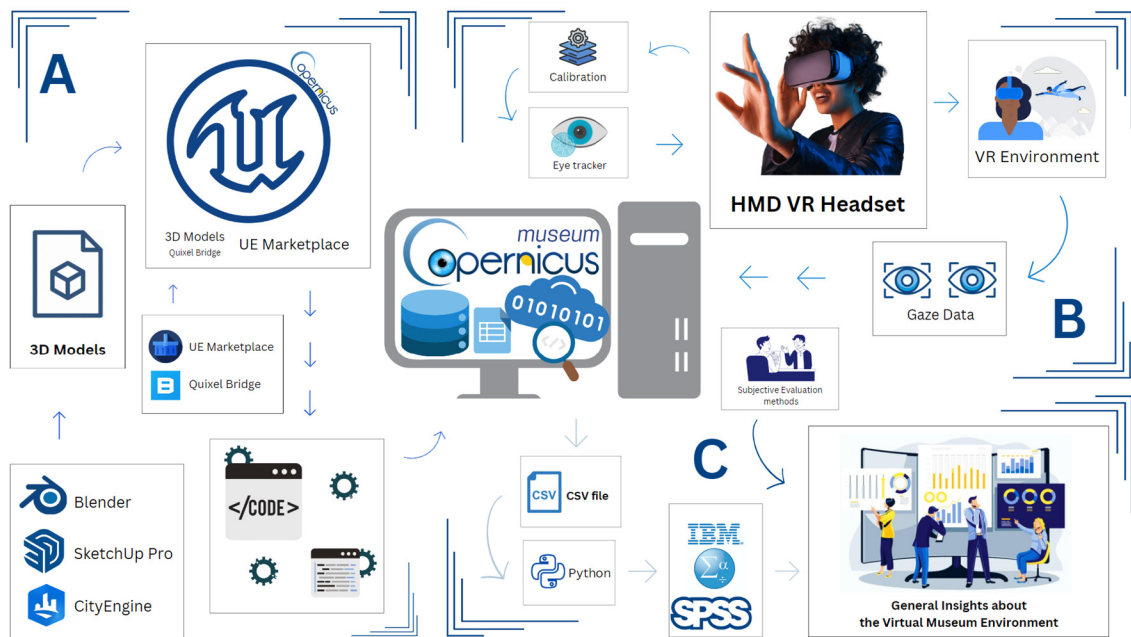
Figure 13 Thesis Workflow.

4 DEVELOPMENT OF VIRTUAL GEOGRAPHIC LEARNING ENVIRONMENT

This chapter serves as a comprehensive tutorial, offering a detailed and methodical approach to creating the COPERNICUS MUSEUM environment. It presents a step-by-step guide, beginning with the installation of the required software and continuing through the process of incorporating user input. The chapter covers various elements, such as Widget Interaction, Managing User Input, Navigating within the environment, and Creating Dynamic Actors. The provided guidelines are thorough and systematic, providing a clear roadmap for building the desired virtual geographic learning environment.

4.1 Development of Geographic Exhibits

This section provides the descriptions of how Geographic Exhibits are produced utilizing various 3D modeling software programs. The proposed approach is based on open-source software.

3D model of ESTEC in Blender

Blender[10] provides the functionality to create 3D terrain models of any location worldwide by utilizing Google Maps[11] and a specific add-on designed for Blender. To create 3D model of ESTEC in Blender, the "BlenderGIS" add-on was downloaded and installed in Blender. This add-on integrates GIS data, including Google Maps, into Blender, offering users access to NASA's[12] elevation data, such as the Shuttle Radar Topography Mission (SRTM) data[13], which provides global elevation information. Within the BlenderGIS panel, the desired location was set to the southern region of Noordwijk, The Netherlands in the Google Maps section. By specifying the location, the add-on retrieved satellite imagery for that particular area and generated a texture suitable for application to a mesh in Blender. Google Maps' satellite imagery was utilized as a texture.

After generating the 3D terrain of ESTEC, next step was involved importing OSM building data[14] into the model. To accomplish this, Blender-OSM add-on was utilized. The final 3D representation of ESTEC was exported in the STL (.stl)[15] file format.

3D model of Falcon 9 Rocket in SketchUp

SketchUp Pro[16] 2022 emerged as the optimal choice for crafting an intuitive, detailed 3D model of the Falcon 9 Rocket. SketchUp was utilized primarily for its capability to provide a straightforward and accurate graphical representation of the elements, without the need for incorporating parametric properties and the intricacies

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[10] https://www.blender.org/

[11] https://www.google.com/maps

[12] https://www.nasa.gov/

[13] https://www2.jpl.nasa.gov/srtm/

[14] https://osmbuildings.org/data/

[15] https://www.iso.org/standard/61944.html

[16] https://www.sketchup.com/products/sketchup-pro

commonly found in more advanced building information models (Lucas, 2020). The final 3D representation of Falcon 9 Rocket was exported in the Collada (.dae)[17] file format.

3D model of Copernicus Sentinel-6 satellite in SketchUp

The 3D model of the Sentinel-6 satellite[18] was constructed within SketchUp Pro 2022. The employment of textures elevated the model's realism, faithfully capturing the intricate features of the Sentinel-6 satellite within the digital realm of SketchUp Pro 2022. The final 3D representation of Sentinel-6 satellite was exported in the Collada (.dae) file format.

Visualizing 3D model of Sea Surface Temperature Trends

Blender was used to create a 3D model illustrating the trends in sea surface temperature. The model employed a UV Sphere mesh, while the Global Ocean Sea Surface Temperature trend map was utilized as a texture. The final 3D model was exported in the FBX (.fbx) file format.

3D model of Venice city, Italy in CityEngine

After obtaining the accessible Venice city sample from Esri's[19] online platform, the model was imported into CityEngine[20]. In CityEngine, the three-dimensional depiction of Venice was then exported in the Collada (.dae) format, guaranteeing its compatibility and readiness for smooth integration into the Unreal Engine.

4.2 Development of Virtual Environment in Unreal Engine

This section documents the steps and achievements of the creation of virtual geographic learning environment. The environment developed in Unreal Engine 4.27.

4.2.1 Installing Unreal Engine software

To begin the process of installing Unreal Engine, select the appropriate operating system, as Unreal Engine supports both Windows[21] and MacOS[22]. Here's the step-by-step process for installing Unreal Engine:

1. Access the Unreal Engine website (https://www.unrealengine.com) through your preferred web browser. If you already possess an Epic Games[23] account, you can log in using your existing credentials. Otherwise, create a new account. Upon successful login, you will be directed to the Unreal Engine page.
2. Locate and click on the "Download launcher" button to initiate the download of the Epic Games Launcher installer.
3. Proceed by executing the Epic Games Launcher installer.
4. Once the installation process is finalized, the Epic Games Launcher should automatically launch. In case it does not, you can manually open it from either the Start menu or the desktop.

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[17] https://www.iso.org/standard/59902.html

[18] https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-6

[19] https://www.esri.com/en-us/home

[20] https://www.esri.com/en-us/arcgis/products/arcgis-cityengine/overview

[21] https://www.microsoft.com/en-us/windows?r=1

[22] https://support.apple.com/en-us/HT211683

[23] https://store.epicgames.com/en-US/

5. Sign in to the Epic Games Launcher using your Epic Games account details. Following this, you can proceed with the installation of Unreal Engine. Upon completion of the installation, you can launch Unreal Engine by selecting the "Launch" button within the Epic Games Launcher, specifically under the "Unreal Engine" tab. Alternatively, you may locate shortcuts to Unreal Engine in your Start menu or on your desktop.

With the successful installation of the Unreal Engine on the operating system, the software was ready to the development of virtual geographic learning environment.

4.2.2 Acquiring Assets

After becoming familiar with the Unreal Engine (UE) software, attention was directed towards exploring the possibilities of creating a museum environment within UE. To facilitate this, the decision was made to leverage the assets available on the UE Marketplace[24]. An Asset is a piece of content for an Unreal Engine project, and can be thought of as a UObject serialized to a file (Unreal Engine, n.d., Assets and Packages). This platform provides UE users with a diverse range of free assets on a monthly basis.

There exist multiple avenues of acquiring assets in UE, including utilizing the pre-existing functionalities offered by the software, importing assets from 3D modeling softwares such as Blender or SketchUp, or directly obtaining assets from the UE Marketplace. After careful deliberation, the conclusion was reached that procuring assets from the Marketplace offered the most advantageous and optimal solution tailored to the specific requirements. Assets from the UE Marketplace were acquired, specifically opting for the Bank Building/Interior (Modular) collection developed by Leartes Studios, which was provided free of charge. The assets showcased in Figure 14 exemplify the visual elements utilized in the study.
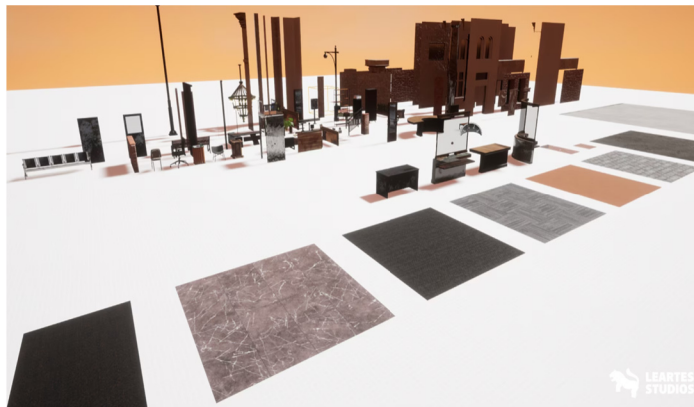
Figure 14 Bank Building / Interior (Modular) by Leartes Studios (UE Marketplace, n.d.).

4.2.3 Migrating Assets

Within the Content Browser, Migrate Tool serves the purpose of copying assets from one project to another. This tool not only copies the selected asset but also takes care of any dependent assets that are associated with it. For instance, if user chooses to

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[24] https://www.unrealengine.com/marketplace/en-US/store

migrate a Material, the Migrate Tool automatically includes any Texture assets that are utilized by that Material, ensuring a comprehensive transfer of all necessary components (Unreal Engine, n.d., Migrating Assets). The Bank Building/Interior project's assets were migrated, and the task of resizing them was carried out to fulfill the specific requirements.

4.2.4 Manipulating Actors

After importing assets into the project, the task of resizing the actors was undertaken. Manipulating actors in Unreal Engine encompasses the actions of relocating, rotating, or resizing them, playing a vital role in the process of level editing and creation (Unreal Engine, n.d., Manipulating actors). By utilizing the selection feature, objects can be chosen and their position can be manipulated by moving them in the desired direction. The rotation functionality allows to adjust the orientation of selected objects along different axes. Additionally, the scaling capability enables to resize objects proportionally or non-uniformly according to users' requirements. These versatile tools empower users to precisely control and customize objects, resulting in the desired visual and spatial outcomes within the virtual environment. In Figure 15, a visual illustration is presented to showcase the act of manipulating actors.
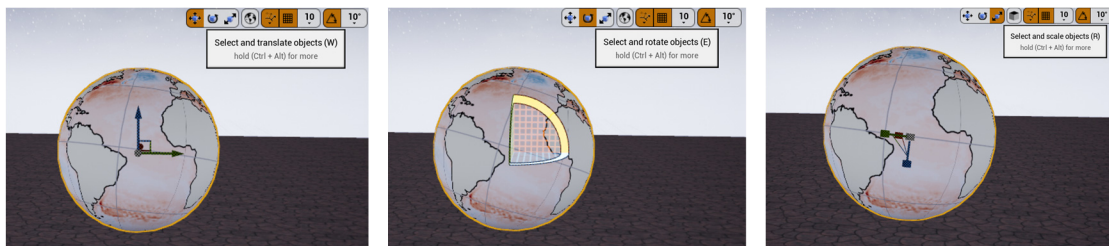
Figure 15 Manipulating Actors.

The Museum building's walls within the virtual environment were created by employing migrated assets, which were subsequently adjusted in size and positioned accordingly within the virtual environment.

4.2.5 Importing Geographic Exhibits to Virtual Environment

Upon the completion of exporting geographic exhibits, the subsequent task entailed their importation into UE. This process necessitated the consideration of specific file formats. To facilitate a smooth importation into UE, a two-step approach needs to be followed. Firstly, for exhibits saved in the Collada (.dae) format, it is crucial to activate the "Datasmith Importer" within the plugin settings of UE (Unreal Engine, (n.d.), Importing Datasmith). By activating this plugin, users unlock the necessary functionality to facilitate the seamless importation of Collada (.dae) files into the engine. On the other hand, when dealing with exhibits formatted as FBX (.fbx) files and STL (.stl), a more straightforward procedure can be employed. Utilizing the content browser in UE, users can employ a simple "drag and drop" technique. UE promptly recognizes the file formats and automatically initiates the importation process.

The outlined approach facilitates the seamless transfer of diverse assets from any 3D modeling software. Once the geographical exhibits were imported, next steps were to precisely placing them within their respective positions in the virtual museum setting.

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4.2.6 Creating Dynamic Actors

To achieve an authentic visual representation of clouds on the Falcon 9 Rocket, the Niagara System was utilized for simulation, ensuring a realistic viewing experience.

Creating Clouds with Niagara System

Unreal Engine's Niagara is a cutting-edge Visual Effects (VFX) system. Niagara systems serve as a framework that combines multiple emitters into a unified visual effect (Unreal Engine, n.d., Niagara Overview). The following steps were fulfilled:

1. Begin by right-clicking on the Content Brother and navigating to FX, then select the Niagara System.
2. Choose the option "Create a new system from the selected Emitter" and double-click on the "Fountain" option.
3. Rename the Fountain and proceed to drag and drop it into the Virtual Environment, as illustrated in Figure 16.
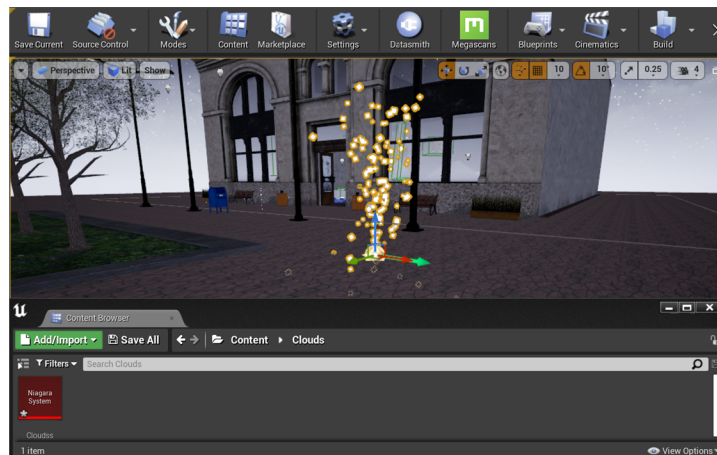
Figure 16 Fountain in Niagara System.

