APPLICATION OF VR TECHNOLOGY IN THE ARCHITECTURAL VISUALIZATION OF A SAMPLE PROJECT

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Approval sheet of the Thesis

This is to certify that we have read this thesis entitled **"**Application of VR technology in the architectural visualization of a sample project**"** and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

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ABSTRACT

APPLICATION OF VR TECHNOLOGY IN THE
ARCHITECTURAL VISUALIZATION OF A SAMPLE PROJECT

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Recent developments in visualization technology feature the emergence of virtual reality (VR) application. In the field of architectural design, the implementation of such technologies pushes realism to new extents, making it more engaging to demonstrate to the viewer and to discuss ideas with them easily. The importance of this implementation lies on the fact that it aids the viewer in getting the feel of the space, the human dimension and the atmosphere of the interior.

The aim of this study is to demonstrate the effectiveness of virtual reality in architectural visualization. In order to achieve this aim, there is conducted a detailed study of previous literature on the field of virtual reality to examine its origin, recent developments, tools and the features that it can offer to the user.

The following step consists of producing a VR application and a test project, using “Unreal Engine 5”, which exhibits the features that virtual reality can provide. This process is presented as a suggestive guide in VR development and optimization. The produced scene was presented to a group of architecture students. By allowing them to experience it in VR, data was gathered through their reactions and feedback. This information was further administrated via two questionnaires, aimed at gauging their perceptions and opinions regarding the use of virtual reality, identifying aspects they found useful, impressive, or problematic.

In conclusion, the findings of the study demonstrate the effectiveness of VR technology in architectural visualization in terms of a deeper understanding of the project, as well as a superior visual quality.

Keywords: *Virtual Reality, Architecture, Interior Design, Visualization, Application, Unreal Engine, Meta Quest 2.*

ABSTRAKT

PERDORIMI I TEKONLOGJISË “REALITET VIRTUAL” PËR VIZUALIZIMIN ARKITEKTONIK TË NJË PROJEKTI MOSTËR.

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Zhvillimet e kohëve të fundit në vizualizim shfaqin përdorimin e realitetit virtual (VR). Në fushën e dizajnit arkitektonik, implementimi i kësaj teknologjie shtyn realizmin drejt skajeve të reja, duke e bërë rezultatin më të prekshëm dhe përfshirës për shikuesin. Kjo e bën më të lehtë shkëmbimin e ideve. Rëndësia e implementimit të kësaj teknologjie qëndron në faktin se do të ndihmonte shikuesin të ndjente hapësirën, dimensionet reale dhe atmosferën që krijohet.

Qëllimi i këtij studimi është të demonstrojë efektivitetin e realitetit virtual në vizualizimin arkitektonik. Për të arritur këtë qëllim u bë një analizë mbi literaturën ekzistuese rreth realitetit virtual me qëllim për të ekzaminuar origjinën e kësaj teknologjie, zhvillimet e fundit dhe mundësitë që i ofron përdoruesve.

Hapi i radhës konsiston në përgatitjen e një aplikacioni VR dhe një projekti mostër, me anë të “Unreal Engine 5”, në të cilin tregohen aftësitë e kësaj teknologjie. Ky proces është paraqitur si një udhëzues me sygjerime mbi zhvillimin e realitetit virtual dhe optmizimin. Projekti i përftuar ju prezantua një grupi studentësh të arkitekturës. Duke i lejuar ata të perdorin këtë aplikacion, u mblodhën të dhëna në lidhje me reagimet e tyre. Ky informacion u administrua më tej me anë të dy pyetësorëve, te ndërtuar rreth karakteristikave që studentëve ju dukën pozitive, impresionuese apo problematike. Si përfundim, gjetjet e këtij studimi demonstruan efektivitetin e teknologjisë së realitetit virtual në vizualizimin arkitektonik për sa i përket një perceptimi më të thellë te projektit, si dhe cilësisë superiore të pamjes.

Fjalët kyçe: *Realiteti Virtual, Arkitekturë, Dizajn interiori, Vizualizim, Aplikacion, Unreal Engine, Meta Quest 2.*

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CHAPTER 1

INTRODUCTION

1.1. A present overview on Virtual Reality.

In the recent years, Virtual Reality (VR) technologies are becoming widely available, and there are encountered more and more creative uses in various fields of the industry. In the majority, this concept is used for 3D gaming and entertainment, which shows how powerful it is for visualizing scenes and experiences.

Architectural visualization is a very crucial part of delivering a project and how it is perceived by the viewer, especially when they are not professionals in the field. In the present, there are numerous ways used to present a project visually. The main theme is photorealism, using 3D models and rendering engines to produce images shown on screens and projectors. This method has surely been effective in getting a sense of what the project or building will appear to be, but it allows little to no lifelike interaction.

The importance of a building fundamentally lies on the people that use and perceive it. The way they interact with the building and what feelings the ambient evokes in them are what differentiates a well-achieved project from others. Architects and designers strive to foresee and guide these impressions and feelings, but it can be easily misleading based on just a rendered image on the screen. By employing VR technology and commonly available equipment such as headsets or do-it-yourself VR cardboards, the architectural design and visualization can be pushed to the next stage of being immersive and qualitative simultaneously.

1.2. Objectives.

The main focus of this thesis is showcasing the effectiveness of the integration of Virtual Reality technologies can be in the process and visualization of architectural projects and interior design. With the aim of bringing a new dimension to these practices, the result of this thesis aims to provide a more immersive experience to the viewer, allowing them to interact with a project in a way that is not possible with current means.

To achieve this aim, the primary goal is to prepare a program that serves as the environment to place a project and the virtual avatar of the user in order for them to experience the surroundings in VR. The requirements of this application are: being intuitive and user-friendly, especially for the creative producer; providing impressive graphics, interactions and hand gesture functions for the user. An accompanying goal is to make the final process of this interaction natural and immersive.

1.3. Literature review.

In order to get a broad understanding of the Virtual Reality technology there was conducted a literature review regarding the history and first steps of VR, the evolution of software used to program these artificial environments, as well as the hardware and equipment necessary. There were examined different uses of Virtual Reality in various fields with a focus on how it has been implemented in architecture specifically. This was surveyed by inspecting similar past research and several use cases in interior and exterior design. In addition, there are presented interesting uses of VR technology as a learning mean. By going through the results of the aforementioned reviews, important data was extracted regarding the positive aspects of VR implementation in architectural design and the challenges that accompany it.

1.4. Methodology.

Upon getting a broad understanding on the evolution of the Virtual Reality technology, its recent developments and uses, as well as its fundamental concept, the following step is to proceed with the methodology of this study. This thesis is based on delivering a virtual reality project to a group of participants and gathering their impressions on the use of this technology. The purpose of this methodology is to demonstrate the VR technology capabilities in the field of architectural visualization. In order to experience that in a practical way, the first objective of this methodology is the preparation of the VR application software that features a chosen project. This project can be observed and interacted with in a virtual environment using adequate equipment. The contents of the methodology include: the presentation of the chosen project and its characteristics; the process of 3D modelling and exporting; tools used in the methodology and why they were chosen; a step-by-step explanation of how a VR application for architectural visualization can be produced; challenges and limitations encountered and how they were addressed.

The project at hand is the interior and exterior of a two-storey villa, "Maison Mentana" by EM Architects in Montreal, Canada shown in *Figure 1*. Being an already built project, it gives the opportunity to examine the effect of VR in perceiving the project compared to actual photos of the final design.

Figure 1. EM Architects.(2015) "Maison Mentana" Villa. [Photograph]. Montreal, Canada. Photographed by: Williams, A.

There are several software and VR techniques to display a project. The study describes the technicalities of the most used ones. Based on that was decided on which software and technique to use for preparing the application, which are "Unreal

Engine" and "immersive VR systems", respectively. A similar process was followed regarding the VR equipment chosen, which as a final choice is "Meta Quest 2".

Several tests and changes were made to the 3D model of the villa and the real-time rendering specifications in order to optimize the appearance of the final result without losing frame rate when viewed in a headset. The final product was tested with architecture students using the VR headset and the data gathered by their reaction was included in the study.

Upon project completion, there are explained the survey methods chosen, participant selection, data collection procedures and the data analysis. A scheme displaying the entire methodology process visually is shown in *Figure 2* below.

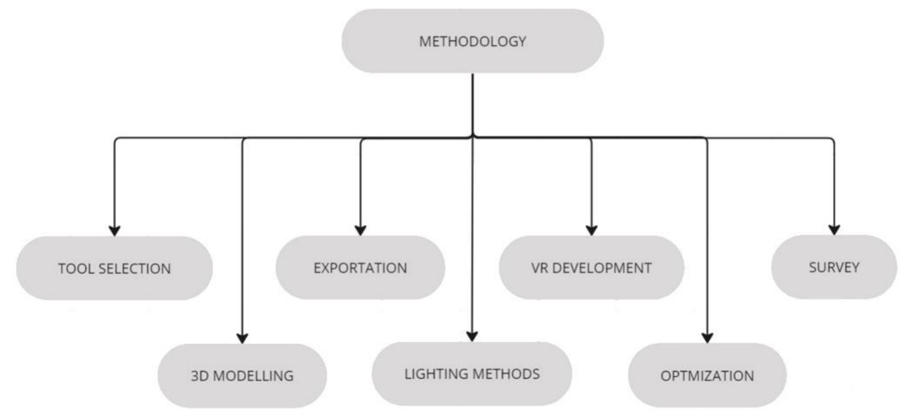

Figure 2. Scheme displaying the methodology structure. Source: Author.

1.5. Thesis overview.

This thesis is divided in 5 chapters. The organization is done as follows:

Chapter 1 includes the situational overview on Virtual Reality, thesis objectives, and the scope of works. Chapter 2 presents the literature review relevant to the study, focusing on the evolution of Virtual Reality, similar studies and case studies. Chapter 3 delves into the VR development process including the tool selection, scene creation, VR implementation and the survey methodology. Chapter 4 presents the results retrieved from the questionnaires. In Chapter 5 are included the discussion and conclusion of the thesis.

CHAPTER 2

LITERATURE REVIEW

2.1. Literature overview.

Virtual Reality technology appears like a very modern idea and concept, but it has been present with its aim of giving users the freedom of submerging into an imaginative world for a considerable period in different manners. This literature review presents the history behind VR, its elements, the equipment and the software used to achieve it. Coming to the modern days of Virtual Reality is further analyzed the different fields that take advantage of its abilities in general and the uses in architectural design in particular, which can be further subdivided into the uses of architectural design and visualization. Similar papers conducted in recent years are examined in order to gather insights on the methodology used in these studies and the relevant results they provide. The aim of this literature review is to examine what this evolution has offered so far and, more importantly, to embrace the core of VR technology and what it represents in order to implement it with mindfulness and efficiency.

2.2. Evolution of Virtual Reality technology.

2.2.1. First steps toward today's Virtual Reality.

Storytelling can be considered as one of the first attempts of humans to materialize a fantasy world into words, scenarios or pictures. This is the first step of Virtual Reality as it is a guided fantasy induced into a person by another using their creative thinking and way of expressing (Bown, 2017). Even though it is guided, this type of virtual world leaves generous space for imagination, which makes it very personal to each individual. With each developmental step of technology, less is left to the imagination of the viewer by presenting more information to the senses.

The first appearance of Virtual Reality in the manner of visual images is panoramic paintings, such as the one shown in *Figure 3*. They became widespread at the end of the 19th century. Robert Barker is considered their inventor, turning the interior faces of rotundas into a 360-degree painting with the idea of creating the illusion of a 3D space within which the viewer is immersed. The first recorded scene painted in this way is one of Edinburg, Scotland. Later they would spread worldwide, with artists also placing objects matching the scenes in these buildings to add depth to the perception (Woeste, 2009).

Figure 3. Dumoulin, L. (1912). Panorama of the Battle of Waterloo [Mural painting]. Waterloo Battlefield Museum, Braine-l'Alleud, Belgium.

In terms of what can be considered a well-achieved Virtual Reality, panoramas offer vivid and very detailed scenes, which is crucial to the result, but they lack interactivity and only affect the visual sense.

During the late 19th century and the 20th century, Stereoscopic 3D photos got popular as a form of entertainment to the point that in almost every home of middle or higher-class people in Britain, you could find one of them (Gamber & Withers, 1996). The way that a Stereoscopic 3D photo worked was by having the person's eyes look at two slightly different images that create the illusion of a 3D scene or object by giving it depth, a predecessor of today's 3D glasses. Some famous Stereoscopic 3D photos, like the one displayed in *Figure 4* were those of different cities around the world. Being affordable and a system you could have at home, people couldn't resist this almost magical way of looking into parts of the world that they would never have a chance to see in real life. The major step forward with these devices was the recreation of one's spatial awareness of reality by using the perception of depth, binocular view and parallax effect.

Figure 4. Holmes, O. (1905). Holmes Type Stereoscope. National Science and Media Museum, Bradford, England.

The following stepping stone of virtual reality evolution, and probably the most important one, had the name of Morton Heilig on it. He is considered as the father of virtual reality, and his initial idea wanted to realize an experience that included imagery, multi-source sound and even odors and vibrations. (Carlson, 2007) His ideas were consolidated in the form of the Telesphere Mask. This equipment was made up of the following components: optical TV tubes for each eye, a pair of headphones and tubes that ejected air. With this combination, the viewer could live the illusion of a 3D image or video, hear the sounds of the environment and have air and odors ejected to their face to enhance the experience.

One of the most successful experiences was one of being on a motorcycle going through the streets of New York. To accompany the visuals, there was added a vibrating seat and smells of the street and cooking of stores nearby. While testing this scene, they got impressions from people that the motorcycle driver was incautious, making the experience thrilling and slightly concerning. This was a great achievement. Even though being uncomfortable, this was a great proof that the user found the experience very immersive, and it arose feelings in them.

2.2.2. The new age of Virtual Reality.

With continuing advancements of technology, VR took many steps in terms of equipment. The initial prototypes required people to be seated or have the headset hanging from the ceiling due to the enormous weight of these equipment. The development of these gadgets was very costly at the time, and it was far off from being accessible to the general public.

A development worth mentioning was Visual Programming Languages (VPL), which was one of the first companies to develop and sell VR products to consumers, founded by Jaron Lanier in 1984. Lanier is thought to be the initiator of the term "VR". This company invented the Dataglove, the Eyephone, and Audiosphere, these devices that, when used together, create a new type of immersive VR experience.

The rear of the Dataglove was wired with fiber optic connections, which sent out small light beams as the wearer bent and moved their hands in any direction. A computer processed the light beams and then created a picture on a tiny screen inside a headset in the shape of a helmet (i.e., the Eyephone) or on a computer screen, where the user could see a computer-generated model of their hand, which they could control and interact with virtual items in a completely other artificial environment (Sturman & Zeltzer, 1994). The Dataglove's success was restricted by two factors: it was too pricey for the typical user (it cost thousands of dollars), and it was a one-size-fits-all glove (Burdea & Coiffet, 2003). The glove also lacked tactile feedback, which did definitely weaken any sensation of presence because it was not at the same pace as reality expectations.

The Eyephone employed two miniature (stereoscopic) LCD television displays that were seen via lenses to create the sensation of depth. The Eyephone allowed onlookers to join a computer-generated environment however, the visuals were typical of 3D graphics during 1980 (e.g., 360x240 pixels) and only produced 5-6 frames per second, compared to the 30 frames per second produced by TV sets at the time (Teitel, 1990). Although it lacked the vividness we know today, the Eyephone was superior to anything that came before in terms of generating presence through VR technology.

The Dataglove was used by the Eyephone to navigate the z-axis in the virtual world. The user would fly in a virtual world by controlling the direction and forward velocity with their index finger. Keeping their thumb near their palm caused them to fly faster, and holding their thumb out from their hand (straight out) caused them to halt (Sturman & Zeltzer, 1994). Enabling users to manage their flight in a virtual world was a significant step toward exceeding our physical boundaries since it provided interactivity to an otherwise impossible physical action. The combination of these devices, shown in *Figure 5* met several standards for creating presence but may have fallen short on vividness metrics. Graphic quality and complexity (as well as interactive complexity) have a long way to go.

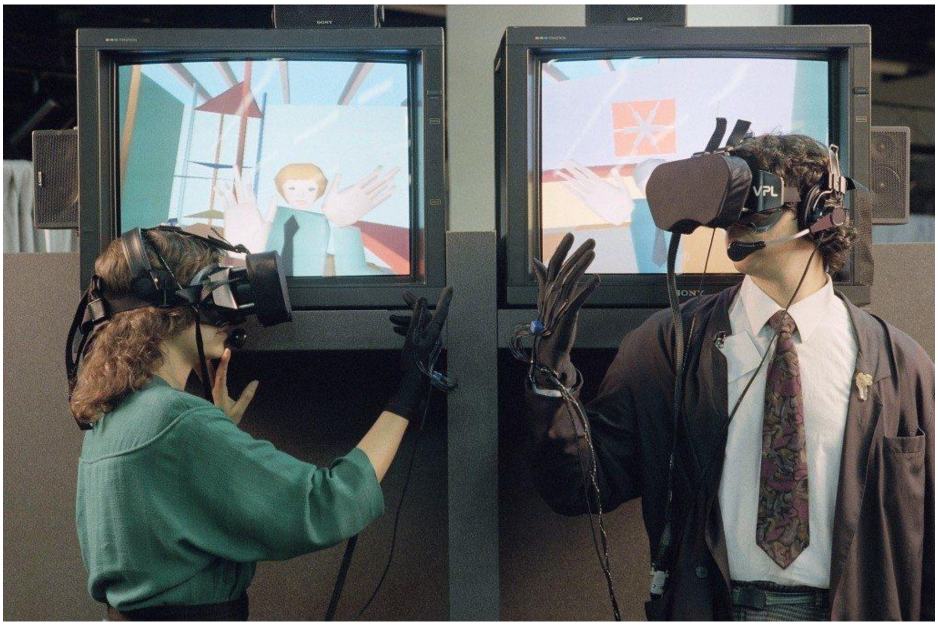

Figure 5. Two people presenting the use of the Eyephone and the Dataglove(1989). [Photograph]. San Francisco

2.3. Present Virtual Reality gadgets.

In the present day, the Virtual Reality technology headsets and gadgets available have been revolutionized, which has made them way more affordable and available in the market while also providing a more qualitative way to experience digital content. These devices usually come in sets containing headsets and their chargers, accompanied by hand controllers designed in a way to allow smooth interaction with objects and performing actions in the virtual world.

Virtual reality headsets are mainly used for gaming, but they also find usage in various fields, including: health, engineering, architecture and education, so various companies have invested in producing quality products that are competitive in the market. Some of the most popular virtual reality headsets on the market today include: Meta Quest 2, HTC Vive Cosmos, PlayStation VR, Valve Index and Google HoloLens. (Angelov, Petkov, Shipkovenski, & Kalushkov, 2020)

Some of the differences telling apart the fore-mentioned choices, that are crucial in choosing the most appropriate headset are the following:

Meta Quest 2: One of the most important features of the Quest 2 is that it is a wireless headset, which means users don't need to have a PC (personal computer) in order to run the applications on this headset and don’t need to worry about tangling wires while using it. In this way it allows to run standalone programs. The price of the Meta Quest 2 is also among the most affordable VR headsets. (Meta Platforms, 2023)

HTC Vive Cosmos Elite: The Cosmos Elite is a high-end headset powered by a PC that offers full-body tracking, which gives users the possibility to track their head, hands, and feet. It is also constructed by modular elements, which allow it to be easily customizable and upgradable. (HTC Corporation, 2023)

PlayStation VR: This type of headset is designed to work only with the PlayStation 4 or PlayStation 5 consoles. It has a comfortable and lightweight design. There is a camera installed on the headset that tracks the user’s hands. This is the most affordable VR headset in the market and offers a wide range of games and applications, but it comes with the preset condition that it only functions when connected to PlayStation devices. (Sony Electronics Corporation, 2023)

Valve Index: The Index has a special feature, which is hand gesture tracking which allows users to perform proper hand movements in Virtual Reality. At a higher price range, it also offers high-quality graphics per each eye. (Valve, 2023)

Google HoloLens: The HoloLens is actually an augmented reality headset developed by Microsoft, and it has the ability to track hand movements, a high-resolution display, a wide field of view, and standalone functionality. The particular characteristic of this headset is the ability to overlay content into the real world.

