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MASTER THESIS

The Metaverse Classroom: Development and Evaluation of an Engineered Educational Metaverse

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"When I was in the Navy, I was never afraid. They would call for volunteers for the examinations, and I would always go first. You know what De Filippo used to say? That exams never end! So, you shouldn't worry about these things!"

- Nonno Ugo

Dedicated to Nonno Ugo and Nonno Vincenzo, who more than anyone else would have wanted to be here today.

Abstract

Recently, the Metaverse has gained significant interest thanks to rapid technological advancements and its potential applicability in various contexts. The Metaverse is, in its essence, a highly immersive 3D environment where users interact with each other through avatars in real-time. This versatility allows it to find potential applications in fields. Notably, education is one area where the Metaverse holds excellent promise. With the outbreak of the COVID-19 pandemic, educational institutions had to pivot to remote learning using traditional 2D platforms to continue their activities. Today, remote learning continues to be adopted due to its flexibility. However, these 2D solutions come with limitations, such as a low sense of self-presence, isolation, and a consequent low engagement. In this context, envisioning a Metaverse platform for education could offer significant advantages. Initial prototypes are beginning to emerge very recently, mainly focusing on the educational or social aspects. There is a need for a tool suitable for both conducting educational activities and collaborative purposes. In light of these considerations, this thesis aims to develop a tool that embraces both the educational and the collaborative aspects. The *Metaverse Classroom* has been developed, which is a 3D platform embodying the main characteristics of a Metaverse and resembling a real university classroom. Within the platform, users access the environment through avatars and engage in real-time activities like lectures, exams, seminars, and group discussions. The platform's usability was assessed using an iterative approach called Rapid Iterative Testing and Evaluation (RITE), where feedback from each iteration guided improvements. Results indicated that the platform was intuitive, easy to learn, and provided a satisfying and engaging experience, effectively overcoming the limitations of typical 2D platforms. This thesis represents an initial exploration of Metaverse solutions in education, paving the way for the future development of more immersive, realistic, and robust educational experiences.

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CHAPTER 1

Introduction

This chapter introduces the thesis work, beginning to outline the context in which it was conducted. The identified limitations and the resulting objectives will be discussed, briefly mentioning the adopted methodology to achieve them.

1.1 Context and Limitations

Recently, the concept of the Metaverse has gained substantial attention, increasingly being viewed as an emerging frontier that holds the promise of transcending physical boundaries and being capable of providing a remarkably realistic experience in immersive virtual environments. As technological progress continues to advance unrestrainably, such an interest in the Metaverse field has grown exponentially, fueled by the anticipation of its transformative potential across many contexts and the advantages it may offer in each. For these reasons, big companies like META[1] —*a.k.a* as FACEBOOK— have begun to believe in this new reality and invest in dedicated projects to promote and adopt Metaverse solutions across various domains [1].

The Metaverse, in its essence, represents **a highly immersive three-dimensional digital world** where users engage in real-time interactions with both the environ-

[1] *Meta website*: `https://about.meta.com/en/`

ment and other participants through customizable avatars [2]. Given this platform's immersive and seemingly boundless nature, it is increasingly evident how it could be harnessed to revolutionize various application domains. The key concepts to consider when it comes to envisioning a Metaverse platform are (1) a highly realistic experience that can engage its users actively; (2) a ubiquitous connection so that the platform can be accessed anytime, anywhere; (3) an acceptable level of interoperability, to allow smooth exchange of information among various virtual worlds; (4) a scalable architecture, to enable the simultaneous connection of a large number of users [3]. Given these characteristics, it is simple to envision how this platform could benefit different areas. In entertainment and social contexts, platforms like SECONDLIFE[2] and SPATIAL[3] are leading the way, providing highly immersive experiences where people can interact with each other and virtual worlds in exciting new ways. The professional world also embraces the Metaverse, with tools like HORIZON WORKROOMS[4] facilitating meetings and collaborative work. The Metaverse also holds potential applications in simulations, such as medical or pilot training [4, 5].

Among all the currently relevant contexts, the **educational and academic sphere** is gaining the most attention. Such attention is not surprising, considering the transformation this domain has undergone following the outbreak of the COVID-19 pandemic, which affected 98.6% of students worldwide [6]. Educational institutions had to find ways to adapt and implement digital solutions quickly to ensure the continuity of educational activities. For these reasons, remote communication platforms like TEAMS or ZOOM have been widely adopted to support lessons, exams, and all necessary educational activities. Today, despite many activities returning to their in-person form, the advantages demonstrated by remote learning have been remembered. It is important to continue researching and refining digital solutions, allowing educational and academic contexts to explore new frontiers [7]. In this vision, adopting a Metaverse platform has the potential to advance the currently available solutions and overcome some of the persistent limitations identified, such as a low sense of self-perception, a feeling of absence and loneliness, and the resulting

[2] *Second Life site*: `https://secondlife.com`
[3] *Spatial site*: `https://spatial.io`
[4] *Horizon Workrooms site*: `https://forwork.meta.com/horizon-workrooms`

inactivity and limited expressiveness [8]. The immersive and social environment that the Metaverse offers can overcome these limits and create new ways of teaching, leveraging its simulation and interactive capabilities.

Despite these potentials, the development and adoption of Metaverse solutions in education still need to be explored, and **research in this context is only beginning to take its first steps**. In fact, in this initial exploratory phase, what is emerging is the beginning of an analysis of potential frameworks and methodologies that could be adopted to develop Metaverse platforms in the academic context, remaining at a predominantly theoretical level [9, 10, 11]. At the same time, some prototypes have also started to emerge. However, they are restricted in the specific context they were designed, primarily presenting themselves as social interaction [12] or educational platforms [13, 14]. Solutions capable of encompassing both of these Metaverse characteristics still need to be included, creating an educational yet highly collaborative environment that can overcome the limitations of remote teaching and communication.

1.2 Objectives

The motivations behind this thesis work stem from current limitations and the need to develop a tool capable of combining the strengths of existing tools and addressing their limitations. Therefore, the main objectives of this work are summarized below.