4. The cloud material is already pre-built in the "Starter Content" by default and this material was used in the project. If you don't have it, you can search Advanced settings of Content Browser and import it into the Content Browser.
5. Following the acquisition of the materials from the "Starter Content," the cloud settings were appropriately configured.
6. Double click on the Clouds to access its settings.
7. Within the Sprite Renderer, configure the material to be Smoke (Figure 17).
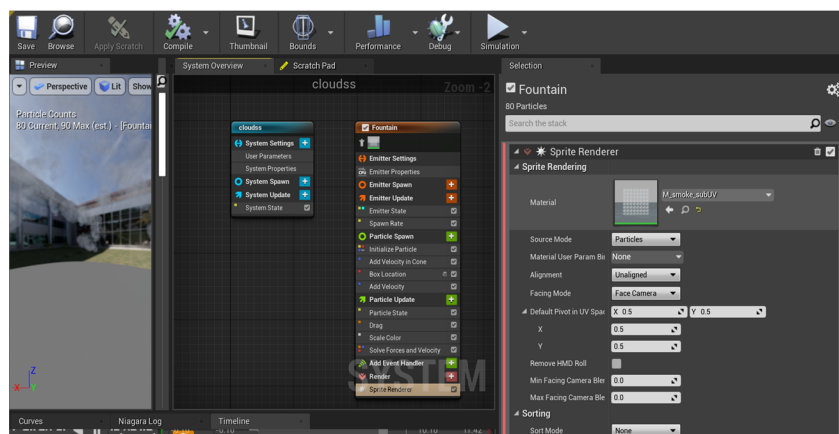
Figure 17 Settings of Niagara System.

8. Adjust the Sub UV settings to a value of 8 by 8 as illustrated in Figure 18.
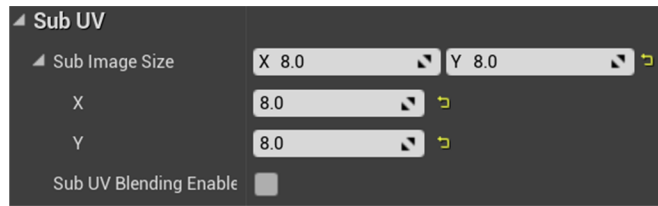
Figure 18 Settings of Niagara System.

9. The "Box Selection" button enables to specify the sizes of the clouds according to users preference. Likewise, the "Velocity" button allows to manipulate and experiment with different speeds in Settings of Niagara System.

Once the speed and sizes were set, the clouds were positioned in the desired location within the Virtual Environment.

Creation of Fire with Niagara System

To achieve a realistic representation of fire, the Niagara System was employed and made use of materials available in the Starter Content. The activation process for the Niagara System follows the same steps that were used for generating the clouds. After dragging and dropping the Fountain into the Virtual Environment, proceed to configure the settings for the fire. The "Fire" material was used and adjusted the necessary parameters as displayed in Figure 19.
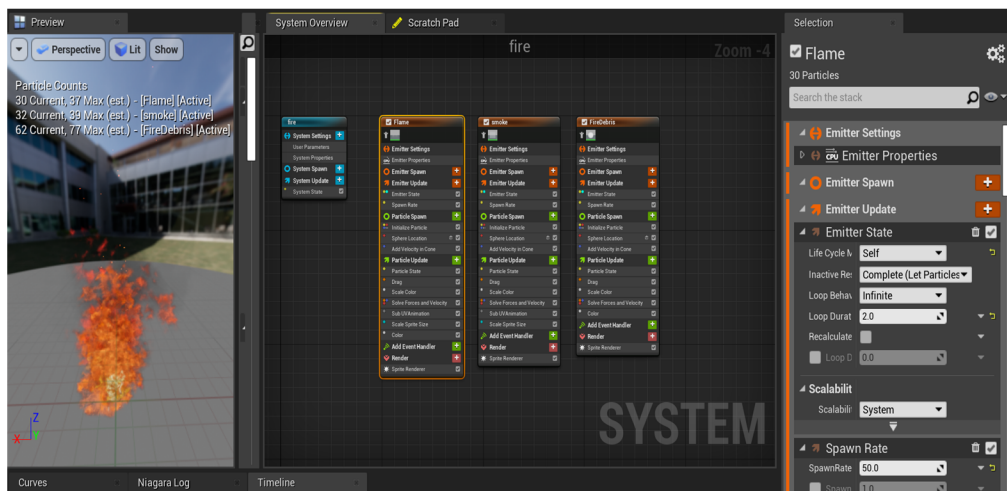
Figure 19 Settings of Fire.

4.2.7 Rotation of Actor

The goal in this step was to rotate the imported 3D Model of Globe from Blender. To do so, open the Content Browser and create a new folder. Give it a name of your choice, it was named as Blueprint. Right-click within the Blueprint folder and choose the Blueprint -> Actor option. Open the Actor that was just created. In the Content Browser find and select the 3D Model and proceed by dragging the model into the interface of the Actor, as demonstrated in Figure 20. This selection was made because the 3D Model serves as a mesh object within the Actor, allowing to manipulate and rotate the 3D Model according to requirements.

Figure 20 Actor Blueprint Interface.

Access the Components interface in Actor then add the Rotating Movement component and close all relevant interfaces. Drag and drop the Actor into the Virtual Environment. If desired, adjust the rotation speed of the Actor by modifying the Rotation Rate in the Actor's details settings. Refer to Figure 21 for a visual representation.
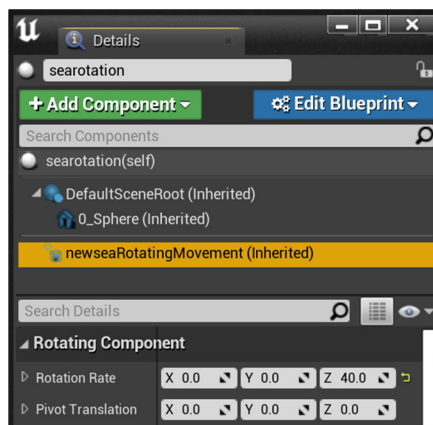
Figure 21 Details Section of Actor Blueprint.

4.2.8   Animating UV Coordinates & Assets

Animating UV Coordinates refers to the action of shifting a Texture's UV coordinates either horizontally (U), vertically (V), or both, creating the illusion of intricate animation (Unreal Engine, n.d., Animating UV Coordinates). The image displayed in Figure 22 was employed as a texture in the creation of an ocean surface.

Figure 22 Texture for Animation of Material (sourse: https://www.vox.com/science-and-health/23030491/ocean-scientific-mysteries-unexplainable-podcast).

The goal in this step was to imbue the texture with a sense of movement that evokes the feeling of the ocean. To achieve this, the following sequence of actions were undertaken. Initially, the Content Browser was right-clicked and selected the Material option to initiate the creation of a new material. Once the material was opened, the settings were adjusted accordingly. Figure 23 displays the visual representation of the Material Interface. In the settings of Material two distinct textures were utilized where the first texture was used as the Base Color and Emissive color, and the second texture was employed for Normal Color. To manipulate the textures' movement, the Material interface was right-clicked and accessed the Panner node, which was subsequently connected to the UV of the textures. The Panner node serves the purpose of manipulating the texture's movement. The material was saved and it was ready for application onto the mesh (Unreal Engine, n.d., Animating UV Coordinates).
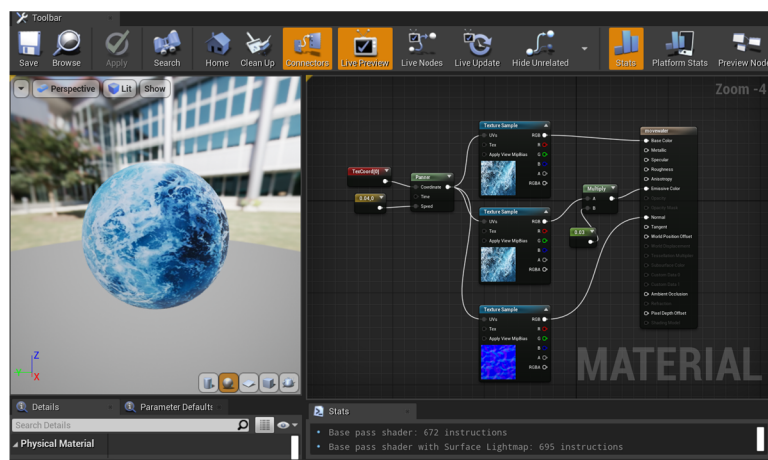
Figure 23 Material Interface.

3D model of Ocean was specifically designed to simulate the visual representation of the ocean in conjunction with 3D model of Sentinel-6 satellite. In order to achieve this, a transparent material was applied to the mesh's height to create the desired effect. The transparent material was generated in the Content Browser by creating a new material and adjusting its settings to achieve the desired transparency effect. The remaining assets used in the model were obtained free of charge from the Marketplace known as Underwater World / 70 Assets by Pack Dev. The Material displayed in Figure 18 was used on the top surface of 3D model of Ocean in the Virtual Environment.

Quixel Bridge[25] offers thousands of 3D assets, tileable surfaces, imperfections, vegetation, atlases. The Arctic assets showcased in Figure 23 were sourced and adjusted from Quixel Bridge for this particular study.

4.2.9 Lighting the Environment

A fundamental element in the creation of a VE lies in effectively lighting the surroundings. Unreal Engine 4 offers four categories of lighting: Directional, Point, Spot, and Sky. The Directional light is commonly employed for outdoor illumination or when a light source needs to simulate light originating from extremely distant or nearly infinite distances.

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[25] https://quixel.com/bridge

Point lights resemble traditional light bulbs, radiating light in all directions from a singular point. Spotlights emit light from a specific point, but their illumination is confined within a defined cone shape. Sky lights capture the scenery of VR scene and utilize it to illuminate the objects in VR level (Unreal Engine, n.d., Types of Lights). The Light within the VE was adjusted.

4.2.10 Bringing 2D Videos into Virtual Environment

This section provides instruction on how to incorporate 2D videos into a virtual environment. Primarily, the section presents a detailed walkthrough on creating logical blueprint that triggers the playback of a video when the user presses a widget using a controller.

Widget blueprint setup

To begin, the initial task was involved in creating a widget. To achieve this, the subsequent steps were carried out:
1. The Content Browser was right-clicked and navigated to User Interface -> Widget Blueprint.
2. The blueprint was renamed as WB_estec, and then opened. The Blueprint referred as WB_estec in subsequent steps.
3. Inside the Canvas Panel, a Button and a Text component were added, as illustrated in Figure 24. The properties of the Button and Text components were customized in the details section.
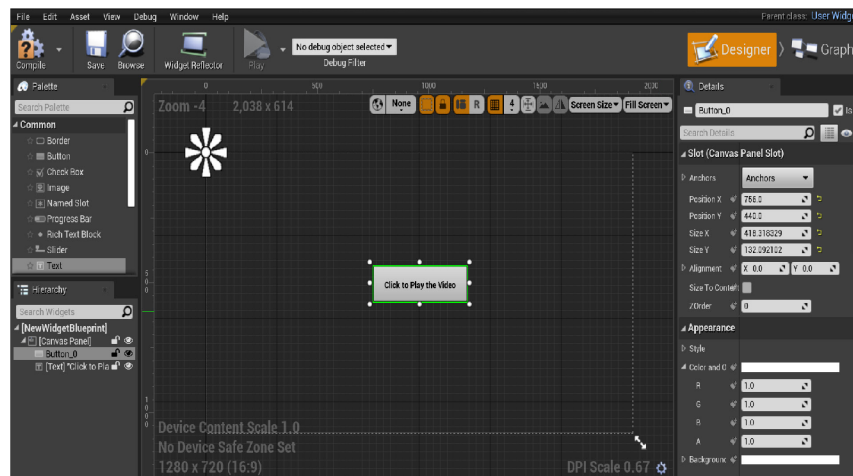
Figure 24 Canvas Panel of Widget.

Next course of actions was to formulate a blueprint that facilitated the translation of this UI widget into the realm of three-dimensional space.

Integrating Widget in a Blueprint Actor

To get started, the Blueprint class in the Content Browser was right-clicked. From the context menu, Actor was selected and named as BP_TV. BP_TV was opened and from the Components section Widget was selected. This step allows to incorporate a 2D UI widget into a 3D space. Progressing further, in the Widget's Detail Section under the User Interface settings, the WB_estec widget was chosen for the Widget Class option, as illustrated in Figure 25.
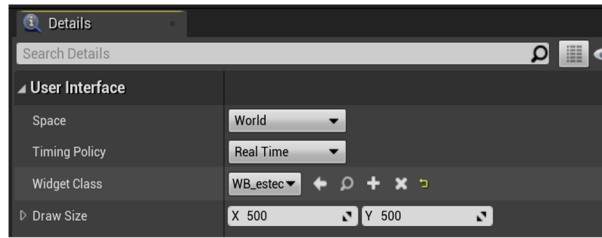
Figure 25 Detail Section of Widget.

The result of these steps described above is key for placement of UI widget in the 3D space. The Blueprint was compiled and saved. With the UI now prepared, the next step involved configuring the blueprint for the character to interact with it.

Widget Interaction Component

The current task in this section entailed enabling users to interact with the newly created user interface by attaching it to the hand controller. Consequently, the primary focus moving forward revolved around scripting for the VRPawn, as it played a crucial role in implementing this functionality.

In the context of Unreal Engine, a Pawn serves as the physical representation of the user, dictating their engagement with the virtual world. In the VR Template, the Pawn plays an important role by incorporating the necessary logic to handle input events generated by the motion controllers (Unreal Engine, n.d., VR Template).

To utilize the functionality within the Pawn, it is necessary to include the Widget Interaction component. Considering that most of the interface scripts for the Pawn were initially created for the "Church project", in this specific situation, both the Widget Interaction Left and Widget Interaction Right components were already included. However, if you do not have these components, you can easily add them from the designated "Add Component" section as displayed in Figure 26.
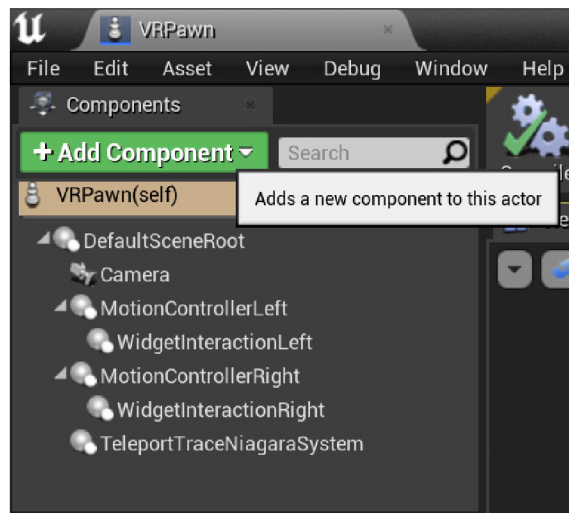
Figure 26 Components section of Pawn.

To ensure that the Pointer indices were unique, it was necessary to set the value 0 for the Widget Interaction Left component and the value 1 for the Widget Interaction Right component in their respective details' sections. Furthermore, Trace Channel was set to WorldDynamic.