Table 1. VR headset options' specifications.

VR headset	Meta Quest 2	HTC Vive Cosmos Elite	Valve Index	Sony PlayStation VR
Display Resolution	1832x1920	1440x1600	1440x1600	960x1080
FOV	100°	110°	130°	100°
Tracking system	Inside-out	Full body	Hand-only	Camera based
Refresh rate	90 Hz	90 Hz	120 Hz	120 Hz
Weight (grams)	503	470	809	610
Standalone	Yes	No	No	No
Price	299$	799$	999$	550$

Based on the analysis above and further consideration of specific features and details about each of the options, it was decided that for the proceeding steps of this thesis the most appropriate choice would be the Meta Quest 2 as the VR headset choice for architectural visualization, shown in *Figure 6*. The decisive features that guided this choice are as follows:

- Portability: The Quest 2 is lightweight and very portable in its own case, making it easy to take to client meetings or project sites. This would allow the architect and designers to showcase their work at need.

- Multi-User Support: It allows multiple people to participate in VR environments at the same time, which can be beneficial for project presentations.

- A Wireless, standalone system: Unlike some other VR headsets that require a PC or external device to function, the Quest 2 is a standalone device that does not require any cables. It performs all the needed computations inside the headset. This allows more freedom of movement when presenting projects.

Figure 6. Meta. Meta Quest 2 Advertisement Picture (2023). [Rendered image].

2.4. Virtual Reality programming software alternatives

In order for an architect to utilize the opportunities given by the Virtual Reality technology and the available hardware, there needs to be done some prior programming. To prepare the architectural project for viewing in Virtual Reality and to perform the programming for the interactivity there are several alternatives of software such as: Unity, Unreal Engine, Blender and Vuforia. Some of the specific features of each of them are:

Unity: Unity is a cross-platform VR programming software that supports multiple VR headsets. It provides a visual editor to design and modify 3D objects and environments, as well as scripting tools that support multiple programming languages, such as C# and JavaScript. It can produce highly interactive VR environments, but it requires high knowledge in programming and has a steep learning curve. (Ciekanowska, Kiszczak-Glinski, & Dziedzic, 2021)

Unreal Engine: Unreal Engine’s most distinctive feature is its advanced graphics quality capabilities, providing highly realistic and immersive VR experiences. It has a large gallery of free content such as: photo-scanned objects, vegetation, textures etc. It offers a visual scripting system called Blueprints, enabling developers to create complex interactions. It is very easily approachable from architects because Blueprints works without the user needing to code. (Ciekanowska, Kiszczak-Glinski, & Dziedzic, 2021)

Blender: Blender is an open-source software that provides a wide range of modeling and compositing tools for VR development. It includes tools for 3D modeling, texturing, rigging, animation, and more, making it a versatile choice for creating VR experiences. Blender supports multiple VR headsets and platforms and it is free to download and use. (Blender Foundation, 2023)

Vuforia: Vuforia is a software platform that supports both AR and VR projects, making it a proper choice for creating mixed reality experiences. It includes tools for scanning and image recognition, enabling developers to create VR and AR experiences that can even correspond to real-world objects as overlays. Vuforia supports multiple platforms including iOS, Android, and can contribute to Unity. (Vuforia PTC Inc., 2023)

Table 2. Software options' specifications.

Software	Unity	Unreal Engine	Blender	Vuforia
Platform	PC, Mac, Linux, Mobile, Console	PC, Mac, Linux, Mobile, Console	PC, Mac, Linux	Mobile, AR Glasses
Purpose	Game development, AR/VR, simulations	Game development, AR/VR, simulations	3D modeling, animation, rendering	Augmented Reality
Programming Language	C#, JavaScript, Boo	C++, Blueprints	Python	C#, Java
3D Modelling Capabilities	Yes	Yes	Yes	No
Real-Time Rendering	No	Yes	Yes	No
Node-Based programming	No	Yes	Yes	No

Based on the above descriptions and further analysis, Unreal Engine, shown in *Figure 7* below, was selected as the most appropriate app for the use of architectural VR visualization and for producing the application that will serve for the remainder of this study. Among the decisive arguments for these choice are:

- High-fidelity graphics: Unreal Engine provides highly realistic and immersive VR experiences. This gives it a strong advantage over other options because its results are very visually stunning.

- Real-time rendering: Unreal Engine's real-time rendering technology allows architects to see their designs in VR in real-time, making it easier to make changes and adjustments as needed. This can save time and reduce the need for multiple iterations of a design.

- Customizable environments: Unreal Engine provides a range of tools for creating custom environments, including lighting, materials, and effects. This enables architects to create customized environments that showcase their designs in the best possible way.

- Collaboration: Unreal Engine offers built-in collaboration tools that enable architects to work together in real-time on the same project. This can be especially useful for teams working on large-scale projects or for architects who want to collaborate with clients.

- Beginner friendly: Many architects don't have much prior experience in coding languages which in other software choices are required in order to write actions or interactions. Instead Unreal Engine has Scripts, pre-coded strings for several actions, which can be integrated without knowing how to code and has a very intuitive interface.

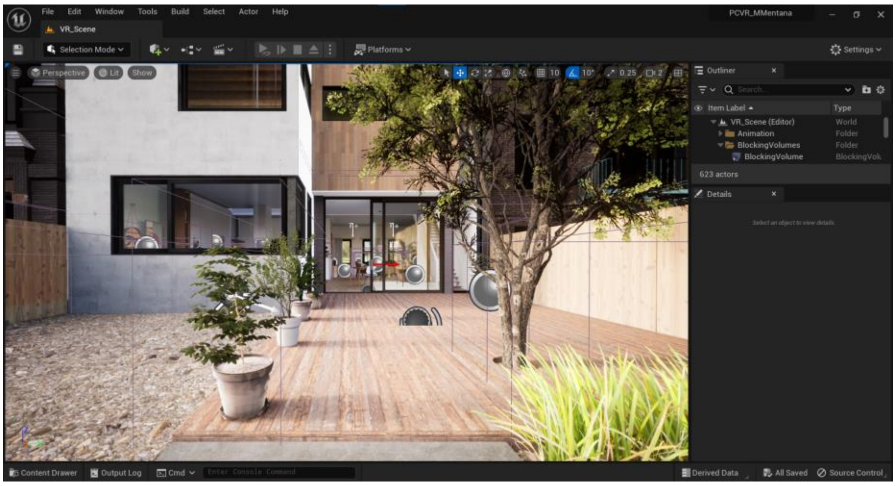

Figure 7. Unreal Engine Interface Editor [Screenshot]. Source: Author.

2.5. The use of Virtual Reality in Industry.

In recent years, many fields are taking advantage of Virtual Reality to enrich their practices and experiences. Some of the fields that employ Virtual Reality into their activities are presented below in *Figure 8*.

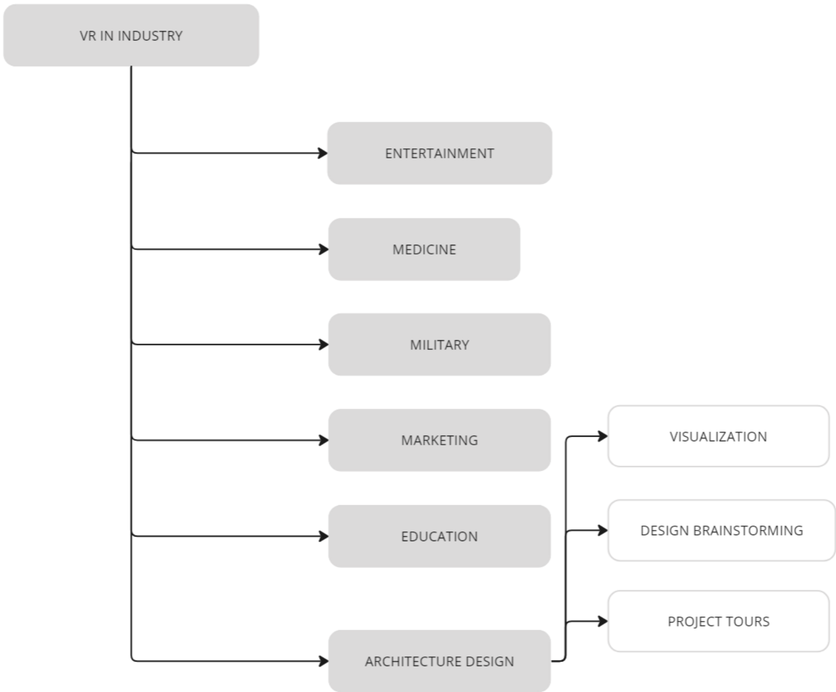

Figure 8. Scheme displaying the VR usage in the industry.

Entertainment might be the most spread use of Virtual Reality. In this field, VR provides immersive and interactive experiences for users in dozens of videos and games for every type of platform, as shown in *Figure 9*.

Figure 9. Stéphane Bernard. (2020) Person using a VR gaming system. Retrieved from Unsplash.com

In education, VR creates engaging and interactive learning experiences. It is seen, as will be portrayed below, the attention span of a student can be extended much longer when there are employed methods such as Virtual Reality, which encourage them to interact with what they are learning and being presented.

Medicine is also an important field that utilizes this technology. VR is used for training medical professionals and simulating surgeries, as shown in *Figure 10* without needing to put lives at risk. In several cases, VR headsets have been used by psychologists to treat the phobias of their patients as well.

Figure 10. Ferguson P. (2021) Dr. Shields, (an orthopedic surgery resident at the University of Toronto,) performs a simulated procedure. [Photograph]. Toronto, Canada.

In military services, virtual experiences are used for training soldiers, simulating combat actions and situations, as well as testing new equipment and technology with an example shown in *Figure 11*.

Figure 11. Hannah Y. (2021) Staff Sgt. Annette Hartman with a virtual reality headset used in a suicide prevention exercise. [Photograph]. Retrieved from: New York Times

Being as immersive as it is, VR is used in real estate as well to provide virtual tours of properties, sometimes in cases that a building is being restored or it's too far to make a meeting, allowing potential buyers to experience and interact with the property which may lead to them making a purchase.

Lastly, and our main focus, VR can be revolutionary in the way that architects approach building design and a great help in project visualization and presentation. Virtual reality technology has significant applications in architecture, enabling architects, builders, and clients to experience building designs in a more immersive and interactive way.

With VR technology, architects can create a digital 3D model of the building design, with an example shown in *Figure 12*, allowing the client and other stakeholders to experience and understand the design in a more realistic and comprehensive way. Clients can take a virtual tour of the building, exploring different rooms, levels, and features, as if they were physically present in the building.

VR technology also enables architects to make changes to the design based on feedback from clients or other stakeholders. Clients can provide real-time feedback and suggestions, and architects can make changes to the design in the virtual environment, eliminating the need for costly and time-consuming physical model iterations. (Racz & Zilizi, 2018)

Furthermore, VR technology in architecture enables architects to collaborate more effectively with other professionals involved in the building project, such as engineers, builders, and interior designers. By using VR, these professionals can work together in a virtual environment, making it easier to identify potential issues and develop solutions before construction begins. It can be useful as well for prior quality control, logistics, cost estimation etc. (Schiavi, Harvard, Beddiar, & Baudry, 2022)

Figure 12. A2VR. (2023) WebVR Sample. [Application preview screenshot]

In addition, VR technology allows architects to explore different lighting conditions and material choices for the building design. Architects can simulate different lighting and weather conditions to visualize how the building will look at different times of the day or during different seasons.

2.6. Case studies of VR technology use in architecture design and visualization.

One basic but important use of VR in architecture is “Walkthroughs”. This term refers to virtual presentations of an architect’s designs, allowing clients and stakeholders to explore the building or space in a more immersive way. This can be especially useful for large, complex projects or those that are difficult to visualize in 2D because the feel of the space can be more important than the plan view. A practical example of the use of Walkthroughs is the "The Oculus" at the World Trade Center by SOM. The Oculus is a multi-modal transport hub located at the World Trade Center in New York City. The architecture company that prepared the design have showcased that in the process of planning the main ideas for this project, they used VR technology to get a proper idea of how the geometry fits into the site and ensure that it could be constructed efficiently and accurately. (SOM Architects, 2016)

Collaborative platforms set in virtual environments are also an important use of VR in architecture. These platforms serve as meeting spaces for teams of architects as well as other professionals of the field to come together and be creative with limitless tools available to design in 2D or 3D. One case study of this type of use is: "Collaborative Virtual Environments" by the University of Michigan. Several researchers of this university have developed a collaborative VR environment that allows architects, engineers and construction professionals to work together in real-time on building designs. The VR environment enables users to make changes to building designs and see the impact of those changes in real-time, enhancing collaboration and communication among team members. It also offers real time updates on anything that each of the team members is working in, which makes it similar to a BIM functionality.

Another similar case, shown in *Figure 13* is that of "The Wild" by Gensler, a global architecture firm. They developed this VR platform as a way to enable architects and clients to collaborate in a virtual environment. With The Wild, clients can take virtual tours of building designs and provide real-time feedback to architects, enabling more efficient and effective design iterations. It features multiple benefits and capabilities such as: VR and AR integration, cloud-based processing, realistic rendering, interconnectedness with other software such as Sketchup and Rhino, security etc. (Gensler Architects, 2023)

Figure 13. The Wild. Space to Ideate. [Presentation picture]

The interior design market has already been majorly influenced by Virtual and Augmented Reality. Several companies focused on design or furniture sellers have released versions of their applications that allow users to view a virtual version of the furniture they want to purchase in their home environments using just a smartphone. In the journal article "User-centered design of augmented reality interior design service " by Sanni Siltanen, Virpi Oksman and Ainasoja, they explore cases similar to the ones mentioned. They investigate the use of virtual reality in user-centered design of interior spaces. The authors analyzed several apps that utilize VR technology in this way, among which:

Roomle: An app that allows users to design and visualize their living spaces in 3D using VR technology.

Ikea Place: Free app that allows users to place virtual furniture sold at Ikea in their real-world environment using AR technology, shown in *Figure 14*.

SketchUp Viewer: Lite smartphone version of Sketchup that allows users to view and interact with 3D models created in SketchUp using VR technology which a designer or architect can propose to them.

Google Tilt Brush - an app that allows users to create and manipulate 3D art in a VR environment

The authors of this article focus on the importance of user-centered design in developing these types of apps, emphasizing how involving clients in the design process in this manner and providing them easy to use app, can alter the process positively. (Siltanen, Oksman, & Ainasoja, 2013)

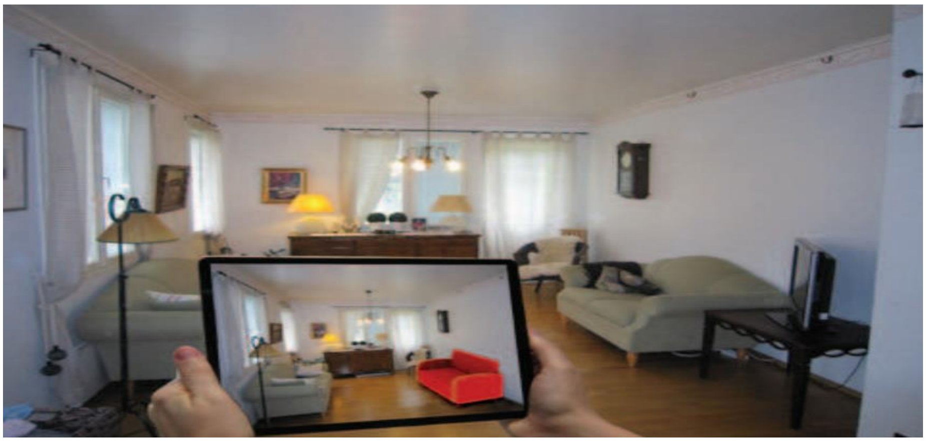

Figure 14. Ikea App. Concept of AR Furniture. [Presentation picture]

2.7. Case studies of Virtual Reality technology uses in educational practices.

For this study, it is important to analyze thoroughly how Virtual Reality can be utilized in education, in order to examine its potential in boosting understanding..

One clever case of using VR in education is the project "Expeditions" by Google, shown in *Figure 15*. Google's Expeditions project uses VR to provide immersive educational experiences for students. Using Expeditions, teachers of any subject can take their students on a virtual field trip to their preferred location all over the world, such as museums, historical sites, and wonders or even time travel to certain events in the past. By using VR, students can explore these locations in a more interactive and engaging way, enhancing their learning capabilities and extending their attention span. (Google LLC, 2023)

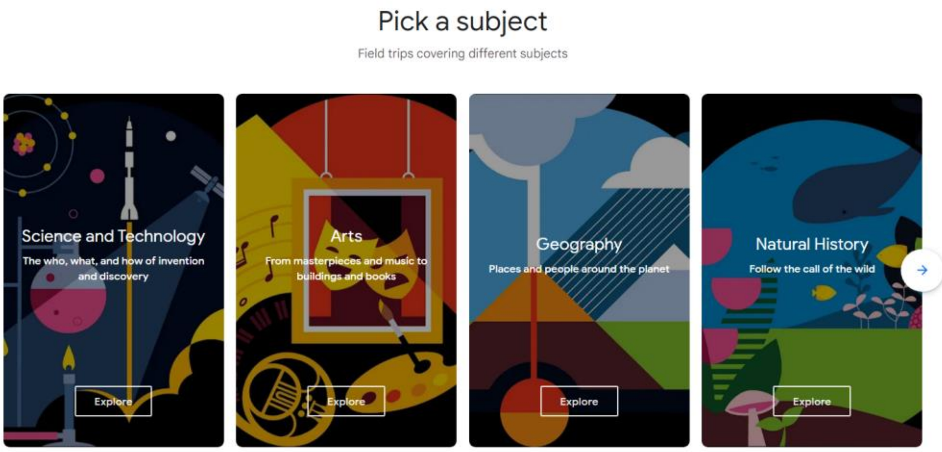

Figure 15. Google Arts & Culture. Variety of subjects. [Website screenshot (Google LLC, 2023)]

"Mission: ISS" is another educational program powered by Meta and NASA. Mission: ISS, shown in *Figure 16*, is a VR set of environments that give the user the ability to explore the International Space Station and perform tasks just like real astronauts would do in space. The experience is designed not only to be appealing to space enthusiasts but also to provide a realistic way for students to learn about space and the duties of an astronaut crew. (Oculus Team, NASA, 2023)

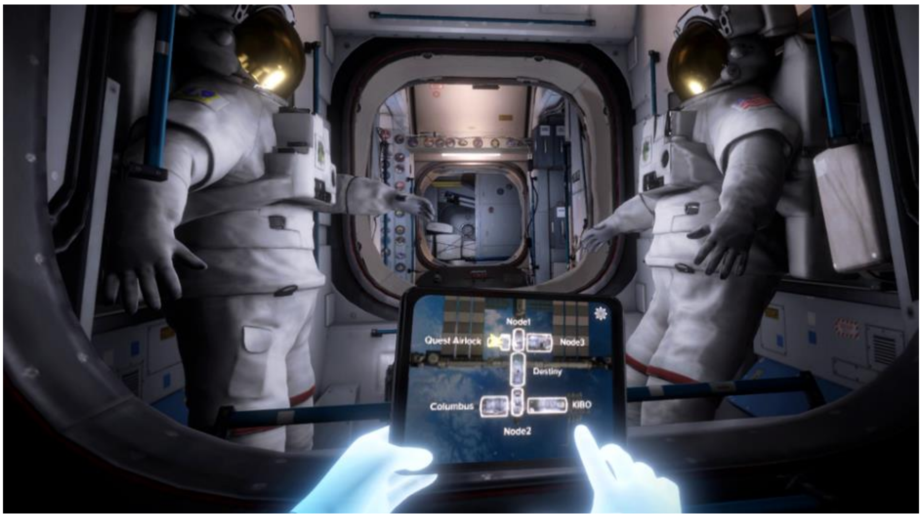

Figure 16. Mission: ISS. (2022). Example snapshot of the interface and appearance. [Presentation Picture]

2.8. Virtual reality for preserving heritage. Case Study.

The literature review conducted above examined cases in which Virtual Reality can assist different fields in planning, designing and presenting projects which, in the majority, would at one point be implemented in reality. But it doesn’t necessarily need to always be the case. One of the most recent and innovative undertakings in Virtual Reality is the project of Tuvalu Island.