> ◎ **Thesis Work Main Objectives**
>
> *The objectives of this thesis work are as follows:*
>
> - ***develop a tool*** *capable of supporting educational and collaborative activities in academic contexts,* ***embodying the key features of a Metaverse*** *by providing an interactive and realistic three-dimensional environment;*
> - ***evaluate the tool*** *by putting it into practice for actual activities,* ***focusing on usability****, and involving participants in the testing activities selected from potential tool end-users.*

The ultimate goal is to create **a tool that can be effectively adopted and exploited in educational and academic contexts**. It should encompass the critical characteristics of a Metaverse, providing a three-dimensional and realistic environment where users can connect simultaneously and interact with each other and the environment in real-time. Within this tool, it should be possible to conduct lessons, seminars, and other educational activities, as well as collaborative tasks and peer-to-peer or teacher-student communication. From an educational perspective, the tool should allow for various teaching activities. These should encompass traditional frontal lectures and other learning techniques, such as *learn-by-doing* or *cooperative learning* through group activities in which all participants can actively engage. Equally important will be testing the tool's usability in the real-world context for which it was designed, conducting experiments with participants who could be potential end-users of the tool, and collecting feedback for improvement. **The RITE methodology will be followed** for this activity: it is an iterative usability testing approach where each experiment is repeated multiple times, and any identified issues or bugs are promptly addressed at the end of each iteration [15, 16]. This approach will be adopted to ensure that the tool is genuinely usable and that user interaction is central, observing their experiences and collecting feedback to enhance the tool until it reaches an entirely acceptable state.

1.3 Thesis Structure

In light of the outlined framework, the following document is structured as follows:

- **Chapter 2** provides a comprehensive background on the Metaverse and its main components and characteristics, followed by a description of related work in the field;
- **Chapter 3** presents the developed tool, listing its main features, potential user scenarios, the designed architecture, and interface;
- **Chapter 4** describes the usability evaluation phase of the tool using the RITE methodology, detailing its various iterations and the obtained results;

- **Chapter 5**, finally, draws the conclusions of the work carried out and presents potential future developments.

CHAPTER 2

Background & Related Work

This chapter will explore the basics of the Metaverse concept and look at existing works related to our research. Section 2.1 provides a comprehensive background on the concept of the Metaverse, defining its essential characteristics and examining the current state of technologies utilized for its implementation. Subsequently, Section 2.2 will discuss related works and prototypes developed in the context of the educational Metaverse, highlighting their unique features and objectives. By doing so, the aim is to contextualize the study within the broader context of educational Metaverse applications.

2.1 Background

In this section, a background on the topic of the Metaverse will be provided. The aim is to define and analyze its main characteristics, followed by an overview of the currently prevalent hardware and software technologies for its implementation. Finally, a specific focus will be placed on the Metaverse in the educational context to assess its current status and highlight its potential.

2.1.1 Metaverse's Definition

The first time the term "Metaverse" was ever used was in Neil Stevenson's science fiction novel *Snow Crash*, published in 1992, and it referred to a world where virtuality and reality were mixed and in which people could be able to interact through avatars [17]. Nowadays, the concept of Metaverse has expanded and evolved, and the term includes many aspects and features within it [2, 18, 19]. Many definitions have been provided in the literature, each varying differently from the others and focusing on a particular aspect depending on the application domain [19]. In general terms, a Metaverse has been defined as a three-dimensional online environment where users, represented by avatars, interact with one another within virtual spaces, which are free from the physical constraints of the real world [19]. Dionisio et al. [3] defined a series of characteristics that generalize the most important aspects to achieve a fully functional Metaverse, described below.

- *Realism*: To deliver an engaging and believable experience to users, a Metaverse must maintain a high level of realism, which primarily derives from elements that revolve around the senses of sight, hearing, and touch. A Metaverse experience focuses on such elements to increase immersivity and provide a higher sense of realism, resulting in better psychological and emotional involvement.

- *Ubiquity*: A Metaverse platform must have widespread availability and accessibility across various platforms. This aspect is highly achievable nowadays, thanks to the advancements in ubiquitous computing [20], enabling access to the same platform and account from a wide range of devices, including desktop PCs, tablets, smartphones, and also web browsers, which overcome the need for time-consuming software installation or updates.

- *Interoperability*: A Metaverse must achieve a reasonable level of interoperability, defined as the smooth exchange of information among various virtual worlds. The primary focus is the definition of format and data standards to transfer 3D models and objects between virtual worlds environments and communication protocols, locators, identities, and currency standards.

- *Scalability*: A Metaverse must possess scalability to accommodate a large number of concurrent users, by providing ample resources and power for their participation without compromising the system's efficiency or the users' experience. Accommodating massive user interactions while maintaining optimal performance is crucial for creating a thriving, immersive Metaverse environment.

2.1.2 Key Concepts and Components of a Metaverse

After defining the primary attributes that characterize a Metaverse, it is essential to highlight its key components and concepts. The following subsection presents and describes these key concepts and main components, offering a comprehensive overview of the essential elements within a Metaverse.

- *Avatar*: An avatar is a digital representation of the user in the Metaverse, serving as the means through which they interact with the virtual world. An avatar must be controllable in real time and strive to be as synchronized with the user as possible. The representation an avatar provides of the user is a crucial and widely debated aspect [21, 22, 23]. An avatar can be a faithful representation of the user's physical appearance or a completely distinct one, depending on their choice. At the same time, the platform itself may adopt various representation strategies, such as highly realistic, stylized, or even non-human avatars [18]. Kim et al. [21] conducted a study on the impact of using different levels of realism in the avatars' style, and surprisingly reported that high realism decreases the sense of social presence and increases the perceived psychological distance. Moreover, the choice of avatar representation must necessarily consider legal aspects, such as fraud, identity theft, and defamation [22], as well as ethical considerations, like the representation of diversity and disability, to avoid any form of discrimination [23].

- *Dimensions*: As introduced in Subsection 2.1.1, the Metaverse is generally defined as a "three-dimensional virtual world." However, the aspects and characteristics that a virtual world may possess vary significantly. Smart et al. [24] have provided a classification into four different dimensions of the Metaverse, helpful in understanding its various contexts. The four dimensions are summarized in Figure 2.1. They have been classified based on the technologies' level of *External*—i.e., information and controls of the external world—versus *Intimate*—i.e., identity and actions of individual objects— and the level of *Augmentation*—i.e., augmentation of the capabilities of existing systems—versus *Simulation*—i.e., modeling of new environments. Table 2.1 defines each of the identified dimensions.