Show Debug was enabled feature to facilitate the visualization of interactive objects when utilizing the controller. This functionality provides users with visual feedback in the form of displayed lines, which aid in accurately determining the specific objects being interacted with. The option to customize the color of the visual indicators is available, allowing users to tailor the display according to their personal preferences. For instance, in the accompanying Figure 27, a purple color was employed to illustrate the configured visual feedback.
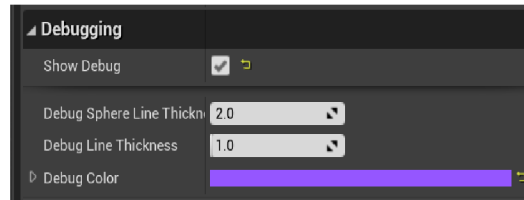
Figure 27 Debugging Color for VR Controller.

A stage was reached where the evaluation of the Widget Interaction was ready to be performed. The testing could be carried out by utilizing the VR headset and enabling the Play mode within the VR Scene. Upon immersion in the VR environment, a visible line should have appeared on the controller. If the setup was done correctly, the cursor could be positioned over the button in the widget's interface. However, it is important to note that the buttons were not activated by clicking on them directly. To accomplish this, it was necessary to proceed according to the instructions outlined in the following section.

Triggering Widget Interaction

The immediate step ahead was involved establishing a blueprint within the VR Pawn to configure its logic, enabling recognition of the aim or tracker as a mouse input. This configuration allows the engine to perceive the aim or tracker as a cursor, facilitating widget interaction. In VR Pawn, the main goal was to establish the logic for TriggerLeft and TriggerRight when they interact with the Widget Interaction Component. The Press Pointer Key function was utilized to activate their respective actions upon triggering, and the Release Pointer Key function was employed to release the key when necessary. The Left Mouse Button was selected as the key of choice, as indicated in Figure 28.
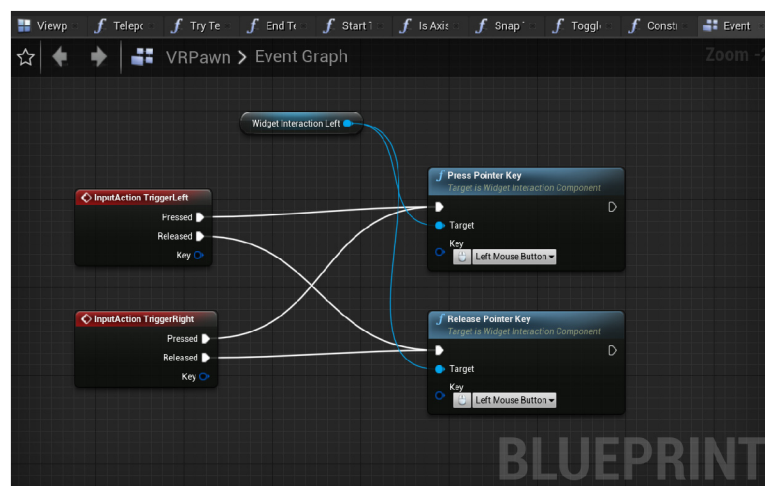
Figure 28 User Input Blueprint.

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The progress was saved and performed testing using a VR headset. When the widget interface is tested in a VR headset, it becomes interactive within the VE. The next step was to create a logical system that enables the video to start playing within the VE when the widget is clicked.

Importing 2D Video and Applying Media Texture

To import a video (media) from the computer to the Content Browser, the Import button was used. The imported video was opened by double-clicking it and copied its file path. The file path was pasted into the designated section for packaging specific movies in Project Settings of Engine. The steps below explain working with the Blueprint that was created in early steps:

1. Begin by opening the BP_TV. Look for the "Add Components" option and search for Plane. The Plane component was used to display the video. User can adjust its scale according to their requirements.
2. In the Content Browser, right-click and create a Media Player. Give it a name of your choice. For the sake of the following steps, a Media Player referred as estec. The Media Player automatically generate a Media Texture. User can assign a name to it, the Texture was referred as estec_Video in the subsequent steps. Open the estec and choose the desired video. Save the changes and close it.

Moving on, a material of the video was created. To proceed with the creation of material, follow next steps:

1. In the Content Browser, right-click and create a Material. Give it a name. For the sake of the following steps, the Material was named as ectecoo.
2. Open the material just created and drag & drop the estec_Video Texture onto the Material Interface.
3. In the Details section of ectecoo, select "Unlit" as the Shading Model.
4. Connect the RGB output to the Emissive Color input, as shown in Figure 29.
5. Compile and save the changes. The material is now ready to be applied in the BP_TV blueprint.
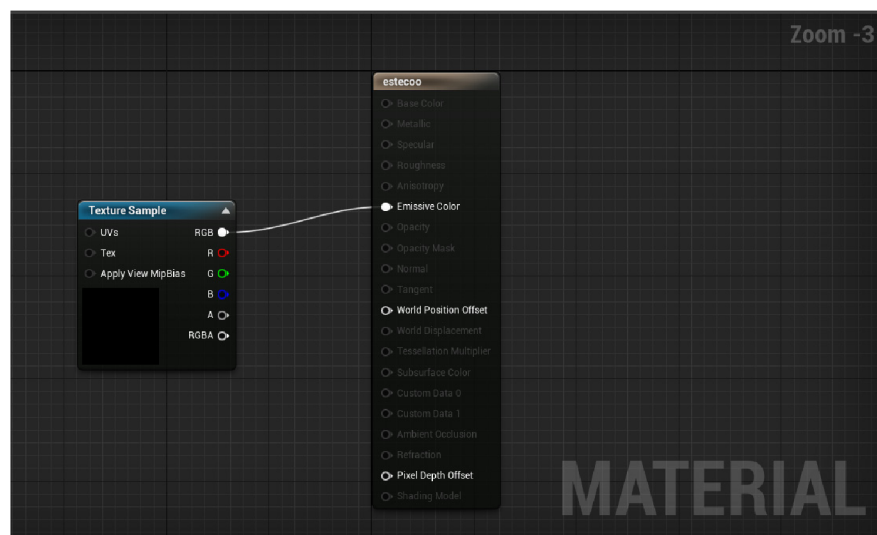
Figure 29 Interface of the material.

Access the BP_TV blueprint and navigate to the Plane's Detail section. Within the Material Section, choose the recently created Texture. In this study the estec_Video Texture was chosen.

The current focus entails configuring the Widget buttons, specifically establishing the logic in the Blueprint to initiate video playback upon button press. This logic enables the activation of video playback. In early Section the BP_TV blueprint, a Widget was generated and chosen the WB_estec widget from its Detail Section. The following steps explain the Blueprint event for Widget buttons:

1. To begin, navigate to the WB_estec Widget, select the Button, and proceed to the Events Section to choose "On Clicked." This facilitates communication with the Blueprint.
2. After compiling and saving, return to the BP_TV blueprint and right-click within the Event Graph Interface to create a Custom Event, name it as StartVideo. This Custom Event can now be invoked in the Widget. The purpose of this approach is to establish bidirectional communication between the Blueprint and the Widget.
3. Next, revisit WB_estec, select "On Clicked", and perform a Cast to BP_TV. In the "My Blueprint Section", generate a new Variable of type Actor and name it Estecoo. Drag and drop this variable onto the Widget blueprint interface and connect it to the object.
4. Drag off the Cast to BP_TV and search for Start Video. Figure 30 provides a visual depiction of these steps.
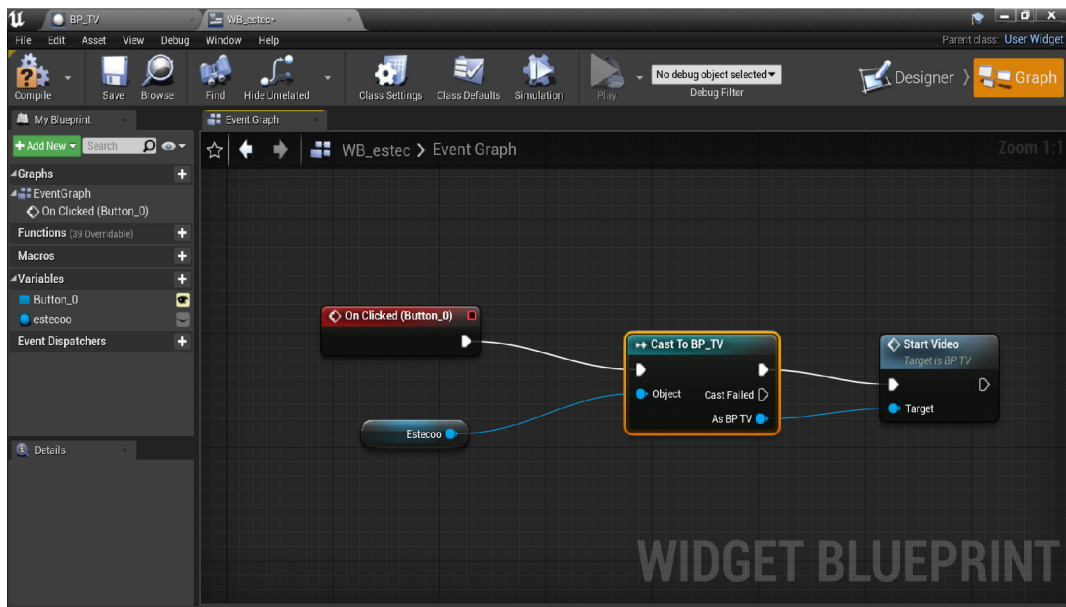
Figure 30 On Clicked Event in Widget.

5. Proceeding back to the BP_TV blueprint, initiate a right-click action and select "Event BeginPlay." Then, drag and search for Cast to WB_estec.
6. To acquire the object, drag the widget from the Components section and locate "Get User Widget Object," subsequently connecting it to the Cast to WB_estec.
7. Now assign the Estecoo Variable to the Cast to WB_estec.
8. From the Cast to WB_estec, drag and search for Set, setting it to Self.
9. Compile and save the blueprint.

Next steps involve the configuration of the Media settings for video playback initiation:

1. To begin, create a variable in the "My Blueprint Section" and specify it as a "Media Player Object Reference," naming it "2dvideo_estec."
2. By dragging and dropping this variable onto the interface, access its details section.
3. Within the Default Value Section, select the desired video. In this project the "estec" video was selected.
4. Compile and save the blueprint.
5. Select the "2dvideo_estec" variable once again and search for "Open Source Latent." This specific blueprint logic ensures that the video is loaded and maintained upon the level's BeginPlay event, persisting until the user activates the button using the controller. For a visual representation of the Open Source Latent configuration and the entire blueprint logic, refer to Figure 31.
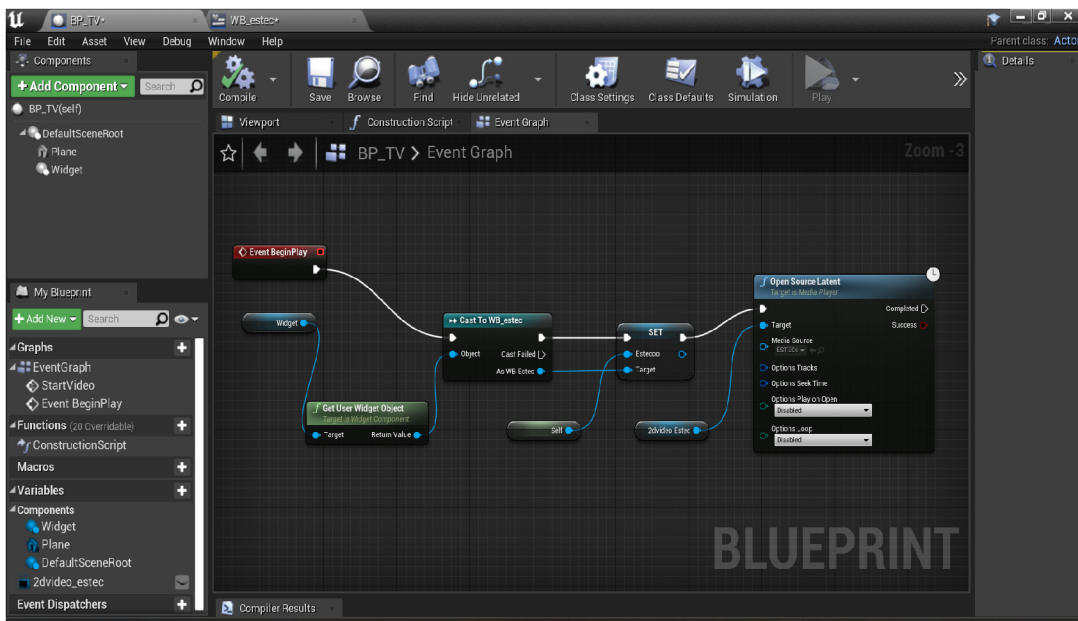
Figure 31 Event BeginPlay Blueprint for Media.

Figure 31 represents the comprehensive outcome of the implemented processes thus far. Upon initiating the VE, the video does not play automatically. To achieve a realistic television-like effect, the steps of on hiding the video initially and making it appear and start playing once it is pressed is explained. This entails modifying the StartVideo logic:

1. By dragging and dropping the Plane from the Components Section onto the StartVideo, search for "Set Visibility" and set it to True.
2. The same logic can be applied to the Widget.
3. Drag & drop the 2dvideo_Estec media player onto the interface and search for Play.
4. Connect all the relevant components as illustrated in Figure 32.
5. Compile and save the blueprint.

This particular blueprint logic addresses the visibility of videos. When the Virtual Reality Environment commences, the videos remain hidden. However, upon clicking the appropriate button, the videos become visible, triggering their playback.
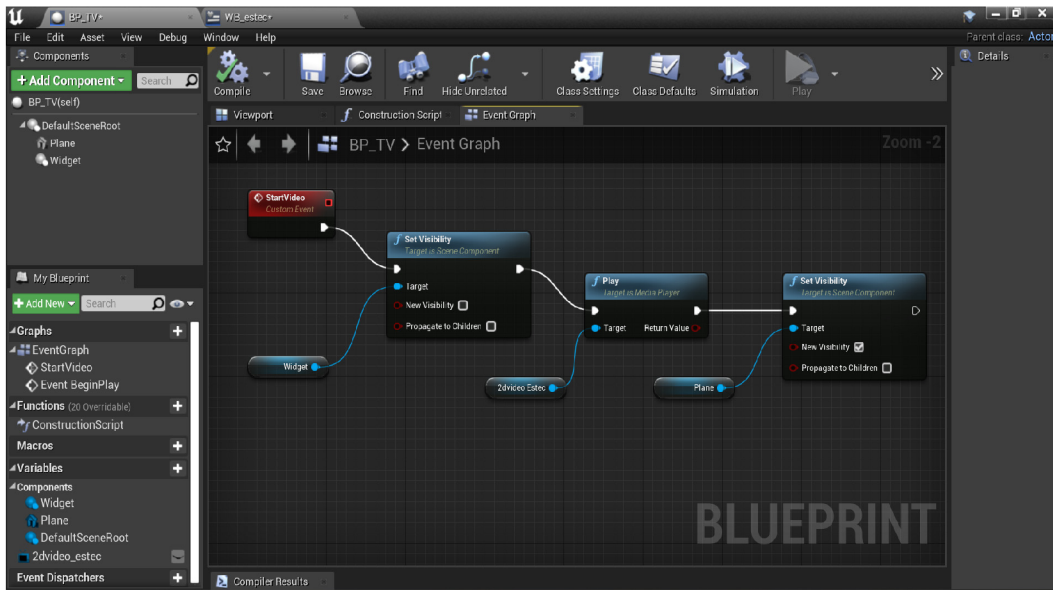
Figure 32 Visibility Blueprint of Media (Video).

