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Option: **Image and Artificial life**

Integration of virtual reality (VR) in architecture, particularly in the context of heritage restoration.

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Dedication

With love and gratitude, we dedicate this humble work to those who have been a light in the darkness, a spring in our veins, and hope in every moment of doubt and despair.

To our dear parents... You are our greatest blessing, our answered prayers, and our true support in every step we take. To you, we dedicate every success, for it is the fruit of your effort, patience, and unlimited support. You have been and continue to be the source of our determination, the wellspring of our values, and the reason for our insistence on achieving our goals.

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Abstract

Algeria, a country rich in cultural heritage, faces significant challenges in preserving its historical and archaeological sites. Many of these sites have suffered damage due to natural factors or human activity, leading to alterations in their original materials and structures. These monuments are not only essential to the nation's history but also integral to its collective memory and cultural identity. However, limited resources and difficult terrain often hinder on site preservation efforts, making it necessary to explore alternative and innovative solutions.

Modern technologies offer promising tools for safeguarding Algeria's heritage. Among them, virtual reality (VR) stands out as a powerful medium for reimagining, documenting, and presenting archaeological sites in immersive and interactive ways. Through 3D modeling and digital reconstructions based on archaeological findings and historical images, it becomes possible to recreate virtual environments that preserve the essence of lost or degraded sites. This approach allows users to experience and explore historical spaces even when the original locations have deteriorated beyond recognition.

One real world application involves using devices like the Oculus Quest 2 to create an educational and accessible digital experience for visitors, students, and educators without requiring physical travel to fragile or remote locations. Our project aims to develop a unique model for restoring a degraded archaeological site in Algeria through virtual reconstruction. By integrating phases of restoration into an engaging, interactive format, users can navigate through time and space, experiencing the architectural evolution of the site in a contemporary and meaningful way.

ملخص :

تواجه الجزائر، البلد الغني بالتراث الثقافي، تحديات كبيرة في الحفاظ على مواقعها التاريخية والأثرية. فقد عانى العديد من هذه المواقع من أضرار بسبب العوامل الطبيعية أو النشاط البشري، مما أدى إلى تغييرات في موادها وهياكلها الأصلية. هذه الآثار ليست أساسية لتاريخ الأمة فحسب، بل هي أيضاً جزء لا يتجزأ من ذاكرتها الجماعية وهويتها الثقافية. إلا أن محدودية الموارد ووعورة التضاريس غالباً ما تعيق جهود الحفظ في الموقع، مما يجعل من الضروري استكشاف حلول بديلة ومبتكرة .

تقدم التقنيات الحديثة أدوات واعدة لحماية التراث الجزائري. ومن بين هذه الأدوات، يبرز الواقع الافتراضي كوسيلة قوية لإعادة تخيل وتوثيق وعرض المواقع الأثرية بطرق غامرة وتفاعلية. من خلال النمذجة ثلاثية الأبعاد وإعادة البناء الرقمي استنادًا إلى الاكتشافات الأثرية والصور التاريخية، يصبح من الممكن إعادة إنشاء بيئات افتراضية تحافظ على جوهر المواقع المفقودة أو المتدهورة. يسمح هذا النهج للمستخدمين بتجربة واستكشاف الأماكن التاريخية حتى عندما تكون المواقع الأصلية قد تدهورت إلى درجة يصعب التعرف عليها .

يتضمن أحد تطبيقات العالم الواقعي استخدام أجهزة مثل Oculus Quest 2 لخلق تجربة رقمية تعليمية يسهل الوصول إليها للزوار والطلاب والمعلمين - دون الحاجة إلى السفر الفعلي إلى المواقع الهشة أو البعيدة .

يهدف مشروعنا إلى تطوير نموذج فريد لترميم موقع أثري متدهور في الجزائر من خلال إعادة البناء الافتراضي. من خلال دمج مراحل الترميم في شكل تفاعلي جذاب، يمكن للمستخدمين التنقل عبر الزمان والمكان، ومعايشة التطور المعماري للموقع بطريقة معاصرة وذات مغزى .

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Introduction

Entering the world of computer graphics has always been the beginning of an endless fascination, often beginning with video games. It leads users into immersive digital worlds that allow them to see reality from a new perspective, or even experience places and objects that don't exist in the real world. In this context, virtual reality (VR) stands out as one of the most important and cutting-edge technologies of our time. It allows users to interact with digital environments that simulate reality or create entirely new worlds by combining the senses, imagination, and technology.

The concept of virtual reality first emerged in the 1950s, but it didn't gain widespread popularity until the late 1980s, thanks to the efforts of pioneers like Jaron Lanier, who coined the term "Virtual Reality." Since then, virtual reality has seen tremendous advancements in hardware and software, enabling it to enter numerous sectors such as education, healthcare, industry, and entertainment. However, one of its most promising applications is in the fields of architecture and cultural heritage, where it contributes to the preservation and revitalization of historical sites in a realistic and safe digital manner.

With the continued deterioration of many heritage sites due to natural or human factors, and the rising costs of traditional restoration, there is a need for alternative digital solutions that combine accuracy, effectiveness, and affordability. This project aims to provide a practical solution: the development of a virtual reality application that simulates endangered heritage sites and reconstructs them in 3D within an interactive virtual environment.

This application enables users, whether students, researchers, professors, or even tourists, to explore these sites remotely in an immersive manner, enhancing understanding, education, and cultural awareness. It also offers extensive customization capabilities and a safe experience, free from the challenges of physical restoration.

This thesis is divided into several interconnected chapters:

Chapter One: Provides a comprehensive definition of virtual reality, its history, mechanism of operation, types, areas of use, and the difference between it and augmented reality and virtual environments.

Chapter Two: Reviews the relationship between virtual reality and architecture, focusing on its uses in heritage restoration, particularly in the Algerian context.

Chapter Three discusses the concepts of heritage preservation through technology and presents the proposed system for virtually reconstructing historical sites.

Chapter Four describes the technical solution used in developing the application, from the development environment, hardware, and software, to the design of scenes and user interfaces, and presents the results obtained from the application prototype.

This study aims to demonstrate the effectiveness of virtual reality as a tool for preserving cultural heritage and pave the way for the adoption of innovative and sustainable digital solutions in the field of architectural heritage.

Chapter 1

Introduction to Virtual Reality

1 Introduction

In recent decades, the world has witnessed tremendous technological advancements, and Virtual Reality (VR) technologies have been at the forefront of these innovations. These technologies are no longer limited to entertainment, but have expanded to encompass multiple sectors such as education, health, industry, engineering, and the arts. Virtual reality is a computer-generated digital environment that allows users to fully immerse themselves within an artificial world, stimulating human senses to simulate a real or imaginary experience. Augmented reality, on the other hand, integrates virtual elements with the real world, allowing the user to see virtual objects interacting with their natural environment. Mixed reality, on the other hand, combines the advantages of both realities, allowing for direct interaction between real and virtual objects. To understand these technologies more deeply, it is necessary to understand the definition of virtual reality, its history, how it works, its different types, and its diverse applications. It is also important to examine the concept of augmented reality and its comparison to virtual reality, the idea of a virtual environment, how it is created, and the nature of virtual space. Finally, mixed reality, its definition and how it works, will be highlighted to understand how the interaction between the real and virtual worlds has evolved. This study aims to provide a comprehensive and integrated overview of these revolutionary technologies and their profound impact on the future of technology and human communication.

2 Definition virtual reality

Virtual reality (VR) is an interactive,[1] three dimensional computer generated environment that immerses users in a simulated multimedia world. It enables individuals to engage directly with digital settings that closely resemble real world scenarios. Today, VR is increasingly used as an educational and training tool across various domains, such as engineering, medicine, design, architecture, construction, education, and professional training, offering significant potential to enhance learning and performance.

Based on the immersion and user engagement level, virtual reality can be broadly categorized into two main types: immersive and non immersive VR. Immersive VR typically involves advanced display systems such as large room-sized screens or stereoscopic head-mounted displays (HMDs). These systems are often complemented by specialized equipment like motion tracking suits, gloves, and high performance computers to enhance the sense of presence within the virtual environment.

In contrast, non immersive VR relies on conventional personal computers for simulation, facilitating interaction through standard input devices such as keyboards, mice, joysticks, or touchscreens.

Virtual reality is often considered the natural evolution of 3D computer graphics, a technology rooted in advanced input and output systems. Only recently has it matured enough to support meaningful technical applications. Numerous businesses and government agencies are actively exploring ways to integrate VR into their design and manufacturing processes. With today's technological capabilities, projects demonstrating the practical benefits of VR in product development and design are now feasible.

Virtual reality refers to any synthetic environment capable of creating a convincing sense of reality. Any artificial setting that gives users the feeling of "being there" fits this definition. While most virtual environments are computer-generated, some may incorporate real world elements such as video feeds or hardware augmented immersive systems for telepresence applications .

3 History of Virtual Reality

The evolution of virtual reality since its inception can be [2]summarized in the following figure 1.1, which outlines the key stages and milestones that have contributed to the development of this technology over time.

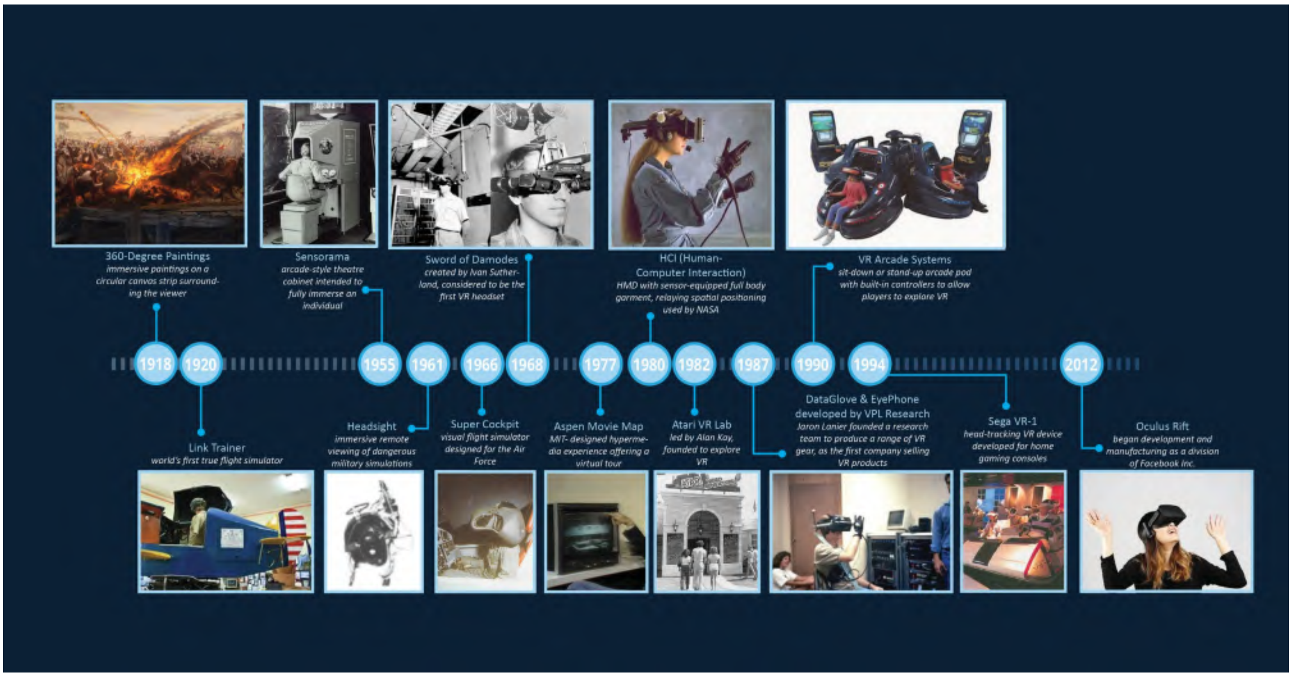

Figure 1.1: Timeline of Historical Events Surrounding VR Creation & Implementation [2]

4 What is Virtual Reality

In contemporary usage, when someone refers to virtual reality (VR), they typically mean a binocular head-mounted display (HMD) that presents a two dimensional (2D) perspective projection of a virtual scene to each eye. Like the natural retinal projections experienced in the real world, these dual images allow the brain to perceive three-dimensional (3D) depth and spatial relationships. [3]

To simulate this natural visual mechanism, VR systems incorporate motion parallax, which arises from the observer's movement within the 3D environment. This dynamic visual feedback distinguishes VR from static 3D technologies such as stereoscopes, haploscopes, and conventional 3D monitors. As the user moves, their changing viewpoint generates new image pairs, helping the brain resolve ambiguities in scene structure by comparing successive retinal inputs just as it does in the real world.

5 How Virtual Reality Works

The core principle behind VR is to create a convincing sense of presence (the feeling of "being there") by delivering visual stimuli that closely mimic what the eyes would receive in a real world environment. Crucially, these visual inputs must update instantly as the viewer's point of view changes. Spatial perception in VR relies on various visual cues such as relative size, brightness, and angular motion, with perspective being one of the most influential. In binocular vision, the differing views seen by each eye known as binocular disparity form the basis of stereoscopic depth perception. [4]

A phenomenon called eye parallax contributes significantly to this illusion of depth. Each eye sees a slightly different image, especially for nearby objects, enabling the brain to infer distance and spatial positioning. However, this effect diminishes for distant objects, where both eyes receive nearly identical images.

Standard VR equipment includes a head-mounted display with separate screens for each eye, simulating natural binocular vision. These displays render slightly different perspectives of the virtual environment, updating in real time as the user moves their head. This responsiveness creates a compelling illusion: users feel like they are actively controlling their movements, rather than being passively tracked by the system they perceive themselves as the cause, not the consequence, of the visual change .

5.1 Working Principle of Virtual Reality

At its core, a VR system operates through a continuous loop of input, processing, and output:[5].

- First, the system captures the user's real world movements.
- A computer then updates the virtual environment based on these inputs.
- Finally, the updated scene is rendered and displayed to the user via a head-mounted display or other immersive output device.