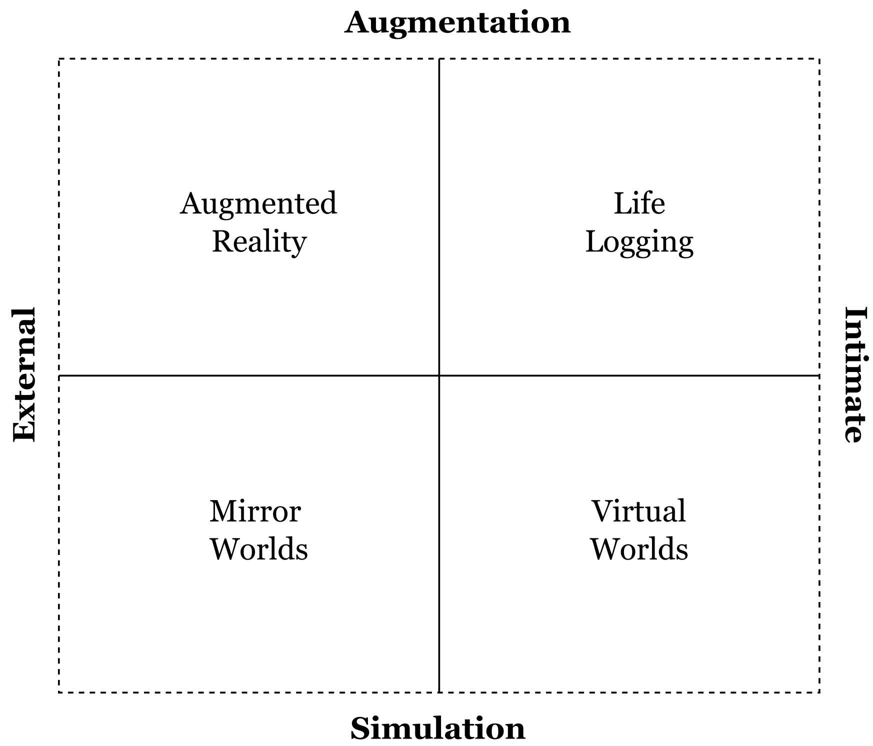


Figure 2.1: Classification of the Metaverse into four dimensions.

- *Digital twin*: A digital twin is a virtual and digital representation of a real-world object, system, or process [25]. Digital twins within the Metaverse enhance the immersive experience by providing users with a seamless connection between the physical and digital worlds, fostering a more engaging and dynamic virtual environment. The creation and interaction design of the digital twins in the virtual world is a multidisciplinary field involving material science, signal processing, Internet of Things (IoT), pattern recognition, and rendering techniques. [12]. A Metaverse platform has to carefully choose what objects in the physical

Table 2.1: Summary of the possible dimensions of a Metaverse.

Metaverse's Dimensions	Definition	Classification
Augmented Reality	Enhancement of the physical world for individuals by utilizing location-aware systems and interfaces. It processes and overlays networked information on top of our everyday perception of the world, providing users with additional digital content and context in real-time	External - Augmentation
Life Logging	Augmentation technologies for recording and documenting objects' and users' states and life histories. They support object and self-memory, observation, communication, and behavior modeling. Object Lifelogs maintain a narrative of use, environment, and condition for physical objects	Intimate - Augmentation
Mirror Worlds	Representations of the physical world enriched with information, typically built with virtual mapping and modeling technologies, and annotation tools	External - Simulation
Virtual Worlds	Digital environments that increasingly enhance the economic and social life of physical world communities. The sharp distinctions between the virtual and physical realms are gradually diminishing	Intimate - Simulation

world should be mapped as digital twins and how to use them in the Metaverse to effectively benefit the real world [12].

- *Content Creation and Virtual Economy*: A crucial feature of a Metaverse environment is the ability to create personalized virtual content. This feature should be accessible not only by professional designers but also by all users: the operators should create and provide the essential elements, while users fulfill the Metaverse with innovative user-generated content (UGC) [12, 26]. This is a crucial aspect when considering the promotion of diverse creator cultures, cross-generational content, and preserving a digital heritage [18]. Concerning this aspect, within a Metaverse platform, it should also be possible to make purchases, and it should have a showcase for selling users' creations, facilitating the development of a genuine virtual economic system. [18, 2]. For example, Momtaz [27] highlighted the defining aspects of a Metaverse economic model, describing it as a decentralized digital world where UGC and non-fungible tokens (NFTs) will serve as enablers of such an economy. Furthermore, the study highlights how the development of an economy in the Metaverse can open new frontiers in the fields of marketing and advertising, while also having a positive impact in terms of social and environmental sustainability.

- *Social Acceptability, Security and Privacy*: At the core of the primary objectives of a Metaverse lies real-time social interaction among connected users. Social aspects and all ethical precautions and related issues must be carefully considered. *Social acceptability* refers to the reflection of collective behavior and thoughts of the users inhabiting the Metaverse [18]. Fairness, user diversity, and privacy issues are all factors that heavily influence this aspect. In essence, the Metaverse has the potential to establish a proper society, making it crucial to define rules and norms to regulate and mitigate instances of discrimination, cyberbullying, and potential cyber crimes [28]. Moreover, a Metaverse platform must address its users' security and privacy concerns. Each user possesses a distinct digital identity within the Metaverse, necessitating the implementation of effective authentication and recognition methods for access [18]. Likewise, users and their activities will generate substantial amounts of data, which could be vulnerable to leaks or unauthorized acquisition for purposes like user profiling. Managing privacy issues, establishing regulations, and addressing security concerns within the Metaverse are vital aspects [29].

2.1.3 Hardware and Software Technologies for the Metaverse

As introduced in Subsection 2.1.2, a Metaverse is a potentially very complex platform encompassing numerous components. It requires a 3D rendering engine for its three-dimensional virtual environment and tools for creating and modeling avatars, environments, and objects. It must have a robust large-scale persistence management system, be scalable, and handle the simultaneous connection of many users. It must address privacy and security concerns and incorporate a system for purchases and economic transactions. Additionally, it can leverage Virtual Reality (VR) or Augmented Reality (AR) technologies to enhance realism and immersion, providing a far more engaging experience than typical software applications. Therefore, it is natural to wonder how such a platform could be implemented and what are the most commonly used hardware and software technologies for this purpose. This subsection will describe the most commonly found hardware devices in Metaverse applications and the software technologies most frequently utilized to meet all the Metaverse requirements.