To integrate the BP_TV blueprint into the VR Scene, simply drag & drop it from the Content Browser and position it at the desired location. Open the BP_TV blueprint once again and navigate to the Details section of the Plane component. Within the Rendering Section, ensure that the options for Visible and Hidden in Game are both set to False. Subsequently, when testing the VR experience using a headset, the video should play correctly without any issues.

4.2.11 Activation of Teleportation

In this section, Teleportation process was explained. Teleportation refers to a technique used in VR or game development to move a player or object instantly from one location to another within the virtual environment. Due to the existence of a prior Church project, the primary blueprints were already established there, and a majority of those blueprints were used for the current study, as shown in Figure 33. The next steps were involved activating these blueprints and ensuring their smooth integration into the project. To gain a better understanding of this process, following the steps are outlined below.
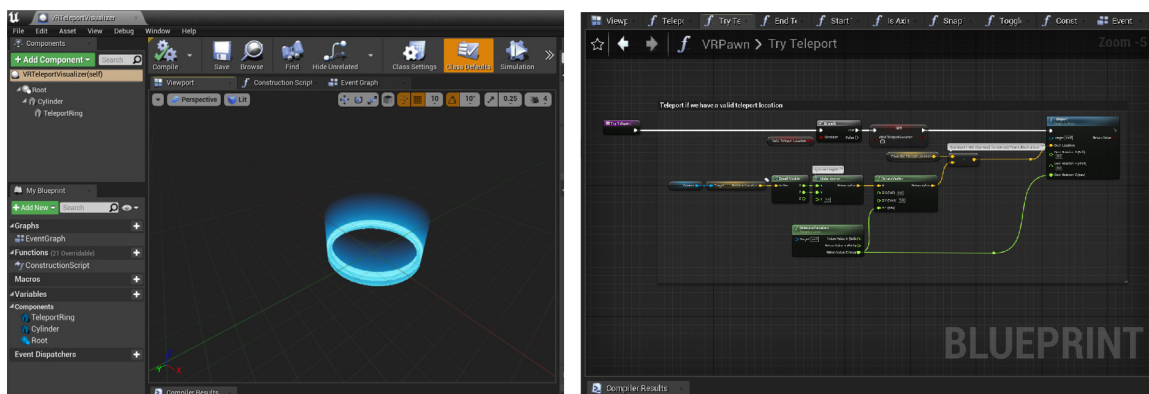
Figure 33 Left: Teleport Visualizer. Right: Blueprint for Teleportation.

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Despite the presence of blueprint logic, the ability to teleport within the VR environment was inactive. To activate teleportation, it was necessary to define the specific area where teleportation should be possible. This can be done by accessing the "Place Actors" section in the scene and locating the Nav Mesh Bound Volume. By dragging and dropping this volume into the VE, it serves as a spatial marker for the desired teleportation region. The activation or deactivation of the game mode can be accomplished by pressing the "G" key on the keyboard. By pressing the "P" key, a visible green area becomes apparent within the Nav Mesh Bound Volume, indicating the designated region eligible for teleportation. To encompass the entirety of the level, appropriately adjust the scale of the Nav Mesh Bound Volume. Refer to Figure 34 for a visual representation of a scaled Nav Mesh Bound Volume.
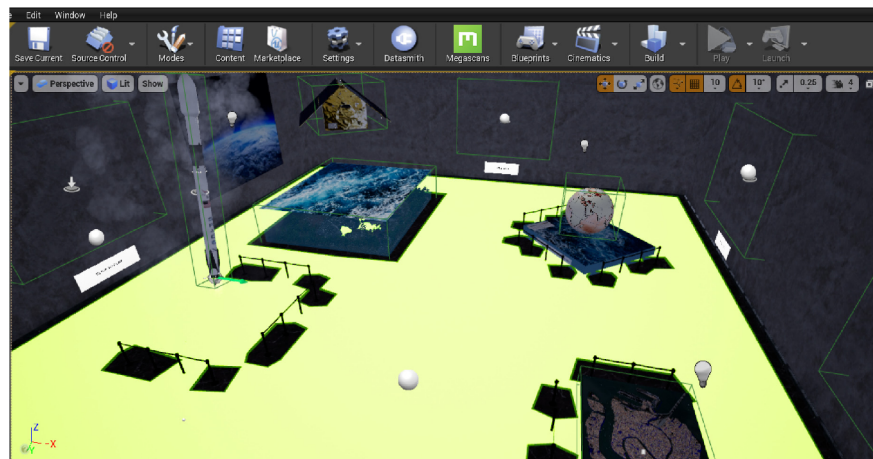
Figure 34 Nav Mesh Bound Volume for Teleportation.

Presently, upon conducting a trial using a VR headset, user have the ability to teleport accurately within a VR environment.

4.2.12 Packaging Project

To prepare an Unreal project for distribution to users, it is necessary to package it correctly. Packaging guarantees that all the code and content are current and in the correct format to run on the intended platform (Unreal Engine, n.d., Packaging Projects). Under the main File menu, there is an option called Package Project, with a submenu. This submenu presents a comprehensive list of all the supported platforms on which developers can package their projects. In the case of packaging the COPERNICUS MUSEUM project, the Windows(64-bit) option was specifically chosen from the submenu. The project was packaged into an .exe file, enabling it to be executed as a standalone application.

4.2.13 Results of Development the Virtual Environment

Figure 36 displays the final version of the COPERNICUS MUSEUM Virtual Geographic Learning Environment. It showcases various exhibits including ESTEC, Falcon 9 rocket, Sentinel-6 satellite, Ocean, Globe, and Venice city. Each geographic exhibit is accompanied by relevant video materials, with each video lasting approximately 1 minute. These exhibits are considered AOIs within the COPERNICUS MUSEUM environment. The exhibits are arranged in a specific order to tell the story of the Sentinel-6 Mission and SLR. When participants enter the VE using a VR Headset,

the story begins with ESTEC on the left side, followed by the Falcon 9 rocket, Sentinel-6 satellite, Ocean, Globe, and Venice city. The corresponding videos for ESTEC provide information about the organization's purpose. The Falcon 9 rocket video showcases the rocket and its launch. The Sentinel-6 satellite video explains the purpose of the satellite and how it aids researchers in measuring global sea level height. The Globe videos present the impact of sea level rise on coastal areas and present relevant statistics. Moreover, the COPERNICUS MUSEUM VE presents Venice city as a case scenario, highlighting its architectural significance and raising awareness about sea level rise in coastal areas.

To enhance immersion, the Falcon 9 rocket exhibit incorporates dynamic features like clouds and fire. The Globe exhibit is rotated to create a more realistic experience. Participants can navigate within the VE using HTC Vive controllers (Figure 35 (a)). The Blueprint for Teleportation is developed in VE. These controllers also enable video playback, allowing participants to initiate videos by pressing the "Click to Play" button (Figure 35 (b)).
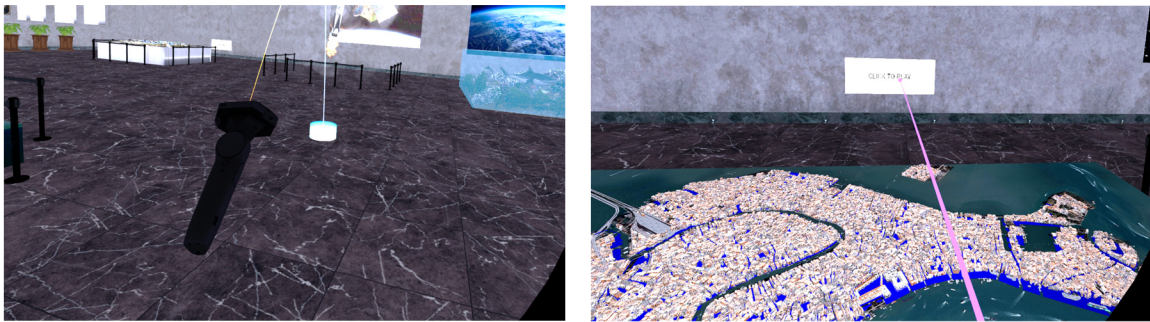
Figure 35 (a) Teleportation; (b) Video Playback Controller

The LogOpenXRUpol_BP Blueprint was integrated to enable the collection of eye-tracking data within the VE. With these advancements and functionalities, the COPERNICUS MUSEUM Virtual Geographic Learning Environment is fully prepared to fulfill the second objective of this study.

Figure 36 Final version of the COPERNICUS MUSEUM Virtual Geographic Learning Environment.

5 EYE-TRACKING ANALYSIS

This chapter documents the methods of analysis eye-tracking data from Virtual Environment. Data and output from this experiment provides general insights about Virual Learning Environment.

5.1 Connection Virtual Environment to Varjo XR-3 headset

This chapter outlines the procedures for linking a Virtual Environment with the Varjo XR-3 headset to obtain eye-tracking data from participants. Blueprint Visual Scripting system was used to ensure the proper functionality of the VE with the Varjo XR-3 headset.

5.1.1 Configuring the Blueprints within the Virtual Environment

The Church project generated a Blueprint called LogOpenXRUpol_BP, which was stored in the Content Browser within the Upol folder. Figure 37 depicts the visual representation of this Blueprint. Essentially, LogOpenXRUpol_BP is responsible for collecting various data related to eye-tracking, including time, gaze direction, AOI and other pertinent data from the Virtual Environment. This data will then be stored in a CSV file.
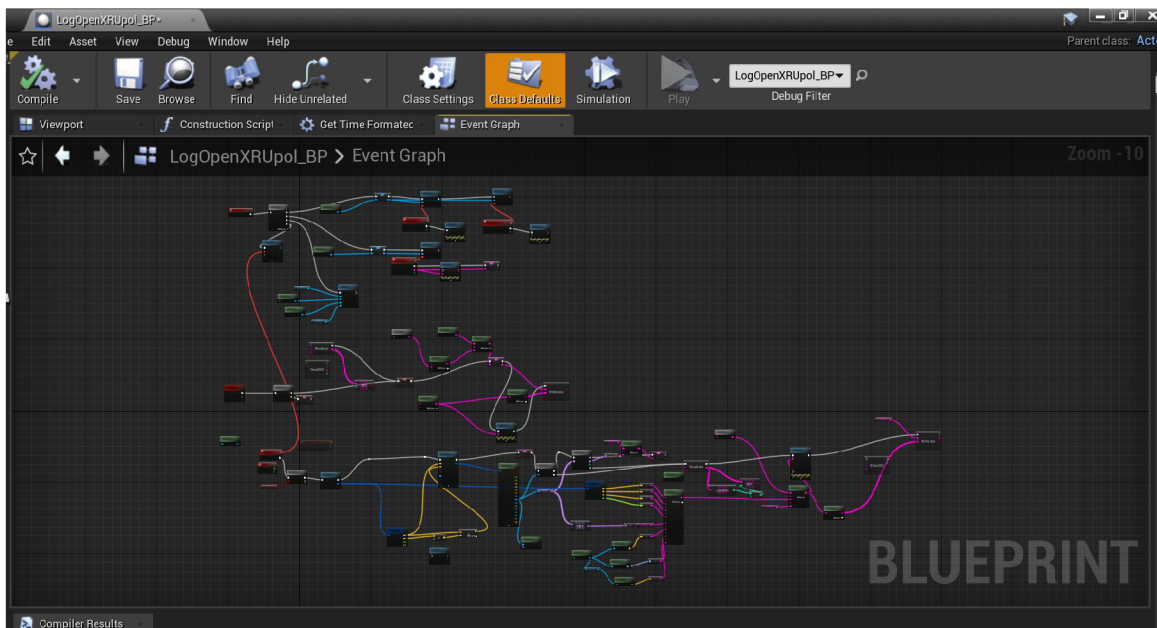
Figure 37 The LogOpenXRUpol_BP Blueprint Interface.

To make use of this blueprint, the LogOpenXRUpol_BP was dragged and dropped into the Virtual Environment. Subsequently, the blueprint should be opened, compiled, and saved in order to ensure its proper functioning.

Within the settings of UE, under the Plugins category, the OpenXR, OpenXREyeTracker, and Varjo OpenXR plugins were enabled. OpenXR[26] is a freely

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[26] https://www.khronos.org/openxr/

available and open standard that offers efficient access to XR platforms and devices. In Unreal Engine, the OpenXR plugin allows the incorporation of additional features to OpenXR independently, without having to wait for engine updates. The engine release already includes OpenXR extension plugins (Unreal Engine, n.d., OpenXR). Varjo headsets fully support OpenXR. The Varjo OpenXR runtime provides complete support for the XR_EXT_eye_gaze_interaction extension (VARJO, n.d., OpenXR).

5.1.2 Trigger Actors

Triggers are actors in a level that initiate an event when interacted with by another object. In simpler terms, they are employed to activate events in response to specific actions within the level. The default Triggers typically share similarities, with the only distinction being the shape of their detection area (box, capsule, or sphere) used to identify if another object has triggered them (Unreal Engine, n.d., Trigger Actors).

The Box Trigger component was selected from the Basic section in the Place Actor menu and then placed into each AOI by dragging and dropping. The boxes were subsequently resized to match the dimensions of the respective AOIs. In Figure 38, the rectangular shape outlined by a green line represents the Box Trigger. In the Actor section of the details for this particular AOI, shown in Figure 37, a tag was included and named "Satellite Sentinel-6." This assigned name will appear as the actor's label in the corresponding column for the AOI in the CSV file.
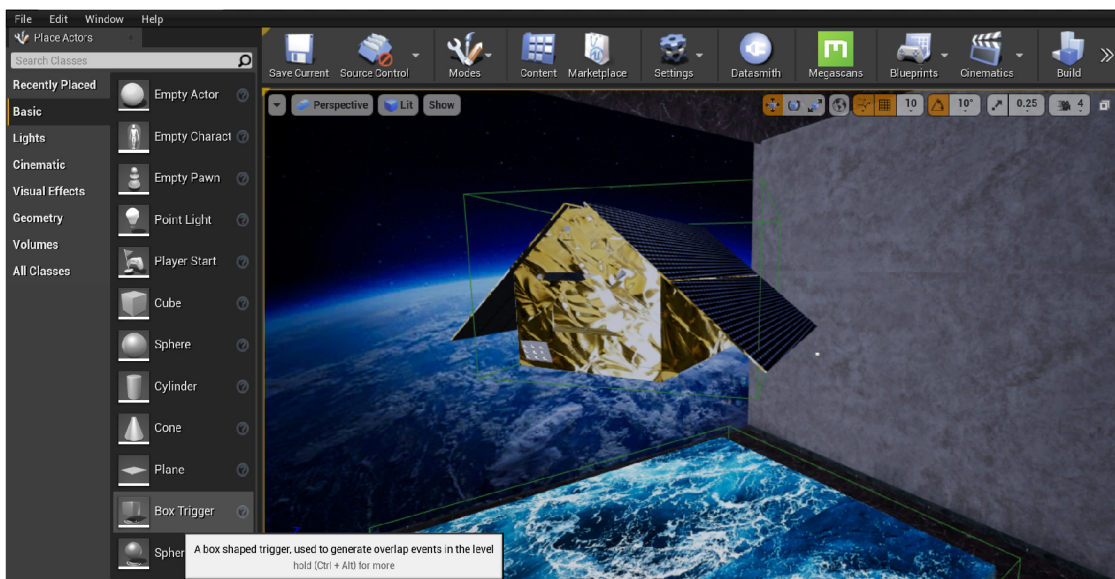
Figure 38 Placing a Box Trigger into the Area of Interest (AOI).