Tuvalu, shown in *Figure 17*, is a small island state located in the Pacific Ocean, and it is one of the countries that is expected to be destroyed by the effects of climate change, particularly rising sea levels in the following decades. As a result, the island is slowly disappearing into the ocean, and its residents are facing the inevitable need to be the first immigrants of the effects of climate change.

Placed in this situation, the Tuvalu's Foreign Minister Simon Kofe proposed that it was time to look at new ways for the island not to totally disappear from existence. His idea was to make Tuvalu become the first digitized nation in the Metaverse. The project, known as "The VR Tuvalu Project" aims to create an immersive experience that will give people the opportunity to visit and explore the island and learn about its culture and tradition virtually, even if it meets its end in the real world. The hope is that this will also serve as a way to raise awareness of the impact of climate change on small communities and to encourage greater understanding of the demand for urgent action to address this global phenomenon.

Figure 17. Getty: Mario Tama. (2022) Tuvalu Island. [Areal Photograph]

The VR Tuvalu project is an ambitious effort that combines advanced 3D modeling, interactive storytelling, and real-world data to create a detailed and accurate replica of the island, preserving its culture, tradition and history. (TRT WORLD, 2022)

2.9. Relevant previous research on the use of VR in Architecture.

This topic has gained interest regarding its use in architecture, especially in recent years. "Virtual Reality As A Spatial Experience For Architecture Design: A Study of Effectiveness for Architecture Students", a study conducted by Pamungkas et al. (2018), delves into the usefulness of Virtual Reality technology as a tool that enhances the spatial awareness of the viewer. The significance of this study lies on the emphasis it gives to the implementation of this technology in architecture with the aim of innovating communication project teams and their personal design skills.

This study uses questionnaires with architecture students in its methodology in order to draw the results. These results indicate that Virtual Reality is a useful method that enhances spatial awareness, which directly affects the design abilities of the students by triggering their life-scale perception and three-dimensional thinking. As specific data, this methodology results in 39% of the 2nd year students agreeing with the good quality of the Virtual Reality visual appearance. In a similar trend, 34% of the students gave the highest rating to the virtual experience and its ability to make them feel a sense of presence. The study also asked the students about uneasy feelings during the process, to which 17% of the participants stated that they felt uncomfortable or dizzy while using the VR headset.

This paper also states that there is needed optimization of VR software and hardware with an architecture-directed approach in order for this technology to gain more use. (Pamungkas, Meytasari, & Trieddiantoro, 2018)

Virtual reality gives designers the ability to create immersive experiences, and the study "How Virtual Reality Impacts the Landscape Architecture Design Process during the Phases of Analysis and Concept Development at the Master Planning Scale" explores this ability used in landscape architecture. This study by Hill et al. (2016) delves into the effect of Virtual Reality in the landscape design process and the perception of it by the viewer.

The study methodology is built around a student design team that constructed an accurate 3D model of their concept design, shown in *Figure 18*, for an existing ski resort. This methodology focuses on the ability to incorporate VR in the design process and the ability it gives to virtually visit the site.

The results of this study suggest that the integration of Virtual Reality in the process of designing a landscape architecture project offers several advantages. These advantages include: the ability to better understand the regional context when designing; making the design immersive and interactive, facilitated communication between interested parties.

This study also brings forward the limitations of this technology, such as the cost of the equipment needed. The systems needed can also be time-consuming to set up and require expertise in specific skills of this field. Another factor considered is the fact that not all projects can be suitable to be designed or portrayed in Virtual Reality. (Johnson, George , & Hill, 2019)

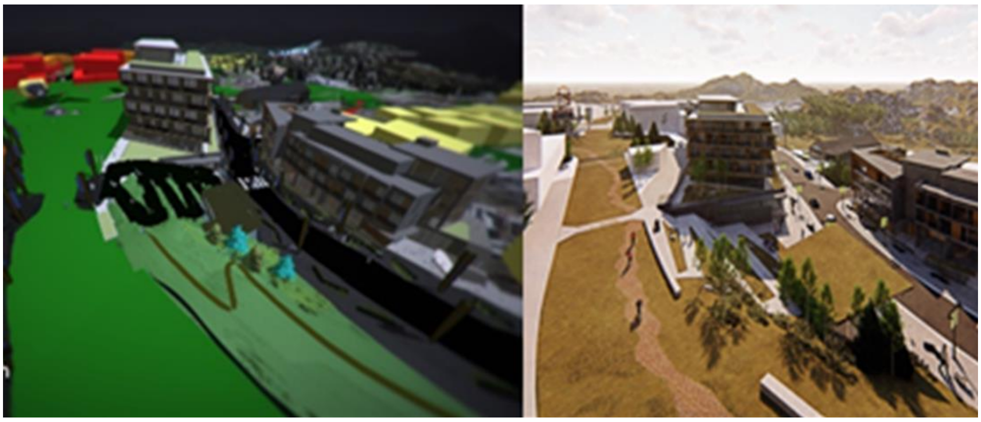

Figure 18. VR design (left) and final rendering of the proposal created with Rhino and Lumion. Note. Reprinted from "How Virtual Reality Impacts the Landscape Architecture Design Process during the Phases of Analysis and Concept Development at the Master Planning Scale", by Hill et al. (2019).

2.10. Summary.

The literature review provides an overview of the evolution and applications of Virtual Reality technology form the rotundas to today's VR headsets. It offers insight on how this technology came to be and its aim to provide the user an impressive new method of consuming content.

The information provided about the specifications of different hardware and software helps in making informed decisions on the next steps of the study.

Virtual Reality technology has found applications in the industry, revolutionizing the way tasks are performed. Exploring the broad range of use in various fields, shows how VR provides a safe and controlled environment for learning and practicing which is at the same time entertaining. Its recent use in architectural design features new visualization methods, collaborative virtual working spaces, virtual tours etc. The previous research similar to this thesis offer insightful data on how the technology is perceived in the surveys they provide.

Embracing the evolution of VR technology and embrace its core concepts is a crucial factor in implementing it effectively in architectural design and visualization.

CHAPTER 3

VR DEVLOPMENT PROCESS

3.1. Tools selection.

3.1.1. VR headset selection

In order to complete the task of developing a VR application for architectural visualization, there are two major tools needed. These tools include the headset equipment that will be used to experience the scene and the software used to prepare the VR app and interactions. As briefly mentioned above, the VR headset chosen for this study is Meta Quest 2.

Selecting a VR headset for the study is a very influential element of the methodology. In order to make a valid decision, a list of factors was taken into consideration including the price, availability, screen resolution, computational power etc.. While there are several headset choices more powerful and capable with regard to computational power, the chosen headset is Meta Quest 2. One of the primary factors for this choice was the cost-to-value ratio. The aim of this thesis is to provide results that encourage current or future architects to incorporate the use of Virtual reality into their workflow. In order to appeal to these professionals to give this technology a chance, it’s crucial to demonstrate that they can achieve a pleasing and presentable result even at a lower price point. In that regard, the main reason the Meta Quest 2 was chosen is due to its affordability with a price of 299$.

Another deciding factor in choosing Meta Quest 2 is its functionality as a standalone system. For a system to be standalone, it means that the VR headset is able to perform all necessary processes within itself, without any wires connecting it to a computer. While it is not as powerful as a separate computer and it will require more thought and awareness when preparing an application, the Meta Quest 2 is chosen the convenience that a wireless experience can provide in this study and in professional practice.

The Meta Quest 2 provides impressive visual quality with its 1832 pixels x 1920 pixels resolution displays for each eye. The high refresh rates provide a higher FPS (frames per second) output, which allows for a more pleasant viewing experience and more engaging virtual projects.

One influencing factor that enriches the realism in the virtual world is sound and reality overlay, which this headset provides via its built-in spatial audio system and hand tracking realized by remotes and several cameras in the headset. In this way, the user can interact in a more natural way with the virtual environment by controlling different elements with the virtual version of their hands. (Meta Platforms, 2023)

3.1.2. Software selection.

While there is a set of software that provide the tools necessary to prepare the architectural visualization required for this study, the most suitable choice is Unreal Engine 5 by Epic Games. This selection was made based on certain factors and criteria explained below:

Unreal Engine 5 offers integrated Virtual Reality capabilities that are easy to set up via its templates and highly intuitive to use. The software user interface is built around flexibility, featuring blueprints, scripts and pre-coded strings for several actions, which make it easier for users that don’t have experience in coding languages to develop an application.

An obligatory factor for developing the VR project used in this study is real-time rendering. The traditional type of rendering requires setting up the scene, lighting, cameras and choosing one or several cameras to render a realistic image. The new technology of real-time rendering enables the user to get the final appearance of the project at all times without the need to wait for a rendering process. This is very useful for making changes to elements, objects, materials or lighting and seeing their effect on the final look instantaneously.

Combined with the use of Meta Quest 2 as a headset, Unreal Engine 5 can be used to package an application and launch it online. This is very useful in enabling collaboration when the parties involved are not in close proximity. The possibility for the architect to be inside the VR environment together with their team or with the clients allows clear communication with little misunderstandings and easier decision-making.

A last but very important factor in choosing Unreal Engine 5 as the software for this study is the cost. Unreal Engine 5 is completely free to download and use for any need, and it features various free and paid libraries ranging from models to materials, textures, vegetation etc. (Epic MegaGames, Inc., 2023)

It is important to mention that the computer used throughout the process is required to be capable of running Unreal Engine 5. The requirements include a minimum of 8GB RAM memory and a minimum of 4GB dedicated graphics card of any kind. For this particular study, the machine used is Asus FX505D with the Nvidia GTX 1650 4GB.

3.2. Scene creation.

Before being able to implement the VR capabilities to the project, the scene needs to be created. After choosing the sample project that will be used for this study, the following steps include the 3D model preparation, exporting from the modelling software to Unreal Engine, choosing the lighting method for the scene and materializing all the assets.

The scene creation steps are displayed in the scheme below (*Figure 19*).

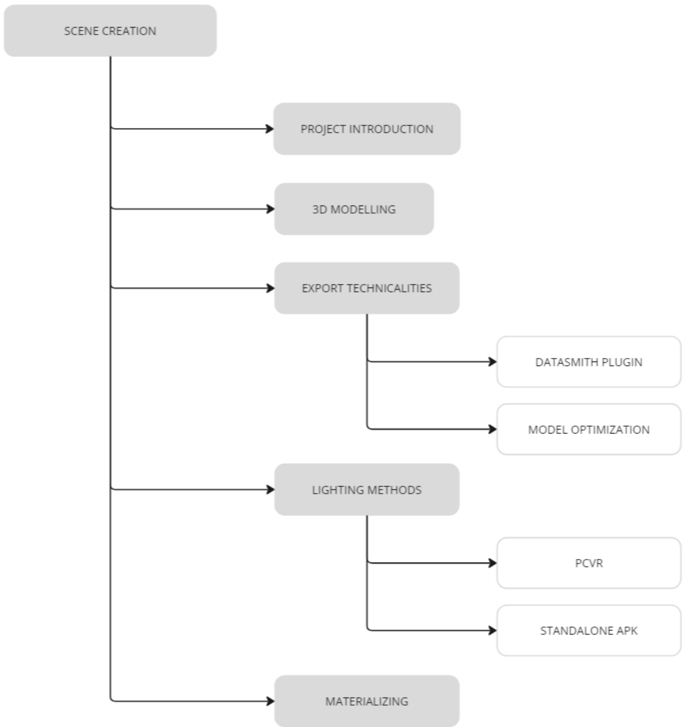

Figure 19. Scheme displaying the scene creation process. Source: Author

3.2.1. Project introduction.

The project chosen to demonstrate the use of VR technology is a two-storey villa with a patio up front. This project, named “Maison Mentana” is a renovation work of “EM Architecture” built in the year 2015, located in Montreal, Canada.

“EM Architecture” took the existing half-abandoned two-storey building in need of many renovations and turned it into a contemporary single-family home. The interventions consisted of removing most interior separating walls allowing more modern lighting via the already existing skylight in the building core. The villa consists of a partly paved outdoor area which leads to a living, dining and reading area as well as a kitchen on the ground floor as a common space without dividing walls. A run of stairs leads up to the second floor, composed of four bedrooms, two bathrooms and a laundry room. (EM Architeture, 2023)

Plan views (*Figure 20*) and photographs of the project (*Figure 21-23*) are presented below in order to be familiar with what the VR project will include.

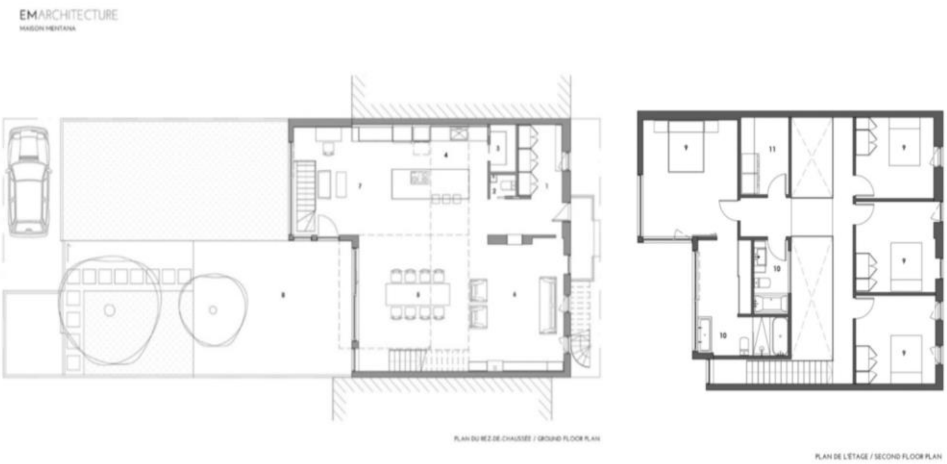

Figure 20. EM Architecture (2015). "Maison Mentana" Floor plans [Architectural plan drawing]. Montreal, Canada.

Figure 21. EM Architecture (2015). "Maison Mentana" Interior views [Photograph]. Montreal, Canada. Photographed by: Williams, A.

Figure 22. EM Architecture (2015). "Maison Mentana" Interior views [Photograph]. Montreal, Canada. Photographed by: Williams, A.

Figure 23. EM Architecture (2015). "Maison Mentana" Exterior views [Photograph]. Montreal, Canada. Photographed by: Williams, A.

3.2.2. 3D model preparation.

The modelling process is the initial step in constructing a VR Application. This study employs SketchUp as the primary modelling software. Since many of the following steps, such as materializing and lighting will be performed on Unreal Engine 5, SketchUp is a reasonable choice with its intuitive interface and vast libraries available online.

The references used when creating the 3D model of "Maison Mentana" were the original floor plans and photographs of the finished house available online. These sources were followed rigorously in order for the result to be as similar to the original project as possible. This allows easier comparison with the VR experience in the following steps.

The first step in modelling an accurate 3D model of the scene is using the tools SketchUp provides to create the base structure, consisting of the walls, floors, ceilings and door and window openings. The dimensions and proportions were followed according to the source.

Detailing the interior spaces is the following step of 3D modelling. An important factor for the scene to be realistic and immersive is to provide as much detail as possible. This was achieved by focusing on realistic decor, natural positioning of furniture and organic repetition of elements. Attention was given to minor components such as smoothed-out furniture edges resembling real-life edges, which are never perfect right angles.

The goal in the finish of the modelling phase is to come up with a realistic, detailed scene as well as a manageable file size, which wouldn’t compromise the work process of the next steps. To ensure those two aims are completed, the modelling will be focused on the outdoor area, living room, kitchen and dining area on the base floor. As for the second floor, there will be only one of the rooms and bathrooms modelled for VR demonstration.

The base structure and various elements, such as kitchen cabinets, doors, windows etc., are modelled from scratch in SketchUp. As for complex furniture and decor models, they were retrieved from two websites that provide free scenes and models for any type of use. These websites include:

The Sketchup Texture Club: A no-profit website with a focus on information and education under the company “Image Promotion Association”. The core of this portal is architectural visualization, interior design and tools, which aid with producing diverse renders. Professional architects and CGI (Computer-Generated Imagery) artists share their experiences with others by posting their works, tips, models and scenes. (SketchupTextureClub, 2023)

The SketchUp 3D Warehouse is an online user-generated gallery of a vast collection of components, materials and 3D models. This source is completely community-driven, where users can download their preferred models and assets to implement into their projects for free, as well as upload their own creations. On every 3D model available, there are shown data about its dimensions, number of polygons, file size and other details that are very useful in picking the most suitable assets for this project. (Trimble Inc., 2023)

Even though the creation of materials and textures of every object will be done later in Unreal Engine 5, in this step, it is very important to give a distinctive ID to every material which is planned to be applied. A material ID is assigned in order for Unreal Engine to differentiate them when the model is imported. The ID can be a random material, such as a color of a simple texture applied in SketchUp which will not affect the final look in Unreal Engine.

In the *Figure 24-28* below are displayed several views of the model in the current step:

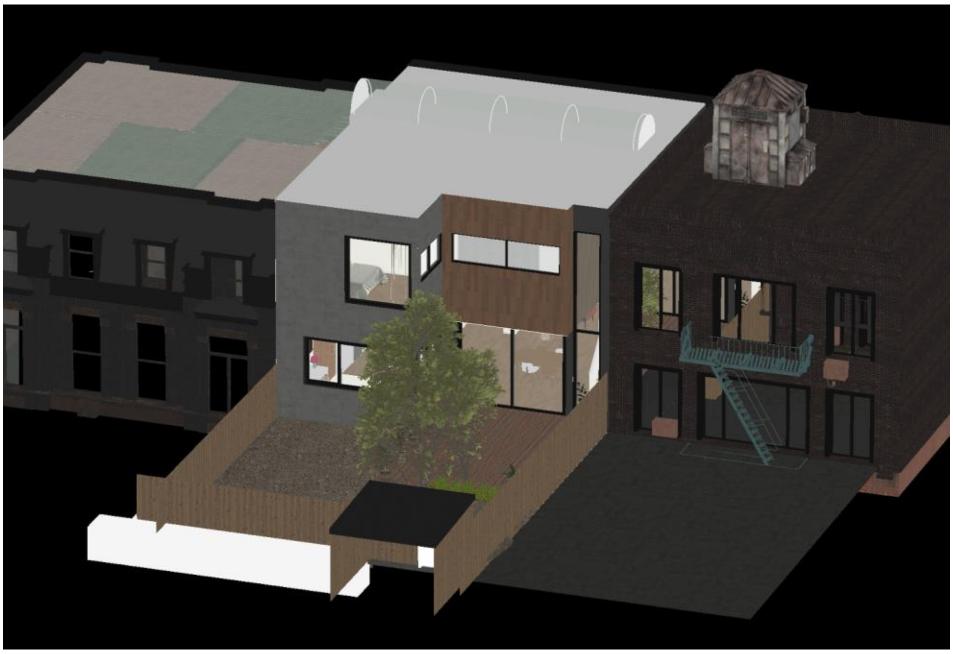

Figure 24. Overall axonometric 3D model view. [Software screenshot] Source: Author

Figure 25. Reading area 3D model view. [Software screenshot] Source: Author

Figure 26. Living area 3D model view. [Software screenshot] Source: Author

Figure 27. Bedroom 3D model view. [Software screenshot] Source: Author

Figure 28. Kitchen 3D model view. [Software screenshot] Source: Author

3.2.3. Export technicalities.

After having the scene completely modelled, the following step is to perform the export from Sketchup to Unreal Engine 5 for further processing and interactivity implementation. When working with two distinct software for modelling and visualization, there is a need for a bridge between them, which allows an accurate transfer of the 3D assets as well as the preservation of textures and material IDs from one to the other. This process was majorly facilitated by using a free plugin named Datasmith.