Hardware Components

One of the critical features of the Metaverse is ubiquity, making it essential for the platform to be accessible from various devices [3]. Achieving this ubiquity may come at the cost of some immersive and realistic experiences, as a Metaverse platform should ideally run on ordinary desktop computers, laptops, tablets, and smartphones. However, advanced hardware technologies are gaining traction and started being more commonly used to create increasingly engaging Metaverse experiences that provide visual, auditory, and even tactile feedback. Indeed, Head-Mounted Display (HMD) devices are becoming progressively more popular when it comes to implementing a Metaverse. These wearable devices come in various types: (i) non-see-throughs, which block entirely the real world to enable a 360-degree view of a fully virtual world, typically used in VR applications—e.g., the Meta Quest by Meta, or the HTC Vive by Valve—, (ii) optical see-throughs, which overlay virtual elements onto the real world—e.g., the Microsoft HoloLens or the Google Glasses—, commonly found in AR applications, and (iii) video see-throughs, which capture the real world through cameras and add virtual components to it—e.g. the device developed by Takagi et al. [30], an HMD device with a wide field of view— [2, 31]. Devices like the non-see-through HMDs allow users to fully immerse themselves in the virtual environment and provide an experience that cannot be otherwise achieved with traditional 2D displays. However, to date, the widespread adoption of these devices faces some obstacles. Caserman et al. [32] examined the issue of *cybersickness* when wearing HMDs, defined as a collection of symptoms such as nausea, disorientation, confusion, and headaches caused by the prolonged use of an HMD device. They reported that 60–95% of participants experience cybersickness during exposure to a virtual environment, while 6–12.9% prematurely terminate their exposure due to this discomfort. Moreover, ensuring a ubiquitous Metaverse that fully exploits these technologies is challenging due to their expensive nature, which makes them mostly unaffordable for the general public [31]. See-through devices tend to be less bulky and more accessible. Typically, they are wearable devices similar to lightweight glasses, designed to overlay elements or annotations onto the user's standard view of the real environment. Applications leveraging AR elements are becoming increasingly popular, as demonstrated by the study by Olsson and Salo [33], who conducted an online qualitative survey on user satisfaction with mobile applications utilizing AR devices, reporting generally positive results. Furthermore, Fernandes et al. [34] compared two multimodal interfaces for an immersive video game: (i) a VR interface with an HMD in an entirely virtual environment and (ii) an interface with AR glasses in an augmented environment. The results showed the VR experience was immersive and engaging, but the AR interface caused much less cybersickness and disorientation.

Moreover, in addition to wearable devices for visualizing the Metaverse environment, input devices also play an important role in the experience. Alongside the most common interaction devices used in 2D display applications, such as the mouse, keyboard, touchscreens, and joysticks, some input devices have been specifically designed for improved interaction when considering VR or AR technologies. These devices are essential for real-time interaction with the platform and serve as the primary means through which users control their avatars, explore, and interact with the surrounding environment. In the comprehensive study conducted by Park et al. [2], the input devices were divided into three categories: (i) hand-based, (ii) non-hand-based, and (iii) motion input devices. The hand-based input devices are designed to be held or attached to the user's limbs. They use typical buttons and triggers and position and rotation sensors to capture and map body movements into actions. These devices serve as input mechanisms and provide haptic feedback to users, enhancing the sense of realism and immersion by engaging the sense of touch. The second category of devices is typically used to aid those mentioned earlier, utilizing different input types than those related to limb movement. For instance, even when using HMDs, one can employ eye-tracking to rotate the character's avatar head or use voice input as an alternative input mode. The last category encompasses all auxiliary devices capable of capturing the full-body movements of the user to enhance the physical sense of space or gravity. These devices offer greater freedom, such as walking and moving around at 360 degrees. However, they are expensive and may pose a risk of injury to the user, making them too costly for widespread adoption in the short term.

Therefore, the current diverse hardware devices each present limitations and strengths, and there are obstacles to address for solid, realistic, and ubiquitous Metaverse platforms to spread consistently. Table 2.2 summarizes the described hardware devices.

Table 2.2: Summary of the mostly used hardware devices for the Metaverse.

	2D Technologies	VR & AR Technologies
Visualization devices	Desktop computers, laptops, tablets, smartphones	Non-see-through HMDs, see-through HMDs, video-see-through HMDs
Input devices	Mouse, keyboard, touchscreens, joysticks	Hand-based input devices, non-hand-based input devices, motion input devices

Software Technologies

When it comes to software technologies for the implementation of a Metaverse platform, the core resides in the 3D rendering engine. All the main components of the Metaverse—e.g., *virtual environments*, *avatars*, *digital twins*—are practically 3D objects and models that need to be created, textured, rigged, and made accessible through real-time rendering [18, 2, 3]. When considering suitable 3D engines for a

Metaverse, one of the most widely adopted is Unity3D.[1] Unity3D is a free-to-use cross-platform development engine, and the developed application can be deployed on smartphones, PCs, and browser-based cloud streaming. It offers a vast asset store, facilitating the creation of diverse virtual environments and avatars. An alternative popular choice is Unreal Engine,[2] a 3D engine that excels in rendering high-quality, photorealistic graphics, making it ideal for projects that demand visual fidelity. It provides advanced tools for creating immersive worlds and can handle large-scale environments effectively. For the creation of 3D models and environments, specialized software is commonly used, such as the open-source software Blender[3] or other licensed software like Maya[4] or ZBrush.[5] These tools allow the modeling, texturing, and rigging of models, enabling them to be exported and used within development platforms.

However, a Metaverse does not only require a proper engine to handle the creation and rendering of its elements. In fact, such a platform must also leverage technologies that ensure scalability and efficient data management. Potentially, a Metaverse will generate and need to handle a massive amount of data, making it impractical to rely on a single cloud server for storage. In light of this, a solution that has gained significant traction in recent times is the *blockchain*. The blockchain is a distributed database where data is organized into blocks rather than structured tables [35]. Users, also known as nodes, generate data organized into blocks. The network of users is typically a peer-to-peer (P2P) network, in which participating nodes act as both clients and servers, enabling them to share resources directly with each other without the intervention of a centralized server. Each block of data generated by the network is linked to previous ones, forming a chronological chain; each node stores blockchain data locally and synchronizes it with other nodes through a consensus model, i.e., a mechanism used in distributed systems to achieve agreement among nodes on the validity and order of transactions or events [35]. Every single node maintains a complete record of the chained data, ensuring two fundamental

[1] *Unity3D website*: `https://unity.com`

[2] *Unreal Engine website*: `https://www.unrealengine.com`

[3] *Blender website*: `https://www.blender.org`

[4] *Maya website*: `https://www.autodesk.it/products/maya`

[5] *ZBrush website*: `https://www.maxon.net/en/zbrush`

characteristics of a Metaverse: decentralization and security. If an error occurs on one node, other nodes can cross-reference to correct it. Figure 2.2 shows the architecture of the blockchain. Such technology, due to its distributed nature, represents a valid way to address problems of large data storage and sharing among the Metaverse's users. Zyskind et al. [36] introduced a decentralized system for managing personal data, using blockchain technology and ensuring a high level of security. In fact, the system ensures a secure data access channel, where the data owner shares a key with all authorized users who request access. Blockchain appears to be a promising technology for proper and efficient management of a Metaverse, but there are still technological developments needed for it to spread and be more widely adopted [35].