This real-time interaction allows users to see only the rendered virtual world, creating a strong sense of immersion. They feel as if they are physically present within the digital environment, interacting with it naturally and intuitively

5.2 Types of Virtual Reality

There are 3 primary categories of virtual reality simulations used today: non immersive, semi-immersive, and fully immersive simulations. [5]

5.2.1 Fully Immersive Virtual Reality

An immersive system substitutes computer generated graphics that respond to the user's position and orientation for our real world vision. [5]

One can view such an environment using a head mounted display (HMD). When using a fully immersive device, the user genuinely feels a sense of presence in the surroundings. In this situation, the user is not in visual contact with the real world. figure 1.2

Figure 1.2: Immersive Virtual Reality
[5]

5.2.2 Non immersive Virtual Reality

However, a non immersion technology allows the user to see the virtual world through a display while being visually aware of the real environment, such as a graphics workstation. Another name for it is a semi-immersion system. [5] Advanced virtual reality simulators for ships, cars, and flights are semi-immersive. While the outside world's perspective is computer-generated (usually projected), the cockpit, bridge, or driving seat is a real replica.figure 1.3

Figure 1.3: Virtual Reality that is not immersive [5]

5.2.3 Virtual Reality Hybrid

With virtual graphics placed on top of the real environment, the user can see the latter. [5] These systems are sometimes referred to as "augmented virtual systems of reality" figure 1.4

Figure 1.4: Virtual Reality Hybrid
[5]

5.3 Components of Virtual Reality

1. **Stimulus:** Objects or targets designed to facilitate face-to-face interaction with users. [6]

2. **Environment:** A virtual training environment includes a variety of equipment operation scenarios intended for instruction and learning.

3. **Tools:** These refer to machine end-effectors interacting with the environment or stimuli during virtual reality training.

4. **Realism of the input device:** Reflects how accurately the input device replicates real-world functions and operations, enhancing immersion and effectiveness in training.

6 Application of Virtual Reality

There are many uses for virtual reality these days, but some of the most significant ones are as follows:[5]

- Sports and Training
- Business and Marketing
- Education and Learning
- Medicine and Healthcare

- Engineering and Design
- Architecture and Urban Planning
- Manufacturing and Industry
- Art and Culture
- Entertainment and Gaming
- Data Visualization and Concept Development

6.1 Business

The business community uses virtual reality in a variety of ways, such as: [5]

- training for new hires.
- and virtual tours in a commercial setting.
- A 360-degree perspective of any product figure 1.5

Figure 1.5: VR in Business
[5]

6.2 Simulation and Training

Virtual reality environments have been used for training [5] simulators. VR from a training perspective allows professionals to conduct training in a virtual environment where they can improve their skills without the consequence of failing the operation. Examples include flight simulators, battlefield simulators for soldiers, paratrooping, and combat training for the military figure 1.6

Figure 1.6: Simulation and Training
[5]

6.3 Education and Conferencing

Another field that has embraced virtual reality for teaching and learning scenarios is education. This allows extensive student groups to engage with one another and in a three-dimensional setting. It can make difficult information understandable and enjoyable for kids. [5] Additionally, these kids can learn more about the objects in that environment by interacting with them. The best illustration of how virtual reality can be more beneficial is when medical students create 3D pictures of the human body or surgery simulations that they can safely explore This figure 1.7

Figure 1.7: VR in education
[5]

7 Definition of Augmented Reality

A subset of virtual environments (VE), or virtual reality as it is more well known, is augmented reality (AR). A user is fully submerged in a synthetic environment thanks to VE technology.[7] The user is unable to see the actual environment around him. AR, conversely, enables the user to view the real environment with virtual things composited or superimposed on it. As a result, AR enhances reality rather than replacing it. In an ideal world, the user would think that the virtual and actual things were in the same room, much like the effects in the movie "Who Framed Roger Rabbit?" is an illustration of how this could appear. It displays an actual desk and phone. Two virtual chairs and a lamp are also present in this space. Remember that the items are merged in three dimensions, with the real table partially covering the two virtual chairs and the virtual lamp covering the actual table. AR can be viewed as the "middle ground" between telepresence (wholly real) and virtual reality (VE).

8 Main differences between VR and AR

Characteristic	**Virtual reality (VR)**	**Augmented reality (AR)**
User experience	VR completely immerses users in a simulated environment, disconnecting them from the physical world.	AR integrates virtual content with the real world, enhancing the user's perception of reality in the physical world.
Interaction with the environment	VR restricts interaction to only the virtual environment and requires specialized controllers or hand-tracking devices.	With AR, individuals can engage with virtual and physical objects in their real-world environment.
Hardware requirements	VR experiences often require a dedicated VR headset with controllers and other sense-tracking devices.	AR experiences can be accessed through smartphones, tablets, or specialized AR glasses.

Table 1.1: Comparison between Virtual Reality (VR) and Augmented Reality (AR) [8]

Virtual Reality (VR):

- Where VR is replacing our vision.
- Virtual reality is regarded as a fully immersive experience that isolates the real world.
- Wearing a particular headgear allows users to go from the actual world to a virtual imagining setting. The HTC Vive, Oculus Rift, or Google Cardboard are high-priced headsets.
- VR transformed our surroundings and transported us to new locations for both games and apps. It makes no difference where we are physically located.[9]
- 75% of VR is virtual and 25% is real.

- Users who utilize virtual reality technology are cut off from reality and transported to a fictional or imaginative world.

Augmented Reality (AR):

- It is enhanced by augmented reality.
- Augmented reality adds 3D digital items or features to our live perspective of the outside world.
- Examples of augmented reality experiences include Snapchat lenses and filters and the game *Pokémon Go*, which uses the smartphone camera to add virtual objects to real-world views.[9]
- A clear disadvantage of augmented reality is that its apps can only project visuals within a specific region in front of a user's eyes and only appear on their smartphone or tablet screen.
- Approximately 75% of AR is real, while 25% is virtual.

9 Definition of environments

The engineering team at AIRETT developed a virtual system. This system can identify the body's position in real space and recreate it in the virtual environment. The girl's movements are so determined and then replicated in a virtual environment, leading to virtual object interaction. A stereo camera detects body movements and applies artificial vision techniques to accurately recreate a simplified representation of the body (skeleton) in a virtual environment. AIRETT's team created a three-part Web application to track the girl's interactions with the virtual world.[10] First, a computer vision component was built to detect and depict the individual's skeleton. Additional analysis of the skeleton revealed the participant's reaching motion. Google MediaPipe served as the basis for this component. Second, Unity created a virtual environment that replicated the scene in which the objects appeared. Third, a user interface was created to establish the movement parameters, about the participant's physical characteristics or preferences (e.g., the choice between the left and right arm, the magnitude of the shoulder angle to activate the reaching movement), or to select an object from a list of objects that appeared in a scenario, or, ultimately, to simultaneously record the participant and the computer screen for additional analysis.

10 Creation of the virtual environment

Creating a virtual environment is a complex process that combines various disciplines such as 3D modeling, programming, software architecture, and sometimes even artificial intelligence. This environment can be used for various applications, including architectural reconstructions.

10.1 Main steps for environments creation

1. **Define the objectives:** Before any creation, it is essential to determine the objectives of the environment: Is it a realistic or stylized space? Is it intended for navigation, interaction, or simply observation?

2. **Worldview:** This phase consists of drawing models, defining the topology of the space, establishing the list of interactive elements, and planning usage scenarios.

3. **3D modelling:** Using specialized software like Blender, Maya, or 3ds Max, Unity 3D, artists create the objects, buildings, and landscapes that will make up the universe.

4. **Integration into an engine:** The 3D models are then imported into a game or simulation engine like Unity or Unreal Engine. This is where we manage:

   - Lighting
   - Textures
   - Animations
   - Interaction scripts

5. **Programming interactivity:** Developers code the behaviors of the environment: how the user moves, interacts, or triggers events.

6. **Optimization:** To ensure a smooth experience, environments must be optimized: reducing texture weight, simplifying models, managing collisions, and dynamic loading of scenes.

7. **Tests and adjustments:** numerous user tests allow us to correct bugs and improve the immersive experience.

10.2 Tools and technologies

- Modeling software: Blender, 3ds Max, SketchUp
- 3D engines: Unity, Unreal Engine
- Programming languages: C#, C++, Python
- Virtual reality headsets: Oculus Rift, HTC Vive, Meta Quest

10.3 Concrete applications

- **Architecture:** Virtual tours of buildings before construction
- **Education:** Immersive training
- **Health:** Exposure therapies
- **Heritage:** Reconstruction of ancient monuments in VR

11 Mixed Reality

11.1 Definition of Mixed Reality

According to Croatti and Ricci (2018), MR is the blending of the real and virtual worlds to create new landscapes and scenarios in which digital and physical items coexist and communicate in real time. Milgram and Kishimo have characterized the MR hardware[11]:

- Video displays that use immersive head mounted displays (HMDs) in place of monitor based (non immersive) video displays, such as "window on the world" (WoW) displays;
- Head-mounted displays (HMDs) with see through capabilities allow computer generated graphics to be optically superimposed onto directly viewed real world scenes using half silvered mirrors.
- Systems similar to the above, but using video viewing of the external world instead of direct optical viewing.
- Fully graphic display environments that can be fully immersive, partially immersive, or otherwise enhanced, with video "reality" added to the experience.
- Completely graphic but partially immersive environments (such as large screen displays), where real physical objects in the user's surroundings are integrated into the computer-generated scene for example, allowing the user to reach in and "grab" a virtual object with their own hand figure 1.8[11]

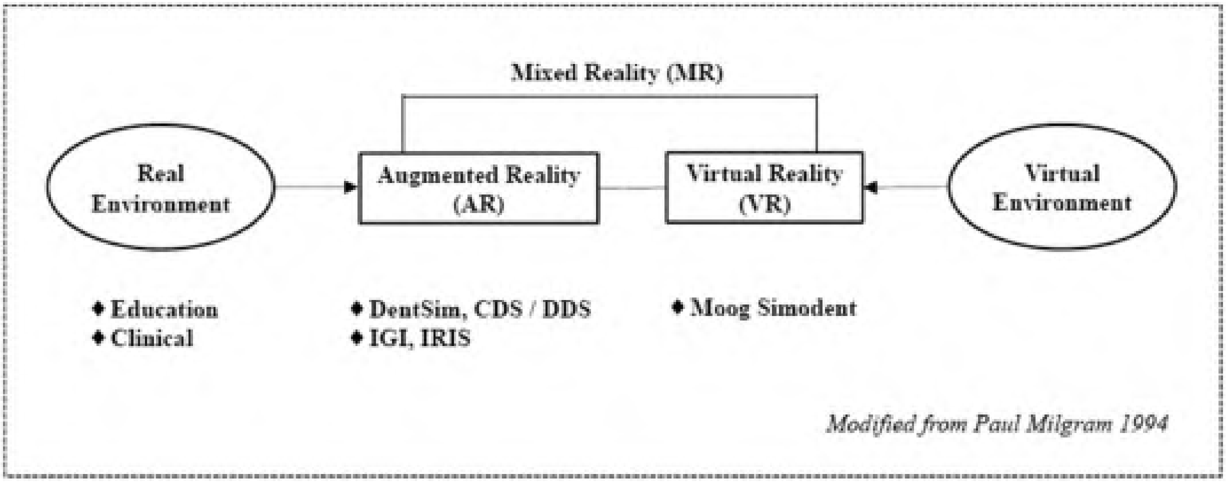

Figure 1.8: Mixed Reality[12]

11.2 Mixed Reality works

Sensors give a computer information about our physical environment, which is how mixed reality operates. From our perspective, the computer appears to be experiencing reality. A computer processor can sense a wide range of information about our environment by using various sensors, including the locations of items in a room, the amount of ambient light and sound, and our precise location as we move through space.[13]

- **Computer vision:** This technology enables a computer to interpret visual data such as images or videos and respond appropriately. In mixed reality, computer vision is used to perceive and understand the real world.
- **Cloud computing:** This allows access to software, systems, or other information over the cloud instead of locally on a device. An example in mixed reality is Azure Remote Rendering, which provides on-demand graphical processing via the cloud.
- **Input systems:** These include controllers and other devices that allow users to interact with the mixed reality environment. Other examples include gesture recognition and pointer-based interaction.
- **Graphical processing:** To render 3D visuals, graphical processing units (GPUs) are used. This component enables the projection of digital visuals onto real-world environments in mixed reality.
- **Display technologies:** These include smartphone screens, computer monitors, and television displays that render visual information. Display hardware is essential for viewing digital content in many types of mixed reality.

12 Uses of virtual reality

12.1 Healthcare

Virtual reality (VR) is revolutionizing training and therapy in the healthcare industry[14]. The FDA authorized EaseVRx, a prescription VR system for managing chronic pain, in November 2021. The technique treats individuals with chronic pain using deep relaxation, attention-shifting, cognitive behavioral therapy (CBT), and interoceptive awareness. Virtual reality has been proven to be an effective and non-invasive tool for treating pain associated with burn injuries.figure 1.9

Figure 1.9: VR in Healthcare[14]

12.2 Retail

"The metaverse" is going to impact how we shop online [14]significantly. Thanks to body scanning technologies and virtual reality retail experiences, we can try on clothing in the virtual world to see how it would appear in person. Customers can determine whether the item fits their size and shape before placing their order, saving time and reducing the environmental impact of producing and transporting fast fashion.

Numerous businesses, such as the European retailer ASOS, have invested in software development firm Trillenium to provide us with the VR shopping experience. Similar to fashion weeks held in New York and Paris, the Metaverse now has its own.

12.3 Architecture

Virtual reality (VR) is revolutionizing how architects plan and envision places by providing a more engaging and dynamic means of seeing structures before they are built. Designers can make more accurate and effective design choices by exploring areas, materials, and lighting in a 3D virtual world, just as they would in real life. Changes can be made in real time, enabling tight collaboration and project improvement between architects and clients throughout the design stage.