Developed by Epic Games, the company behind Unreal Engine, Datasmith takes in consideration every aspect needed for a project to be compatible with Unreal Engine. There are versions of this plugin, shown in *Figure 29*, that allow conversion for the most renowned modelling software available in the market. Its ability to translate assets of these different software into a Datasmith, which is read by the Unreal Engine importer. (Epic Megagames Inc., 2023)

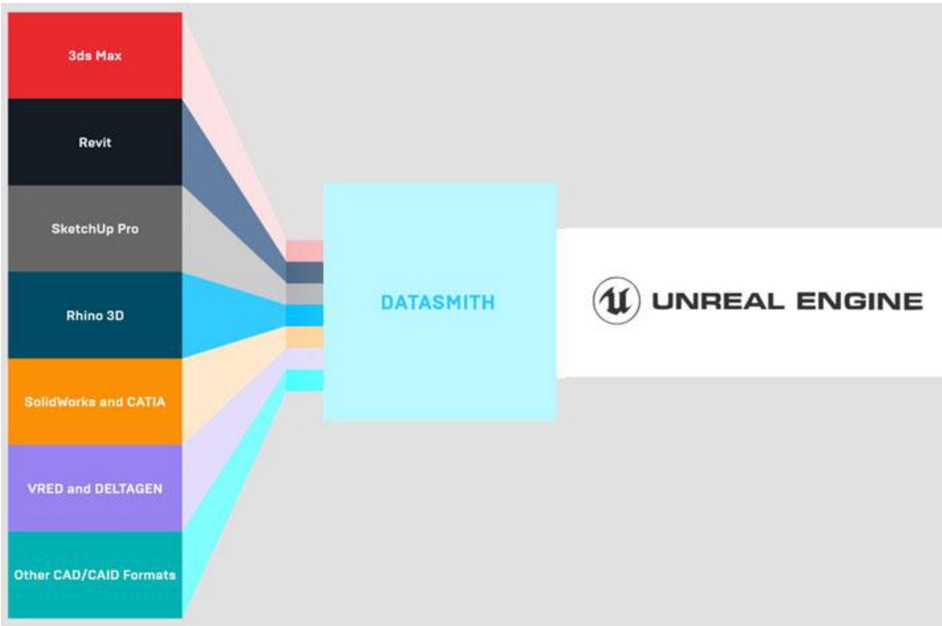

Figure 29. Software supported by Datasmith conversion plugin. Retrieved May 20, 2023, from www.evermotion.org

In order to achieve better performance taking into consideration the system resources, there is also needed attention on optimization during this step. Optimizing is realized by reducing the file size. This is done by simplifying the geometry, removing unnecessary objects and choosing furniture with a low polygon count. The optimization process is specific for every project and comes down to the decision-making of the designer on what they think can be taken out or simplified to get a better VR performance without affecting the concept of the project.

3.2.4. Lighting methods.

After having imported the model, the following step performed inside Unreal Engine is lighting. There are two lighting systems to choose from in this software, which are Lumen and Built Lighting. Each choice has its advantages and preferred use cases for achieving the desired result. In order to make an informed decision for the method used in this study, there should be an attentive analysis of both.

Lumen is one of the new technologies that was included in the Unreal Engine 5 update. It is a system that uses real-time GI (global illumination). This enables dynamic and interactive lighting effects. This system is highly realistic and natural due to its feature of indirect lighting. Using its advanced algorithm, Lumen can capture light bouncing from reflective surfaces and redirect it to other objects as it would naturally. These reflections also take into consideration the color and texture of objects. The user can control the amount and intensity of light bounces based on their computer system resources to get the finest result. When using this lighting method, the lights used to illuminate the scene, such as the sun, the ambient light and interior lights are movable, and the lighting is updated instantly. Lumen works simultaneously with a system called Virtual Shadow Maps which enables the shadows cast by the present lights to update accordingly.

Built Lighting is the traditional lighting system used in Unreal Engine 4 and above. This type of scene illumination is referred to as precomputed lighting. In this system, when light sources are placed, they do not affect the scene instantaneously.

Instead there is needed a second step known as light baking. This process calculates how light behaves and stores that information inside the scene. Every model asset in the scene has a primary channel where is stored the information about its appearance, texture, bump, reflection, mesh coordinates etc. When working with Built Lighting, a secondary channel is activated where is stored the light and shadow information. Unlike Lumen, in this case, the lighting is not real-time. Instead, the shadow on the secondary channel acts as a texture overlay. By lighting the scene in this way, the user can produce highly qualitative lighting with the compromise that every light and object has to be stationary. Another drawback of built lighting is that it has to be recalculated every time a new light or object is placed in the scene. The main reason built lighting is still widely used is performance. The light baking process can take a considerable time based on the complexity of the scene, but once it is finished and the lighting doesn't need to be computed in real time, the performance and FPS are drastically improved compared to lumen.

The choice between Lumen Lighting and Built Lighting is based on the specific elements of the architectural project and what the designer is trying to achieve. Practice is needed on each system to determine easily from the start of the project, which would be more suitable, but the main factors to take in consideration are: the desired level of realism, the hardware quality and the type of VR interaction required.

For the current demonstration project, the most suitable lighting method is Built Lighting. Considering that the VR headset chosen is Meta Quest 2, performance is a very important aspect. In order to take advantage of the headset's standalone capabilities, there is a need to consider the hardware limitations and to minimize the computational power needed. By choosing Built Lighting, the real-time calculations are considerably lowered without compromising visual quality and frame rate.

The architectural project in this study features elements that don't require dynamic animated objects. In predominately static environments as such, built lighting is the most suitable choice.

Consistency and workflow efficiency are also influencing factors in choosing Built Lighting as the lighting method. After placing the necessary lights into the scene, working with other elements such as materials, interactivity and VR menus can be developed faster in a streamlined workflow. There is no abundant need of testing between the software and the headset because once the static lights are baked into the scene, they will display the same visual output inside the headset, ensuring consistency.

3.2.5. Materializing.

Unreal Engine 5 offers an intuitive and rich workflow for creating materials, allowing the designer to produce impressive and realistic materials. The creation process is performed within the Material Editor, revolving around a node-based method.

A node-based system, as the one shown in *Figure 30*, works by connecting nodes of several material properties to sliders or textures that affect the final preview of the material. This net of connections can control texture size, color, saturation, brightness, color blending etc. Nodes are connected via a simple drag-and-drop interface, which provides ease of work and an intuitive process.

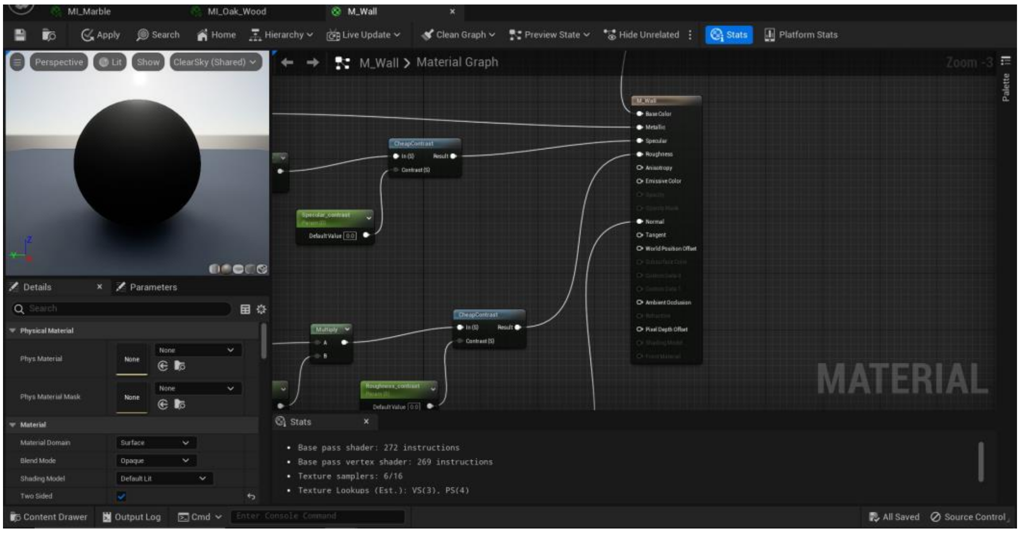

Figure 30. Node-based Material Editor sample. [Software screenshot] Source: Author

What makes the Unreal Engine Material Editor useful for architects is also the parent-child behavior of master materials and material instances. In order to retrieve a realistic material, the node net in the Material Editor gets quite crowded and complex. Doing this for every single material in the scene would be time-consuming and repetitive. To deal with this come in handy the master materials. These materials serve as templates for different instances. Each designer has their own workflow when deciding the number of material instances. A simple and efficient distribution list would be: metallic materials, opaque materials, transparent materials and emissive materials. For example, oak wood and marble slab as material instances both fall under the opaque material category. While they are considerably different, they both share similarities in terms of how a material is programmed, such as metallic property set to zero, opacity set to full etc. By having a common master material, shown in *Figure 31*, the user can build in these similarities and convert every other node that represents a difference into a parameter. When converting a node of any kind into a parameter, the user is telling the program that we want this node to be edited in each material instance.

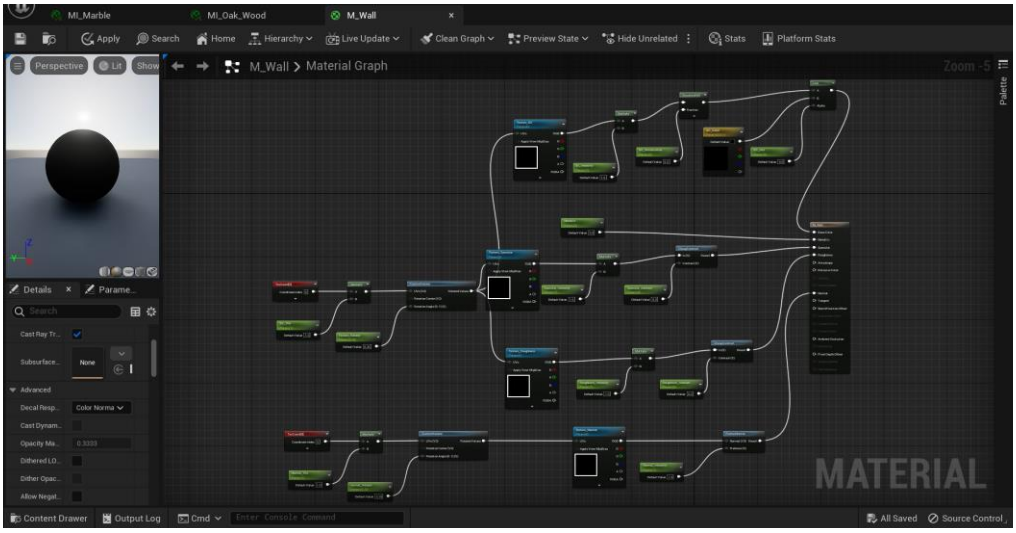

Figure 31. Master material overall net scheme. [Software screenshot] Source: Author

As was mentioned above, every designer can produce their own version of master materials. Even though background knowledge in Unreal Engine is needed to perform these processes, below will be shown and explained fragments of this master material, also displayed in *Figure 32* and *Figure 33*, which can serve as a guide.

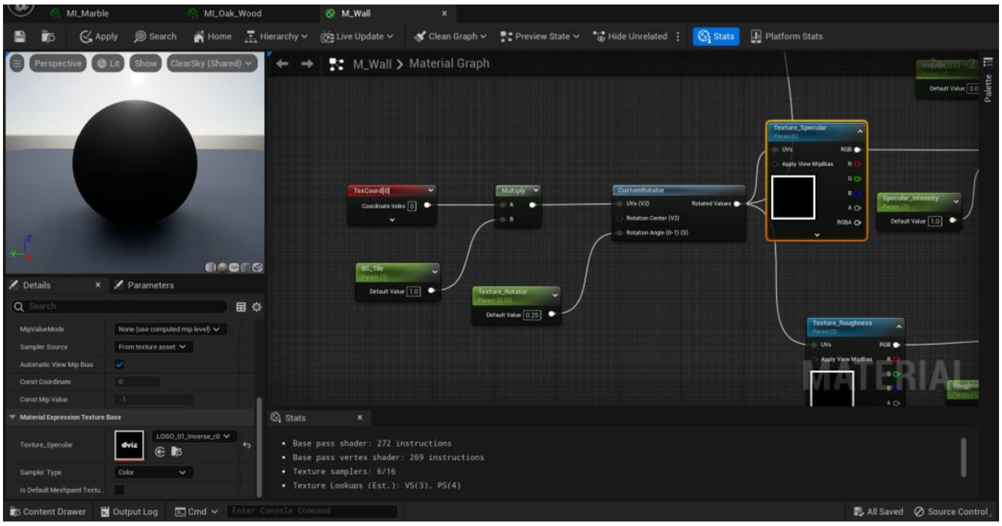

Figure 32. Master material fragment. [Software screenshot] Source: Author

The figure displays several parameters that control the texture placement. “TexCoord” is a node that represents the texture coordinates and size. “BC_tile” is a number parameter that controls the size of the texture tile. “Texture Rotator” is also a number parameter that controls the rotation of the texture, where a value of 0.25 represents a 90-degree rotation. These nodes are tied into the “CustomRotator” which can transmit these parameters into every texture needed to produce the material. The black squares displayed under each texture serve as placeholders for material instances.

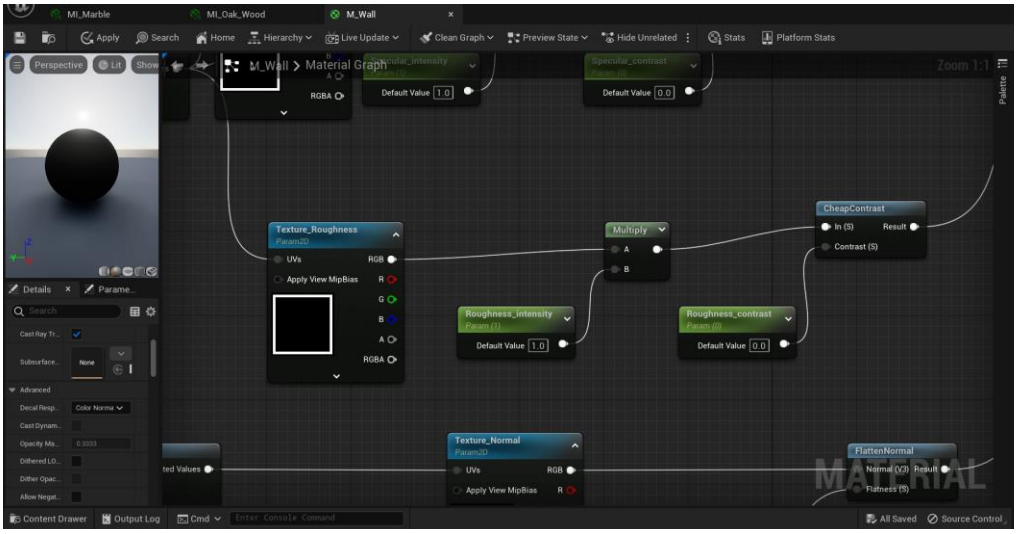

Figure 33. Master material fragment. [Software screenshot] Source: Author

After having placed parameters that control the coordinates of the texture maps, in the figure above are displayed the multiplier parameters that control the appearance of the texture maps. “Roughness_intensity” controls the brightness of the texture map and “Roughness_contrast” controls the contrast of the texture map. These multipliers are repeated for every texture present in the master material.

This master material can serve as a parent for several opaque material instances. Inside the material instance editor, the user can input the specific texture maps for every material and tweak the parameters, which were set in the master material. In *Figure 34* and *Figure 35* below are displayed the material instances of oak wood and marble slab, respectively, which both originate from the same master materials.

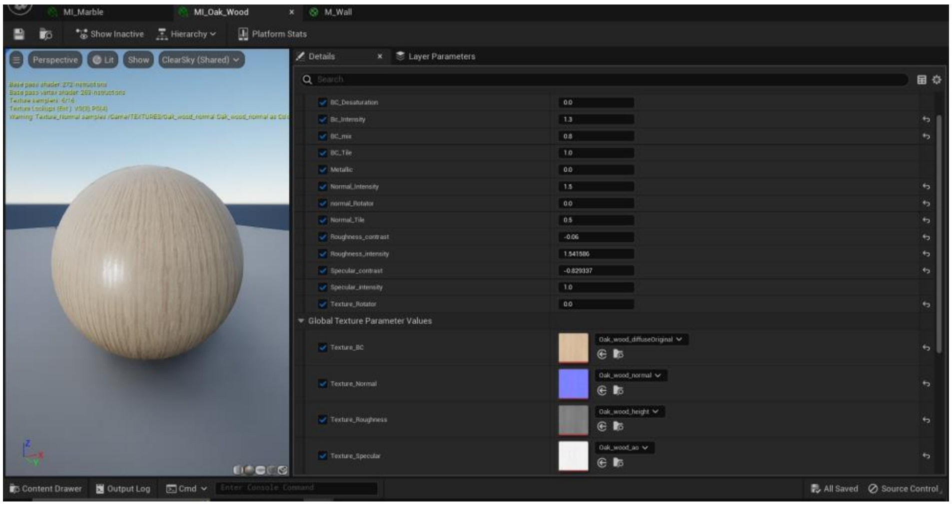

Figure 34. Oakwood instance material editor. [Software screenshot] Source: Author

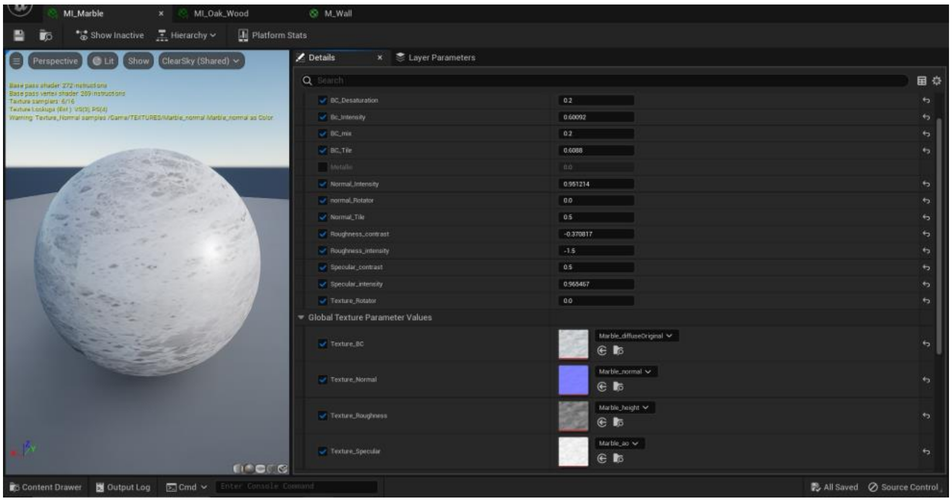

Figure 35. Marble slab instance material editor. [Software screenshot] Source: Author

This type of modular workflow makes the process highly efficient and consistent. When using the method used above, the designer can produce their own library of materials being in full control of the outcome. This library can be migrated and reused in other projects if needed, but in addition to this Unreal Engine offers a wide library of materials on its platform called Quixel Bridge.