5.1.3 Modifying the Project Settings

In the Maps & Modes section of the Project Settings, suitable blueprints were chosen in the Default Modes. For example, the VRGameMode blueprint, specifically created for this project mode was selected as the Default GameMode. Moving on to the map mode, the Editor Startup Map is the map that will open in the project whenever the user opens it. Additionally, the Game Default Map refers to the VR Scene that opens in the VR Headset. COPERNICUS VR Scene Map was selected for Default Maps. Figure 39 provides a visual representation of these steps.
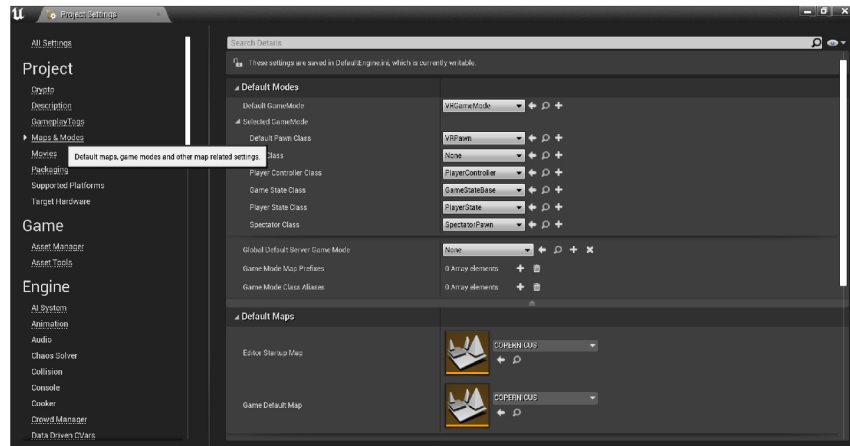
Figure 39 Maps & Modes section of the Project Settings.

In this COPERNICUS MUSEUM, all the project settings for the VR environment were adjusted to match the settings of the Church project. It was crucial to configure the settings to mirror those of the Church project, as it ensures proper functionality of the VR environment with the Varjo XR-3 headset. The VR environment was fully equipped to acquire eye-tracking data.

5.2 Experiment design

At the outset of the experiment, the participants were warmly welcomed and their comfort was prioritized. They were given information that the purpose of the study was to explore the level of attention and interest in a virtual museum setting, rather than assessing their personal abilities.

The participants received an explanation regarding the content presented within the virtual museum environment. The objectives of Sentinel-6 and the significance of promoting awareness about sea level rise were introduced.

The participants were given a detailed demonstration on correctly wearing the Varjo XR-3 headset to ensure a comfortable experience. They were then provided with an explanation of the Navigation in the Virtual Museum Environment, which involved using HTC Vive controllers. The process of activating video play was also clarified. To ensure that participants felt at ease during the actual experiment, they were given approximately five minutes each to familiarize themselves and practice using the controllers in the Virtual Environment.

The procedure was initiated by conducting a calibration to ensure the accuracy of data capture. Once the calibration was successfully completed, participants were given the opportunity to explore the Virtual Museum Environment at their own pace. Additionally, video recordings of the eye-tracking experiment were taken to record.

Participants were informed that they could express their desire to conclude the experiment at any point. Upon finishing the experiment, a one-on-one interview was conducted with each participant to gather their impressions and reflections on their experience in the Virtual Museum Environment.

At the conclusion of the interview, a final message of gratitude and farewell was conveyed to the participants, officially marking the end of the experiment.

5.3 Experimental Setup

Following the preparation of the COPERNICUS MUSEUM VR Environment, the subsequent task involved the collection of eye-tracking data using the Varjo XR-3 Headset at the Faculty of Arts at Palacký University Olomouc, Czechia.

The Varjo XR-3 Headset[27] boasts the highest resolution in the industry, with over 70 pixels per degree (ppd), and offers an exceptionally wide field of view of 115°. It also features the broadest color gamut ever achieved, with a 99% match to the sRGB (Red Green Blue (colour model)) color space and 93% match to the DCI-P3 color space, resulting in the most lifelike and realistic scenes ever produced. To enhance depth perception, it utilizes LiDAR (Light Detection and Ranging) technology, enabling precise real-time occlusion and 3D world reconstruction at the pixel level. Moreover, the headset integrates Ultraleap hand tracking and 200 Hz eye tracking, allowing for natural and intuitive interactions with the virtual environment (VARJO, n.d., Introducing Varjo XR-3, the only true mixed reality headset).

Varjo Lab Tools software was utilized for masking purposes, while the eye-tracking data from the virtual environment was gathered using the Varjo Base software. The laboratory computer has already acquired and installed the software. Figure 40 shows the laboratory's workspace.
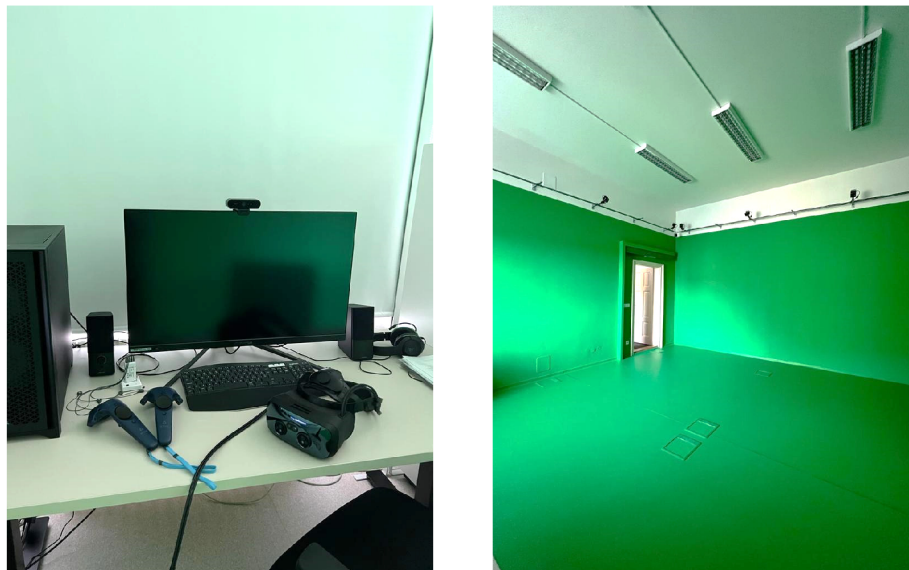
Figure 40 Left: laboratory equipments; Right: Masked area at the laboratory.

Lab Tools provides two modes: one for user's editing setup and another for utilizing it. Users have the freedom to switch between these modes at any time by pressing the dedicated mode buttons (VARJO, n.d., Varjo Lab Tools). When conducting testing of the final version of the COPERNICUS MUSEUM VR Environment using a VR headset, an issue occurred with the semitransparency. Essentially, the virtual environment was not being displayed correctly within the VR headset, as the user could see the physical walls of the laboratory and the surrounding workspace instead of the intended virtual environment. To resolve this issue and ensure a complete visual immersion, adjustments were made to the Edit Mode in Lab Tools software (Figure 41).

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[27] https://varjo.com/products/xr-3/
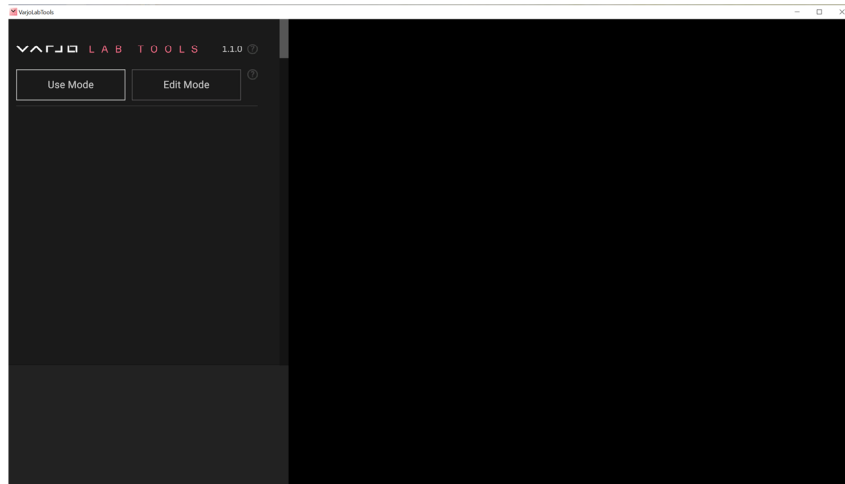
Figure 41 Interface of Lab Tools.

Varjo Base functions as the software that regulates the VR headset (VARJO, n.d., Using Varjo Base). The visual representation of the software interface is depicted in Figure 42. Following the correct placement of the VR headset, participants performed eye-tracking calibration within Varjo Base. By selecting the "Calibrate eye-tracking" button in the software, participants tracked a moving dot with their eyes to complete the calibration process.
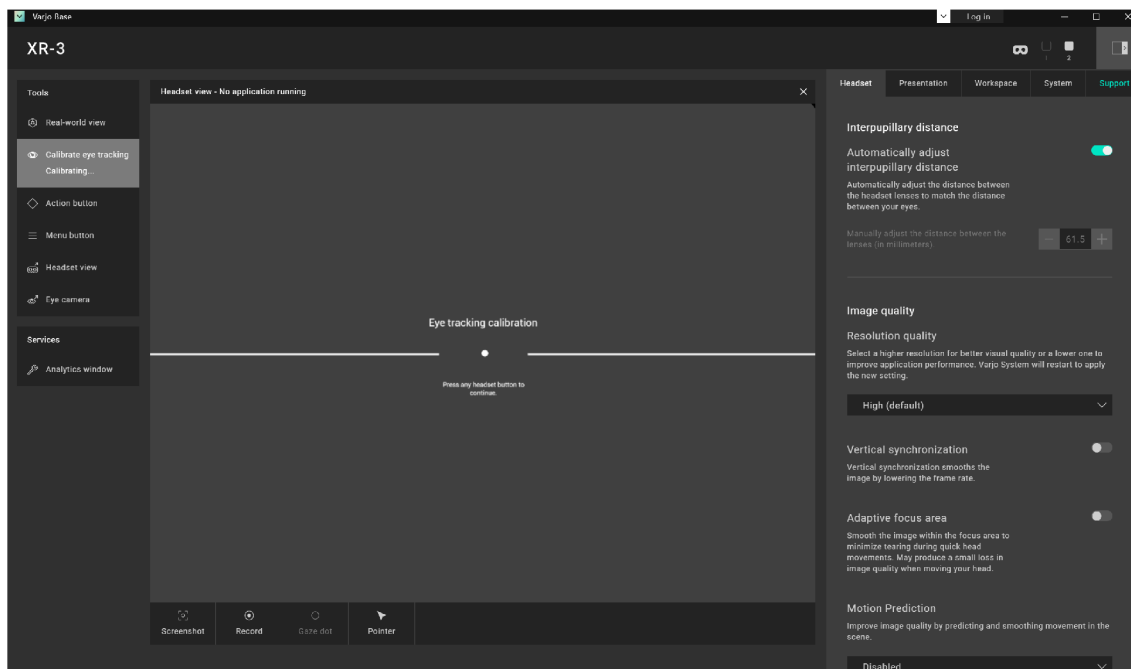
Figure 42 Interface of Varjo Base.

The tools located beneath the Headset View in Figure 42 are designed for users to record their observations and provide guidance to the viewer as necessary. Table 2 provides detailed information regarding the tools available in the Headset View (VARJO, n.d., Using Varjo Base).

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Table 2 Hosting a session in Varjo Base

Tools	Functionalities
Screenshot	Captures a screenshot of the Headset view. The image file is saved in the Pictures -> Varjo folder on user's Windows computer.
Record	Records video of the headset view. The video file is saved in the Videos -> Varjo folder on user's Windows computer.
Gaze dot	Visualizes the eye tracking feature to see where the viewer is looking. This feature is only accessible if eye tracking is calibrated.
Pointer	Turns user's mouse cursor into a VR pointer that is visible inside the headset.

By clicking the "Record" button within the Varjo Base interface, a video recording of the eye-tracking data was captured.

5.4 Participants

Between 8th and 18th of May (2023), an eye-tracking experiment was conducted with 20 participants. The experiment included participants with diverse backgrounds and varying ages (Table 3). Out of these participants, 30% had a GIS background. In a distinct manner, the wide range of participant ages necessitated careful consideration of how age would impact the experimental findings.

Table 3 Participant Demographics

Demographic Characteristics	Parameters	No. of Participants (%)
Total no. of Participants		20 (100%)
Gender	Male	8 (40%)
	Female	12 (60%)
Age	18-28	10 (50%)
	29-59	10 (50%)
Previous VR Experience	Yes	11
	No	9

5.5 Data analysis

5.5.1 Eye Movement Metrics

A total of 11 AOIs were identified and grouped into two categories: geographic exhibits (e.g., ESTEC, Falcon 9 Rocket, Sentinel-6 Satellite, Ocean, Globe, Venice city) and supplementary videos related to these exhibits (e.g., videos about ESTEC, Falcon 9 Rocket, Sentinel-6 Satellite, Globe, and Venice city).

The primary focus of this study was to investigate the visual attention of participants toward AOIs using eye-tracking metrics. Specifically, the analysis focused on key performance indicators of eye-movement, including Total Dwell Time (TDT) and the Visual Intake (VI). According to Albert et al. (2022), "The dwell time is the total amount of time spent looking within an AOI. This includes all fixations and saccades within the AOI, including revisits. Dwell time is an excellent metric that conveys the

level of interest with a certain AOI. Obviously, the greater the dwell time, the greater the level of interest in the AOI". AOI are regions marked on stimuli, which determine how they captured the participant's attention, the number of fixations recorded in specific AOI, the order in which the areas were visited, and so on (Popelka, 2018).

5.5.2 Methods of Analysis

The Varjo dataset comprises a multitude of recorded matrices, but specific recordings necessary for the analysis were chosen based on their relevance. Figure 43 illustrates an instance of eye-tracking data recorded in a CSV file. Python[28] was selected to analyze the overall duration of participants' gaze within specific AOI through importing CSV file. This decision was made relying on prior academic knowledge regarding the utilization of Python. The code associated with this analysis has been saved in this repository: https://github.com/Guldariya-Kurbonova/AOI_Python.