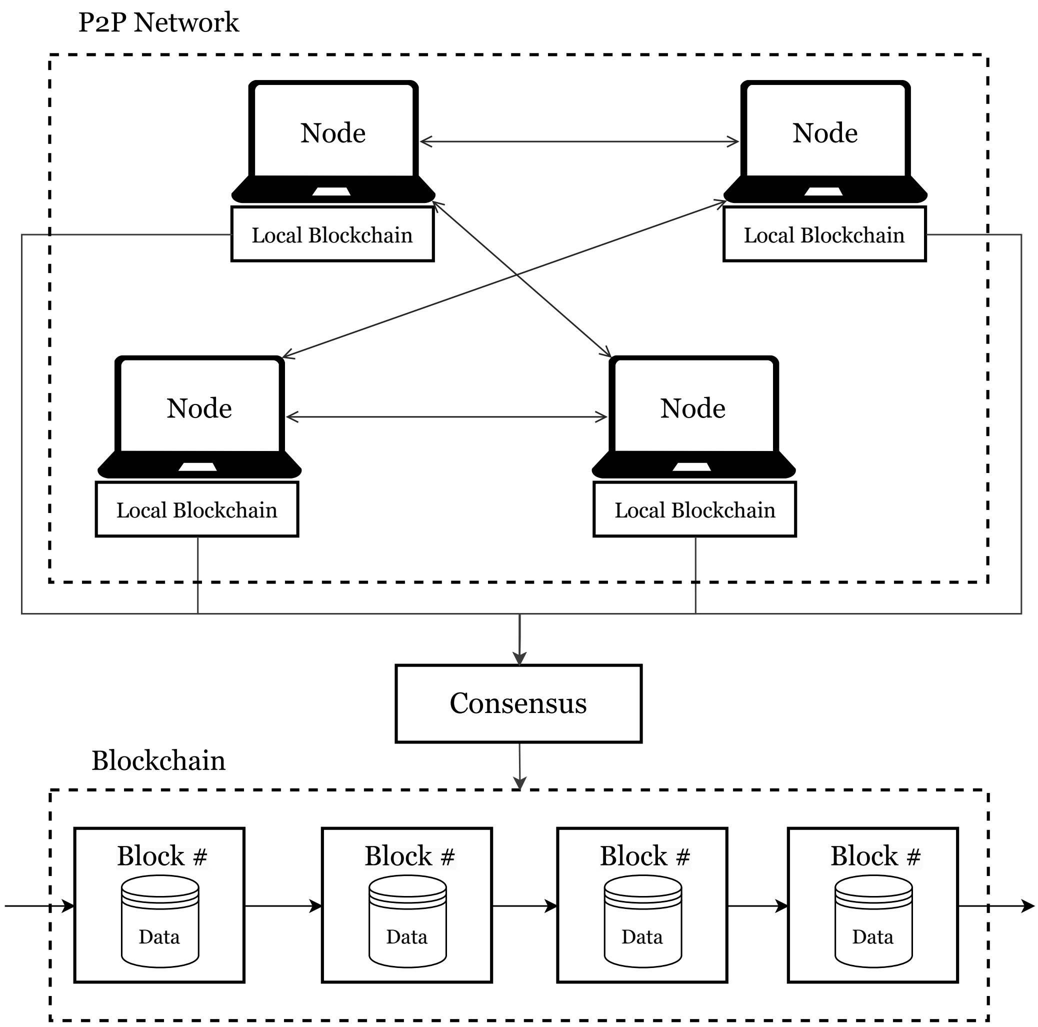


Figure 2.2: Architecture of the blockchain.

Not only technologies like blockchain can bring significant benefits to the Metaverse, but also the vast field of artificial intelligence finds ample space. Indeed, there are several points where artificial intelligence technologies can be used to implement essential features and requirements within a Metaverse platform. One of the most common applications is the implementation of non-playable characters (NPCs). Specifically, NPCs are AI-driven characters that are not controlled by any user, serving as assistants, partners, or even antagonist figures to present challenges, offer assistance, and contribute to the realism of the platform. [12] Advanced AI techniques, such as Deep Learning (DL) and Reinforcement Learning (RL), are usually exploited for the implementation of the NPCs, as well as the Natural Language Processing (NLP) techniques, which allow the understanding and the generation of human-like texts to make them effectively interact with the users. Populating the Metaverse with entities like NPCs can bring various benefits and offer a more engaging experience, creating a more populated environment. Additionally, a study conducted by Soni et al. [37] demonstrated that users testing a video game preferred having robot entities trained to behave like humans over simple computer-controlled opponents or assistants. Furthermore, as introduced in Subsection 2.1.2, one of the main components of the Metaverse is the digital twin. It is essential to emphasize that digital twins are not simple 3D objects replicating a real-world item but rather an actual replica of an entity within the Metaverse. For these reasons, if the state of the physical object changes in the real world, it must also change for the digital twin in the Metaverse [25]. It is appropriate to use artificial intelligence technologies capable of mapping, tracking, and updating the existing digital twins to achieve such a goal. By using AI algorithms, digital twins can stay in sync with their real-world counterparts, ensuring continuous and responsive integration between the physical and virtual worlds [18]. A concluding remark describing AI's potential uses in the Metaverse involves Computer Vision technologies, which enable computing devices to comprehend and process visual information about the environment and entities. In the Metaverse, the interaction system must understand complex environments that integrate virtual objects with the physical world. Therefore, Computer Vision algorithms can aid in adequate spatial and scene understanding. They can also be used for the automatic generation of avatars from a user's facial image or for the automatic creation and correction of objects and textures [38].

In conclusion, the continuous advancement and dissemination of software technologies continuously open new frontiers for Metaverse applications. In this section, the main and currently most widely used categories have been summarized.

2.1.4 Metaverse for Education

A Metaverse platform can be conceived and used in many application fields, from gaming, simulations, remote work, and communication, to marketing [18, 2]. However, for this work, it is important to focus on the impact of the Metaverse in the educational context, how it has been exploited so far, and what are the main findings.