The Quixel Bridge library, shown in *Figure 36*, provides photo-scanned materials that are free to use for any need. They can offer added realism to an architectural scene when picked carefully. Something to be aware of when using Quixel Bridge materials is the size of the texture imported. They can be highly detailed and impressive in their highest available quality ranging from 4k to 8k resolutions, but in many cases, it’s needed to import them in a lighter resolution in order not to put a high toll on the system resources and graphics card. (Quixel Bridge, 2023)

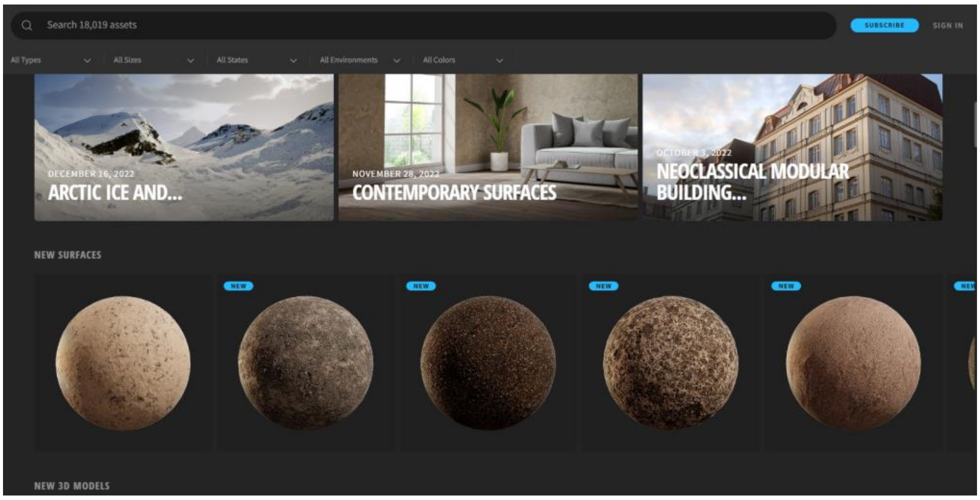

Figure 36. Epic Games. Quixel Bridge asset gallery. Retrieved May 22, 2023, from www.quixel.com/megascans/home [Website screenshot]

After creating every material needed, the application to objects of the scene is a simple drag-and-drop action. Having assigned the material IDs to every object in Sketchup, which was explained in the modelling section, the materialization process is rapid and efficient. Every object in the scene that has the same material ID will be applied the chosen material even if we drag and drop the material to only one of them. The material creation and application is repeated for every instance in the project.

After concluding with the modelling, lighting and materialization steps, the project has taken a proper shape and visual appearance. This is a rough version of how the scene will look inside the VR headset. In *Figure 37-44* below are displayed several views captured at this stage of the project development.

Figure 37. Front facade rendered view. [3D render] Source: Author

Figure 38. Entrance area rendered view. [3D render] Source: Author

Figure 39. Kitchen area rendered view. [3D render] Source: Author

Figure 40. Reading area rendered view. [3D render] Source: Author

Figure 41. Living area rendered view. [3D render] Source: Author

Figure 42. Dining area rendered view. [3D render] Source: Author

Figure 43. Kitchen area rendered view. [3D render] Source: Author

Figure 44. Bedroom rendered view. [3D render] Source: Author

3.3. Virtual Reality development.

At this stage, the project is ready for proceeding with the virtual reality (VR) development. In this section of the methodology will be discussed the types of VR interactions, how they are implemented and what effects they bring into the scene, such as enabling the user to explore the project, perform real-time changes, interact with objects etc. There is explained how the user can take advantage of the VR template provided by Unreal Engine and how they can utilize the Blueprint system. This is performed while focusing specifically on the utilization of the Meta Quest 2 headset, its hand controllers and the methods employed to make the VR experience more immersive and engaging. In the subsequent sections will be provided the detailed development blueprints for each interaction, which users with some basic prior experience with Unreal Engine can follow. A scheme depicting this process is displayed in *Figure 45* below.

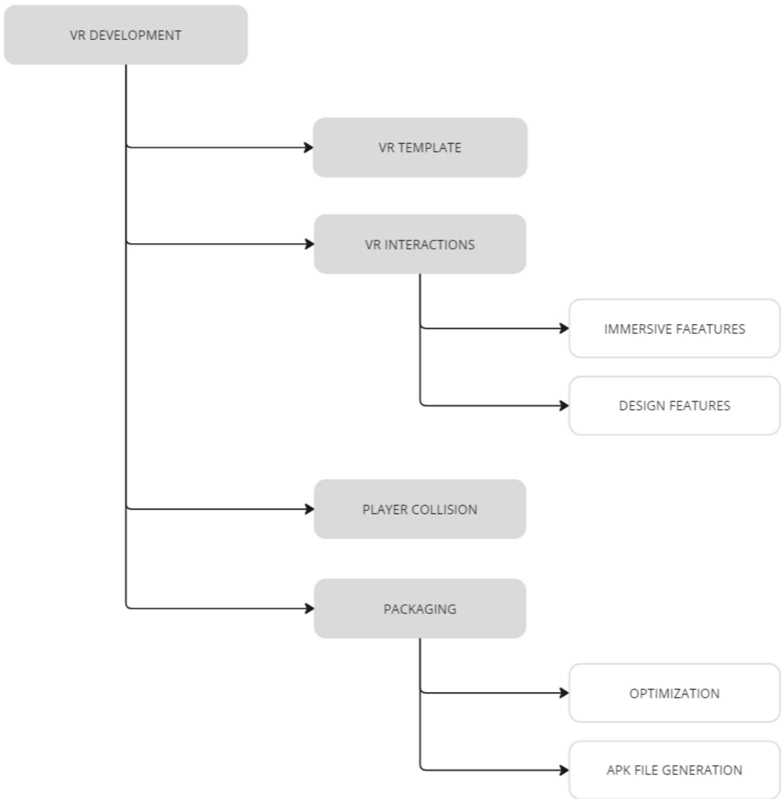

Figure 45. Scheme displaying the virtual reality development process. Source: Author.

3.3.1. Unreal Engine virtual reality template.

Among many templates, Unreal Engine 5 offers a specific template for virtual reality. This template is a pre-built framework provided by the software creators in order to facilitate the user with the VR development process. Every project template offers all capabilities for developing a VR experience, but this specific template comes with several settings preset to the needed values and with some essential features.

Part of the essential features is the VR game mode. Unreal Engine is a platform that is primarily used for game development, and since there are different types of gameplay and different types of game modes. This template comes with the game mode settings set to VR gaming which supports hand tracking, head tracking, controller support, stereoscopic rendering for each eye and spatial audio.

Performance optimization is also a very crucial element provided by this template via built-in tools. In order to achieve high frame rates and a comfortable user experience, there are implemented optimization techniques such as level of detail (LOD), rendering quality adjustments, reflection detail adjustments etc.

3.3.2. Virtual Reality interaction features.

The most differentiating aspect of Virtual Reality compared to traditional means of representing a project is the ability to view the scene as a 360-degree real-time render. The accompanying factor that makes this experience truly immersive is the incorporation of Virtual Reality interaction features. These VR features allow the user to interact with the virtual environment and engage with objects and programmed actions. By leveraging the capabilities of the software and the headset controllers. The designer can offer the viewer a realistic type of interaction and a sense of presence.

The interactions implemented into the project can be classified into two categories: design features and immersive features. The ones referred to as design features are the interactions that foster a better understanding of the architectural design choices, enable real-time insightful decision-making, as well as encourage effective communication between architects, their teams, and clients. Some examples of this category of interactions are: scrolling between different types of flooring; changing cabinet colors; changing countertop materials; turning lights on and off etc.

Immersive features refer to the type of interactivity that enhances the user experience and make the project more immersive. Even though interactions of this category are not as practical as design features, they are just as crucial for creating a sense of being present in the scene and adding to the realism. Immersive features include interactions such as: opening/closing doors; climbing stairs; opening/closing cabinets; lifting up and moving objects; controlling the TV with a remote etc. By performing these types of actions, the user can get a glimpse of how they would feel inside the project if it was built, something traditional representation methods such as renders or atmospheres do not fully transmit.

Below will be explained how Unreal Engine can be utilized to program these VR interactions via its system of "Blueprints". A list of interactions chosen to be implemented will be explained in detail on what they provide to the scene and how they can be programmed. As mentioned before, these detailed explanations can serve as a guide for designers that have a general prior knowledge of working with Unreal Engine.

3.3.3. Blueprints.

Unreal Engine offers one of the most intuitive and friendly user interfaces available for programming inside a game creation software. This user interface is named Blueprints, and it is an efficient visual scripting tool. Using this system, the user can set up various mechanics, object, character actions, as well as interactivity between all of them. These elements are programmed using a system of connections between nodes that are logically and visually understandable, which doesn't demand knowledge of traditional programming because the actual coding happens in the background. By being beginner friendly and a visual process, this method can help artists, designers and clients collaborate.

Some specific key features that the Blueprint system offers are as follows:

The drag-and-drop functionality is one of the most important time savers of this method. The user can create their own interactions, import them and/or add elements to them simply by dragging them from other files into the working file. These imports can come from previous files that the user has worked on, and they can also be downloaded from several sources, sites and forums.

Another important feature is modularity. This allows for the ability to create tailored behaviors with regard to the project requirements. Segmenting these strings into blocks of features with apparent encapsulating logic turns them into reusable functions shared across different elements or projects.

Debugging is another important ability of Unreal Engine. The system itself includes debugging tools that can aid users in identifying and troubleshoot issues in their blueprints. Users can set breakpoints in the execution and inspect where the errors are occurring, causing unexpected behavior.

The fact that the Blueprint system is an integrated part of Unreal Engine instead of a plugin makes the process seamless. The blueprints will recognize audio files and textures present in the file, and take into consideration the physics, dynamic elements etc.

Below will be presented in more detail some of these VR interactions implemented in the scene and partial guided phases on the process of their Blueprint creation.

- **Simple opening door.**

The simple opening door interaction is integrated into the upper-floor bedroom door. This interaction allows the user to grab the door handle by pressing a designated button on the VR hand controller. Once they are in close proximity to the door handle and the button is pressed, the user receives a visual indication that the command is registered, and they can open the door. While having this indication active, showing they are still grabbing the handle, the user can perform a simulated arm-swinging motion as they would while opening a door in reality. This action can manipulate the position of the virtual door asset in order to allow access to the room space. This interaction is classified under the immersive features category as it adds a layer of interactivity to the virtual environment. While this type of action doesn't change any aspects of the project design choices, it makes it more engaging, giving a sense of presence to the user.

This blueprint process involves several steps and it is displayed in *Figure 46* and *Figure 47*. The first step is setting up a "trigger press" event node. This node is connected to the "Begin Play" event node, and it guides the program to start the interaction when the decided hand controller button is pressed.

The "Grab helper" action is tied to the "Get world rotation" node. The latter mentioned enables the rotation of an asset, ignoring any other transformation added to it. This blueprint is provided with a reference actor, which is the door geometry, the rotation of which we are trying to receive. "Grab helper" requires information about any transformations occurring to the asset after rotation, which is why we use the "Get world transform" node and tie it to the initial scale of the asset.

After that, there is created a link between the "Value Z (Yaw)" underneath "Get world Rotation" and a set degree. The "Value Z (Yaw)" option is chosen because the type of rotation needed to be achieved is of the vertical hinge nature. The set degree is linked to a 90-degree variable, which tells the program we want the door to stop at a right angle as its maximum rotation. For the minimum angle of rotation, there is no value set because it is in the user's hand when to stop rotating the door.

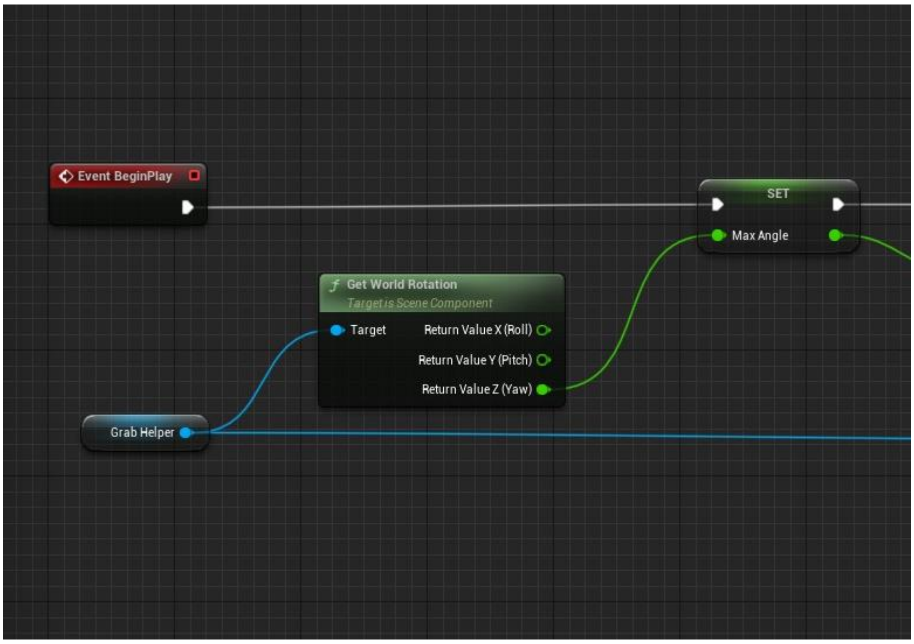

Figure 46. Simple door Blueprint system section 1. [Software Screenshot] Source: Author

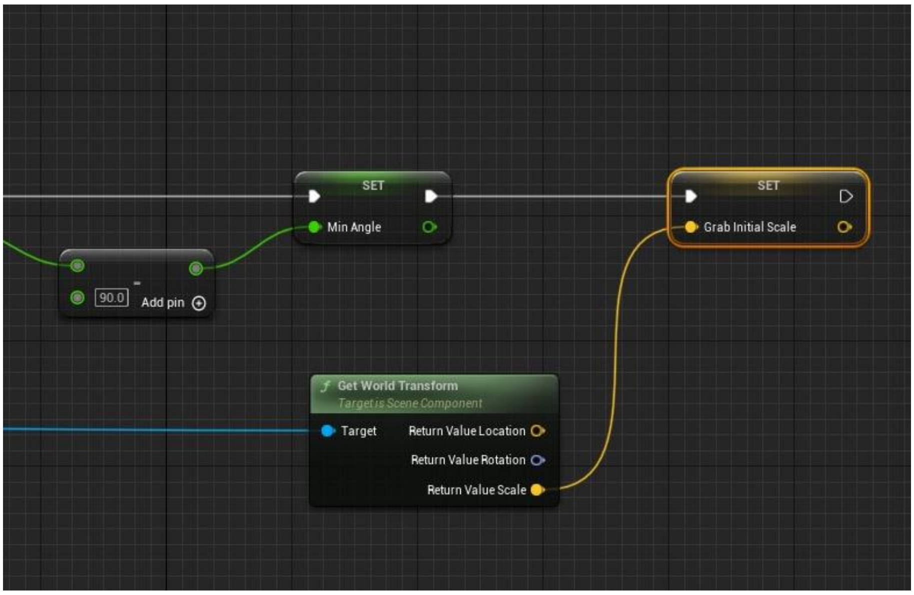

Figure 47. Simple door Blueprint system section 2. [Software Screenshot] Source: Author

In *Figure 48* below is shown the bedroom door asset to which this blueprint is attached and the action it performs.

Figure 48. Simple rotating door asset. [Software Screenshot] Source: Author

- **Light Switch.**

The light switch interaction enables the user to virtually press on a light switch, which makes the lamp asset in the scene illuminate as well as turn it off. This feature is integrated into the night light present in the bedroom on the upper floor. By pressing the trigger button in any of the two hand controllers, the user will see their virtual hand models get a finger-pointing pose. While doing that pose, they can simulate the action of pressing the light switch, and the program will trigger the event of making the lamp illuminate. This feature falls under the immersive category as it encourages the user to perform natural actions, even though it does arguably affect the design decision-making as well because it makes the user experience the scene in different lighting conditions.

The first step in creating this blueprint is creating an “OnComponentBeginOverlap" event node. This type of node makes an event start happening inside the program when two objects collide. In this particular case, it is used to detect if there is a collision between the virtual hand of the user and the light switch asset in the wall. If it detects a collision, it proceeds with the next steps inside the event. This process needs to be prepared twice for the case in which the light is on and needs to be turned off and the case in which the light is off and needs to be turned on. These cases are named “MaterialOFF” and “MaterialON” respectively. These nodes are tied to “Set material” nodes, which set the material of the lamp to a white plastic or an emissive material. Both these materials are prepared beforehand and are located in a designated folder inside the project contents. This blueprint is shown in *Figure 49* displayed below.

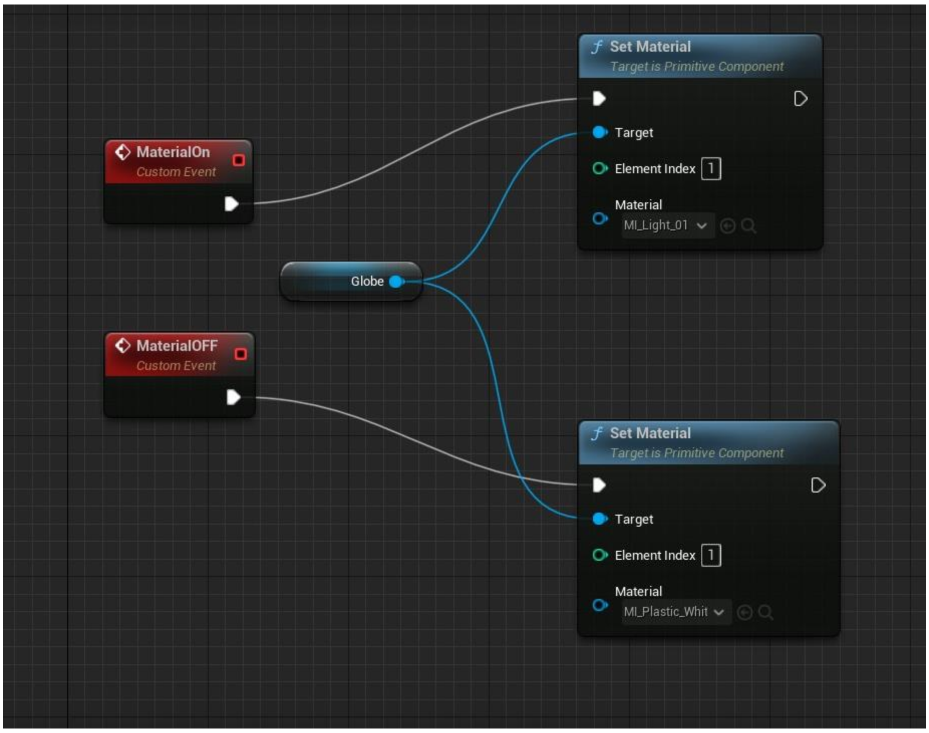

Figure 49. Light switch Blueprint system. [Software Screenshot] Source: Author

In *Figure 50* are shown the light switch and night lamp assets to which this blueprint is attached.