Foster + Partners, for instance, used virtual reality (VR) to create the Bloomberg European Headquarters in London. This allowed clients and architects to tour the virtual building and make changes before the final design was finalized.[14] Homeowners who wish to expand or remodel their properties may benefit from virtual reality. Before building starts, they can experience and see how the room will feel and appear, making any necessary alterations. Ensuring that the end product meets their expectations saves time and money, while boosting customer satisfaction. This strategy is even used in popular media, like the UK TV program Your Home Made Perfect, where competing architects show homeowners their virtual reality ideas before the commencement of actual construction figure 1.10

Figure 1.10: VR in Architecture
[15]

13 Conclusion

In this chapter, we have defined Virtual Reality, its basic components, how it works, how to interact with it, and how the virtual environment affects this world through its components and how it interacts with them. We have also provided an explanation of the differences between virtual and augmented reality, how to combine the two worlds, and how they work. Many fields utilize virtual reality, including education and healthcare. Through this master's thesis, we have chosen to utilize virtual reality in architecture, with a specific focus on heritage reconstruction.

Chapter 2

Heritage restoration

1 Introduction

Architecture is a branch of both art and design, as well as a branch of engineering. With the development of the world, architecture has evolved alongside it in all its specializations, including construction and building. Virtual reality has facilitated the work, as it has become possible to see the building as it will be before it is built in reality. We have chosen the field of heritage restoration, as heritage sites have become extinct due to weather factors and the age factor, as virtual reality has become an assistant in rebuilding heritage and preserving it from extinction.

2 Definition of architecture

The art and science of designing and building buildings and other structures is known as architecture. It includes not just the building's aesthetics but also its functionality, security, and comfort. The architects are responsible for designing buildings, planning their locations, selecting building materials, optimizing the buildings' functionality and security, and overseeing their construction.

One could argue that architecture manifests a society's values and culture. Different architectural styles can be found in various eras and regions, depending on factors such as climate, technology, available building materials, and cultural beliefs.

Iconic structures like the Burj Khalifa, the Taj Mahal, and the Tour Eiffel are frequently seen as representations of human ingenuity and outstanding architecture.[16]

Architecture can be seen as an expression of a society's culture and values. Architectural styles vary from one era to another and from one region to another, depending on climate, technology, available building materials, and cultural beliefs. Iconic buildings such as the Eiffel Tower, the Taj Mahal, and the Burj Khalifa are often symbols of remarkable architecture and human creativity. Figure 2.1.

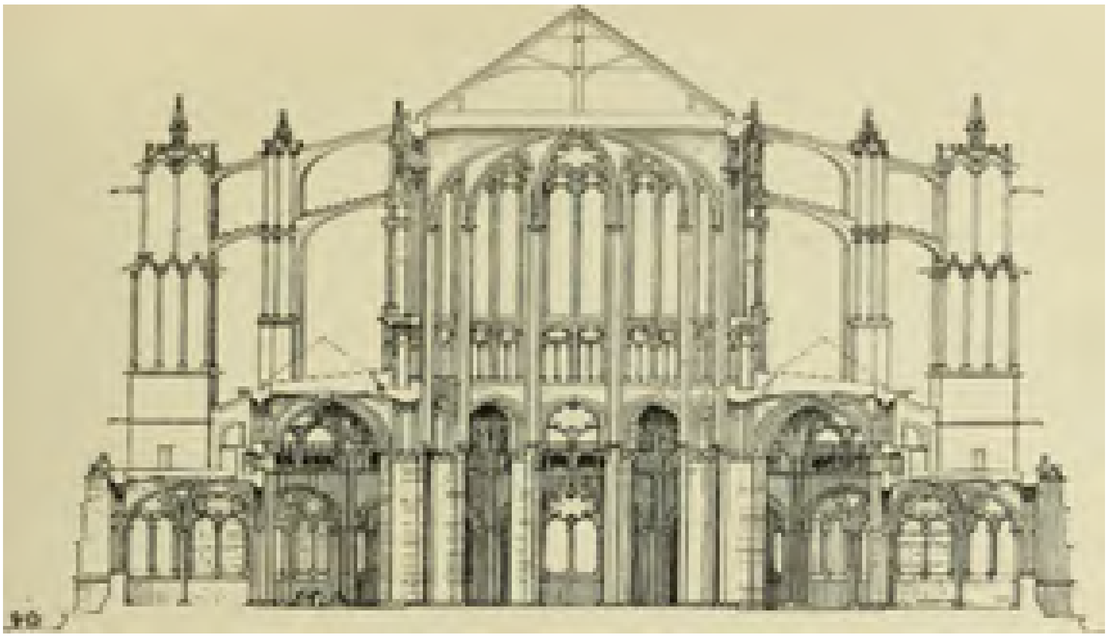

Figure 2.1: Architecture[17]

3 Virtual Reality for Architects

3.1 Definitions

As VR technology has advanced, its applications have expanded to nearly infinite levels. Virtual reality has transformed how people use technology by providing new channels for knowledge sharing, process visualization, communication, and the expression of original concepts. Virtual reality (VR) depicts real-world 3-dimensional environments, including buildings, landscapes, archaeological sites, sculptures, and reconstructions. These virtual environments have the potential to be shared, animated, interactive, and to reveal features and behaviour.

One of the main fields where virtual reality is having a significant impact is due to its immersive nature and the crucial role of visualization in it. Buildings can be simulated and explored virtually through virtual reality (VR), enabling research on topics such as functionality, construction technology, and performance. Architects can utilize virtual reality (VR) to enhance the quality of their designs by studying and evaluating the final product before it is completed. Architects can better communicate design concepts to clients and consumers by using virtual reality (VR) without requiring them to comprehend technical presentation notation .[18]

Additionally, VR makes it possible to compare different design options according to user requirements and aesthetic impact in addition to technical and functional criteria . VR allows the student architect to enhance design abilities by more accurately relating abstract representations to the actual sense of shape and place. The use of virtual reality (VR) also enhances the design training process since it makes it easier to understand criticism and remarks that may be difficult to realize from traditional abstract representations when a simulation of the building is experienced.

3.2 Integrating VR in Architecture

Businesses have been increasingly utilizing technology in recent years to transform their designs and create virtual worlds that are ready for exploration. Virtual reality is a crucial component of that. VR makes it easier to explore the area up close. To get a better look at a listing's various features, viewers can zoom in and out, examine it from multiple perspectives, and interact with interior aspects, such as opening and closing doors.[19]

To provide stakeholders with a more thorough and accurate understanding of the actual design, it offers a more immersive experience.

It creates an emotional bond with clients by illustrating how the place might appear when constructed, including floor plans, layout, texture, materials, and other elements. They can actively explore well-planned locations for themselves rather than scouring technical and occasionally uninspired 2D drawings and sketches.

3.3 The uses of VR for Architects

Undoubtedly, the patterns in the utilization of virtual reality for visualization walkthroughs and analytical simulations like energy, circulation, facilities management, virtual construction, marketing, teamwork, design decision-making, and rebuilding are all significant and considered. Architecture is arguably one of the most effective real-world uses for virtual reality. It can effectively increase one's comfort level when walking on an imaginary surface, such as a building. Furthermore, BMI enhances 2D and 3D CAD by fusing 4D (time) and 5D (cost) dimensions, enabling informed information management across the project lifecycle. [20]

For instance, a building's plans provide only a 2D representation, whereas 3D copies displayed on a standard computer screen convey the building's spatial relationships very straightforwardly. Virtual reality, on the other hand, can create an immersive, nearly lifelike display of architecture. It can be used not only to visualize the virtual world but also to create the environment itself. This relatively new approach to virtual reality in design aims to demonstrate its viability.

For instance, the Shadow Light Mirage project is a third-generation software program that enables the development and exploration of completely realistic virtual reality environments. It allows users to utilize space as a design medium, drastically speeding up the design process and encouraging creative invention. It is likely to observe improved proficiency in everyday productive use while examining the application of virtual reality in architecture. The descending level of immersion is used to list the potential practical applications of Head-Mounted Displays (HMD), Computer Audio-Visual Environment (CAVE) technologies, Single Wall Projection Displays/Power Walls, Workbenches, and WIMPs (windows, icons, and menus, pointing) in architecture practice. Figure 2.2.

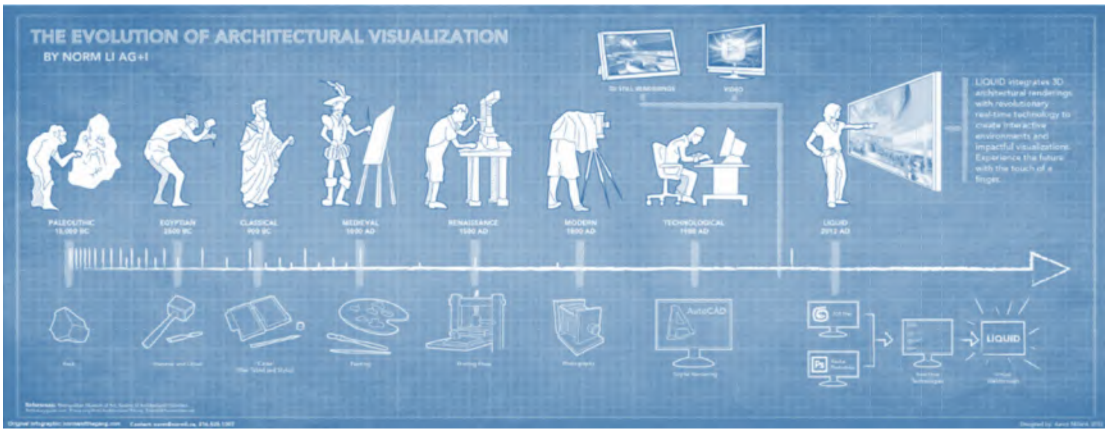

Figure 2.2: Uses of VR for Architects[20]

4 Heritage restoration

4.1 Definition of Heritage restoration

The process of accurately displaying a historic building's condition as it existed in the past and restoring it using various methods while maintaining its heritage value is known as building restoration. Restoration entails eliminating accretions or reassembling existing parts without adding new materials, thereby returning a location's fabric to a known previous state. [21]

Maintaining a structure's historical, architectural, aesthetic, and cultural significance is a form of conservation. While reconstruction refers to bringing a location as close as possible to its known previous state and is characterized by adding materials to the fabric, preservation refers to maintaining a place's fabric in its current state and delaying degradation.

The act of accurately capturing a property's form, characteristics, and features as they existed at a specific point in time through the removal of features from earlier eras and the reconstruction of any missing features from the restoration period is known as restoration..

4.2 VR for Heritage restoration

Virtual reality (VR) is a term used to describe a highly interactive computer-generated multimedia environment in which users are immersed as active players. It offers a three-dimensional experience that encompasses width, height, and depth, visually representing the real or imagined world.

Additionally, VR may include real-time motion-based interactive visual elements, audio signals, and possibly other feedback methods. According to Top of FormIsdale , virtual reality (VR) is a technology that allows people to view, manipulate, and engage with extremely complex computer-generated data. Using specialized computer hardware and software, VR produces a simulated environment that appears and feels realistic .Virtual reality is a three-dimensional digital environment that allows multiple users to interact with replicated physical elements. Sometimes, people might also engage with historical personalities, fictitious characters, or imaginary animals.

This technique utilizes computer-generated images, sounds, and other stimuli to simulate various sensory elements of complex situations. Since they became viable options, there has been considerable interest in utilizing virtual reality (VR) technologies to portray, preserve, and reconstruct cultural assets .[18]

These technologies provide an engaging and aesthetically pleasing way to teach a large audience about historic artifacts or sites. They also enhance accessibility and inclusivity by enabling viewers to virtually visit locations that may be difficult or impossible to access in person. Users can engage in interactive and interesting experiences by incorporating information into virtual worlds . As a result, the growing popularity of these technologies can be attributed to their intuitive user interfaces and the limitless possibilities they offer. Even on personal computers, real-time rendering techniques known as virtual reality (VR) have become increasingly popular in recent years due to advancements in computer technology.

4.3 Difference Between Virtual Reality Heritage Restoration and Traditional heritage restoration

Aspect	Traditional Heritage Restoration	Virtual Reality (VR) Heritage Restoration
Definition	Physical repair or reconstruction of heritage buildings or artifacts.	Digital reconstruction of heritage sites in immersive virtual environments.
Goal	To preserve or restore the original physical structure.	To simulate or visualize heritage digitally for educational or tourism purposes.
Tools	Manual tools, traditional materials, archaeological techniques.	3D scanning, modeling software, VR headsets, photogrammetry.
Result	A real, tangible structure or object.	An intangible, interactive virtual experience.
Intervention	Involves physical contact, often irreversible.	Non-invasive, no contact with the original object.
Access	Requires physical presence at the site.	Can be accessed remotely from anywhere.
Risk	Risk of damaging original materials.	No physical risk to the original heritage.
Educational Value	Provides authentic, real-world context.	Allows exploration of lost or historical phases interactively.
Cost and Time	High cost and long duration.	Lower cost, faster production time.
Use Cases	Museums, site preservation, and national heritage programs.	Virtual museums, digital education, remote tourism, and research.

Table 2.1: Difference Between Virtual Reality Heritage Restoration and Traditional Heritage Restoration

4.4 Advantages of VR in the heritage of cultural heritage

Generally speaking, virtual reality is a type of artificial reality primarily based on computer technology and produced by contemporary high-tech advancements. It is a virtual world with lifelike touch, hearing, and vision. To engage naturally with the virtual environment, users can utilize specialized input and output devices to see and manipulate objects in real-time, allowing for immersive sensations and experiences. Cultural history can be better preserved and passed down through the use of virtual reality technology.

4.4.1 Protection and inheritance of cultural heritage

Many cultural heritages are complete in and of themselves. They are typically on exhibit in museums by customary preservation and inheritance practices. However, if cultural heritage is separated from its natural habitat, the entire concept becomes disjointed, which is detrimental to the actual cultural heritage's traits. We can create an "experience museum" to recreate and restore a thorough and full virtual simulation legacy space using virtual reality technology.

Cultural artifacts can be returned to their virtual original setting in this way. The educational value of cultural heritage can be fully realized by allowing viewers to explore the virtual cultural heritage space and experience its overall impact using devices connected to virtual reality. Character interviews, text recording, article gathering, photography, and video recording are examples of traditional methods used for the inheritance and protection of intangible cultural assets.

Even though many priceless intangible cultural heritages have been preserved using these techniques, the information can be readily distorted by the deterioration of the tapes and the mildew of the books. Additionally, if intangible cultural heritage leaves its original setting of formation and development, it can be challenging to preserve in its whole, much like cultural heritage like relics.