The pandas library of Python was employed to analyze the visual intake. In this study, visual intake specifically refers to the sequence of AOI in a row of CSV file. The code's fundamental task involves calculating the subsequent order in which these observations occur. This analysis was conducted on the Kaggle[29] platform, which serves as an online community and data science competition platform hosted by Google LLC[30]. The code executes a series of tasks including importing necessary libraries, reading and loading a CSV file into a pandas DataFrame, cleaning column names, iterating through rows, comparing values in the "Actor Label" column, storing outcomes, printing the summary DataFrame, and saving it as a new CSV file. The code corresponding to this analysis has been saved in this repository: https://github.com/Guldariya-Kurbonova/Visual_Intake/tree/main.

Figure 43 A fraction of the eye-tracking data derived from the Varjo XR-3.

IBM SPSS Statistics[31] was employed to conduct statistical analyses for further examination. The approach used in the study by Kim & Lee (2021) was adopted for the SPSS analyses process. The t-test was employed to determine if there were noteworthy variations in gender and age.

After the completion of the eye-tracking experiment, the interview was conducted to uncover further insights regarding the virtual museum experience. The participants were presented with a range of inquiries aimed at gathering comprehensive feedback. Specifically, they were queried about the elements of the VR museum environment that stood out to them as particularly realistic or immersive. There were questions to evaluate the overall learning experience. Feedback on participant satisfaction was also sought, with specific prompts such as whether they felt the VR museum experience was worth their time. The interview questions are available in Attachment 1, where Table 4 presents a distinct set of questions that were asked.

5.6 Results

5.6.1 Visual Attention

Total Dwell Time per AOI

Analyzing the total TDT, the general observation indicates that the preferences of the majority of participants varied significantly, making it challenging to identify clear patterns from the graph presented in Figure 44. However, it is worth mentioning that the duration spent on videos exceeded the time dedicated to exploring the exhibits. This is substantiated by concrete evidence, as participants P08, P11, P14, P18, and P20 allocated a greater amount of time to watching videos in the COPERNICUS MUSEUM VLE.
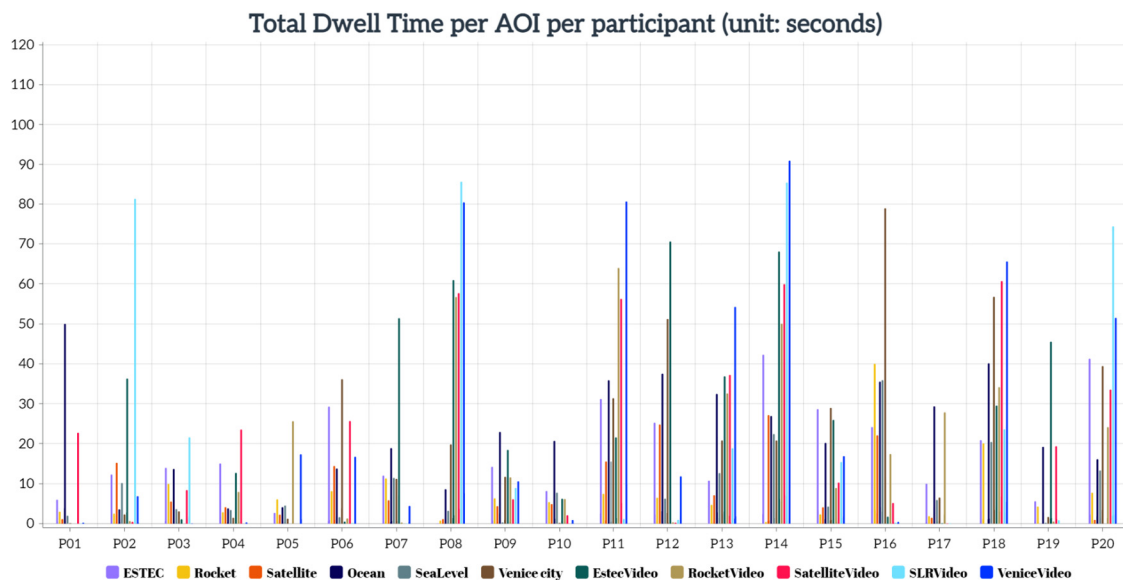
Figure 44 TDT per AOI per participant.

Distribution of Visual Attention for AOIs

Greater TDT and TFC indicative a higher visual attention (Kim & Lee, 2021). Table 5 displays the means and standard deviations (SD) for the total dwell time per AOI in seconds. Based on the statistical data, VeniceVideo had the highest mean value (M = 25.50; SD = 31.89), while Rocket had the lowest mean value (M = 7.59; SD = 8.83). The mean values for the remaining AOIs varied from 8.12 (Satellite) to 24.39 (EstecVideo). Figure 45 displays the mean TDT values per AOI across all participants.

Table 5 Means and standard deviations for total dwell time per AOI (seconds)

AOI	Mean	Standard Deviation
ESTEC	17.69	12.17
Rocket	7.59	8.83
Satellite	8.12	8.61
Ocean	22.68	13.11
Earth	9.26	8.96
Venice city	21.20	22.20
EstecVideo	24.39	24.48
RocketVideo	18.52	20.29
SatelliteVideo	21.47	22.24
SeaLevelRiseVideo	20.94	32.22
VeniceVideo	25.50	31.89
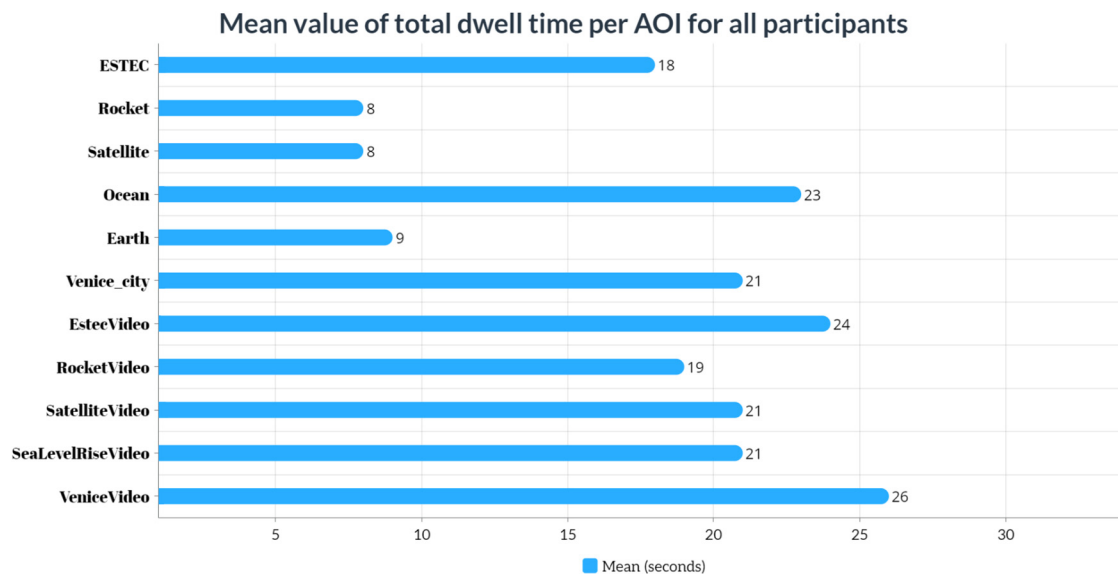
Figure 45 Mean value of total dwell time per AOI for all participants.

For all participants, the visual intake was assessed per AOI. The AOIs exhibited the highest mean value of VI for the Ocean (M = 11.60; SD = 4.46), while the SeaLevelRiseVideo AOI recorded the lowest mean value (M = 3.30, SD = 2.99). Among the other AOIs, the mean values varied from 11.00 (Rocket) to 4.20 (VeniceVideo). Table 6 provides the mean and SD values for VI per AOI for all participants, presented in number units. Additionally, Figure 46 presents the mean VI value per AOI for all participants.

Table 6 Means and SDs for visual intake per AOI for all participants (numbers)

AOI	n	Mean	Standard Deviation
ESTEC	142	6.35	4.41
Rocket	220	11.00	6.59
Satellite	147	7.35	4.80
Ocean	232	11.60	4.46
Earth	122	6.10	2.86
Venice_city	101	5.05	2.81
EstecVideo	96	5.15	3.36
RocketVideo	141	7.60	6.17
SatelliteVideo	98	4.90	3.21
SeaLevelRiseVideo	67	3.30	2.99
VeniceVideo	81	4.20	2.87
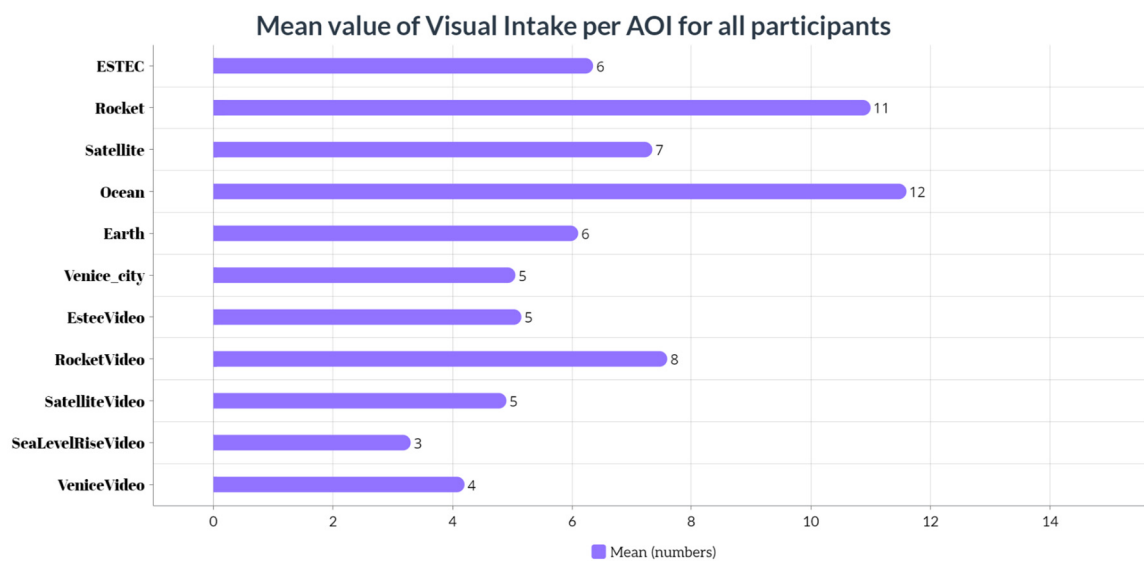
Figure 46 Mean value of VI per AOI for all participants.

Gender Differences in Visual Attention

Based on the mean values, the t-test results comparing gender revealed notable differences in TDT at the ESTEC exhibit (t = 1.538). The mean values for male and female participants were 22.65 and 14.40 seconds, respectively. This suggests that, on average, male participants showed a greater interest in the ESTEC exhibit compared to female participants. Similarly, the t-test results on the VI at ESTEC showed a slight difference (t = 0.841). The mean values for male and female participants were 7.38 and 5.67 seconds, respectively. Thus, the mean interest level of male participants in the ESTEC exhibit was higher than female participants.

Age Differences in Visual Attention

To examine the impact of age differences among 20 participants, they were divided into two groups of 10 each: individuals aged 18-28 and individuals aged 29-59. Figure 47 depicts that the participants in the 29-59 age category had a higher mean value of TDT for VeniceVideo compared to the 18-28 age category, with mean values of 33.92 and 17.09, respectively. Conversely, the 18-28 age category exhibited a higher mean value of TDT for Venice city compared to the 29-59 age category, with mean values of

26.86 and 15.54, respectively. Even though the 18-28 age category showed slightly higher mean values of TDT for ESTEC, Rocket, and Earth, the mean values of TDT presented in the graph indicate that the 29-59 age category had a higher mean value overall. Specifically, videos highlighting exhibits in the Virtual Museum had a higher mean value within the 29-59 age category. In contrast, the 18-28 age category showed a higher mean value for dynamic exhibits such as Rocket and Earth.
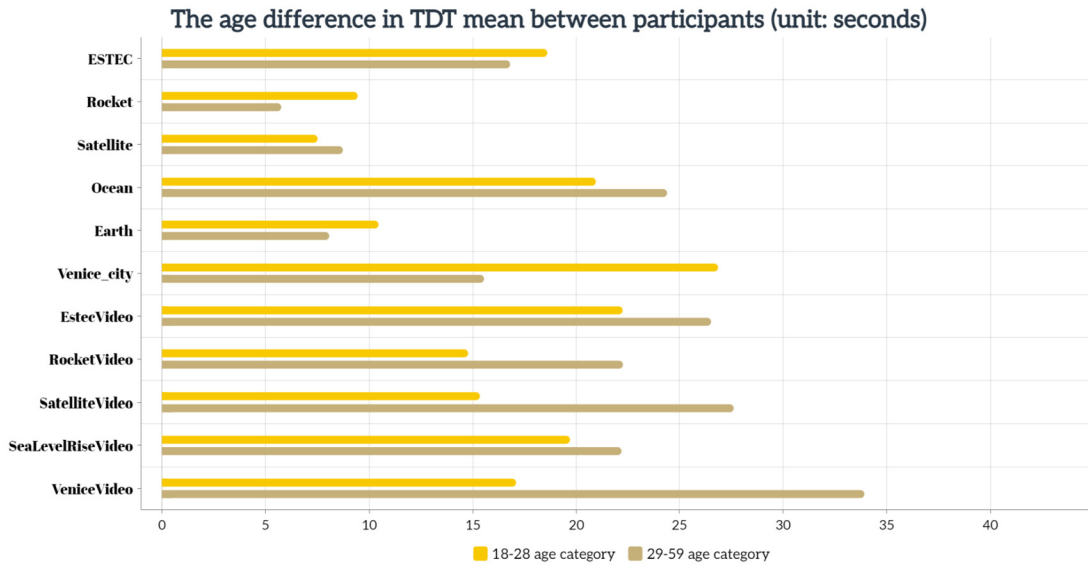
Figure 47 The age difference in TDT between participants.

Visual Intake per AOI

The data in Figure 48 reveals that the Ocean exhibit received the highest number of VI, indicating that it attracted the greatest amount of attention from participants. The exhibits of Rocket and Satellite also received significant attention, indicating that participants found them equally interesting and attractive to explore. This suggests that participants found the Ocean, Rocket, and Satellite exhibits particularly intriguing and appealing to visit.
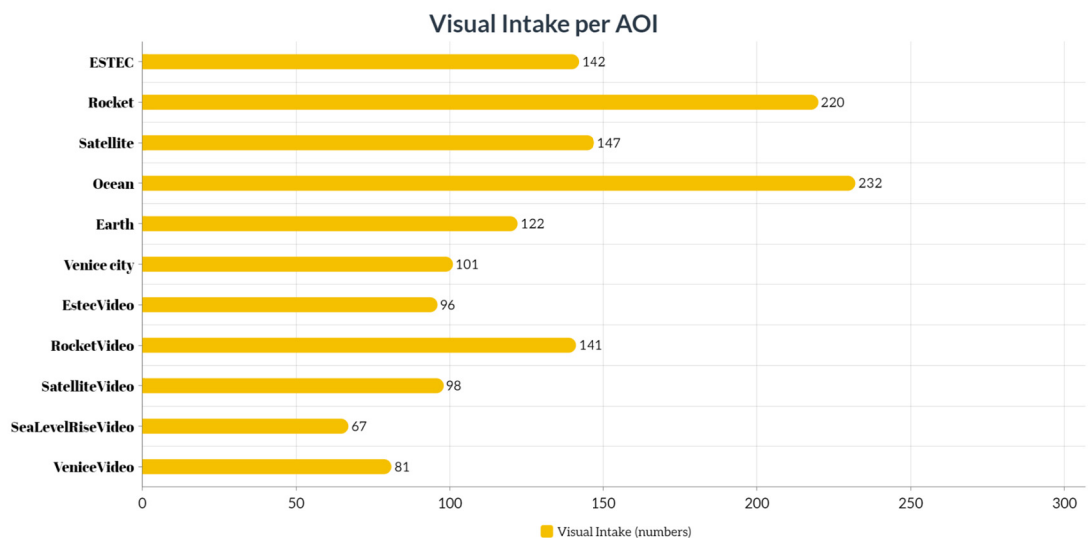
Figure 48 Visual Intake per AOI.