Figure 50. Interactive light switch and night lamp asset. [Software Screenshot] Source: Author

- **Sliding door**

The sliding door VR interaction is similar to the simple door in characteristics and in blueprint creation. It also falls under the immersive feature category providing engagement of the user inside the scene. This interaction will be implemented into the main entrance door connecting the interior to the patio. After approaching the door in a reaching distance, the user can aim at the door handle and press a designated button in the hand controller. While keeping this button pressed, the user can perform a sliding motion to open the glass door and allow access into the interior. The blueprint creation process is also similar to the simple door, with some differences explained below.

Under the "Get World Location", the target is set as "Return Value y" because in this case there is a need for a horizontal movement in the Y axis instead of a rotation. Another difference is that instead of the maximum angle of rotation in this case is used a maximum distance value. This variable is set to 140 units which is the length of the sliding door. By not connecting the minimum distance to another node, the program will allow the user to slide the door as far as they want and constrain it to stop at the starting position. The blueprint with all the differences mentioned is cut into two continuous sections, and it is displayed below in *Figure 51* and *Figure 52*.

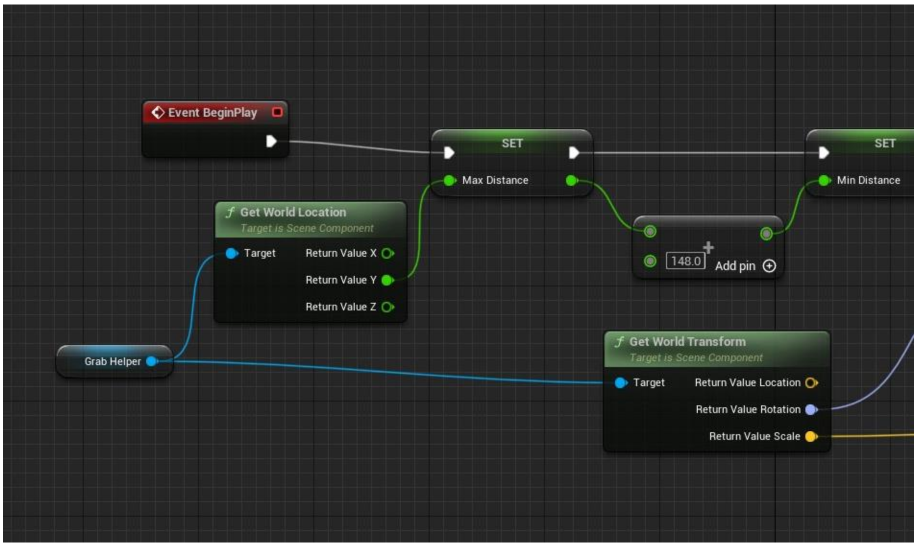

Figure 51. Sliding door Blueprint system section 1. [Software Screenshot] Source: Author

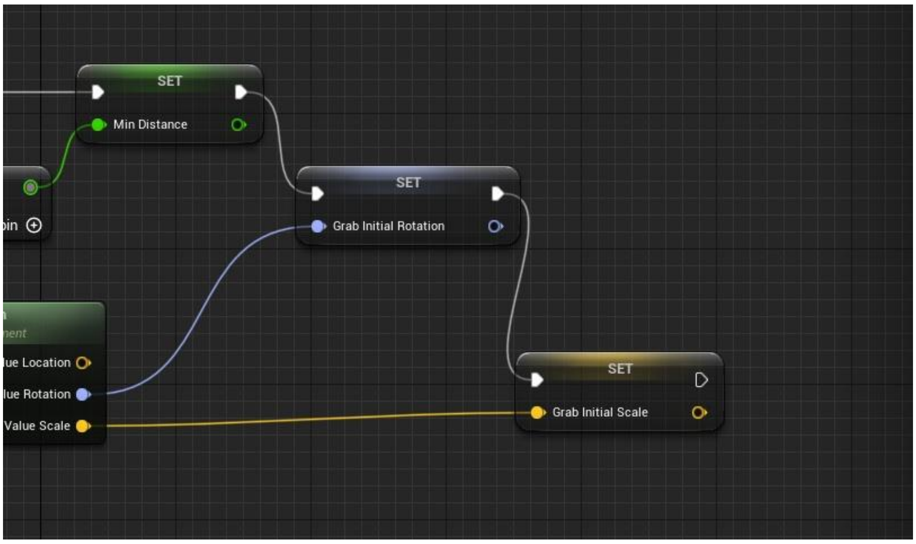

Figure 52. Sliding door Blueprint system section 2. [Software Screenshot] Source: Author

The asset to which this action is attached to and a simulation of what movement it is expected to make is displayed below in *Figure 53*.

Figure 53. Interactive sliding door asset. [Software Screenshot] Source: Author

This type of blueprint, which enables the user to move one or several objects to a certain distance in one determined axis, can be reused in different cases. Within this project, it is reused for the action of opening the kitchen cabinets. The user can grab the handle and slide the cabinet to open or close it. The asset to which this blueprint is attached for demonstration in *Figure 54* below.

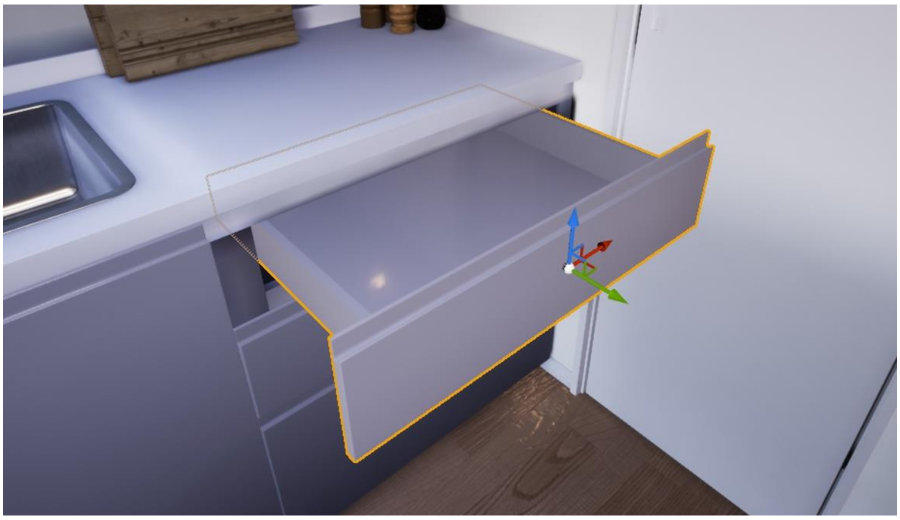

Figure 54. Interactive sliding cabinet asset. [Software Screenshot] Source: Author

- **Countertop material changer.**

A useful VR interaction in the design feature category is the countertop material changer. When the user moves close to one of the corners of the countertop, three spheres appear on top of it, displaying different material choices. By pressing the trigger of the controller, the virtual hand model of the user takes a pointing pose. While in that pose, they can move the controller in order to touch any of the spheres, and the material of the countertop will change accordingly and remain like that. This way, the user can keep moving around and see how this change affects the overall look of the environment.

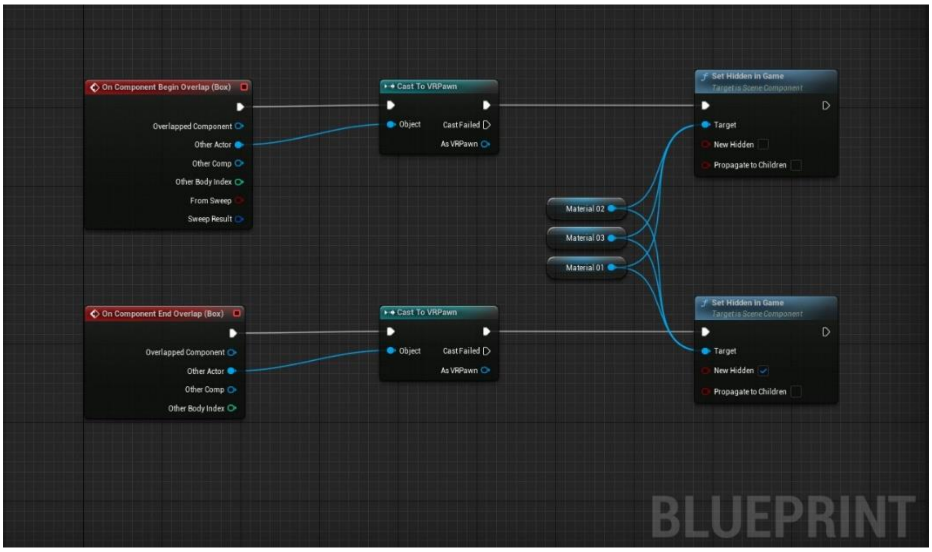

Figure 55. Countertop material changer. Blueprint system. [Software Screenshot] Source: Author

In order for this virtual event to occur, there is prepared the blueprint system featured above in *Figure 55*. The "On Component Begin Overlap" is a trigger that occurs when there is detected an overlap between two objects. This is one of the most used methods for detecting when the user enters a certain area. An invisible box is placed around the countertop corner. This box will represent the area where the user can stand in order to view the material spheres. Once the program gets the information that there is an overlap of the player and the box, "Cast To VRPawn" is activated, which makes the three material spheres appear. The opposite of this process is set up to occur when the "On Component Begin Overlap" detects that the overlap between the user and the box ends, making the spheres disappear. In *Figure 56* below is displayed the appearance of the material spheres when the user is in close proximity to them.

Figure 56. Spheres assets representing the countertop material choices. [Software Screenshot] Source: Author

The architect or designer can reuse this blueprint system in every occasion that they want to test different material options. Within this project, this interaction is implemented in two more cases. The user can test different colors on the kitchen cabinets and different parquet flooring on the base floor with this widget attached to the wall. The appearance of these cases is displayed below in *Figure 57* and *Figure 58* respectively.

Figure 57. Spheres assets representing the kitchen cabinets color choices. [Software Screenshot] Source: Author

Figure 58. Spheres assets representing the parquet flooring choices. [Software Screenshot] Source: Author

3.3.4. Challenges.

At this stage of the project, the VR development is almost complete, with the only step left being the exportation of the program and implementation into the VR headset. During the development of the application, several challenges were presented, and they were addressed with careful consideration and testing. In order for the virtual experience to run as intended, below are described the challenges which were presented and what steps were taken in order to optimize them.

- **Rendering computational power requirements and Level of Detail (LOD) implementation.**

In this project, the standalone mode of the Meta Quest 2 headset was decided as the appropriate to use. While it offers a wireless experience and mobility, it requires that the rendering computations are made inside the headset. Unlike traditional rendering or real-time rendering, which renders a single image, the VR headset needs to render a different view for each eye in order to give a realistic 3D view. This process needs double the amount of computational power. The initial tests without optimization showed a low frame rate of 15 to 18 frames per second when put inside the headset. The human eye requires 30 up to 60 frames per second in order to perceive a fluid movement. This required adequate interventions because a low frame rate can cause the user to feel uncomfortable and experience nausea or disorientation, and that might lead to motion sickness.

In order to deal with this challenge, Level of Detail (LOD) techniques were utilized. LOD allows the user to optimize 3D models by generating multiple versions with varying total number of polygons. LOD can be activated for each asset in the scene, and it's recommended mostly for complex geometry and decorations. When LOD is activated the program created multiple versions of the geometry with varying amount of detail. When the user is at a close distance from the object, the program will display the most refined and detailed version of the geometry. When they move further away from the object, the geometry model will be exchanged with the version that has a lower level of detail. This exchange occurs instantly, and it's not perceivable by the viewer. In this way, the need for computational power is drastically decreased with minimal compromise of the quality of the image. In *Figure 59* below is displayed the difference in polygons between different levels of LOD at different distances for one of the chairs in the scene. The report on top of each of them shows: LOD 1 model (full refinement) is made of 16,296 triangles; LOD 2 model is made of 10,865 triangles; LOD 3 model is made of 8,148 triangles. By reducing the amount of faces by half going from LOD 1 to LOD 3 a considerable amount of processing power is saved, increasing the frame rate.

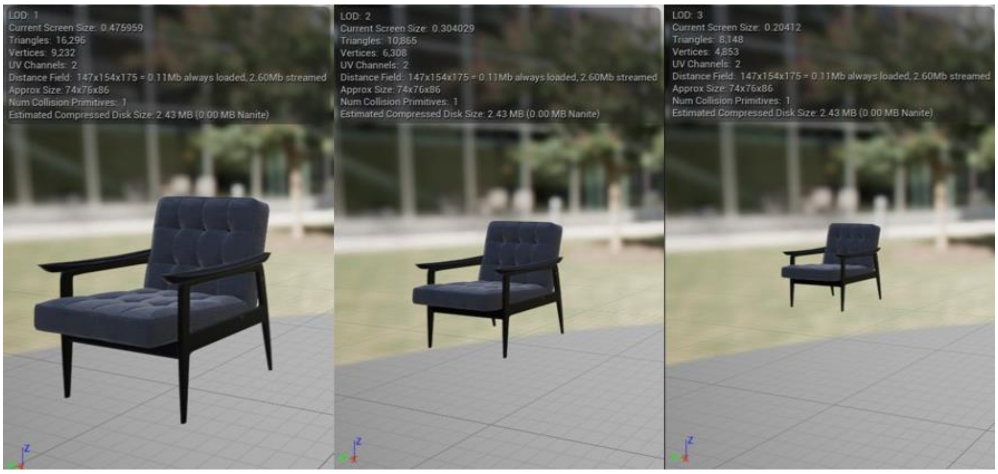

Figure 59. Three levels of LOD on various distances. [Software Screenshot] Source: Author

This LOD technique was implemented into every object inside the scene with the exception of the structure of the villa. This exception was made because the user is always in close proximity to the structure geometry, since it makes up almost the whole scene, and the implementation of LOD would show no difference.

- **Quixel Bridge material optimization.**

Quixel Bridge offers a vast gallery of photo-scanned materials with amazing quality. These textures enhance the scene by making it more realistic. However high-quality textures can significantly affect rendering performance, especially in cases like this project where real-time rendering is necessary. Upon inspection, the Quixel bridge textures sizes were even larger than all other assets of the project combined. In order to tackle this challenge, a balance was needed between realism and performance in order to meet the processing power of the VR headset without compromising the experience of the viewer. The Quixel Bridge materials were reapplied in a downgraded resolution of FullHD (1920 pixels x 1080 pixels) from the previous 8K resolution (7680 pixels x 4320 pixels). This change decreases the number of total pixels per texture by over 90%.

- **Player collision simulation.**

When running the program inside the VR headset, it runs as a game using predetermined physics in the virtual world. The user spawns inside the world and can move around freely. However, there needs to be some logical constraints on these movements, such as not being able to go through walls and making sure the player doesn't fall through the floor. In order to achieve this, collision meshes and adjusted physics settings were implemented to ensure efficient and responsive interactions. A lot of testing and readjustments were made to make sure the collisions were accurate and there were no gaps.

3.3.5. Project Exportation.

After every element described in the previous sections is implemented into the project, the last step of the VR development is exporting the project into the headset. This allows to transfer this experience from the flat computer screen to the headset lenses for the users to experience the virtual environment, bringing the architectural visualization to life. There are two methods available inside Unreal Engine 5 to perform the project data exportation for VR devices. These methods include: PC Virtual Reality (PCVR) and Standalone APK file. Both methods have their own distinct characteristics. They are both very useful in different scenarios, so considerations need to be made. Below are explained the key features of each method and the choice for this particular project.

- **PC Virtual Reality (PCVR)**

PC Virtual Reality (PCVR) is performed directly inside Unreal Engine. It requires the headset to be connected to the computer capable of rendering. A positive aspect of this method is that every headset has the ability to connect via wire to a computer. The computer handles the processing workload in this method, realizing the rendering for both lenses.

One of the biggest advantages of the PCVR method is high performance. The latest technologies in Virtual Reality headsets are considerably powerful on their own, but due to the small form factor and lightweight requirements that it has to meet, any headset is still less capable than a powerful laptop or computer. By having the computer's dedicated graphics card perform the processing, the headset can produce a more visually stunning and immersive experience.

PCVR also allows for real-time rendering, which enables dynamic visuals and making changes in the environment that automatically update, such as adjusting the time of the day.

Flexibility during the working process is also a positive aspect of the wired VR method. The developer can test, debug and optimize different aspects of the projects during the preparation phase in a faster and more efficient way by having the VR headset directly connected to the computer.

- **Standalone APK packaging.**

The Standalone APK method of exportation is a process that packages the whole project, assets and blueprints into an APK (Android Package Kit) file that can be installed on standalone VR devices, such as the Meta Quest or any other android based headset. The drawback of this method is that the performance depends on the computational power of the headset and that lighting in the scene has to remain static. The user also has to rely on the battery life of the headset for this method which varies on different devices. But it offers a lot of advantages as well.

This type of project exportation offers a wireless experience since the computation is performed inside the headset. The prepared APK file is transferred into the headset via USB connection or wirelessly via Wi-Fi or Bluetooth. After that, the user can install the APK from within the headset and launch the program to experience the VR architectural scene.

Portability is another positive aspect of Standalone APK. After the packaging is done, the whole project is compiled into one file that can be easily shared with clients or team members. This makes the process faster and more efficient because it doesn't demand the other parties to have a computer capable of running a demanding program. They can download the file even on their phone and send it inside the headset via Bluetooth.

Another crucial characteristic of the APK method is the easy setup. The PCVR can be more capable, but it requires that the developer and the viewer to be in close proximity. If they are in a remote location, they need to have some knowledge of how to perform the process, and they need to have Unreal Engine installed. For a person using this method for the first time, it can be confusing, and they would need a lot of careful instructions in order to be able to launch. In the case of Standalone APK this need is almost entirely avoided. The project file is packaged in the same way as every other game or software available for VR. Most headset owners are already familiar with this process of installation, and in the cases that they are not it is just a matter of minutes to guide them.

The method chosen for this project is the Standalone APK method. This type of exportation was chosen in order to show the capabilities of VR technology in a constrained situation. The aim of the thesis is to encourage architects, with a demonstration, that an immersive VR architectural scene can be produced even with low investment and the constraints that come with it. Another reason that this method was chosen is that for the following step of demonstrating the project to a group of people, a wireless experience is crucial for the presentation to run smoothly.

CHAPTER 4

SURVEY AND RESULTS

4.1. Survey: Demonstration of VR usage in architecture.

4.1.1. Survey overview.

As part of the methodology of this study, a survey was conducted in order to gather insightful feedback from interested parties on the implementation of virtual reality technology in architectural representation and visualization. The objective of this survey is to understand the perception of the viewer about the overall concept introduced as well as the hands-on experience, its immersion, and engagement within the architectural context. In addition, it aims to identify any limitations or problems encountered during the VR experience and interactions, which will serve for potential future improvements. The survey procedure will be explained in detail and it is displayed in *Figure 60* below.

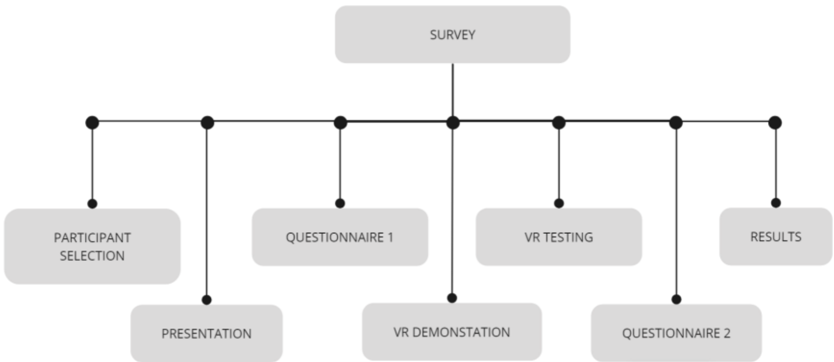

Figure 60. Scheme displaying the survey procedure.