Through action capture, 3D animation, and other means, virtual reality technology cannot only preserve and extend information about intangible cultural heritage but also present and disseminate it in novel digital formats, such as 3D virtual games and 3D animation.

4.4.2 Damage and corrosion of cultural heritage

For material cultural heritage, virtual reality technology can create a three-dimensional digital model that captures precise and authentic texture and shape information. Using the three-dimensional model, researchers can measure and examine the cultural legacy, explore the specifics of the artifacts without direct contact, and support their research.

Details of the cultural artifacts are visible to visitors in the virtual setting from different perspectives using virtual displays and other methods. The exhibition's time and location no longer limit the visitation process, increasing comprehension of cultural artifacts while decreasing physical interaction. Additionally, the three-dimensional digital model provides crucial data support for the repair and enhancement of damaged cultural artifacts.

4.4.3 Expanding the cultural heritage route

A three dimensional representation of material cultural heritage can be created using virtual reality technology and shown from all sides. The audience can become more intimate with the culture through multimedia, interactive roaming scenes, or game scenes produced by virtual reality technology, thereby experiencing the customs, historical culture, and artistic significance of the cultural heritage and piquing their curiosity.

Virtual reality technology can be used to recreate places virtually and preserve those that have not been excavated or destroyed, using information from literature and archaeological studies. Virtual reality technology can be utilized to create a virtual museum, enhancing the preservation and dissemination of cultural heritage. Moreover, leveraging virtual reality for the digital preservation of cultural heritage enables faster and more efficient cultural transmission across networks, promoting resource sharing and deeper insights into local traditions and lifestyles.

4.5 Expanding the path of industrialization and cultural heritage development.

By harnessing virtual reality technology, we can vividly illustrate and interpret the stories embedded in cultural heritage, depict current realities or possible future scenarios, and use interactive features to engage visitors, spark their curiosity, and blend virtual environments with real-world scenic locations to support the development of the travel and tourism industry.[22]

This approach further promotes the dissemination of cultural heritage.

In terms of intangible cultural heritage rooted in literature and oral traditions, virtual reality also contributes to its development by supporting the creation of related industries such as 3D animation, gaming, literature, and television. This, in turn, fosters the growth of the cultural sector and enhances the transmission of intangible cultural assets.

5 Advantages of VR in architecture

The main advantages of VR in architectural design review are :

- Higher design accuracy: Beyond conventional 2D drawings and static 3D models, virtual reality technology enables designers to display architectural projects with an exact 3D image.

  To detect and eliminate potential design issues and ensure the finished design is precise, realistic, and workable, designers and clients can gain a more intuitive understanding of the architectural space, material texture, and light and shadow effects through immersive experiences.

- Faster decision-making process: VR technology enables stakeholders to test and discuss multiple design ideas in a virtual environment, as well as receive prompt design feedback through interactive model exploration and real-time 3D visualization.

  The design review time is significantly reduced, the decision-making process is expedited, and the project's overall efficiency is increased thanks to this direct contact and feedback mechanism..

- Higher customer engagement and satisfaction: Customers can participate more actively in the design review process and gain a deeper understanding and experience of the design solutions, thanks to the immersive experience that virtual reality technology offers.

In addition to increasing client satisfaction, this sense of involvement reduces project costs by minimizing the need for follow-up changes and rework.

- Better team collaboration: Design teams, engineers, construction teams, and other stakeholders may collaborate in the same virtual environment thanks to VR technology, which improves team communication and comprehension. This cooperative approach ensures that the project proceeds smoothly by facilitating the early identification and resolution of potential issues

6 Challenges in implementing VR technology

The challenges in implementing VR are :

- Technical challenges: Although virtual reality technology has advanced significantly, several technical obstacles still need to be overcome before it can be effectively applied in architectural design. For instance, producing high-quality 3D models calls for a substantial investment of both computer power and expertise, particularly in the case of intricate architectural projects.[23]

  Furthermore, technological factors such as the VR device's resolution, tracking precision, and user interface usability may influence the effectiveness of VR and how users perceive it.

- Economic challenges: A certain level of financial outlay is necessary to implement VR technology, which includes buying high-end hardware (such as portable controllers and head-mounted VR displays), purchasing specialist software, and providing personnel with training on these new technologies.

  This might be a significant financial burden for small and medium-sized architectural firms. There will also be additional expenses for items such as routine software updates and equipment maintenance.

- Operational challenges: To deploy VR technology, several operational obstacles must be addressed. First of all, learning and adjusting to new processes and tools takes time and resources, which could have an immediate impact on productivity for design teams.

  Second, the creation and execution of virtual reality experiences require interdisciplinary cooperation in several domains, including computer graphics, architectural design, and user experience design, thereby increasing the team's overall capacity.

  The use of virtual reality technology in architectural design assessment is nevertheless promising, despite these obstacles. Many of these obstacles can be progressively removed with ongoing technological innovation and interdisciplinary cooperation, allowing VR technology to fully realize its benefits and supporting the continuing growth and advancement of the architectural design sector.

7 Definition of patrimony

Modern civilization uses the past as heritage (patrimony). "Our heritage (patrimony) is a contemporary or postmodern reflection of the past that feeds into regional identities and national clichés. It is frequently connected to historic city cores throughout Europe. It is intimately linked to museums, urban art galleries, and national parks in North America. It is also linked to indigenous identity, culture, and landscapes in Australia and New Zealand .[24]

According to Khakzad (2015), heritage is "that part of the past that we select for contemporary purposes, whether economic, cultural, political, or social."

According to UNESCO, cultural heritage is "the legacy of tangible artifacts and intangible characteristics of a group or society, inherited from past generations, preserved in the present, and gifted for the benefit of future generations.

This organization describes three aspects of heritage: monuments, clusters of structures, and sites. Additionally, UNESCO distinguishes between three types of heritage: movable (such as paintings, coins, sculptures, and manuscripts), immovable (such as structures and archaeological sites), and undersea (such as towns, shipwrecks, and submerged ruins).

Historic structures and locations, monuments, relics, etc. that are deemed deserving of preservation for future generations are all termed tangible heritage.

This refers to important items in a certain culture's science, technology, architecture, or archeology.

Intangible legacy, or "the living expressions and traditions inherited by countless groups and communities throughout the world from their ancestors and transmitted to their descendants, in most cases orally," is still considered part of cultural heritage. In 1972, UNESCO introduced the concept of a world heritage to safeguard and preserve sites of cultural or ecological significance as part of the "common heritage of humanity."

The World Heritage Convention has established appropriate practices. Although most of it remains unofficial and unmanaged, legacy has a significant impact on social and economic life. It is the crucial organization that establishes the cultural background of social activity and links history, geography, and society .

8 Virtual Reality for Heritage Preservation

The field of 3D technology has been experiencing tremendous growth for years. Industries using 3D reconstruction techniques, including television, biology, chemistry, aviation, and medicine, are expanding.[25]

With the guidance of academics and art historians, this technology has been widely adopted in the cultural heritage sector to reconstruct destroyed or non-existent sites, with many examples serving as archaeological site reconstructions.

However, 3D technology can also enhance, preserve, and conserve cultural heritage. In the future, an increasing number of repositories containing 3D objects, structures, and monuments will be linked to detailed 3D objects, as well as descriptive text files and images.

Research papers will be accessible at multiple levels.

The application of 3D technology will represent a fascinating and rich development for archives: in addition to standard information and details (see cards for artworks), future cataloging of objects, buildings, and monuments will inevitably include a link to 3D reconstructions.

This will benefit researchers, architects, students, restorers, and the curious.

With 3D modeling of heritage and its online dissemination, public visibility and global reach will contribute to a deeper understanding of currently neglected monuments, sites, and archaeological sites, which are seriously threatened by their very existence (especially those outside city limits). The only way to protect our heritage is to share knowledge and preserve it.

This involves creating a 3D archive and a database of 3D digital documents.

(But not just for this city) The opportunity to simulate how its surroundings were perceived, simulating what the previous "inhabitants" looked like. This resource, which has the potential to be infinite, remains "timeless" with a history that will be passed on to future generations.

Using a dynamic, multifaceted management system and its legacy, new knowledge horizons can be created for each archaeological site. Multimedia devices (such as cards, audio, and video) and information data can highlight or create paths that enable movements and perspectives not available in the real world, allowing visitors to return to each object and highlight its interesting aspects.

Stories and anecdotes, as well as descriptions of the circumstances surrounding the work (interestingly, in some cases, this approach is also a virtual restoration approach), are like visiting a "fly" to fit into a decor (such as the frescoes in the dome of the cathedral, the Dzivari complex) in real time and with complete freedom. This offers a captivating experience that evokes the user's emotions. Thus, the visitor enjoys a unique and distinct virtual experience.

It is important to remember that this kind of experience and more generally, the use of virtual reality techniques in the context of heritage should not be viewed as diminishing its actual worth but rather as an added benefit and a worthwhile motivator to maintain the existence of protected locations, structures, and other properties, revealing information that is challenging to accomplish through "traditional" media.

As a guarantee of the "integrity" of the priceless heritage maintained here, which truly belongs to humanity, transforming historical and artistic treasures and making them accessible to the world through virtual tours would promote collective cultural evolution.

To identify the virtual original locations of extant artifacts, the following three dimensional sites can be imagined: virtual reconstructions of sites that have been substantially destroyed due to extreme neglect and previous mistreatment.

9 3D Reconstruction

Throughout the outbreak, 3D reconstruction was used more frequently, particularly in the real estate industry, since lockdowns prevented buyers from physically inspecting homes.[26] Some companies offer virtual tours of their properties using 3D reconstruction. Customers can view new homes from anywhere and purchase them without visiting in person, just like in the metaverse. The metaverse needs to create a virtual world that is as lifelike as possible. Environments created by 3D reconstruction appear natural. Online, lifelike 3D representations of objects, environments, and buildings are created by specialized 3D cameras.

10 Conclusion

In an era of rapid digital transformation, architecture has evolved beyond traditional design methods to embrace emerging technologies such as virtual reality (VR). This innovation has significantly enhanced the way architects visualize, evaluate, and communicate their designs. More importantly, VR has emerged as a powerful tool in restoring heritage buildings, allowing professionals to recreate historical structures and plan precise, informed interventions digitally.

Algeria, a country rich in cultural and historical heritage, presents a unique opportunity to preserve and revitalize its architectural legacy through the integration of virtual reality (VR) into restoration projects. VR can facilitate the documentation of historic sites, provide training platforms for local engineers and architects, and engage the public in immersive experiences that highlight the value of their heritage.

Ultimately, the intersection of architecture, restoration, and digital technology is no longer a futuristic concept but a necessity. Embracing VR in architectural practice, particularly in heritage conservation, can lead to more sustainable, efficient, and culturally respectful outcomes, especially in heritage-rich nations like Algeria.

Chapter 3

System Description and Architecture Design

1 Introduction

The preservation of cultural heritage has become a pressing priority in a world where many historical sites are at risk due to natural degradation, urban development, and conflict. As physical restoration can be costly, time-consuming, or even impossible, new technological solutions have emerged to support heritage conservation in innovative ways. Virtual Reality (VR) offers a powerful tool for digitally restoring and experiencing cultural patrimony.

This chapter presents a comprehensive system designed to reconstruct and restore historical sites using VR technology digitally. It begins with a definition of patrimony and explores the growing role of VR in heritage preservation. The proposed system is then introduced, detailing its objectives, architectural design, and the different user interactions it supports.

From the creation of a realistic virtual world to the consideration of user roles and interaction methods, the system is built with both educational value and historical accuracy in mind. Finally, the development pipeline is outlined, highlighting each key phase from research and content creation to implementation and testing.

This work demonstrates how immersive virtual experiences can bridge the gap between past and present, making heritage sites accessible, engaging, and meaningful to modern audiences

2 Proposed System for Heritage restoration

2.1 System objectives

The proposed solution aims to develop a Virtual Reality based interactive platform for heritage restoration and preservation, focusing on digitally reconstructing and visualizing culturally significant architectural sites. This platform will allow users such as architects, historians, students, and the general public to explore and interact with historical structures in a high-fidelity 3D virtual environment.

By leveraging VR's immersive capabilities realistic visuals, spatial presence, and interactivity the system recreates lost or damaged heritage sites with historical accuracy. Users can navigate through reconstructed buildings, observe architectural details, and even simulate restoration processes in a safe, virtual setting. This tool is designed for educational and research purposes and to support restoration professionals in planning interventions, visualizing potential restoration outcomes, and engaging stakeholders.

To enhance engagement and understanding, the platform includes guided virtual tours, time-lapse reconstructions of deterioration and restoration, and gamified tasks that challenge users to identify and solve structural problems.

Ultimately, the VR based heritage restoration platform serves as a bridge between the past and the present, ensuring cultural memory is preserved and experienced by future generations.

2.2 System Architecture Design

This section presents the overall structure and architecture of our system designed for virtual heritage restoration. The architecture has been developed to systematically incorporate key factors that influence the VR-based restoration platform's accuracy, realism, and educational value.

It considers the characteristics of the reconstructed virtual environment, the user profile (e.g., researchers, architects, or the general public), and the interaction between the user and the heritage site in the virtual space. Additionally, it considers contextual and technical factors that emerge during real-world usage, such as device capabilities and user immersion levels.

The system comprises multiple integrated modules, including high-fidelity 3D modeling of historical structures, interactive exploration tools, and restoration scenario simulations. These modules are designed to support both educational engagement and professional restoration planning.

Moreover, this architecture provides a foundation for empirical evaluation of the platform's effectiveness in enhancing user understanding, preserving cultural memory, and supporting architectural decision making. The selected evaluation criteria are aligned with the system's goals and are illustrated in the following sections Figure 3.1.