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Initial Gaze Scatter and Exhibit Order

When participants entered the environment, their first gaze dispersion was observed as depicted in Figure 49. Out of the participants, 7 looked on the Ocean while 5 looked on ESTEC initially. The exhibits within the COPERNICUS MUSEUM were carefully arranged in a particular order, as depicted by the arrows in Figure 50. The exhibits followed a specific sequence: ESTEC, Falcon 9 rocket, Sentinel-6 satellite, Ocean, Globe, and Venice city.
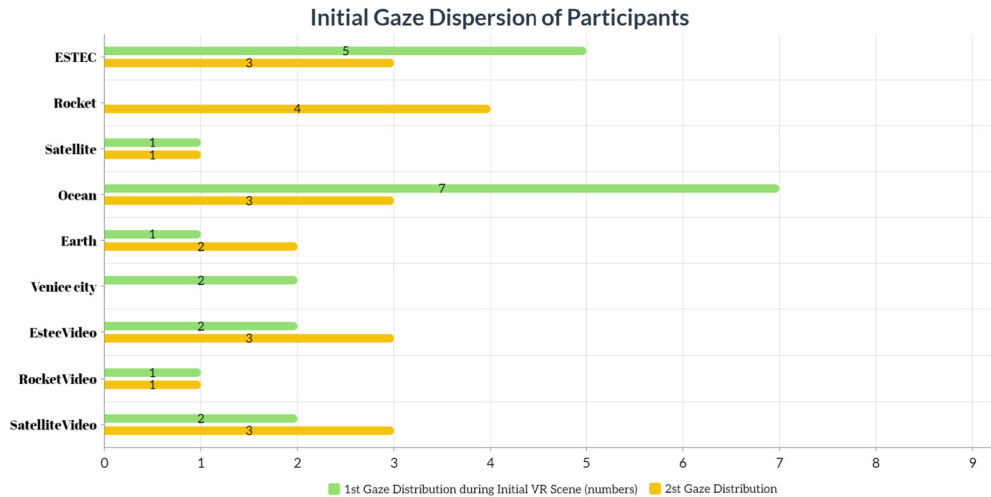
Figure 49 Initial Gaze Dispersion of Participants.

The participants were expected to begin their exploration from ESTEC and proceed to the Rocket and subsequent exhibits in order to grasp the logical sequence of the displays. However, Figure 49 clearly showed that only 5 out of the 20 participants started from ESTEC. This finding served as evidence that participants were provided with subtle hints or guidance regarding the direction to take during the immersive VR Museum experience.
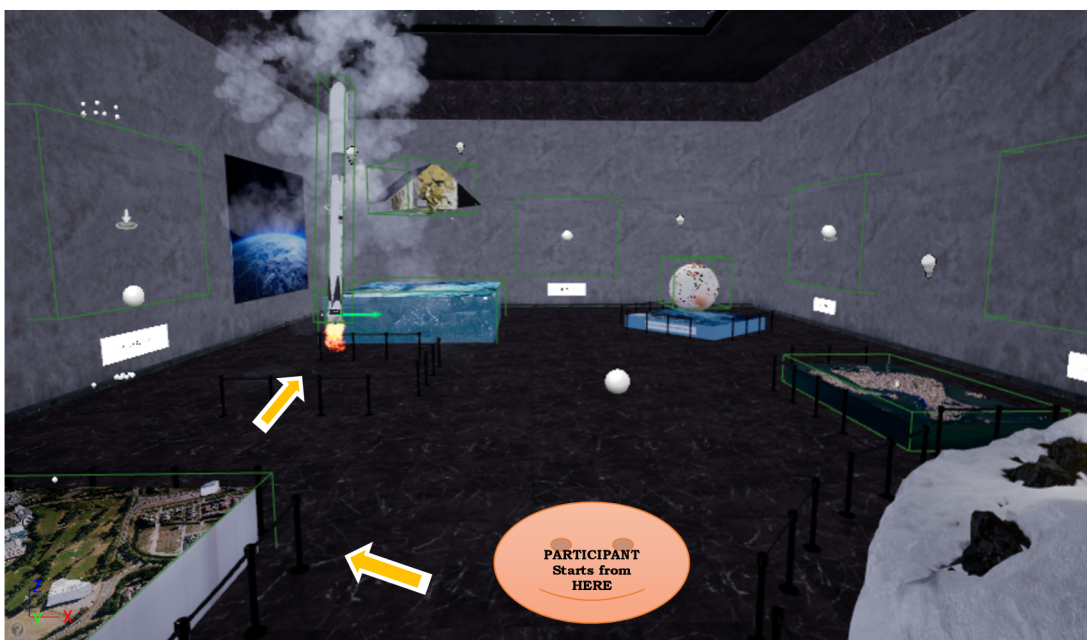
Figure 50 Specific Sequence of Geographic Exhibits.

5.6.2 Interview

Participants were prompted to express their personal thoughts and perceptions of the COPERNICUS MUSEUM environment they encountered during the experiment. This allowed to gain a deeper understanding of participants' perspectives and gather valuable feedback regarding their impressions of the virtual environment.

During the conducted interview, a set of 14 questions were administered to participants with the aim of eliciting their impressions and overall perceptions. Out of the 20 participants, 11 mentioned having prior experience with virtual reality, while for 9 participants, it was their first encounter. However, despite the 11 participants claiming prior VR experience, they clarified that it was not as professional users in their daily lives.

The second question asked whether participants felt that the VR Museum could replicate the experience of a real-life museum. The responses encompassed a range of viewpoints, with some participants expressing an affirmative stance, while others held a contrasting perspective. Those who affirmed the VR Museum's capacity to resemble a physical museum emphasized a sense of immersion within a well-crafted virtual environment that, while distinct from a traditional museum, facilitated a profound level of engagement. Conversely, the dissenting respondents argued that the technology at hand failed to fully capture the profound impression and tangible ambiance characteristic of a physical museum.

Regarding Question 3, all participants provided responses indicating that they experienced full immersion during the VR museum experience. Question 4 aimed to ascertain which exhibits within the museum captured the participants' attention. Figure 51 visually represents the data, demonstrating that participants were particularly drawn to the exhibit featuring a rocket model. Additionally, the models depicting marine life (Ocean) and the city of Venice garnered significant attention and interest from the participants.

Figure 51 Subjective insights on which exhibits within the VE were stood out.

Question 5 aimed to explore participants' perceptions of the VR museum in comparison to a traditional physical museum experience. Participants highlighted

several advantages of the VR museum over its physical counterpart, such as the ability to transport them back in time, the accessibility of various locations, and other benefits. Notable responses included the following perspectives:

- "VR is the future and a good investment."
- "The VR museum is new."
- "VR is good in terms of bringing scenes that do not exist."
- "The advantages of VR include bringing information on different topics into one place. For example, I was able to explore Arctic and Venice city models, and I felt like they were right in front of me, allowing me to thoroughly explore them."
- "The purposes of VR and physical museums are different."
- "The VR environment is not crowded."
- "VR is more interactive than the physical museum experience."

All participants provided consistent responses to Question 6, expressing that the VR museum environment was highly interactive and engaging.

Regarding Question 9, which aimed to evaluate the informativeness of the VR museum environment, participants indicated that they were able to acquire new knowledge from the immersive experience.

Noteworthy responses emerged in relation to Question 10, where participants highlighted initial difficulties with navigating the controllers during the first 3-4 minutes. However, they acknowledged that with time and practice, they became more proficient in operating the controllers.

Question 11 generated intriguing insights. Participants expressed sentiments such as, "Yes, definitely. It was intriguing to witness the advancements in technology and explore the possibilities it offers," and "The information presented within the VR environment was highly interesting." Additionally, participants acknowledged the environmental benefits of VR experiences, noting that it eliminates the need to travel between cities to visit various museums.

Question 12 aimed to gather participants' expectations before the experiment. Their responses indicated: "It was my first time trying VR, so I had limited knowledge about what to expect besides the headset and controllers. However, it turned out to be a fantastic experience. I was pleasantly surprised by how real the exhibits felt, and the overall atmosphere was futuristic."

Moving on to Question 13, participants were asked to provide suggestions, and their responses encompassed the following points:

1. "It would be beneficial to reduce the size of the videos, as they appeared too large in the environment. Adjusting their size would enhance the viewing experience."
2. "Consider providing clearer hints or indications to guide participants on where to start and the recommended sequence to follow throughout the exhibits. This would ensure a more structured and intuitive exploration."

In the final question, Question 14, participants were asked to rate the level of realism and immersion they experienced in the COPERNICUS MUSEUM environment. Using a rating scale from 1 to 5, with 5 being the highest rating, the participants' average rating was 3.7. This indicates that participants generally found the COPERNICUS MUSEUM environment to be immersive and realistic, with a high level of engagement and authenticity.

5.6.3 Insights from Eye-Tracking Experiment

Visual Attention

The eye-tracking analysis provided valuable insights into participants' visual attention patterns within the virtual reality environment. The data revealed that certain areas of interest attracted more attention than others. For example, the VeniceVideo exhibit had the highest TDT, indicating that participants spent more time focusing on this particular area. Similarly, the EstecVideo exhibit also captured a high amount of visual attention. On the other hand, the Rocket exhibit had the lowest TDT, suggesting that it attracted less attention from participants. One possible explanation for this observation could be the duration of the videos, as each of them had a duration more than one minute. This could be influenced by factors such as the video's content and the exhibition's location. These findings indicate that the content and presentation of different exhibits play a crucial role in directing users' visual attention.

Variability in Visual Attention

While the mean TDT values provide an overall understanding of participants' visual attention, it's important to note the variability in attention across different AOIs. The standard deviations associated with the TDT values indicate that participants' attention was not uniformly distributed. Some participants may have shown more interest in specific AOIs compared to others. This variability can be influenced by factors such as personal preferences, individual experiences, and the novelty of the exhibits.

Visual Intake and Visual Attention

Analyzing the VI offers further insights into participants' visual attention. The exhibit that received the highest mean VI was Ocean, indicating that it attracted the most attention from participants. Conversely, the SeaLevelRiseVideo exhibit had the lowest mean VI. These findings highlight the varying levels of engagement participants had with different exhibits. Factors such as the relevance, complexity, and visual appeal of the exhibits may have influenced the overall visual attention.

Gender Differences in Visual Attention

Gender differences were observed in participants' visual attention patterns. Male participants showed a higher mean TDT and VI at the ESTEC exhibit compared to female participants, indicating that they exhibited greater interest and attention towards this particular exhibit. These gender differences suggest that personal preferences and interests can influence visual attention and engagement with specific exhibits within the VR environment.

Age Differences in Visual Attention

Age-related differences were also observed in participants' visual attention. Participants aged 29-59 had a higher mean TDT for the VeniceVideo exhibit compared to participants aged 18-28. Conversely, participants aged 18-28 showed a higher mean TDT for the Venice city exhibit. The age category of 29-59 generally had higher mean TDT values across AOIs, particularly for videos highlighting exhibits in the Virtual Museum. In contrast, participants aged 18-28 showed higher mean TDT values for dynamic exhibits like Rocket and Earth. These age-related differences suggest that different age groups may have distinct preferences and interests when exploring virtual exhibits.

Initial Gaze Dispersion and Exhibit Order

Analyzing the initial gaze distribution provides insights into participants' first points of focus within the VR environment. The data revealed that participants' first gaze scatter were predominantly on the Ocean exhibit, followed by ESTEC. However, the intended exhibit order within the COPERNICUS MUSEUM was different, with ESTEC as the starting point. This deviation from the intended order suggests that participants may have been influenced by subtle hints or cues, leading them to different exhibits initially. These hints may have influenced participants' exploration patterns and initial visual attention.

Interviews

In addition to the eye-tracking data, participants' interviews provided further insights into their perceptions and experiences of the VR Museum environment. Overall, participants acknowledged a sense of immersion and engagement during the VR experience. They expressed particular interest in exhibits featuring rocket, marine life, and the city of Venice. Participants also provided suggestions for improving the VR Museum experience, such as adjusting video sizes for better viewing and providing clearer guidance for navigating through the exhibits.

Realism and Immersion

Participants rated the COPERNICUS MUSEUM environment with an average score of 3.7 out of 5 for realism and immersion. This indicates that participants generally found the VR environment to be immersive, realistic, and engaging.

Overall, these insights reveal valuable information about participants' visual attention, gender and age differences, preferences for specific exhibits, initial gaze distribution, and their perceptions of the VR Museum experience. These findings contribute to our understanding of eye-tracking in VR and can inform further research and improvements in designing immersive virtual experiences.

6 RESULTS

This chapter presents a concise summary of Chapter 4, which primarily focused on the development of the COPERNICUS MUSEUM environment, and Chapter 5, which aimed to analyze the eye-tracking data gathered in the Virtual Geographic Environment.

6.1 Development of Virtual Geographic Learning Environment

A comprehensive tutorial was provided, presenting a step-by-step approach to creating the COPERNICUS MUSEUM environment. The tutorial covered various elements, including Widget Interaction, Managing User Input, Navigating within the environment, and Creating Dynamic Actors. Detailed descriptions were given on the development of geographic exhibits using 3D modeling software programs such as Blender and SketchUp. The results demonstrate the successful implementation of the outlined procedures and guidelines for building the desired virtual geographic learning environment. By utilizing Blender and its BlenderGIS add-on, 3D terrain models of specific locations, such as ESTEC, were generated. SketchUp Pro proved to be a valuable tool for creating detailed 3D models of the Falcon 9 Rocket and the Copernicus Sentinel-6 satellite. CityEngine was utilized to import and represent the three-dimensional depiction of Venice city, Italy.

Furthermore, the Unreal Engine software was installed following a step-by-step process, enabling the development of the virtual geographic learning environment. Assets were acquired from the Unreal Engine Marketplace and seamlessly integrated into the project, including the Bank Building/Interior collection developed by Leartes Studios. The manipulation of actors and the precise placement of geographic exhibits within the virtual museum setting were achieved successfully.

Moreover, dynamic elements were introduced using the Niagara System in Unreal Engine, allowing the generation of realistic clouds and fire within the virtual environment. The rotation of actors, animation of UV coordinates, and application of textures further enhanced the immersive experience of the virtual geographic learning environment.