4.1.2. Participant introduction.

The participants of this study are 43 architecture students on the first questionnaire and 20 of them in the second questionnaire. They were selected based on their interest in architecture and their familiarity and understanding of the present methods of architectural project visualization. This selected group was also chosen due to the fact that they are future potential users of this technology by implementing it into their workflow. The involvement of these participants in the survey was voluntary and based on their interest on this topic after a brief introduction and emphasis on the importance of their feedback on this study.

4.1.3. Survey procedure.

In the initial phase of this survey, a group of 43 architecture students were introduced to the topic of this study and a brief idea of what virtual reality technology is and how it can be used to enhance and add a new dimension to the architectural visualization. A set of case studies, part of the ones included in the literature review of this study, was presented to them. This was done in order to familiarize them with how this technology is present in various fields in practical ways and real-words examples. Following the case studies, they were briefly shown the process of developing the VR application, its visuals and interactive features. After the conclusion of the presentation, the students were invited to complete a questionnaire about the presentation they listened and observed in order to understand if the concept and features of this technology were transmitted to them. This questionnaire, referred to as “Questionnaire 1”, aims to extract attitudinal information capturing data about their level of interest in the topic. It also gathers insight about how familiar they were with Virtual Reality before the presentation and how effectively the presentation conveyed the usefulness of this technology. Part of the questions in this questionnaire aims to assess: the importance the participants give to realism in architecture; their inclination toward implementing this technology in their own workflow or recommend it to peers; how the participants think the VR representation of a project compares to traditional means such as renders which they are familiar with. The participating students’ input is crucial in strengthening the study’s alignment to their interest, a factor in proving its validity. (See Appendix for the full list of Questionnaire 1 questions.)

After having completed this questionnaire, the students were invited to experience a demonstration of this technology and engage with the virtual reality architectural scene firsthand. The group of students was very eager to try using the headset, and the number was limited to 20 participants due to the time needed for each of them to perform the testing. The headset view was wirelessly cast to a monitor in order for the students to see the demonstration and understand how they can use the hand controllers to move and interact with the objects of the scene.

Following the demonstration, the participants took turns in individually wearing the Meta Quest 2 headset and exploring the scene and engaging with the interactive features implemented in virtual reality. This hands-on process is very crucial because it allows the students to have a personal encounter with the immersive VR environment and its potential. Virtual reality is a type of experience that can’t be elaborated with words or shown on a screen, but it requires one to experience it in order to fully grasp it. In *Figure 61* and *Figure 62* below are displayed photographs taken during the VR testing.

Figure 61. Photograph during the VR testing. [Photograph]. Source: Author

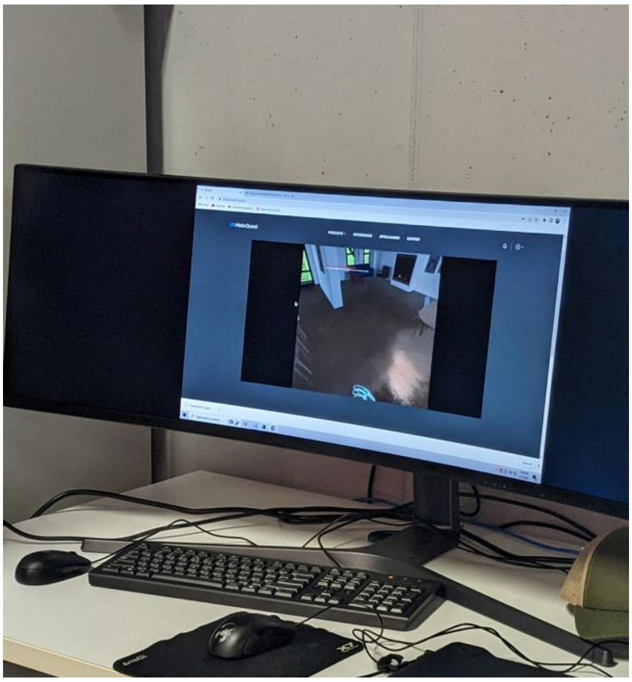

Figure 62. Photograph during the VR testing. [Photograph]. Source: Author

After all the participants engaged in exploring the scene with proper guidance, there were presented with a second questionnaire, referred to as “Questionnaire 2”, that focused specifically on their experience and impressions after trying the VR headset. The aim of this questionnaire is to capture the students’ immediate feedback and to see how the overall perception might change as a result of trying the technology themselves.

This questionnaire includes specific questions about the students’ perception when using the VR headset, and how they found the user interface used to move inside the scene and interact with the implemented blueprints. Important questions that are exclusive to the second questionnaire, because they require that the participant explores the scene firsthand, are the ones delving into the quality of visuals, level of immersion and overall impressions of this practical example of using VR for architectural visualization.

Having tested this method of project presentation, the participants can provide more informed insights and opinions about the practicality and usability of VR in the professional architectural field. Several questions assess how their perception evolves regarding the perspective of a client, decision-making, and the use of VR in architecture as a tool that enhances communication and comprehension. Several questions are repeated from the first Questionnaire in order to see the shift in the participants perspective after having tried the VR experience, which can offer crucial information affecting the results of this study.

This insight is important because it can serve as a guide on what the users may find problematic inside the program and how these problems can be solved in future developments offering an enhanced experience.

4.1.4. Data collection method.

The questionnaires mentioned above were conducted using the online survey platform named Google Forms. This platform offers an intuitive interface for preparing the questionnaires and sharing them with the participants via links or QR codes.

The participants can fill out the responses to the required questions and submit the form. Google Forms automatically collects and stores this data for each student in a structured and accurate way, lowering the chance of missing data. This advantage offered by Google Forms simplifies the data collection process.

This platform also offers the option of exporting the retrieved data into an Excel spreadsheet. After this data is exported into a spreadsheet, it can be further organized and displayed in meaningful graphs or tables. These forms of representation of the data aid the study in drawing insights, results and conclusions.

4.2. Data analysis and results overview.

In this section of the study, there are provided the responses for the questionnaires listed above and an analysis of each of these results. This analysis aims to provide a comprehensive look into the participants' answers, which offer valuable insight about the value of this application and what problematics of it can be enhanced in future developments. This analysis involves quantitative techniques, as the form questions on both questionnaires accepted answers of values 1 to 5, where 1 is "Very negative" and 5 is "Very positive". The goal of this data examination is to identify any trends in the participant answers and to compare the data between the initial set of answers and the second one regarding their opinions, preferences and interests. A combination of responses from different questions also offers a deeper understanding of the correlation of this data and the overall outcome.

In addition to the analysis made of the data extracted from the questionnaires, this section focuses on the overall results during the virtual reality application development. This segment will include final results regarding the optimization of the scene using various methods mentioned in the methodology, such as model polygon count optimization, texture resizing, using LOD (Level of Detail) etc. There will be a comparison of frame rates achieved before and after the optimizations with the goal to determine the effectiveness of these methods as an observed number of FPS (frames per second). The overall guide and workflow provided in the study for the creation of this application will be summarized as an important part of its results. These results are crucial to one of the main aims of this study, which is demonstrating the creation of a well-performing VR architecture visualization application with the constraints of a low investment setup.

4.2.1. Questionnaire 1 recorded results.

Questionnaire 1 was completed by 43 participants and the results retrieved are displayed below in *Figure 63-70*.

"Questionnaire 1" offers insightful results regarding the students' perception of the presentation about virtual reality technologies and their use in the industry, focusing on architecture. When asked about how familiar they were to VR technology prior to the presentation the results show that almost 21% of participants were not familiar with virtual reality technologies at all before listening to the presentation.

Level of interest on the topic of VR application in Architecture.

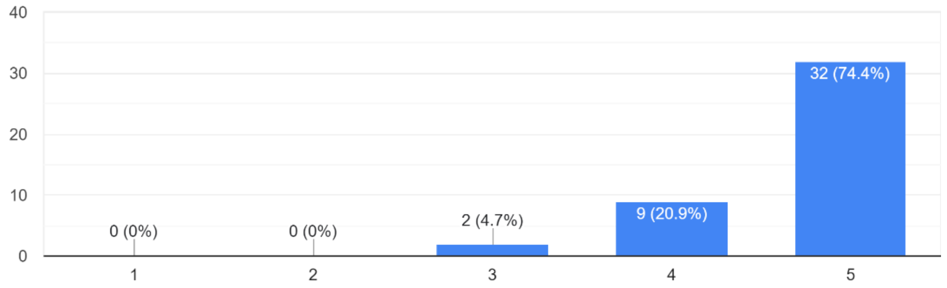

Figure 63. Chart displaying the Q1: Question 2 recorded responses. Source: Author

The results of the second question of this questionnaire show that the presentation given to the students attracted their interest in a large amount with almost 75% of the participants giving it a five rating.

Clearness of the information given in the presentation about Virtual Reality technology.

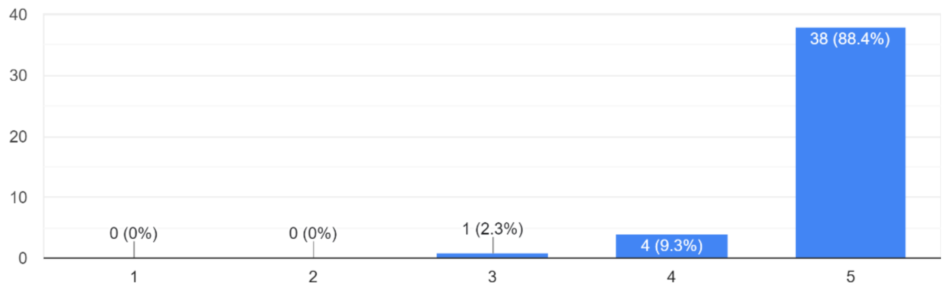

Figure 64. Chart displaying the Q1: Question 3 recorded responses. Source: Author

This question aim to examine the how clear the information given during the presentation was, which appears to have a positive tresult with a 4.86 average on the rating of the clearness of the introduction.

Importance of realism in architectural visualization.

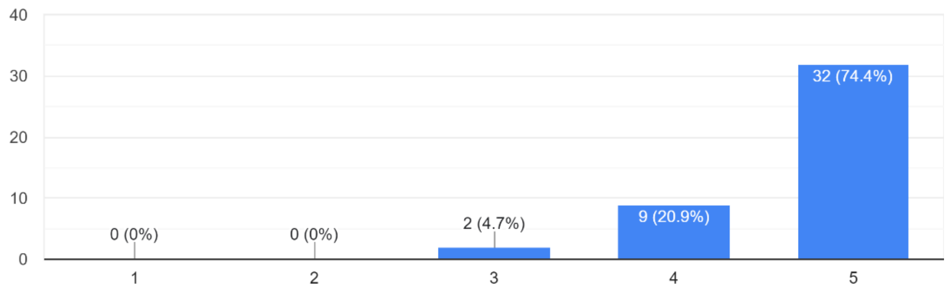

Figure 65. Chart displaying the Q1: Question 4 recorded responses. Source: Author

The results presented on the fourth question's graph display how important students perceive realism in project representation. Retrieving 9 responses with a value of 4 out of 5 and 32 answers of full rating is a very positive result considering that there are many means of visualization used in architecture, many of which are not focused on realism.

Perceived relevance of VR technology in architectural visualization.

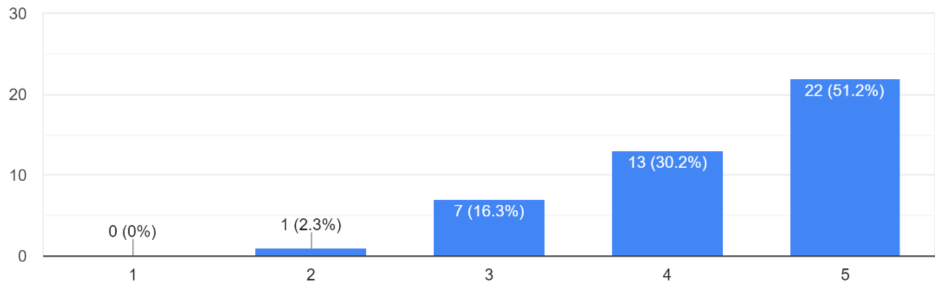

Figure 66. Chart displaying the Q1: Question 5 recorded responses. Source: Author

A slightly less positive trend is examined in the responses of "Question 5" with a 4.3 average rating on the correlation of virtual reality technologies and architecture. A factor of this is the minimal presence of architectural VR in the market, which is needed in order to identify the technology as relevant.

Willingness to use VR technology in architectural visualization in the future.

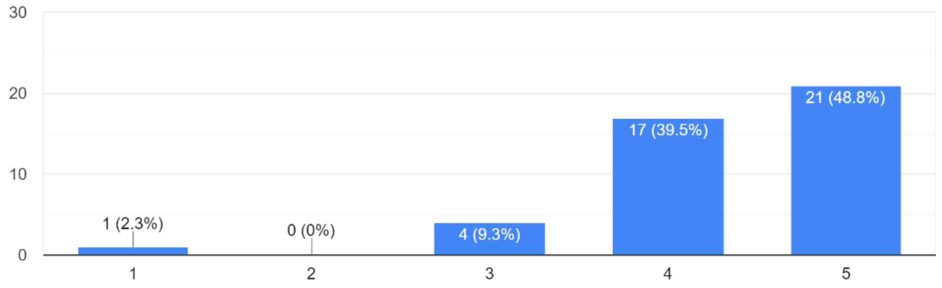

Figure 67. Chart displaying the Q1: Question 6 recorded responses. Source: Author

The results of this question bring forward a slight skepticism from the students about the implementation of VR into their own architecture workflow. Based on the verbal feedback given after the presentation, this perception was related to the complexity of VR. The students appreciated the results can VR can bring to a project but the process of making it seemed hard to learn and complex to adapt. It is insightful to analyze how this perception of the students changes after the firsthand experience of using the VR headset.

Usefulness of VR technology in helping clients understand the architectural design.

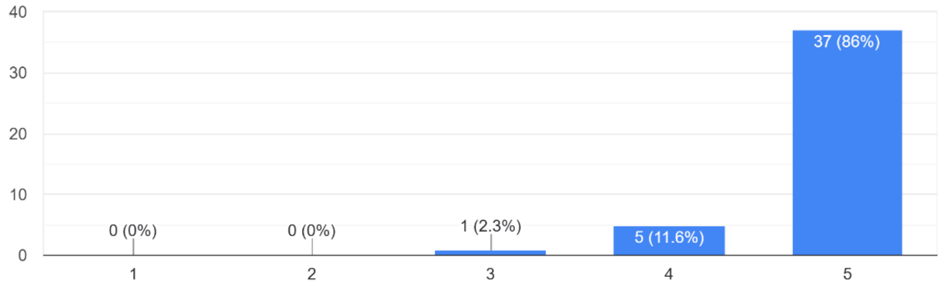

Figure 68. Chart displaying the Q1: Question 7 recorded responses. Source: Author

The high rating retrieved on the seventh question, about the impact of VR on the client's understanding of the architectural project, is one of the most important results of the questionnaire. With over 86% of the participants' rating as 5, they support one of the key points of this study, which is the facilitation of communication between the designer and the client.

Willingness to recommend the implementation of VR technology in architecture to peers.

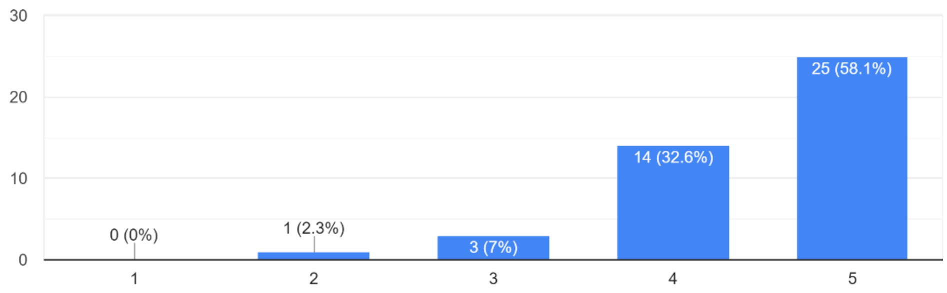

Figure 69. Chart displaying the Q1: Question 8 recorded responses. Source: Author

"Question 8", about the participants' willingness to recommend this technology to their peers, shows an overall positive result with a slightly higher average than "Question 6" about incorporating virtual reality into their own workflow. Once again this proves that the students recognize the value of VR and want to see more of it present in the market but feel not fully competent to realize it themselves.

Level of immersion compared to traditional renders.

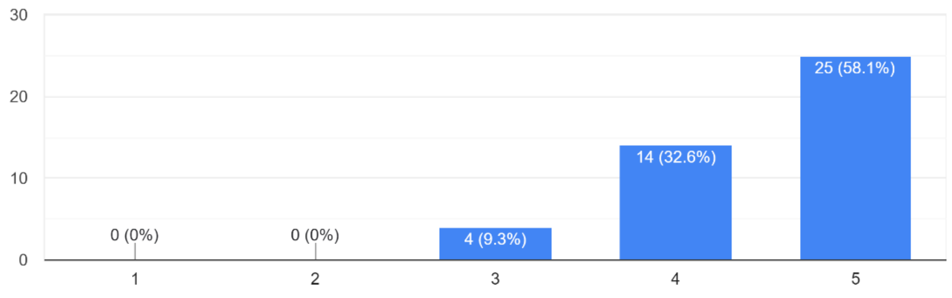

Figure 70. Chart displaying the Q1: Question 9 recorded responses. Source: Author

"Question 9" responses display a slightly doubtful overall opinion on the advantage of using virtual reality as a project representation method compared to traditional means.

4.2.2. Questionnaire 2 recorded results.

The responses retrieved from "Questionnaire 2" reveal information on the participants' opinion about their experience while using the VR headset. This questionnaire was filled by 20 participants. Several results are drawn about the VR architectural scene's realism, engagement, immersion, features and the impact it has on the participants' understanding of the project. Feedback was collected about the physical experience of using virtual reality regarding aspects such as comfort, fit and feelings of dizziness or nausea. When combined with the results retrieved from the first questionnaire, trends can be deduced regarding the students' future intentions of adopting this technology into their workflow or recommending it to other professionals in the field. The results of Questionnaire 2 are displayed below in *Figure 71-80*.

When asked about having used a VR headset prior to the testing, 90% of the students gave a negative response. These results offer insightful data relating to the participants' ease of use of the VR headset. With such a high number of the students having never used a VR headset before, it is to be expected for them to have some level of difficulty when getting used to the controls and the view of the headset lenses. It is also interesting to mention how based on the first questionnaire, almost 80% of the students are familiar with VR technology, but only 10% of the second 20 persons group have tried using a VR headset.

Immersion of the VR experience.

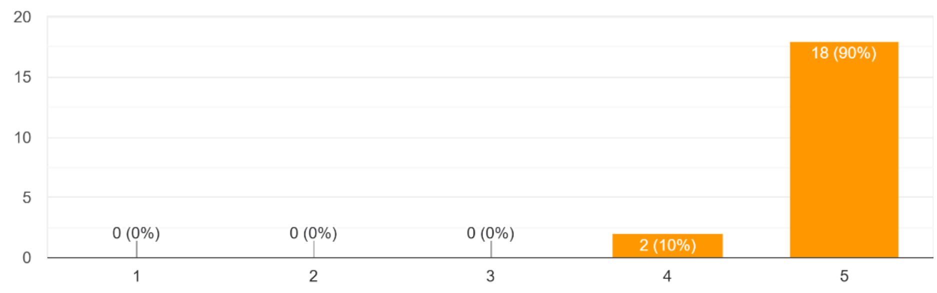

Figure 71. Chart displaying the Q2: Question 2 recorded responses. Source: Author

The results of this question have a very positive rating regarding the immersion of the scene, which is perceived as a result that validates the integration of the VR interactions into the scene as well as the overall usefulness of the headset 360-degree experience in making the user feel present inside the virtual environment.