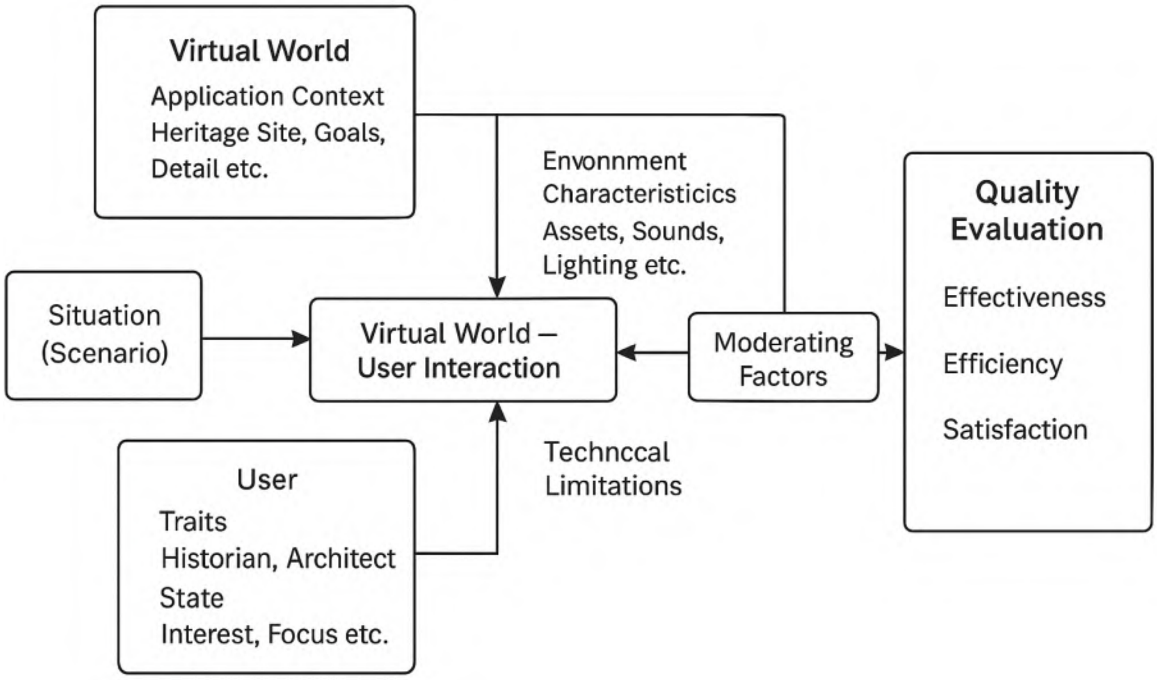

Figure 3.1: System Architecture

2.2.1 Virtual World

Our system is based on true immersive Virtual Reality, where the user is fully surrounded by and engaged within a digitally reconstructed historical environment. To ensure a deep sense of presence and disconnect the user from the physical world, a set of carefully selected features have been designed and adjusted to align with the project's objectives in heritage restoration and cultural preservation. These features include high fidelity 3D models, authentic textures, ambient historical sounds, and natural interaction mechanisms that enable users to explore and experience the heritage site as if they were physically present. This immersive approach not only enhances user engagement but also fosters a deeper understanding of the cultural and architectural value of the reconstructed site

- The application context defines the primary purpose of the system, which in our case is the preservation exploration, and interactive restoration of cultural heritage sites. It encompasses the specific tasks to be carried out by the user such as navigating reconstructed environments, observing architectural elements, or simulating restoration techniques. These tasks are designed to reflect real world restoration and educational objectives and may vary in complexity depending on the user's profile (e.g., student, architect, tourist). The task characteristics, such as levels of difficulty, guided vs. free exploration, and interactive restoration scenarios, are directly derived from the cultural and historical context of the reconstructed heritage site.

- the environment characteristics define how the virtual space should be constructed to prepare it for the design, rendering, and interaction phases. In the context of heritage restoration, the goal is to create a historically accurate and visually coherent virtual environment that evokes a strong sense of presence and authenticity.

A well designed environment is essential for achieving the intended outcomes whether for educational, research, or preservation purposes. Inaccuracies or low fidelity interaction can reduce user engagement and compromise the value of the experience. Conversely, if users can navigate and interact with the virtual heritage site as if they were physically present, the platform can effectively convey cultural meaning and historical depth.

Achieving this requires integrating realistic 3D models, textured architectural elements, ambient soundscapes, and logical spatial organization all of which contribute to a seamless and immersive virtual reconstruction.

2.2.2 User Component

The user component refers to the attributes and conditions of individuals engaging with the VR based heritage restoration system. Users may include professionals such as historians and architects, or members of the general public with varying backgrounds and interests. This component can be divided into two main categories:

- Traits: Stable user characteristics such as profession (e.g., historian, architect), prior cultural heritage knowledge, and familiarity with VR technology. These traits influence the user's perception, interpretation, and interaction with the virtual environment.

- State: Temporary conditions such as level of interest, focus, emotional engagement, or cognitive readiness during the VR session. These factors can fluctuate and have a direct impact on immersion, learning outcomes, and user satisfaction

By considering both user traits and state, the system is designed to provide a flexible and adaptive experience that supports exploration, learning, and appreciation of historical architecture within a highly immersive digital context

2.2.3 Virtual World User Interaction

The third component of our system architecture is the virtual world user interaction, which represents the actual engagement of the user within the immersive heritage environment. In this virtual setting, users can navigate, explore, and interact with historically reconstructed elements and scenarios that reflect real world architectural and cultural contexts. As users engage with the environment whether by observing restored structures, triggering information points, or simulating restoration actions they exhibit behaviours linked to attention, understanding, and performance. For the interaction to be effective, it must be intuitive, meaningful, and consistent with real world expectations. Coherence in interaction design is crucial to evoke the intended psychological and cognitive responses, such as awe, curiosity, or cultural appreciation, similar to what one would experience at a physical heritage site

2.2.4 Controlling Factors

This component ensures that the system is not only visually accurate but also functionally immersive, supporting deeper user involvement and more impactful cultural engagement. The moderating factors emerge directly from the interaction between the user and the virtual environment. They play a significant role in influencing the overall quality and effectiveness of the VR heritage restoration application. These factors can either enhance or hinder the user experience. In our system, such factors may lead to positive effects, such as increased presence, cultural engagement, and cognitive absorption, or negative effects, such as cyber sickness, disorientation, or cognitive overload. These outcomes are shaped by technical performance, interaction design, and user conditions during the use session. For instance, a user deeply focused and engaged in exploring a realistic reconstruction of a historical site may experience a strong sense of immersion. Conversely, latency issues or poorly designed navigation may reduce realism and trigger discomfort. Thus, moderating factors must be carefully considered and minimized through thoughtful design to support a smooth, meaningful, and enjoyable virtual heritage experience.

2.2.5 Quality

We paid special attention to the visual accuracy of the environment in the virtual reality application we designed for the restoration.

The materials used in the stone walls, carved wooden doors, and traditional tiled floors were based on actual photographs taken on site.

We also used a dynamic lighting system to simulate natural sunlight at different times of day. This produces realistic shadows and subtle reflections on painted or metal surfaces.

Visual details were added to enhance authenticity:

- Signs of wear on the walls
- Climbing plants on some facades
- Artifacts such as lanterns, pottery, and traditional tools

These elements immerse the user in a realistic visual atmosphere, close to the historical reality of the site.

3 System Pipeline

The project was developed through four phases. Along the way, in-depth historical research was conducted on the heritage site, collecting old plans and archival images. The user experience concluded that the goal was to offer a free visit to the site, as it was during that era, enriching the interactive information points.

The 3D model wers modifide created using Blender, and elements were imported into Unity, or the virtual world was assembled. Virtual reality features, navigation, and interactions were implemented. In addition, several users conducted real-world user tests to evaluate the fluidity of the experience, graphic realism, and ease of use. Reverting allows for correcting some default settings and improving performance in Figure 3.2 .

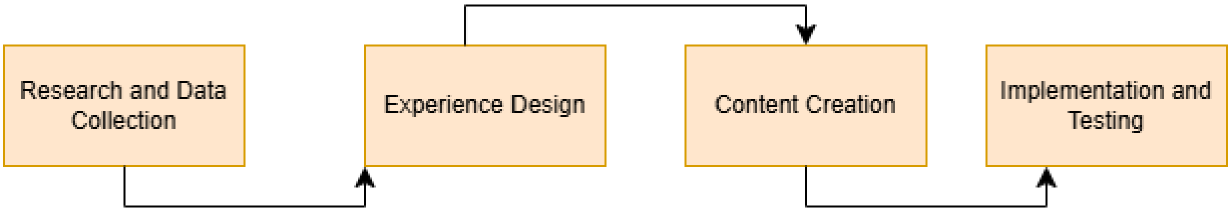

Figure 3.2: System pipeline

3.1 Research and Data Collection

This step aims to gather all the information necessary for a faithful reconstruction of the heritage site.

It includes old photos and studying the current site to understand its state of conservation and architectural details. What we did is that we gathered images that represent the actual ruins from different websites that provides stock photos, editorial photography of old heritages like www.gettyimages.fr and others, we also gathered images for the original forms of these Roman ruins .

This phase is critical for ensuring the historical accuracy and authenticity of the heritage sites digital reconstruction. The process involves comprehensive research and systematic collection of visual and textual data to inform the modeling and restoration efforts.

We conducted a thorough investigation of the current condition of the Roman ruins through the collection of high-resolution images and documentation. This included sourcing up-to-date photographs from reputable stock and editorial photography platforms such as Getty Images, as well as other heritage-focused archives.

Additionally, we gathered visual references and illustrations that depict the original, undamaged forms of the structures. These materials serve as a foundational basis for reconstructing the sites in a manner that respects both their historical significance and architectural integrity in Figure 3.3.

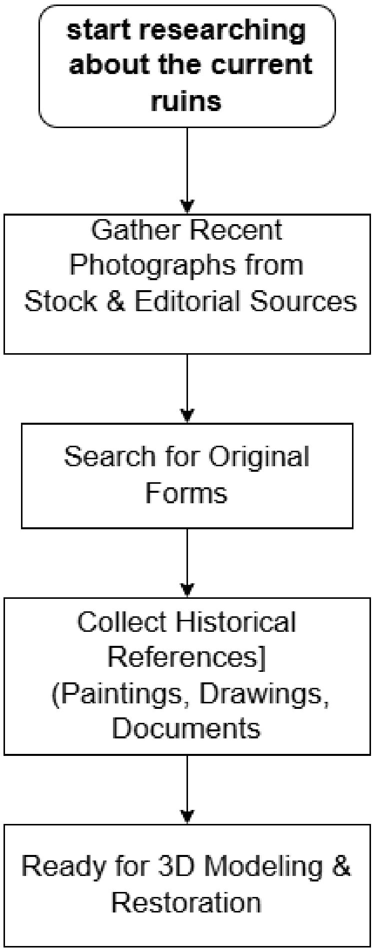

Figure 3.3: Research and Data Collection

3.2 Experience Design

This phase involves defining how the user will experience the immersive experience. It includes plotting the tour itinerary, positioning points of interest, and selecting key historical moments to relive in the virtual environment. The user will be facing 2 options choose to see Egyptian ruins and choose to see Algerian ruins. if he choose the first option it will travel to a green environment filled with old Roman monuments representing Timgad when pressing the secondary button in the VR controller a menu pop up with four options: information:which shows information about the monuments restoration: which restore the destroyed ruins to their original form. Return: it will return to the first scene quit :which exit the application the player also can jump to see the environment from above and grab objects like rocks and pillars in Figure 3.4.

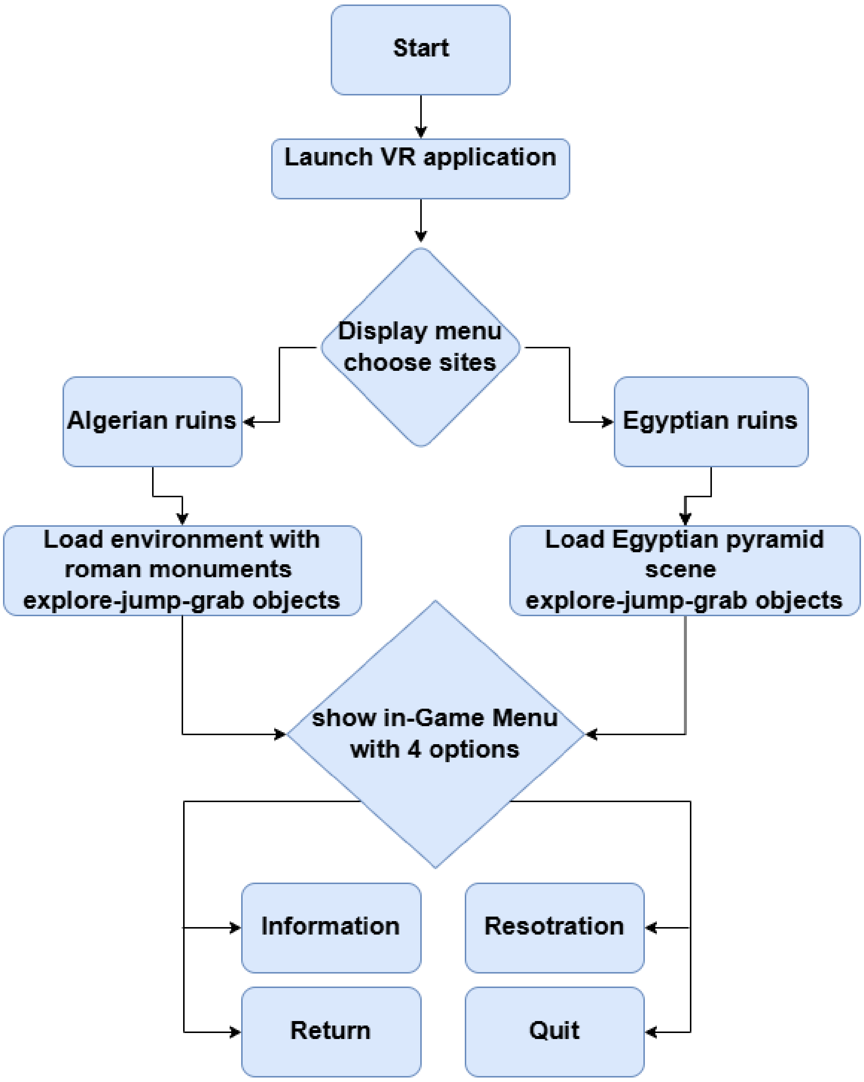

Figure 3.4: Activity diagram of the Player/VR System i

3.3 Content Creation

In this phase, the visual and interactive components of the virtual reality experience are produced. The objective is to bring the heritage site to life through accurate, immersive, and engaging digital representations that are both historically faithful and optimized for user experience.