The interest in the Metaverse for the educational context began to arise following the outbreak of the COVID-19 pandemic. The virus's rapid spread and subsequent lockdowns and restrictions made traditional in-person education a significant health risk. Because of this, 98.6% of students worldwide were affected by the emergency, and educational institutions were forced to find alternative ways to ensure continuity in learning while keeping students, teachers, and staff safe [6]. Distance learning platforms offered a practical solution by allowing schools, colleges, and universities to transition their teaching activities online. Schools and universities widely adopted remote 2D communication platforms [8] such as MICROSOFT TEAMS, GOOGLE MEET, and ZOOM to keep their activity going [6]. The spread of distance or blended learning methods for lessons and other educational activities has shown to have some significant benefits. Remote learning makes education accessible to more people. Indeed, remote communication platforms for education have allowed physically challenged students to participate in learning within the virtual environment more freely since it requires limited movement [7]. Moreover, a study by Soblechero et al. [39] analyzed the effect of activating a remote modality for students enrolled in the Administrative Management vocational program. The results showed that after the implementation of the distance learning mode, the number of course enrollments increased, and more individuals had the opportunity to participate despite working or being engaged in other daily activities.

With these intentions, distance learning holds great potential and can offer substantial advantages to the education process for learners of any age. However, the quality of online learning still needs to be perfected. The need to quickly find a solution to continue education during the pandemic emergency left no time to study and design solutions that could ensure a certain quality of online teaching [7]. Even with a wide range of digital tools available for online education, current technologies have yet to fully replicate the immersive learning experiences offered in traditional classroom settings [40]. The virtual communication platforms described so far indeed have several limitations. Mystakidis [8] identified some crucial negative aspects of using these 2D learning environments:

- *Low self-perception*: In 2D environments, users have a restricted sense of self, appearing as disembodied entities represented by a photo or a live webcam headshot feed, lacking personalization options.
- *No presence*: In web conferencing sessions, participants view them more as video calls to join rather than virtual collective meeting places. As a result, in lengthy meetings, participants may disengage and become distracted.
- *Inactivity*: In 2D platforms, interaction among participants is limited. Without instructors initiating learning activities, students are restricted to passive participation with minimal opportunities to engage actively.
- *Crude emotional expression*: Users have few options to express their feelings, relying mainly text symbols or on emojis.

Using a realistic real-time 3D environment for education could offer a way to address these limitations. However, even though there has been progress in the design and creation of 3D virtual environments, it remains to be seen if the field of education can achieve an experience replicating the cognitive and emotional aspects of in-person activities. The Metaverse, due to its inherent nature, might present a promising solution to these limitations. It is inherently an immersive environment, fostering social exchange and interaction among its users and offering endless possibilities for representing and creating educational content. Research on an educational Metaverse is still in its early stages, and there is still a need to explore its full potential, address technical challenges, and develop effective learning strategies. However, Dwivedi et al. [41] formulated some key points and guidelines that an educational Metaverse must encompass:

1. A Metaverse for education should be a mirror world for real learning environments. When designing a Metaverse platform for education, it is crucial to understand the practical elements of in-person learning and strive to replicate them in the virtual world. This goes beyond creating an environment with recognizable 3D virtual elements similar to the real world. It also involves designing avatar interactions, their expressiveness, and their ability to synchronize with the user.

2. The use of Metaverse should overcome the physical constraints of the real world and combine capabilities of in-person classrooms and e-learning. Indeed, the Metaverse not only has the potential to replicate physical reality but also to extend it. Students and educators can engage with simulations and scenarios that would not be possible in a physical classroom and leverage 3D representations of elements that are not otherwise visible and entirely understandable in a traditional lesson.

3. Teachers should adapt their teaching approaches and course content to instruct within the Metaverse effectively. With the new opportunities that the Metaverse brings and the required technologies for its implementation, pedagogical methodologies and course content must adapt to the new environment in which they will occur. As a result, educators will need to update their skills and be prepared to manage the educational experience effectively.

4. New metrics should be developed to evaluate the Metaverse learning experiences. Indeed, with a large amount of user-generated data in the Metaverse, educators will have access to a wealth of information about students' reactions to educational activities and can use this data to make necessary adjustments. With privacy concerns in mind, student interactions, facial expressions, and even data such as eye tracking can be analyzed to glean relevant insights into their perceived experiences.

5. Education providers should provide new technological tools and train educators to effectively teach students within the Metaverse. Indeed, adopting the Metaverse demands educators to acquire new technical skills. As such, educational institutions must decide on the technologies to be employed and take responsibility for training their staff to master them.

In conclusion, the Metaverse represents an improvement to current distance education through traditional 2D platforms and enhances in-person education, expanding it and enabling new forms of learning otherwise impossible. Table 3.1 summarizes how the use of the Metaverse can help overcome all the identified limitations.This is achieved through immersive 3D environments, breaking barriers of social connection, and facilitating effective virtual participation through telepresence, avatars, and more engaging interactions. The research is still in its early stages, and no established solution fully encompasses all defined guidelines and overcomes current technological limitations [8]. However, the emerging path appears very promising.

Table 2.3: Limitations of traditional 2D platforms and possible solutions in the Metaverse.

Limitations of 2D platforms	Possible solutions offered by the Metaverse
Low self-perception	Representation of oneself through customizable and real-time controllable avatars
No presence	Presence within an immersive 3D world, joining a collective environment where the perception of oneself and others in the space is immediate
Inactivity	Real-time social interactions and the ability to actively engage in educational activities, resulting in an immersive experience that maintains a high focus factor
Crude emotional expression	Greater expression possibilities through various interactions of the avatars, complete control over them, and the ability to give and receive immediate feedback among users

2.2 Related Work

This section discusses the related works presented in the context of an educational Metaverse. Specifically, other Metaverse prototypes proposed for educational or academic purposes will be described, highlighting their features and primary objectives. The goal is to provide an overview of the current experiments and emphasize how our work differs.

Duan et al. [12] presented the Chinese University of Hong Kong, Shenzhen (CUHKSZ) Metaverse, a campus Metaverse prototype developed with Unity3D and Blender. It is equipped with a blockchain-based ecosystem to support creating and exchanging user-generated content. In this regard, the authors have also provided an editor for voxel-based item creation, which can later be built as NFTs. The platform is primarily designed to be accessed by campus students via smartphones, leveraging sensors like the camera and GPS to gather information. Users can explore the campus, interact with others, and the main focus is creating and sharing content among users. However, unlike the proposed work, it does not explicitly focus on academic activities and needs to be shown whether structures like classrooms or other educational environments have been designed.

Jovanović et al. [13] developed VoRtex, a virtual learning environment created with Unity3D, which supports multi-user interaction and is designed for conducting classes and other educational activities. It features a biometric authentication system that connects users to data on a cloud platform. Within the 3D environment, there are virtual classrooms, digital avatars, and learning materials. Additionally, virtual assistants are present, driven to support users. The platform features a virtual classroom equipped with desks, chairs, and a projector and a "MicroLesson" mode with 3D materials designed to facilitate learning in a real-life environment. Users access and control their avatars, communicating with each other and the instructor through a text chat. The platform incorporates a speech-to-text recognition component for using voice commands and interacting with virtual assistants. However, communication with other users is limited to text chat, and no other avatar interactions are illustrated.