According to the outcomes of the subjective evaluation methods, changes were implemented to the videos in the virtual environment. Notably, the size of the videos were reduced, and additional improvements were made. These improvements involved the inclusion of more explicit cues, such as conspicuous arrows, which effectively guide participants on where to initiate their journey and the recommended order to follow throughout the exhibits.

Overall, the results of this tutorial highlight the successful development of the COPERNICUS MUSEUM environment, providing a valuable resource for virtual geographic learning. The step-by-step approach, integration of 3D models, acquisition of assets, manipulation of actors, and implementation of dynamic elements all contribute to the creation of an engaging and interactive learning environment.

6.2 Eye-tracking analysis

The analysis of eye-tracking data conducted in the Virtual Geographic Environment focused on examining participants' visual attention and engagement. The experiment utilized the Varjo XR-3 headset, known for its high resolution and advanced features such as eye-tracking, to capture participants' eye movements while exploring the virtual environment.

The experiment involved 20 participants with diverse backgrounds and ages. Prior to the experiment, participants were given explanations about the virtual museum content and the objectives of the study. They were also provided with instructions on how to wear the Varjo XR-3 headset and use the HTC Vive controllers for navigation within the Virtual Environment.

Calibration was performed to ensure the accuracy of the eye-tracking data captured by the Varjo XR-3 headset. Once calibration was successfully completed, participants were given the freedom to explore the Virtual Geographic Museum Environment at their own pace. Eye-tracking data was recorded during the participants' interactions with the Virtual Environment.

Data analysis was conducted using Python programming language and SPSS software. The analysis focused on determining the participants' visual attention and interest in different AOIs within the Virtual Environment. The duration of gaze within specific AOIs was calculated using the recorded eye-tracking data.

Furthermore, one-on-one interviews were conducted with each participant after the experiment to gather their impressions and reflections on their experience in the Virtual Museum Environment.

The results of eye-tracking data analysis examining visual attention in the virtual museum environment uncovered a number of important findings. The distribution of visual attention for different AOIs was assessed using TDT and VI as measures. The analysis revealed that AOIs with higher TDT and VI values received more visual attention from participants. Specifically, the AOI "VeniceVideo" had the highest mean TDT. In contrast, the AOI "Rocket" had the lowest mean TDT. The mean VI values also varied across AOIs, with the "Ocean" exhibit receiving the highest attention and the "SeaLevelRiseVideo" exhibit receiving the lowest attention.

Gender differences in visual attention were observed, indicating that male participants showed a greater interest in the ESTEC exhibit compared to female participants. This was reflected in both TDT and VI, where males had higher mean values at ESTEC compared to females.

Age differences were also found to influence visual attention. Participants aged 29-59 showed higher TDT for the "VeniceVideo," exhibit while participants aged 18-28 exhibited higher TDT for the "Venice city" exhibit. The overall trend indicated that participants in the older age group had higher mean TDT values, particularly for videos in the Virtual Museum. On the other hand, participants in the younger age group showed higher mean TDT values for dynamic exhibits such as "Rocket" and "Earth."

Analyzing the visual intake per AOI, it was observed that the AOI "Ocean" received the highest number of revisits, indicating that it attracted the most attention from participants.

Furthermore, participants' perceptions of the virtual museum environment were explored through interviews. Participants highlighted several advantages of the VR museum over its physical counterpart, such as the ability to transport them to different locations and the convenience of accessing various exhibits within a single space. They also mentioned the interactive nature of the VR environment as a positive aspect.

Overall, participants rated the COPERNICUS MUSEUM environment positively in terms of realism and immersion, with an average rating of 3.7 out of 5. This indicates that participants generally found the VR museum experience to be immersive, engaging, and authentic.

7 DISCUSSION

The objective of this study was to develop and design a virtual learning environment utilizing virtual reality technology, specifically focusing on the current trends in geography. The research also aimed to assess user experience using eye-tracking technology within this virtual environment. This study offers two main contributions: (1) insights and recommendations derived from the current experience of employing VR technology to create a virtual learning environment with contextualized content, and (2) a discussion on the methodology and findings of collecting eye-tracking data within the VR environment.

Regarding the first aspect, several suggestions can be provided on the development of a virtual learning environment. VR offers vast potential for presenting and making complex subjects accessible to users. By leveraging current 3D technologies in conjunction with VR, even greater possibilities emerge. Utilizing 3D modeling software programs, the 3D models of exhibits were meticulously modeled and textured. This data was then imported into Unreal Engine 4.27 to create an immersive virtual reality museum visit. The Varjo XR-3 headset played a vital role in bringing this immersive learning reality to life, offering users an unparalleled opportunity to explore and engage with the virtual museum environment. This museum visit allows users to explore the Copernicus museum from the perspective of an actual person, complete with interactive elements. Banfi et al. (2023) highlight that the iconic and acoustic representation status enables the user to perceive and comprehend novel information and processes, where variations, conflicts, and aspirations often emerge and merge. In this context, the senses of sight and hearing assume a prominent role, serving as the key modalities through which the user engages with and comprehends the content. The proposed 3D modeling process sought to achieve an accurate and qualitative representation of the geographical exhibits and their associated information due to this particular reason.

To help users navigate in COPERNICUS MUSEUM environment, a teleportation function is available, bridging long distances within the virtual environment. The majority of the work revolved around programming teleportation within the museum's VR setting. Furthermore, extensive efforts were invested in seamlessly integrating Blueprint functionality, enabling users to effortlessly trigger video playback by clicking. Furthermore, considerable programming expertise was employed to incorporate dynamic elements into the immersive VR environment. When developing a similar VR environment, it is important to consider these aspects.

With respect to the second point, the primary focus of this thesis was to collect eye-tracking data within a developed COPERNICUS MUSEUM virtual learning environment. As a result, a significant portion of the research time was dedicated to connecting the VR environment with the Varjo XR-3 headset. The LogOpenXRUpol_BP Blueprint was obtained from a separate project called Church and was incorporated to facilitate the collection of eye-tracking data within the virtual environment. To successfully integrate the blueprint into the COPERNICUS MUSEUM environment, it was necessary to remove the assets from the Church project, retaining only the essential blueprint. Despite the removal of assets, the project size remained unchanged, which had implications for subsequent work. For instance, copying or testing the project became time-consuming due to the loading process. However, for other users who desire to integrate the VR environment with the Varjo XR-3 headset, they would

need to create a new Blueprint Visual Scripting System, which necessitates a background in programming.

During the testing phase of the final version of the COPERNICUS MUSEUM VR Environment using a VR headset, a problem arose with the semitransparency feature. Essentially, the virtual environment was not rendering correctly within the VR headset, resulting in the user being able to see the physical walls of the laboratory and the surrounding workspace instead of the intended virtual environment. To address this issue and achieve a fully immersive visual experience, modifications were made to the Edit Mode in the Lab Tools software.

In the virtual learning environment of the COPERNICUS MUSEUM, participants' visual attention varied based on the spatial arrangements and the emphasis on exhibits or media (video) screens. The data showed that certain areas attracted more attention than others. For instance, the VeniceVideo exhibit had the highest TDT value, indicating that participants spent more time focusing on that area. Specifically, participants aged 29-59 showed high attention to the VeniceVideo exhibit and had higher average TDT values across different AOIs, especially for videos showcasing museum exhibits. On the other hand, participants aged 18-28 had higher average TDT values for dynamic exhibits like Rocket and Earth. This difference could be explained by factors such as video duration, content, and exhibit location. These findings highlight the significance of exhibit content and presentation in directing users' visual attention. Furthermore, gender differences were observed in participants' visual attention patterns. Male participants displayed a higher average TDT and Visual Intake at the ESTEC exhibit compared to female participants. This suggests that males exhibited greater interest and attention towards this particular exhibit. These gender differences indicate that personal preferences and interests can influence visual attention and engagement with specific exhibits within the VR environment. The results of this study provide support for the findings of Herman et al. (2017) and Hadnett-Hunter et al. (2019) that highlight the advantages of gaining insights into how the distribution of visual attention varies based on a user's task. This understanding offers distinct opportunities for advancing these techniques and improving the design of virtual environments. The findings of this study provide a foundation for the development of guidelines that can assist developers in enhancing the appeal of virtual learning environments. These guidelines aim to align the environments with the specific needs and interests of users, ultimately improving their overall attractiveness.

Limitations. Despite the promise of using eye-tracking VR headsets for visual attention experiments, they are still far from being able to completely replace specialized eye-trackers (Alghofaili et al., 2019). While examining the data collected from eye-tracking VR headsets, it became necessary to create Python code specifically designed for analyzing this data. It was evident that there was no existing prototype available for analyzing eye-tracking data specifically from VR devices. This indicates a clear requirement for the development of tools that can effectively analyze eye movement data in the context of virtual reality.

The COPERNICUS MUSEUM project was developed using hardware located at the Faculty of Arts in Palacký University Olomouc in Czechia. In order to publish the project on a website, Unreal Engine provides the option to package it as an HTML5 project. However, there is a limitation regarding the project size, as it needs to be compressed to ensure proper functionality when published. Unfortunately, the COPERNICUS MUSEUM project size is 31.6 GB, which is too large to be published on a website. Consequently, others are unable to access the project online. Given the lack of

an optimal method for releasing the project on a website, access to the project is currently restricted to the hardware located in the laboratory.

VR systems, particularly full-immersion ones, demand substantial financial investment for their creation (Alqahtani et al. 2017). The Varjo XR-3 headset utilized in this research is currently available on the market for EUR 6495. Apart from the expenses linked to the necessary hardware, which can be adjusted based on the number of students, there is a need to develop learning activities that effectively incorporate these software tools (Cecotti, 2022).

Future Work. There is opportunity for improvement in the feature set of the VR environment. One area that could be enhanced is the lighting feature, which can be expanded to include factors like light intensity, shading, and reflection. This would effectively account for the visibility of elements within the VR environment.

Education can benefit from the utilization of virtual reality to establish a more integrated learning environment. The immersive nature of VR enables users to establish a deeper personal connection with their virtual surroundings, thereby facilitating a more effective learning process (Al-Gindy et al., 2020). Given educators' growing interest in interactive techniques to facilitate student learning, this research project has a future-oriented goal of introducing additional interactive and dynamic features to the virtual learning environment of the COPERNICUS MUSEUM. The objective is to equip educators with a wider array of interactive tools and dynamic elements that will elevate the learning experience for students.

Another potential direction for future research involves incorporating memorability (Isola et al., 2011) and visual saliency (Jetley et al., 2016) of the content within the visual elements as supplementary attributes in order to improve the ability of our framework to predict visual attention. This approach has the potential to enhance the applicability of our framework.

8 CONCLUSION

This thesis aimed to create a virtual learning environment and perform its user assessment using eye-tracking technology. The objectives were to develop a VLE that incorporates geographic content and analyze users' visual attention, engagement, and overall experience within the VLE.

The primary objective was to develop a VLE that incorporates geographic content, leveraging Copernicus data and addressing contemporary educational needs. Through a comprehensive literature review and careful selection process, the COPERNICUS MUSEUM environment was established, focusing on Sea Level Rise and the Sentinel-6 mission. This contribution outlines the successful development and implementation of a virtual learning environment for the COPERNICUS MUSEUM virtual reality application, specifically designed for the Varjo XR-3 VR system. The project, which occupies a space of 31.6 GB, was designed as a standalone program compatible with Windows operating systems. The 3D representation of the Globe Exhibit within the VLE showcases the visualization of the Global Ocean Sea Surface Temperature trend map, derived from the ESA SST CCI and C3S global SST analyses. The VLE was designed to provide an immersive and interactive platform for geographic education, incorporating realistic 3D visualizations, accurate geographic data, and interactive features. The VLE has provided participants with an engaging and interactive platform to explore geographical concepts, fostering a deeper understanding of Sea Level Rise and the Sentinel-6 mission.

The second objective was to perform user assessment using eye-tracking technology to gain insights from overall experience within the VLE. The eye-tracking analysis provided valuable insights into participants' visual attention patterns within the virtual reality environment. The data revealed variations in attention across different exhibits, suggesting the importance of content and presentation in directing users' visual attention. Gender and age differences were observed, indicating that personal preferences and interests influence visual attention and engagement. The analysis of initial gaze dispersion also highlighted the influence of subtle hints or cues on participants' exploration patterns. The interviews with participants further enriched the understanding of their perceptions and experiences, providing suggestions for improvement.

In conclusion, the development of the COPERNICUS MUSEUM environment, combined with the eye-tracking analysis, offers valuable insights for optimizing the Virtual Learning Environment. This study presents a pioneering approach to integrating geographic content into a VLE and leveraging eye-tracking technology for user assessment. By showcasing the potential of immersive virtual environments and eye-tracking technology, this research not only enhances the learning experience but also provides valuable information on user engagement and attention.

The knowledge gained from this study holds significant implications for the field of geographic education. It can guide future improvements and refinements in VLE design, ensuring that educational platforms effectively incorporate geographic content. Moreover, the findings underscore the importance of utilizing eye-tracking technology to gain deeper insights into user behavior and preferences, enabling educators to create more engaging and interactive learning environments. This study contributes to the ongoing advancement of geographic education and serves as a foundation for the creation of innovative educational platforms.

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ATTACHMENTS

LIST OF ATTACHMENTS

Bound attachments

Attachment 1 Table 4 Questions and Objectives

Free attachments

Attachment 2 Poster

Attachment 3 Website

Attachment 4 Output Project

- Final VR Project (COPERNICUS MUSEUM Virtual Environment) in ZIP file format and Eye-tracking data are stored in the Data storage of eye-tracking laboratory of Department of Geoinformatics, Palacký University Olomouc

Attachment 1

Table 4 Questions and Objectives

No.	Question	Objective
1	Do you have previous experience with VR?	Determination of participant's prior experience
2	Did you feel like you were in a real museum while you were in the VR scene?	Assessment the participant's perception of the VR museum environment resembling a real museum.
3	Did you feel fully immersed in the VR museum environment, or were there moments where you were aware you were in a virtual space?	Determination the level of immersion
4	Were there any specific elements of the VR museum environment that stood out to you as particularly realistic or immersive?	Subjective feedback on specific elements of the VR museum environment
5	How did the VR museum compare to a physical museum experience?	Subjective feedback on comparison
6	Did the VR museum environment feel interactive and engaging, or did it feel static and boring?	Evaluation the participant's perception
7	Were there any technical issues or glitches that impacted your experience in the VR museum?	Detection of collision with technical problems
8	Did you find the navigation and user interface intuitive and easy to use?	Assessment of the participant's perception of UI and navigation
9	Did you feel like you were able to learn and engage with the exhibits in the VR museum environment?	Evaluation overall learning experience
10	Were there any aspects of the VR museum environment that you found distracting or detracted from the experience?	Subjective feedback on distractions
11	Did you feel like the VR museum experience was worth the time? Why or why not?	Subjective feedback on satisfaction
12	Did the VR museum experience meet your expectations? If not, how could it be improved?	Subjective feedback on satisfaction
13	Would you recommend the VR museum experience to others? Why or why not?	Subjective feedback
14	Overall, how would you rate the realism and immersion of the VR museum experience on a scale of 1 to 5?	Assessment realism and immersion of the VR museum environment