The process begins with the generation and modeling of historical buildings, monuments, and artifacts, based on the visual and textual data collected during the research phase.

To accelerate and enhance the accuracy of this process, we utilized AI-powered platforms such as Poly.cam and Meshy.ai. These tools allowed us to create initial 3D models directly from reference images, effectively reconstructing complex geometries using photogrammetry and deep learning techniques.

Photogrammetry Process Poly.cam employs advanced photogrammetry algorithms to generate 3D models from multiple overlapping images. This process involves two key stages:

- Structure from Motion (SfM): This stage detects unique visual features (e.g., edges, corners) in the input images, and tracks them across multiple photos. Using these feature correspondences, it estimates the camera positions (pose and orientation) and constructs a sparse 3D point cloud via triangulation.
- Multi-View Stereo (MVS): Once camera positions are known, MVS estimates the depth of each pixel by analysing how features appear across multiple views. These depth maps are merged to form a dense point cloud, which is then converted into a detailed 3D mesh. Finally, the original images are used to project high-resolution textures onto the mesh.

This approach allows for photorealistic, high-accuracy 3D reconstruction of heritage elements, even from archival or field collected imagery.

After the AI-generated models are obtained, they are imported into Blender for refinement. In this post-processing step, we meticulously cleaned the geometry, removed unnecessary elements, fixed mesh topologies, and optimized the models for VR performance while maintaining architectural fidelity.

In parallel, we developed interaction scripts within Unity using C# and the XR Interaction Toolkit.

These scripts enable players to perform essential interactions within the VR environment, including grabbing objects, viewing informational panels, triggering restoration sequences, jumping, and navigating in-game menus.

These interactions are designed with a focus on usability and immersion, ensuring intuitive and responsive behaviours using standard VR controllers. To further enhance the realism of the experience, we integrated:

- Lighting setups tailored for different scenes (e.g., daylight, ambient light).
- Environmental effects such as weather conditions and sky boxes.
- All content and assets are rigorously optimized for VR platforms, ensuring smooth performance, stable frame rates, and a responsive user experience.

This phase concludes with the full integration of all assets into the Unity engine, forming a cohesive and fully interactive scene that serves as the core foundation of the immersive heritage restoration experience.

3.4 Implementation and Testing

This step involves the integration of all developed components 3D models, interaction scripts, and UI elements into the Unity game engine, which serves as the foundation for building the immersive VR experience.

During the implementation phase, assets are imported and organized within Unity scene hierarchy. Interaction systems such object manipulation, menu navigation, and environmental triggers are connected using the XR Interaction Toolkit. Special attention is given to ensuring seamless transitions between different environments (e.g., main menu, Algerian ruins, Egyptian ruins), and maintaining consistent player positioning, orientation, and immersion across scenes.

Once implementation is complete, the testing phase begins

- Ensures that the experience runs smoothly across the target VR hardware Meta Quest.
- Verifies frame rate stability .
- Confirms correct functioning of interactions (grabbing, jumping,UI navigation).
- Tests for VR-specific issues such as motion sickness triggers, clipping, or controller input inconsistencies.

4 Conclusion

This system has been specifically designed to support the restoration and preservation of cultural heritage by leveraging the capabilities of virtual reality. The creation of an immersive, interactive, and historically accurate experience enables users to explore reconstructed heritage sites in a way that is both educational and emotionally engaging. By combining realistic 3D modeling, user-centered experience design, and the thoughtful integration of historical and cultural elements, such as artifacts, ambient sounds, and authentic architectural textures, the system brings forgotten or endangered heritage sites back to life in a digital form.

The structured development pipeline, which spans initial research and data collection to final implementation and testing, ensures a rigorous and comprehensive workflow. This approach guarantees not only the system's technical functionality but also the final experience's historical credibility and pedagogical value.

Ultimately, this project highlights the decisive role that immersive technologies can play in the valorization, conservation, and transmission of cultural heritage. By making these sites accessible to a broad audience including students, tourists, and researchers the system contributes meaningfully to the education, appreciation, and long-term safeguarding of our shared human history.

Chapter 4

Implementation, Results and Discussion

1 Introduction

Creating virtual reality applications, particularly in the context of heritage site restoration using virtual reality, is a complex process that requires diverse skills and technologies to ensure successful heritage restoration.

This process involves developing a high-performance, low-power architecture through software and hardware design, and utilizing prototyping tools, development environments, libraries, and frameworks to create an immersive virtual reality experience with human-computer interactions and underlying logic.

This chapter focuses on the application and results of restoration using a virtual reality system, discussing the application details, including the tools and hardware used to develop the system.

2 Application technical description

Before initiating the content creation phase of our heritage restoration VR application, we first developed a detailed description of what the virtual experience should offer to the user and how it should reflect the historical and cultural significance of the site.

Based on this description, we identified the key components, interactions, and requirements of the application, laying the groundwork for the design and development process. We decided that the experience should be accessible to a wide range of users including students, tourists, and researchers and should run smoothly on personal computers equipped with VR support. To ensure historical accuracy and visual fidelity, high-quality 3D models were created, featuring detailed textures, realistic lighting, and atmospheric elements that accurately reflect the period being reconstructed.

Spatial audio also plays a crucial role in creating an immersive and emotionally engaging environment. This includes ambient background sounds (such as wind, birds, or city noise, depending on the setting), interactive sound effects triggered by the user (like footsteps or object manipulation), and audio guides or narrations that explain the historical context of the scene. Motivational feedback, such as sound cues when discovering key points of interest, enhances user engagement.

Users should be able to explore the reconstructed environment freely, interact with historical objects, and trigger contextual information through interactive elements such as panels, videos, or audio narrations. These interactions must follow realistic behaviour based on physics, such as proper object collisions and gravity, to preserve immersion and presence within the environment.

To make the experience more user-friendly and adaptive, a graphical user interface (GUI) was also envisioned, allowing users to start or pause the tour, select historical periods or areas to explore, and exit the application at any moment.

This interface empowers users to control their learning journey through cultural heritage.

3 Development Environment

3.1 Hardware

For the hardware setup of our virtual heritage restoration experience, we are using the Oculus Quest 2 standalone VR headset, developed by Meta (formerly Oculus). The device provides an all-in-one solution, eliminating the need for external sensors or base stations, making it a practical and flexible choice for both development and user experience. The headset features a high-resolution display (1832 x 1920 pixels per eye) with a refresh rate up to 120 Hz, delivering sharp and smooth visuals.

It comes with two ergonomic wireless motion controllers that allow intuitive interaction with the virtual environment, featuring precise tracking and haptic feedback to simulate touch and engagement with digital elements.The Oculus Quest 2 supports inside-out tracking, using four integrated cameras on the headset to detect both room boundaries and controller movement.

This eliminates the need for external base stations, allowing for room-scale VR experiences with minimal setup. The play area can be defined using the Oculus Guardian system, which ensures user safety by displaying virtual boundaries.While the Quest 2 can operate independently, we utilize Oculus Link or Air Link to connect it to a high-powered PC for increased graphical performance and access to advanced VR development platforms like Unity or Unreal Engine. This hybrid setup combines the portability of the Quest 2 with the power of desktop processing, enabling the rendering of high-fidelity 3D models, dynamic lighting, and immersive audio necessary for a realistic reconstruction of heritage environments.

This hardware configuration ensures that users can freely explore and interact with the virtual site while maintaining visual realism, responsiveness, and physical comfort during the experience.

3.1.1 Oculus Quest 2

The Meta Quest 2, formerly known as Oculus Quest 2, is a significant advancement in virtual reality technology. This most recent version, which builds on the success of its predecessor, the Meta Quest, has several important improvements that have helped it become the market leader.[27]

With a resolution of 1832 x 1920 pixels per eye, the most noticeable improvement is the improved display clarity and resolution, which produces a crisper and sharper image. Furthermore, the more potent Qualcomm Snapdragon XR2 CPU in the Meta Quest 2 offers improved performance and rendering capabilities for demanding virtual reality applications. Like the Meta Quest and Oculus Go, the Meta Quest 2 can be played alone, removing the requirement for extra sensors or a separate PC. Thanks to this functionality, users can now enjoy VR experiences without being restricted by a physical workstation or gaming console, which gives previously unheard-of independence and accessibility.

The device's lightweight nature and all-in-one design Its ergonomic design enhances the user experience, making it appealing to both casual shoppers and die-hard virtual reality enthusiasts. To date, little research has been conducted on the forensic analysis of Meta Quest 2. As a result, this study gap presents a significant chance to investigate and identify the particular forensic artifacts produced by this apparatus.

One of its main advantages is Meta Quest 2's broad support for a variety of VR applications. With more processing power and improved hardware, the Meta Quest 2 provides a vast collection of virtual reality experiences, including gaming, entertainment, and the thesis's main focus: social community applications.

This broad support provides access to a wide range of possible forensic artifacts that are amenable to analysis, offering a wealth of chances to investigate the distinctive interactions and activities seen in different virtual reality applications and their consequences for digital forensic investigations Figure4.1.

Figure 4.1: Meta Quest 2 all-in-one VR headset[27]

3.2 Software

3.2.1 Unity 3D

One cross-platform gaming engine is Unity 3D. Unity Technologies created it in Denmark. The initial version was introduced at Apple's Worldwide Developers Conference in 2005. Unity 3D is a sophisticated rendering engine that is fully integrated with a comprehensive game development ecosystem. A collection of quick and easy-to-use tools for producing interactive 2D and 3D content (http://unity3d.com)[28].

There is a vibrant online developer community for Unity 3D. In addition to helping new users (Unity 3D offers web and mobile support), they can also contribute new features to the engine upon user request. Unity 3D's modeling support is one of its primary features. physical characteristics.

For instance, various joints can be used to build items. Moreover, different objects may possess mass, compliance, collision detection, and other attributes. One of the primary distinctions between the realXtend platform and Unity 3D is that the latter is a multi-user social collaboration environment, whereas Unity 3D originates from the FPS (first-person shooting) gaming industry.

Unity 3D is not open-source. Pena Rios, Callaghan, Gardner, and Alhaddad (2014) demonstrated how virtual labs may be supported by Unity 3D. One advantage of adopting Unity is that it is client-based, which makes it easier to manipulate things in the real world than some other platforms that are more server-based. The writers are conscious of the review's shortcomings. One of the limitations is that there is no clear connection between the list of virtual worlds provided in this section and the list of virtual labs shown in Section 4.

We are aware that specific standards for choosing a virtual environment suitable for a particular lab would be appreciated. However, since research on this topic is still ongoing, we choose to present accurate information while deeming the creation of clear rules premature. Figure 4.2.

Figure 4.2: Unity 3D[29]

3.2.2 Blender

Millions of visual effects artists and animators utilize Blender[30], an open-source 3D modeling and animation program. The software is cross-platform, and the download site offers versions for Windows, Mac, and Linux PCs.

Blender supports both 2D and 3D character animation and offers a game engine for interactive graphics in addition to producing visuals from 3D models. Among the many other tools available in Blender are techniques for creating intricate surfaces and volumes (including components for emission, transmission, absorption, reflection, and roughness).

3D stereoscopic graphics support, picture compositing, and the option to export models and lighting in several formats for use with other 3D modeling and gaming programs, including the Unity 4 game engine (in Wavefront (OBJ) format) or 3D printing software (in Stereo Lithography (STL) format), are distinctions between the realXtend platform and Unity Figure4.3.

Figure 4.3: Blender Software[31]

3.2.3 Visual Studio Code

Microsoft's Visual Studio Code (VS Code) is an integrated[32] development environment (IDE) and source code editor. It is cross-platform, open-source, and compatible with Linux, macOS, and Windows. Web developers can use it and also support various programming languages, including Python, Java, C++, and C#. Numerous features are available, including color syntax, auto-completion, error staging, code navigation, debugging, version management, Git connectivity, and more. It is extensively utilized in a wide range of community-developed extensions, enabling anyone to use them for their own personal growth Figure 4.4.

Figure 4.4: Visual Studio[33]

3.2.4 C# (Programming Language)

C# is the top language used by Microsoft for.NET development.

It offers an efficient and effective method of writing applications for the contemporary industrial computer environment by combining tried-and-true features with cutting-edge advancements. By any measure, it is one of the 21st century's most significant languages.

This chapter aims to put C# in its historical perspective, covering the factors that shaped its development, its design ethos, and how other computer languages impacted it.

The relationship between C# and the `.NET Framework` is also explained in this chapter.

As you'll see, the `.NET Framework` and C# combine to produce an extremely sophisticated programming environment

3.2.5 Meshy AI

Meshy is an AI 3D model generator that makes it easier for 3D artists, game developers, enthusiasts of 3D printing,[34] and XR prototype creators to generate high-quality 3D models from text and photos. It makes 3D modeling and animation easier, enabling millions of users with no prior 3D experience to unleash their creativity and produce beautiful 3D assets.

4 Steps to use Meshy AI to generate a 3D model from a 2D image

4.1 Insert an image or 2D model

- The user uploads a single image (or a set of images) of a specific object, such as a chair or a statue.
- The image can be drawn or taken with a camera.

4.2 Shape analysis using artificial intelligence

- The system identifies shape features and properties (edges, shadows, proportions).
- Deep learning models pre-trained on thousands of real objects from databases such as ShapeNet are used.

4.3 Depth Estimation

- Deep neural networks are used to estimate the depth of each point in an image.
- The result: a depth map showing how far each point in the object is from the camera.

4.4 Generate Point Cloud / Voxels

- The depth map is converted into a preliminary 3D representation of the object.
- This representation is incomplete, but it roughly defines the object's shape.

4.5 Improving appearance via diffusion models

- Publishing models are used to generate fine details and improve the quality of the 3D model.
- These models work like converting a blurry image into a realistic image.

4.6 Using Neural Radiance Fields (NeRF)

- To generate a realistic appearance of an object when rotated or viewed from multiple angles
- This technique simulates the interaction of light with the shape

4.7 Mesh Extraction

- The 3D representation (voxel or point cloud) is converted into a surface mesh using an algorithm such as Marching Cubes.
- The result: a 3D model ready for use in software or export for printing.