Level of realism of the virtual environment.

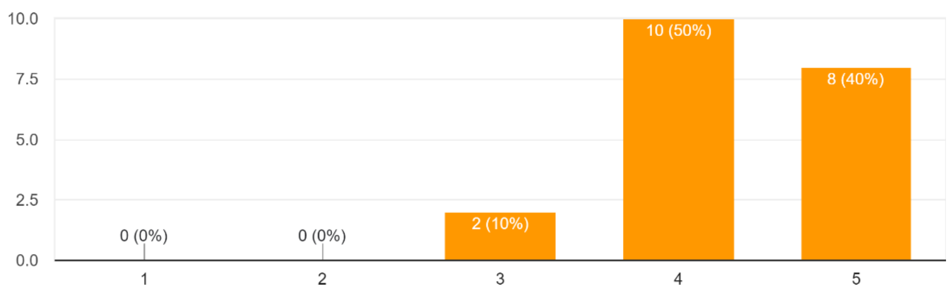

Figure 72. Chart displaying the Q2: Question 3 recorded responses. Source: Author

On the other hand, the third question appears to have a lower average at a 4.2 rating. Even though this rating is still very positive, it shows that there is a need to reconsider the compromises made during the development process about the lighting quality, material texture resolutions and polygon count.

Ease of navigating within the VR scene.

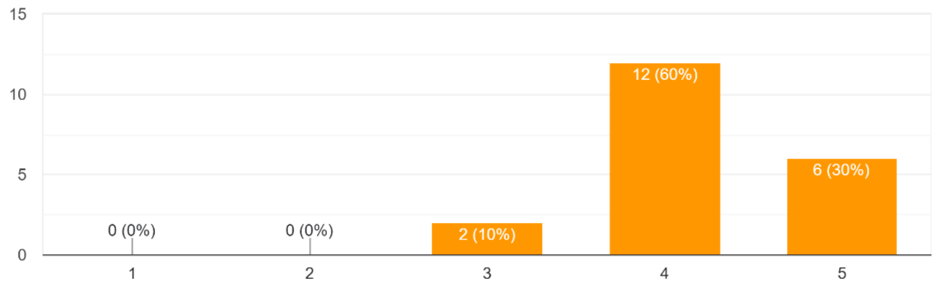

Figure 73. Chart displaying the Q2: Question 4 recorded responses. Source: Author

The forth question, about the ease of navigation inside the scene, provides very positive feedback, especially when paired with the results of "Question 1" which show that only 2 out of 20 people had tried using a VR headset before. These results are important to the study because they demonstrate that this technology can be reliable even in cases when the viewer or client has no experience using a headset before.

Level of engagement of the interactive features of the VR scene.

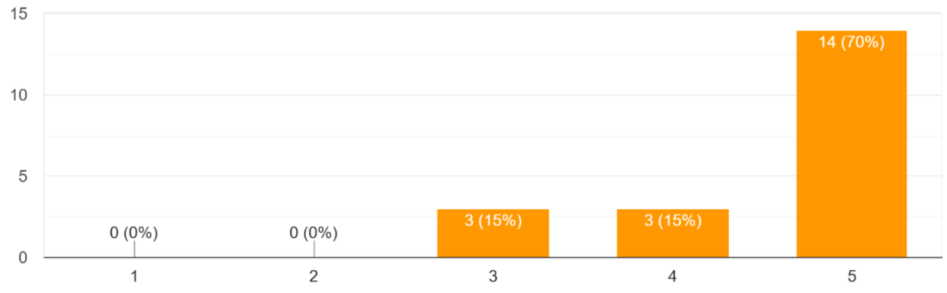

Figure 74. Chart displaying the Q2: Question 5 recorded responses. Source: Author

“Question 5” brings forward a 4.55 average rating, which demonstrates the successful implementation of various VR interactions, including the immersive and design features.

Advantage of VR technology in understanding the design compared to plan view and photographs.

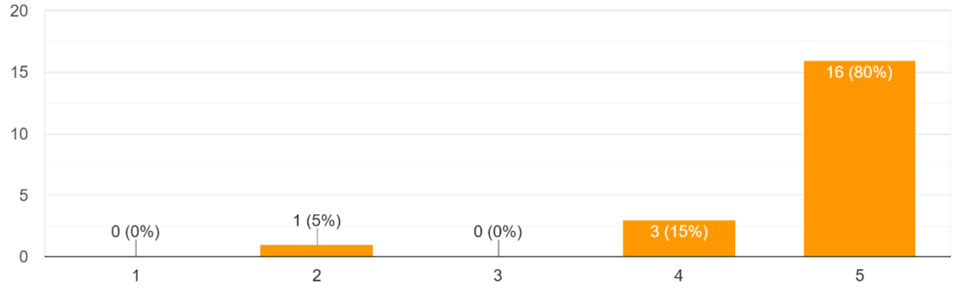

Figure 75. Chart displaying the Q2: Question 6 recorded responses. Source: Author

In the results of this question there is displayed a positive trend regarding the comparison of the virtual representation of the project and the photographs or other traditional means.

Question 7.

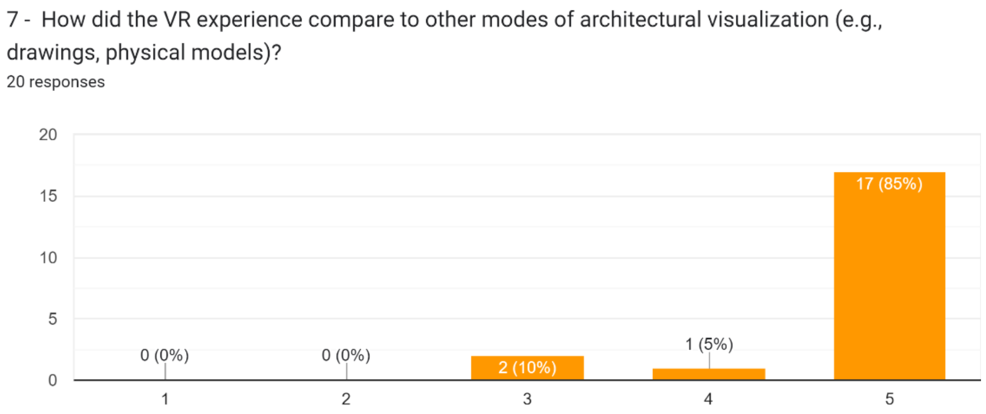

Figure 76. Chart displaying the Q2: Question 7 recorded responses. Source: Author

In a similar way, the seventh question displays very positive results when participants are asked to compare the VR experience they tried to drawings or physical models. When comparing the results of these questions to the similar "Question 9" of "Questionnaire 1" there is detected more positive feedback from the students after having experienced the VR experience themselves.

Comfort of the VR headset.

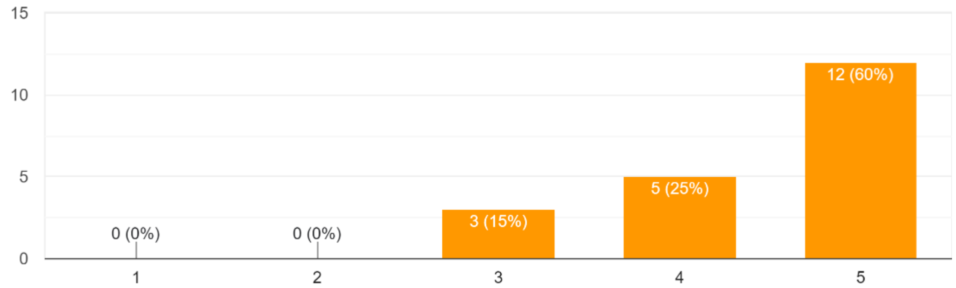

Figure 77. Chart displaying the Q2: Question 8 recorded responses. Source: Author

"Question 8" results offer insight on the comfort of wearing the VR headset. There are mixed opinions about this aspect, with a 4.4 average rating. A potential influencing factor in these results is the fact that the headset had to be passed from one participant to another with no proper time to tweak the straps in the required way for each student to have the best fit. It is important to highlight that the participants didn't experience nausea or other uneasy feelings during the VR testing.

Visual quality of the architectural scene in VR.

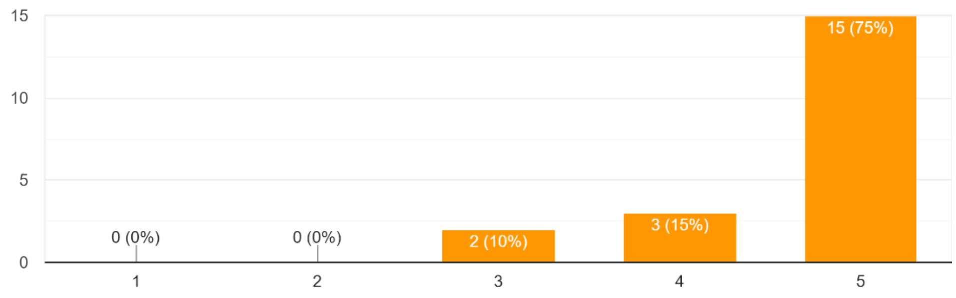

Figure 78. Chart displaying the Q2: Question 9 recorded responses. Source: Author

The positive results of the ninth question validate the optimizations made to the model and the VR components making, as well as the scene creation based on the real-life project.

Participants' willingness to incorporate the VR technology into their own workflow.

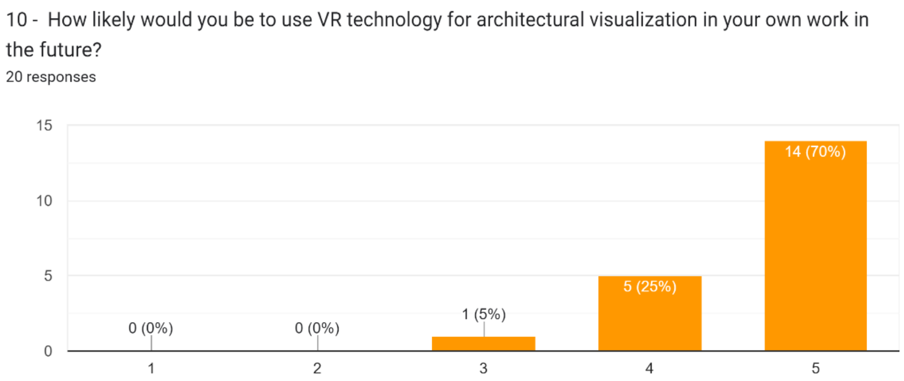

Figure 79. Chart displaying the Q2: Question 10 recorded responses. Source: Author

This question is a repeated question from the first questionnaire, and the results retrieved bring forward a slight increase in the participants' willingness to consider making virtual reality part of their own workflow.

Participants' willingness to recommend the incorporation of VR technology to their peers.

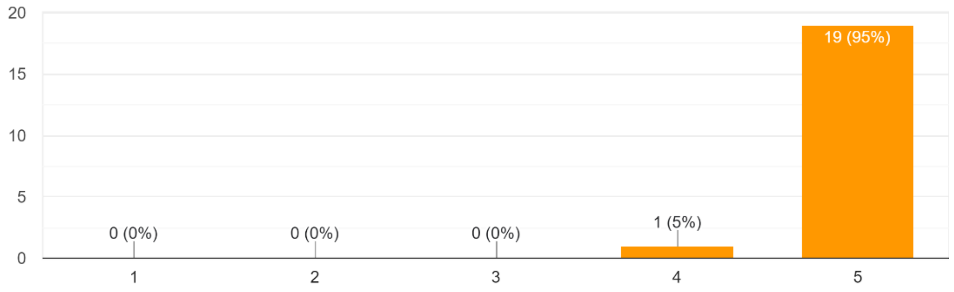

Figure 80. Chart displaying the Q2: Question 11 recorded responses. Source: Author

On the other hand, after having experienced the VR scene firsthand, the results of "Question 11" show that 19 out of 20 participants would recommend this technology to their peers. These answers demonstrate that even though, for several reasons, they are not fully considering using the technology themselves, almost all of the students recognize the potential of this concept and would like to see it being utilized more in the market.

CHAPTER 5

DISCUSSION AND CONCLUSION

5.1. Discussion.

There are several studies in recent years on the use of Virtual Reality in architecture. The relevance of this thesis, when put beside the similar studies analyzed in the literature review, is the combination of the development procedure, present in the study prepared by Johnson, George , & Hill, and the survey method performed, as seen in the study prepared by Pamungkas, Meytasari, & Trieddiantoro. This study offers details on the process of how a virtual reality application can be produced for any project, as well as recommendations on challenges along the development, based on the author's personal experience. This approach offers a comprehensive guide to readers with base knowledge in the software and hardware used. Similar studies don't delve into the specifics in such detail. Another new perspective of this study is also its major focus on one phase of the architectural process, which is the project visualization.

It is important to note that the technology of virtual reality is advancing with major steps, which becomes apparent when comparing the results of this study to the results achieved from experimental studies made several years ago such as the project presented in the study prepared by Johnson, George , & Hill. The visual quality has increased drastically. That can also depend on the methods used, but it is majorly affected by the advancements of this technology in recent years.

There are certain limitations regarding the use of virtual reality in architecture in general and limitations encountered in this specific study. The limitation of virtual reality as a tool used by architects lies on the complexity of VR development. The architect or designer is required to have at least basic knowledge of Unreal Engine 5, the software needed to develop the application. They also need to have experience in using virtual reality equipment in order to tackle challenges and errors along the process.

In the present, another limitation is the fact that virtual reality devices are not a common device for most people to have, but with recent developments in the field, this situation is expected to change with the rate of VR ownership increasing.

A limitation, which is specific to this study, is the computational power of the hardware used. This choice was made with clearly stated intentions of proving that a qualitative result can be retrieved at a low investment, but that doesn't undermine the fact that by using more powerful equipment even more qualitative results can be retrieved.

5.2. Conclusion.

As a conclusion, the outcome of this study has highlighted the potential of virtual reality in the process of architectural visualization regarding the visual quality, immersion and interactivity. The results presented in the thesis point out that implementing the VR development into the architect's or designer's workflow can create a more engaging experience for the viewer. This enables the user to feel a sense of presence in the scene and not only examine the project, but also interact with it in different ways.

Results from the participants of the VR testing show that this technology is highly appealing to potential future users and can surpass traditional project representation methods, such as rendering, regarding the understanding of the project specifics and the communication between architects, designers and clients. There is seen a slight hesitation to implement this technology into their own workflow, due to the lack of experience and steep learning curve of the software needed. While that is true, the fact that the students are almost fully willing to recommend this to peers, shows that they welcome this concept and want to see more of it in the market.

The enthusiasm and positive feedback shown by the students during the virtual reality testing is another positive factor regarding the relevance of applying

VR to architectural visualization. These inputs reinforce the perception that this method of project representation will become increasingly present in the field.

Other than the results and the insight provided by the questionnaires presented above, as part of this thesis outcomes is the workflow presented throughout the process, as well as the practical recommendations on various steps. These insights provide a comprehensive guide for architects or designers with basic knowledge of the software who seek to enhance their visualization process by using virtual reality.

The methodology procedure is structured as a step-by-step workflow that spans the entire project development phase, from the modelling of the scene, to a detailed material creation process and VR capability implementation using tools such as Sketchup, Datasmith and Unreal Engine.

Furthermore, the study gives effective suggestions about the project optimization and achieving a proper balance between the visual quality of the project and the performance of the application by utilizing Level of Detail (LOD), medium-resolution imported textures etc.

The suggestions given throughout the study are based on the author's experience and experimentation when developing the application. By consolidating these suggestions, the study not only offers a demonstration of the advantage of using VR for project visualization but also an easily accessible workflow guide. This guide can serve as an insightful resource that can be further optimized to tackle the complexities of VR development and interactivity.

The development process gives an insightful guide on what to consider when deciding on what kind of product to invest in in terms of VR headsets. It is stated that these types of applications require a lot of computational power. This means that there needs for a careful consideration on the features the different choices provide and the cost-to-quality ratio. In this study, there was used one of the easily accessible options in order to demonstrate the VR capabilities at an entry-level stage. The optimization methods included in terms of lighting methods, Level of Detail and exportation methods accompany the headset choice in delivering a qualitative result.

On the technical aspect of the application prepared in this study, there is demonstrated the effectiveness of the optimization methods proposed. An evidence of that is the ability to run the produced application in one of the most affordable headsets in the market, Meta Quest 2, with moderate computational power. The practical recommendations provided offer a valuable resource for increasing the frame rate of the final result, which reduces the chances of people using the headset to feel dizzy or uncomfortable.

The overall process of this study offers a comprehensive workflow for creating an interactive experience that pushes realism to new extents and empowers architects to explore and present their designs in a more genuine and meaningful way.

5.3. Future development.

The technology of Virtual Reality is advancing with major steps. Any new advancement in the technology allows further optimization and higher quality for applications such as the one prepared during this study. A potential future development and research on the topic is the implementation of Augmented Reality technology in a combined or interchangeable way with Virtual Reality offering more possibilities to the user.

While there are several limitations listed about the use of virtual reality in architecture visualization, future developments are expected to influence this market in a vastly positive way. At the time of this study, there are no major VR headsets that released in the past two years by major companies. This situation is about to change with “Meta Platforms” announcing the release of Meta Quest 3 in the last quarter of the year 2023. (Meta Platforms, 2023) Another major competitor, “Apple Inc.”, announced their product, “Apple Vision Pro”, as well, which will be launched in the market in the first quarter of 2024. (Apple Inc., 2023)

The fact that major companies are investing in virtual reality technologies is a very important factor because it doesn’t only offer more options in the market. But it also gives an incentive for more software developments to occur in the near future. These recent events are expected to make virtual reality gadgets a more common equipment for the average person to own as well as almost guarantee the increase of visual quality retrieved from these gadgets. These factors are very important regarding the use of VR in architectural visualization, which would encourage future architects to implement this method into their workflow.

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APPENDIX

Questionnaire 1 full set of questions.

1. Were you familiar with VR technology before listening to the presentation?

2. How interesting was the introduction to the use of VR technology in architecture?

3. How clear was the information provided about the benefits of VR technology in architectural visualization?

4. How important is realism when visualizing architectural designs?

5. How relevant do you think VR technology is for architectural visualization?

6. How likely are you to consider using VR technology for architectural visualization in the future?

7. How useful do you think VR technology would be in helping clients understand architectural designs?

8. How likely are you to recommend the use of VR technology to other architects or designers?

9. How immersive do you think VR is compared to traditional renders?

Questionnaire 2 full set of questions.

1. How immersive was the VR experience?

2. How realistic did the virtual environment feel to you?

3. How easy was it to navigate within the VR scene?

4. How engaging did you find the interactive features of the VR scene (e.g., opening doors, changing materials, picking up objects)?

5. How well did the VR technology enhance your understanding of the architectural design compared to plan view and photos?

6. How did the VR experience compare to other modes of architectural visualization (e.g., drawings, physical models)?

7. How comfortable was the headset to wear?

8. How visually appealing was the architectural scene in VR?

9. How likely would you be to use VR technology for architectural visualization in your own work in the future?

10. How likely would you be to recommend VR technology to others in the field of Architectural Visualization?