Shen et al. [42] presented V-Classroom, a cyber-physical-social space for teaching, tested in a seminar classroom at the Artificial Intelligence College of Beijing Normal

University. The prototype focuses on reconstructing real physical classrooms into a 3D digital representation through cameras and sensors that capture the real environment and then map it into a virtual environment. The students' images are captured and extracted to be placed in the digital classroom without a virtual representation of the students themselves. Although the study is framed within the context of Edu-Metaverse, it focuses on the methodology of creating the classroom. It analyzes the results from a technical perspective without discussing the distinctive aspects of a Metaverse.

Sin et al. [14] proposed K-Cube VR, a prototype for an educational Metaverse that utilizes an HMD to create a learning experience. The prototype was used to introduce students to introductory concepts of an academic course. Wearing the HMD and holding a hand-based input device, users could view a 3D model of a knowledge graph representing and connecting course concepts. Users could explore the environment containing the graph and then select a node to be transported to a hub containing multimedia content related to the chosen node. The presented prototype is currently under development and still needs to include the ability to create a personal digital representation or features for real-time communication with other users. However, its focus lies in exploring educational theory through knowledge graphs and how it impacts the knowledge of students who interact with it, especially analyzing the efficiency of the experimented teaching method.

The works presented indicate that the main emphasis is often placed on the social [12] or educational aspect [13, 42, 14], with one aspect being prioritized over the other. In contrast, our work aims to draw from the insights gained from these studies and integrate the learning component with the collaborative and social elements among users, resulting in an environment that combines educational and social aspects. This approach seeks to reach a balance and offer a holistic experience in the Metaverse for educational and academic purposes.

CHAPTER 3

The Metaverse Classroom: An Engineered Educational Metaverse

The main goal of this research was to develop and validate a Metaverse platform to support academics and students in collaboration and communication tasks. Concretely, the platform is a large room that implements general tools—inspired by real-world classes—to allow people to collaborate in different scenarios, e.g., conducting or attending lessons, seminars, talks, and working together.

3.1 Requirements and Characteristics

Several factors were considered to define the preliminary functionalities of the tool. Firstly, essential requirements were derived from the context, by analyzing what the tool was intended to accomplish within its intended scope. The basis for the requirements also considered the key elements proposed by Ng et al. [43]. Moreover, the functionalities were also derived from the literature, by examining the features and areas for improvement of existing tools [12, 13, 14, 42]. Subsequently, researchers in the fields of Software Engineering (SE) and Human-Computer Interaction (HCI) from the university were recruited for interview sessions. During these 15-minute interviews, the researchers were asked to discuss how they would implements each of the key elements identified by Ng et al. [43] and to propose new potential functionalities. After these activities, the functional requirements were defined, and the tool entered its development phase.

At the end of its development, the tool appears as a 3D virtual environment where interaction occurs through one's avatar. The environment has been shaped after a real university classroom, featuring key elements such as desks, chairs, a projector, and a whiteboard. The environment has been designed to incorporate a set of essential requirements in order to obtain a functional Metaverse platform. These core requirements are detailed below.

Creation and connection to a room. The platform offers real-time connection with other users as a critical feature. This connection has been implemented through a *room system*, allowing users to choose whom to connect with. The first user intending to connect will create the room, providing it with a password, and then share this information with interested individuals. They can use it to connect to the room and initiate real-time interaction with other users. When each user disconnects from the room and it becomes empty, it is automatically deleted.

Free three-dimensional exploration. Freedom of movement and interaction characterize the virtual environment, allowing users to navigate any classroom area and engage with objects seamlessly through their avatars. Users can walk, sit, and interact freely with various objects in the scene. They can rotate their view and adjust the zoom level of their perspective as well.

Avatar's customization. The user has the option to customize their avatar in various ways. The prototype includes a dedicated interface where users can make different appearance choices for their avatar, including skin color, uniform type and color, eye shape and color, eyebrows and possible beard, hairstyle, and a selection of some additional cosmetics like glasses or eye patches.

Realistic voice communication. Users can engage in real-time communication with each other through voice chat. Using their microphones and voices, they can make their avatars speak and hear others as in genuine verbal communication. Furthermore, the voice chat is equipped with proximity and three-dimensionality features, allowing the tone of voice to vary based on the distance and position of the interlocutor. Such a feature enhances the realism of the experience and enables lifelike communication akin to real-life conversations within physical spaces.

Text communication. It is also possible to communicate through text chat, which is readily available and visible in the platform's user interface. Users can opt for their preferred communication method. Moreover, the text chat is continuously accessible and displays the last ten sent messages on the screen. Additionally, users can review the entire chat history after the session, through a log file stored locally, as indicated upon accessing the virtual classroom.

Non-verbal interaction. The platform also allows interaction with other users through neither verbal nor written interactions. Using various animations available for avatars, users can perform actions such as waving, clapping, or raising their hands. Perhaps more importantly, the platform allows all users in the virtual classroom to be informed when one of these actions is performed, decreasing the likelihood of missing the action not seen directly by the avatar.

Projection and presentation of multimedia content. The virtual classroom is equipped with a projector to transmit multimedia content. Users can upload their slides or images and display them during the platform's runtime. The user can navigate the content on the projector with the *presenter* role. Each user can use the projector to showcase or present their materials and alternate this role with others during the session.

Interaction with the whiteboard. The classroom also has a whiteboard where users can type and write using a keyboard. One user at a time can approach the whiteboard and start writing, and what they write will be visible to everyone, supporting interaction and communication.

The design and implementation of the described requirements were achieved through an incremental process. Core requirements, such as avatar customization and

3D free movement, were identified during the initial stages of platform design before the actual implementation; others were obtained through usability experiments conducted with participants, collecting their feedback. An example is the addition of the zooming feature, which was initially not planned. After participants tried the platform for the first time, visibility issues were noticed from desks farther from the projector, leading to the decision to provide the option to increase the zoom percentage. Further details on the various conducted iterations will be provided in Chapter 4.