4.8 Export the model in 3D format

- The model is presented to the user in formats such as .glb, .obj, or .fbx.
- It can be used in game design, virtual reality, augmented reality, or 3D printing.

5 Development Process

5.1 assets and packages

We used an asset called the XR Interaction Toolkit.This toolkit is Unity's official framework for building virtual Reality (VR) and Augmented Reality (AR) experiences. This toolkit provides a robust and flexible foundation for integrating user interactions, such as grabbing,teleporting, and UI selection in a VR environment in Figure 4.5.

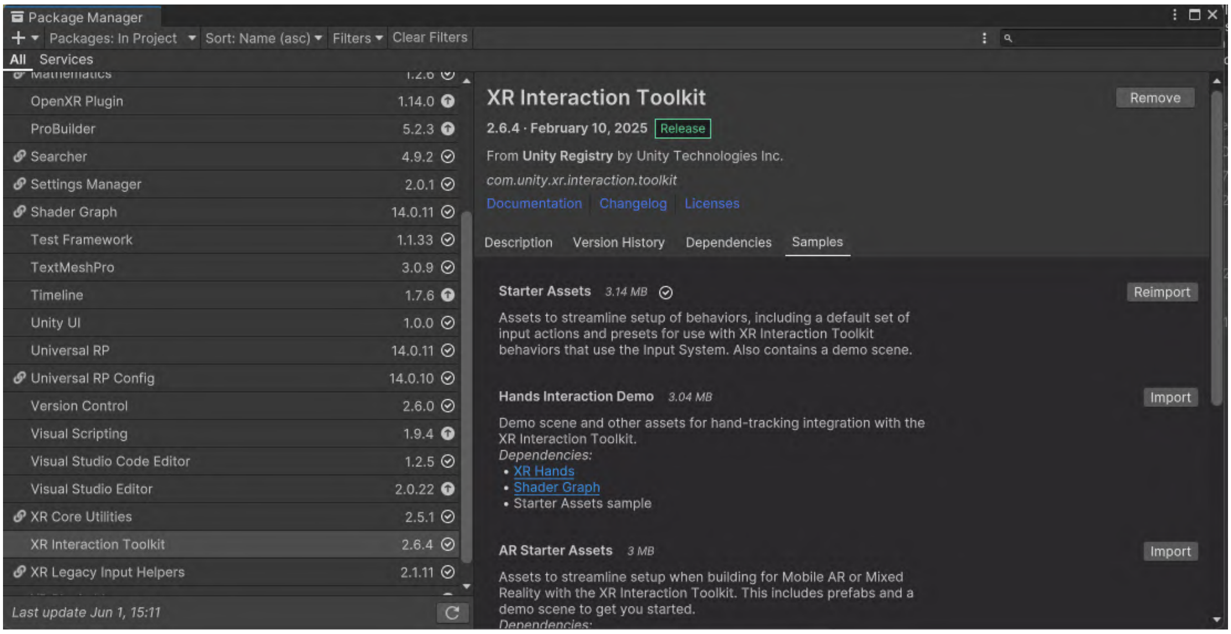

Figure 4.5: XR Interaction Toolkit

5.1.1 Core Features Implemented Using XR Interaction Toolkit

- Hand Tracking and Controller Input: Users can interact with objects using VR controllers through ray interaction or direct grabbing. Inputs such as button presses and joystick movement were mapped to trigger object manipulation, menu interaction, and teleportation.

- Teleportation and Locomotion:To ensure accessibility and avoid motion sickness, a teleportation system was implemented. It allows users to move around the virtual environment intuitively by pointing and clicking where they want to go.

- Interactive UI Panels:VR menus were developed to be world-space, canvases, appearing when players press the secondary button. These include options for Information: "Restore," Return," and Quit, and were made interactable using Unity's XR UI components.

- Object Interaction: Custom scripts were created to enable interactions with monuments and artifacts. Players can grab objects, inspect them up close, and trigger restoration animations that transform ruins into their original state.

- Scene Management: A scene-switching system was implemented, allowing the user to navigate between the main menu. Algerian and Egyptian ruins are based on their respective locations.

- Performance Optimization, lighting, post-processing, and mesh quality were balanced to ensure smooth performance on target VR platform. Occlusion culling and light lighting were used to enhance efficiency. We also used a Unity asset from the Unity

Asset Store.called Fantasy Forest Environment to create a visually rich and immersive natural setting for the Algerian ruins scene. This package provided a high-quality library of:

- Trees, vegetation, and rocks
- Terrain textures and detail meshes
- Environmental elements like fog, lighting presets, and atmospheric effects

By integrating this asset, we were able to design a lush, green environment that contrasts with the arid desert atmosphere of the Egyptian pyramid scene. The natural landscape created using this package added depth and realism to the experience, helping to reinforce the cultural and geographical identity of the heritage site in Figure4.6 .

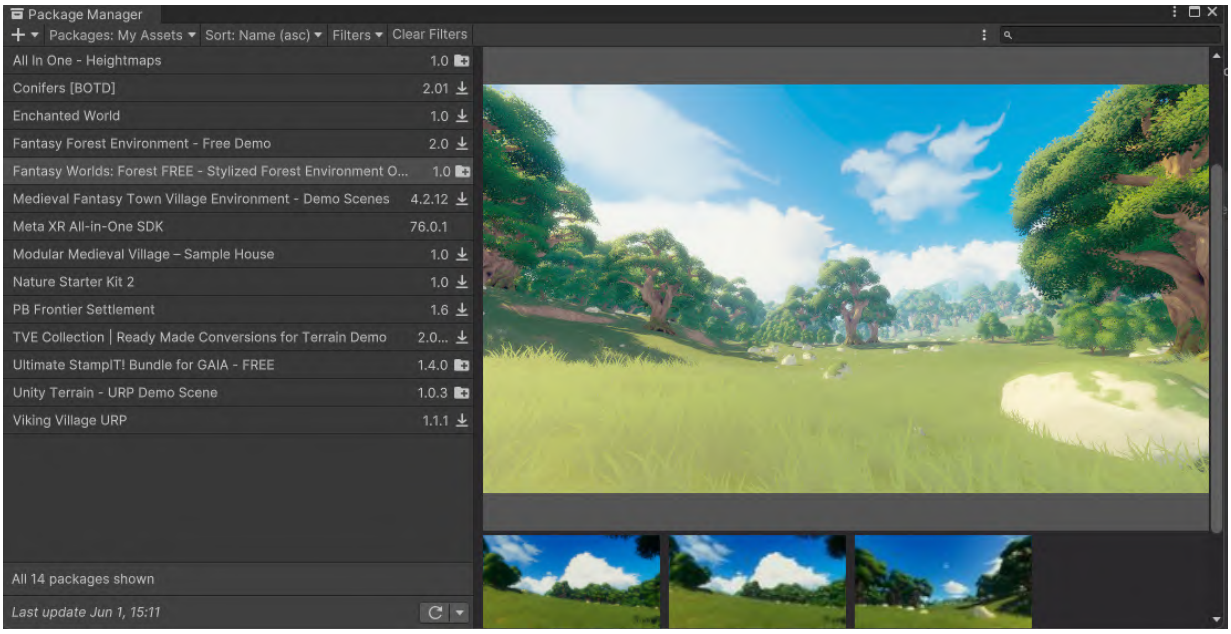

Figure 4.6: Natural landscape Asset

5.2 Environment creation

The development of the virtual environment began with the construction of a simple main menu scene that allows the user to choose between exploring the Egyptian or Algerian heritage sites. This selection mechanism was implemented using Unity's input system and scene management functionality:

if (inputAction.action.WasPressedThisFrame())

SceneManager.LoadScene(sceneToLoad);

This script listens for specific input from the VR controller and loads the corresponding scene based on the player's selection.

We then laid the groundwork for each scene by incorporating a previously developed environment asset, which served as the base terrain and visual backdrop. For instance, in the Algerian ruins scene, we used the Fantasy Forest Environment asset to create a green and vibrant natural setting reflective of the ancient Roman city of Timgad.

Following this, we imported and configured the XR. Interaction Toolkit, which provides all necessary components for immersive VR interactions, including locomotion, grabbing, teleportation, and UI interaction. This toolkit served as the foundation for enabling player movement and object interaction within the virtual space.

We then placed the AI-generated 3D models of ruins created using platforms like Poly.cam and Meshy. ai, into the scene. These models represented fragmented Roman monuments. After cleaning and optimizing the models in Blender, we carefully positioned them in Unity using the Transform tools to adjust their translation, rotation, and scale, ensuring spatial accuracy.in Figure4.7 .

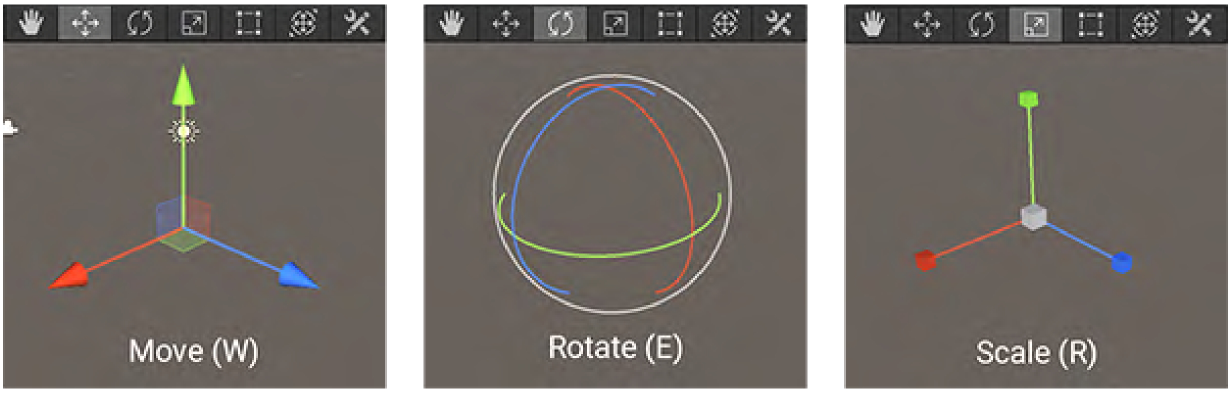

Figure 4.7: Geometric Transform

To enable physical interaction in VR, each placed object was assigned a Mesh Collider. Collider to enable proper physical interactions within the XR space .in Figure4.8 .

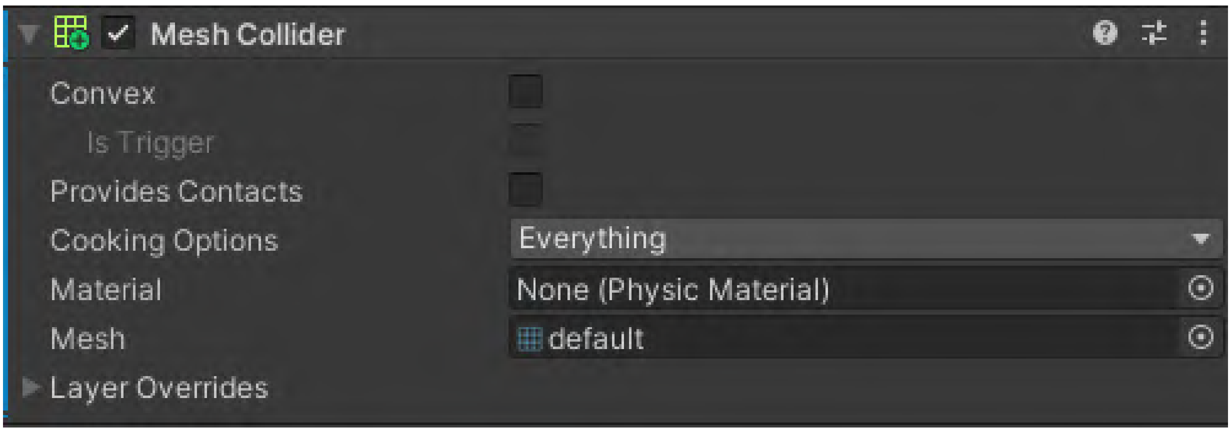

Figure 4.8: Mesh Collider

Finally, environmental enhancements such as lighting and skyboxes were added to elevate the realism and atmosphere of each scene. These components help immerse the user in historically inspired settings that are both visually and interactively compelling. At the end of the environment creation phase, we conducted preliminary tests to ensure navigation was intuitive, performance was stable, and colliders and interaction scripts functioned correctly, laying the groundwork for the final VR experience in Figure4.9 .

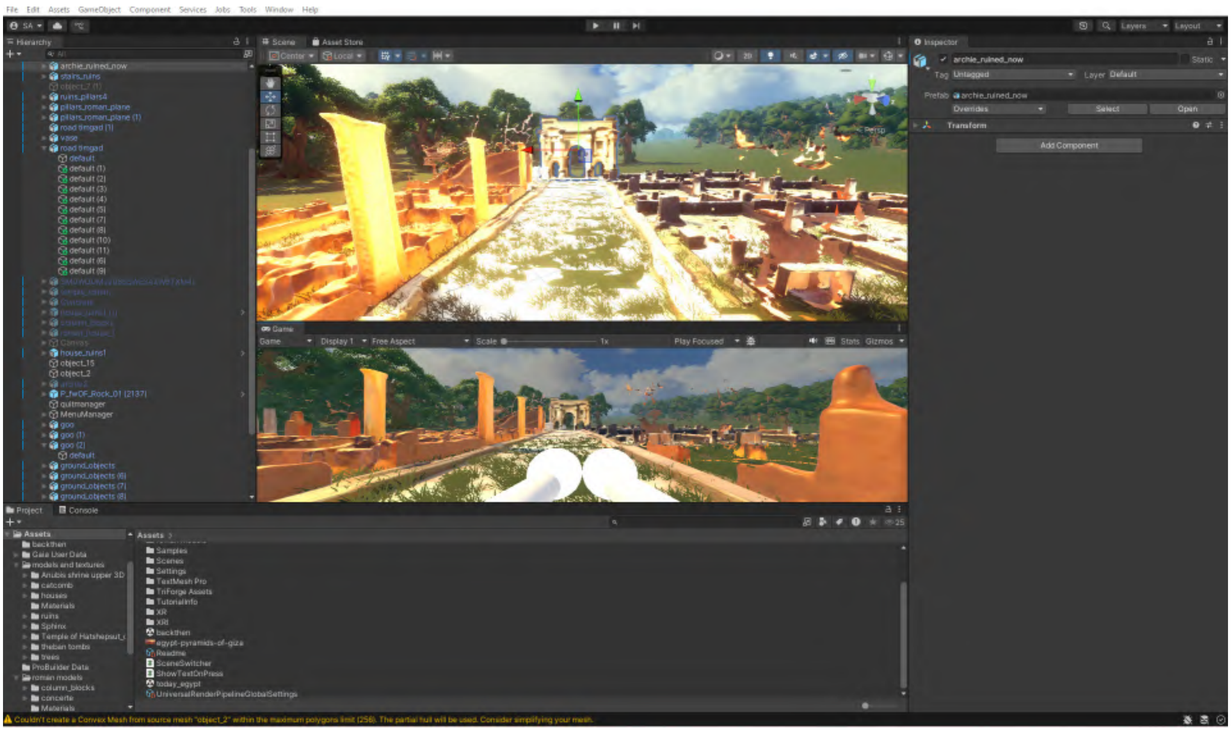

Figure 4.9: Environment Timgad1

5.3 Restoration process

The process of restoration is straightforward. The objects that represent the ruined monuments begin to shrink in size.

5.3.1 Object Swapping Mechanism

The interaction is registered via the button's onClick event:
btn.onClick.AddListener(SwapObjects);

The restoration process was represented through a real time visual transformation between two versions of an object:

- The current (damaged or aged) state.
- The restored (original or reconstructed) state.

  This transformation was triggered via user input, and handled in Unity using the following logic in Figure 4.10.

```
if (objectA.activeSelf)
{
 objectA.SetActive(false);
 objectB.SetActive(true);
}
else
{
objectB.SetActive(false);
objectA.SetActive(true);
}
```

Figure 4.10: Swap object

This code ensures that only one version of the object is visible at any time, swapping between the current and restored states.

5.3.2 Animated Transition with Scale Interpolation

To enhance the visual experience and ensure a more A natural transition was achieved by incorporating a scaling animation into the object exchange process. Instead of abruptly toggling visibility, the active object gradually shrinks to zero scale (simulating disappearance), followed by the activation of the second object, which scales up from zero to its original size. This technique provides a more immersive and aesthetically pleasing user experience in VR.

The animation is handled programmatically using Unity's coroutine system. It captures each object original scale during initialization and applies smooth interpolation using Vector3.Lerp over a defined time duration. This method ensures that each object returns precisely to its intended visual dimensions upon restoration, regardless of its initial size or placement in the scene.

5.4 Graphical User Interface

Once you launch the application, the first thing you see is a canvas positioned in the scene, with two options that allow you to choose between viewing the ruins of Egypt or Timgad. You can press them, and they will take you to the desired area as shown in Figure 4.11.

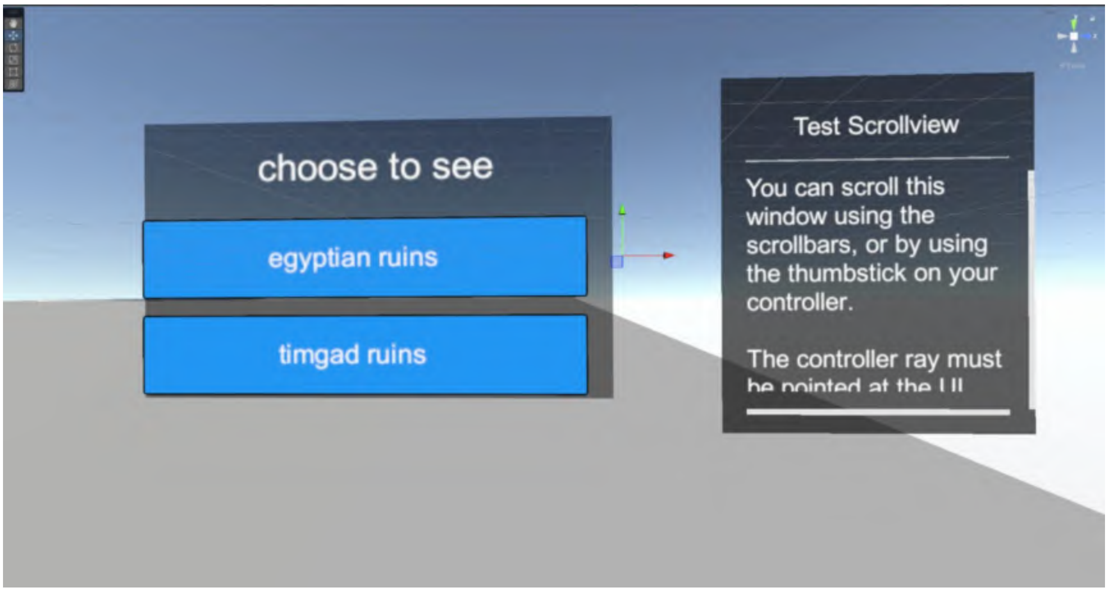

Figure 4.11: User Interface of the Main Menu

If you choose the Timgad option, you travel to another scene where you are surrounded by ancient Roman ruins figure 4.12

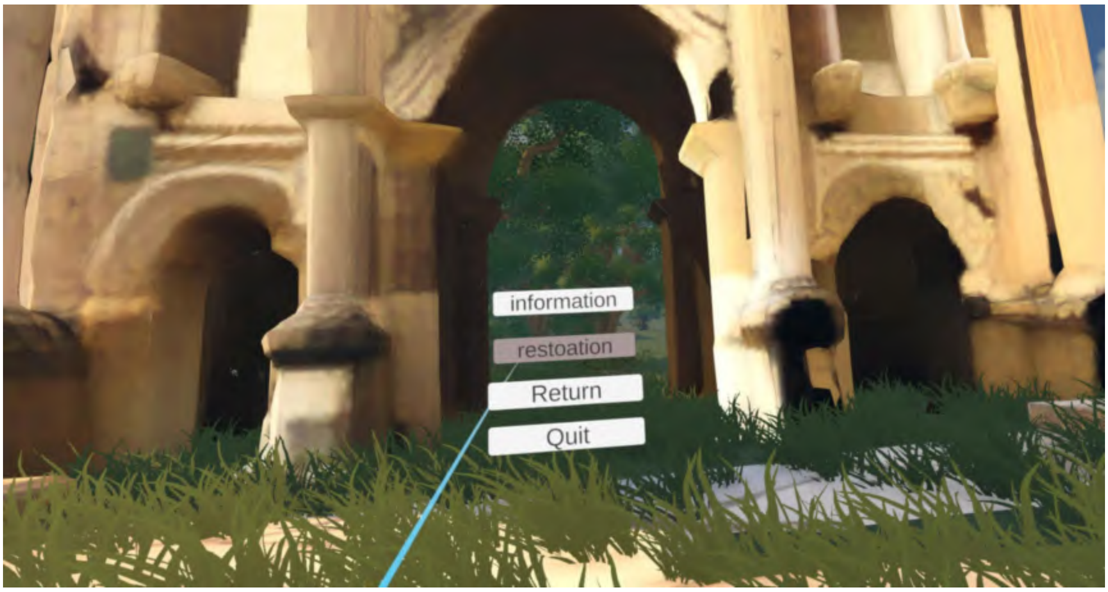

Figure 4.12: Timgad

5.5 Application Scenes

The objective of this app is to allow users to experience the Timgad Roman monuments in the present and provide them with the ability to view their original format.

Therefore, we created an environment to see the Roman ruins in their current condition. We used 3D ruins with textures, some of which were generated using AI.

The user can travel around the environment and observe the objects; it can also jump using the VR controller..

5.5.1 Locomotion and Navigation

When the Timgad ruins environment scene is loaded, the user can move around the environment. Therefore, we added continuous turns because users are used to it in real life.

5.5.2 Interactions and Behaviour

When the scene of the Timgad ruins environment is loaded, the user can move around the environment; therefore, we added continuous turn because users are used to it in real life .

We made a menu with four options: information, restoration, return, and quit as shwon in figure 4.13.

This menu can appear anywhere in the environment by pressing the secondary button on the VR controller.

When information is pressed, a panel will appear with text that describes the monument and gives a couple of information about it figure 4.14

Figure 4.13: Timgad

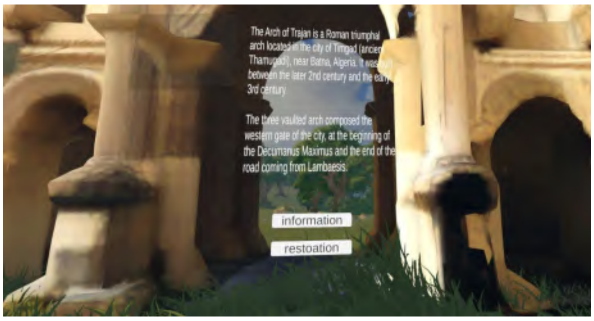

Figure 4.14: Application details

If restoration is chosen, then the current object will start shrinking in size until it disappears then the original model (restored form) will appear gradually, as shown in the figure 4.15 and figure 5.5.2

Figure 4.15: Restoration

Figure 4.16: Original model

Now the user can observe the original format of the monument. In this case, it's the Arch of Trajan, a Roman triumphal arch located in the city of Timgad.

Also, broken houses, pillars, and destroyed temples will be restored as shown in figure 4.17 and figure 4.18.

Figure 4.17: Roman triumphal arch

Figure 4.18: Houses and Temples

We also placed random objects such as rocks, vases, and broken pillars around the environment, and we utilized the XR grab interaction script to pick up the objects, rotate them throw them away, as shown in the figure 4.19 and figure 4.20.

Figure 4.19: rocks

Figure 4.20: pillar

We also placed random objects such as rocks, vases, and broken pillars around the environment, and we utilized the XR grab interaction script to pick up the objects, rotate them, and throw them away, as shown in the figure 4.21

Finally, there is the quit option to exit the application completely, as shown in the figure 4.22.

Figure 4.21: return

Figure 4.22: quit

If you choose to see the Egyptian ruins, you travel to another scene where you are surrounded by destroyed Egyptian ruins Figure 4.25 .

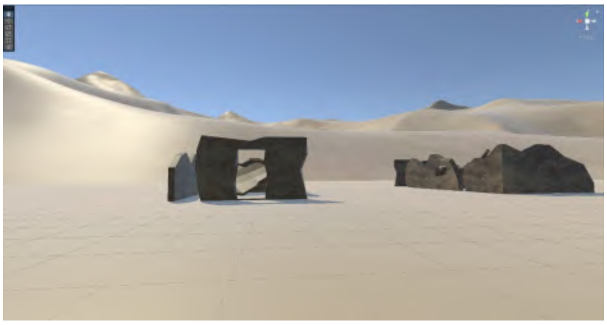

Figure 4.23: Ruined houses

Figure 4.24: Ruined sphinx (Abu alhul)

Figure 4.25: Ancient pyramid of Giza

Just like the Timgad ruins environment, you can choose to see different information about the ruins Figure 4.26.

Figure 4.26: information

And restore them to their original form Figure 4.28

Figure 4.27: Original form of sphinx

Figure 4.28: Original form of the pyramid

6 Application Usability

Through our virtual reality heritage conservation application, we leverage technology to enable users to interact with digitally restored heritage sites in an immersive and culturally enriching environment. During the experience, users navigate virtual reconstructions of historical sites, providing a realistic visualization of architectural heritage, spatial configuration, and cultural identity.

The system enables researchers, heritage and architecture students, and conservation professionals to interact with virtual heritage spaces. The system monitors exploration duration, points of interest, and access to contextual historical layers such as construction periods.

This application is designed for repeated use, allowing for gradual exploration and a deeper appreciation of the historical, artistic, and architectural value of heritage sites. This iterative interaction not only enhances academic and professional insight but also promotes cultural continuity and supports the mission of heritage conservation, documentation, and public engagement.

7 Conclusion

We presented the technical aspects of a virtual reality application designed to revitalize heritage sites. This began with the development environment, which combined the latest hardware and software technologies. The development process included user interface design and the construction of realistic virtual environments, culminating in the application scenes that offer an immersive and integrated experience.

Oculus Quest 2 was used to provide a rich visual and sensory experience, along with the use of powerful platforms, using the C# programming language, which enabled the development of an integrated interactive logic. We also focused on designing an accurate virtual environment that accurately simulates historical landmarks, ensuring ease of interaction and navigation within the virtual scenes.

Finally, we addressed the application's usability, ensuring a seamless user experience for all audiences, from students and researchers to heritage enthusiasts. This provides broader access to the technology and greater impact in the field of cultural heritage preservation and documentation.

This technical framework forms a solid foundation for achieving the project's objectives. It demonstrates how virtual reality tools can be harnessed to create innovative and practical solutions for heritage and education.

Conclusion

Virtual reality (VR) has gained increasing prominence in the field of heritage conservation, particularly in documenting and reconstructing archaeological and architectural sites that are at risk of deterioration or extinction. The use of VR in the restoration of architectural heritage is one of the most promising applications, providing a modern digital means of preserving precise details of historical monuments and making them interactively accessible to the public and researchers alike.

In this context, an application project was developed that reconstructs 3D models of heritage sites within a realistic virtual environment, utilizing sources such as old plans, photographs, and scanned data. The application is divided into integrated virtual scenes, allowing the user (whether a visitor, researcher, or student) to explore historical monuments and interact with architectural elements through a seamless user interface, enhancing visual understanding and appreciation of heritage.

The system was built using the Unity 3D engine with support for VR technologies via headsets such as the Oculus Quest, ensuring high compatibility and an immersive experience. The design also incorporated audio and visual effects inspired by the real historical context, aiming to enhance the sense of time and place within the virtual experience. Particular attention was paid to connecting devices and digital content in a way that provides natural navigation and seamless interaction, without compromising the precision of architectural details.

This project represents an advanced model in the field of digital heritage preservation, combining technology and history within a scalable educational and cultural framework. It also opens the door to the development of advanced educational content and contributes to disseminating architectural and heritage culture to new generations within a safe and stimulating environment, without exposing the original sites to damage or environmental threats.

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