The platform's design has also considered specific side goals and principles. Such aspects have guided the prototype development process, even if not strictly functional. Firstly, the platform has been developed to be **highly compatible** with different devices. The current prototype can be accessed through all desktop devices with any operating system. Furthermore, the development environment in which the platform has been created—i.e., *Unity3D*— will easily allow for compatibility with mobile devices. The platform was also designed to be **ubiquitous**, as users can connect to a virtual classroom anytime. **Accessibility** is also a key aspect: the development considered various options for interaction and communication to meet the needs of different types of users. As highlighted by the functional requirements, communication can take place in different ways: textual, vocal, and also includes non-verbal options. Moreover, in the avatar customization choices, special attention has been given to maintaining a high level of **inclusivity**, ensuring that a wide range of diverse avatars could be created to represent as many people as possible adequately. Lastly, the fundamental requirement that guided the selection of all technologies used was to achieve a fully **open-source** platform. This approach was chosen to ensure transparency and make the research entirely available for communities of researchers and developers.

As a result of the discussed requirements and characteristics, the tool presents itself as a platform that showcases some of the key characteristics of the Metaverse described in Chapter 2. Table 3.1 maps the tool's currently implemented features to such characteristics, highlighting their correspondence.

Table 3.1: Mapping of developed tool's features with Metaverse characteristics.

Metaverse's Characteristics	Tool's features
Virtual World	Real-time interaction which takes place in a three-dimensional digital environment
Realism	Environment resembling a real classroom, free movement and exploration, three-dimensional voice chat
Ubiquity	Capability to create or join a virtual classroom at any time, from various devices
Scalability	The room system that allows for the creation of multiple rooms simultaneously and the removal of empty ones
Customizable avatars	Creation of a customized avatar and exploration and interaction with the environment and users through it

3.2 Actors and Scenarios

This section describes the interaction designed within the tool, outlining the actors involved, their corresponding roles, and examples of how one can use the tool.

3.2.1 Actors

The system does not have a clear-cut division of roles within the environment. However, to describe the potential interactions with the tool, a less strict distinction will be made among the actors who can use the tool. Figure 3.1 details the actors and their role in the system.

The *room owner* is the first user intending to connect, thus creating the room and setting its password. This user also has the complete chat and access log on their device. All other users connecting to the room are *attendees* and can interact with each other and use all the communication methods. If the room owner crashes or disconnects, the second user who joined takes over their role to prevent the entire room from being deleted. The new room owner has access to the room's log from when they assumed the role. When a user approaches the projector, they can take

Name	Role
Room Owner	Creates the room by deciding its password. They will have the complete log of the accesses and the text chat stored on their device
Attendee	Can join an existing room by inserting its password. They can communicate through vocal and text chat, perform emotes and write on the whiteboard
Presenter	Has the control over the projector and can move the projected content forward and backward

Figure 3.1: Actors of the system.

on the role of *presenter* and control the displayed content. There can be only one presenter at a time, and the role is passed when a new user approaches and interacts with the projector.

3.2.2 Scenarios

Scenarios that outline some possible interactions that users can have with the platform are presented below. Each scenario describes how the tool could be effectively exploited for educational, communication, and collaboration tasks in an academic context.

Scenario 1: Collaboration for a Univeristy Project

Personas. Antonio, Ciro, and Giulio are three students enrolled in the master's degree program in Computer Science. They need to work together on a project but cannot meet in person due to the distance between their residences. They would like to collaborate using a remote platform but do not want to use a typical screen-sharing tool where only one person can work while others observe. They would like to experience a greater sense of collaboration and have an environment where they can start defining the initial phases of their project more collaboratively.

Antonio, Ciro, and Giulio decide to use the tool to actively collaborate together and start brainstorming ideas for their project. Giulio accesses the platform and goes to the avatar creation interface, where he customizes his appearance. Later, he creates a room and sets the password as "ACG7," then shares it with his colleagues. Antonio and Ciro access the platform, create their avatars, enter the password, and join Giulio in the room. There, they start communicating in real-time using voice chat and avatars' emotes. They approach the whiteboard and begin discussing, writing down the main ideas they have come up with. After a while, they decide to pause their session and continue next time, disconnecting from the room.

Scenario 2: Remote Exam's Presentation

Personas. Jacopo and Davide are students enrolled in the three-year literature course. They have prepared a presentation for a research project carried out for the history course, but their professor Vincenzo had to travel abroad for a conference. The professor, disappointed by the unforeseen circumstance, still wants the students to give the presentation so that the exam can be concluded. Vincenzo would like the students to take the exam in a way that allows them to present their project seamlessly, in a flexible environment, and quickly alternating during the presentation.

Professor Vincenzo decides to have the students take the exam within the platform. Jacopo and Davide uploaded their presentation to the platform on the exam day. Vincenzo logs in, customizes his avatar, and creates a room, setting the password as "Exam01" and communicating it to the students. After Jacopo and Davide create their avatars, they access the virtual classroom. The projector displays the slides they prepared. The professor sits down to listen to the presentation. Jacopo approaches and takes on the presenter role, starting his presentation using voice chat while advancing his slides. Once he finishes his part, Davide approaches and becomes the presenter, completing the presentation nimbly. The professor then poses his questions to the students through voice chat and finally communicates the outcome of the presentation to the students.

Scenario 3: Virtual Meeting

Personas. Stefano, Dario, and Giulia are three Ph.D. students conducting research projects on artificial intelligence. Every week, the research group holds an update meeting where each Ph.D. student presents their work and seeks feedback from their colleagues. However, both Stefano and Giulia will not be able to be physically present at the university as they have decided to conduct part of their doctoral research abroad. Dario would still like to share his work with them and see what they are working on, enabling them to exchange feedback and ideas just as effectively as if they were physically present.

The group decided to conduct the weekly meeting within the platform, allowing everyone to convene in the same virtual space regardless of the physical location. Dario creates the room with the password "SeSaMeeting" and shares it with his colleagues. They enter the virtual classroom after creating their avatars and uploading their slides onto the platform. Giulia starts her weekly update presentation, approaching the projector and assuming the presenter role. She controls the slides and communicates with her colleagues via voice chat. Upon finishing, she asks her colleagues if they have any questions. Dario raises his hand and poses questions through voice chat while Stefano types his comment in the text chat. Subsequently, all the group members take turns assuming the presenter role and delivering their presentations, while all participants can actively listen and ask questions. At the end of the meeting, everyone disconnects, and the room is deleted.

3.3 Metaverse Classroom's Architecture

This section describes the tool's structure and architecture. As a first consideration, the application has been developed using the *Unity3D* game engine; such a choice influenced the overall application's architecture, as Unity's features and constraints guided the design and development of the entire system. The platform's structure is thus based on three main elements: (1) the game scene, (2) game objects, and (3) assets. The scene is a 3D virtual environment in which all elements are combined and rendered, and interactions occur. In the context of the tool, there are two game scenes: the virtual classroom, which contains most of the application's logic and components, and the character editing scene. Game objects are the elements that make up the scene—e.g., avatars, chairs, desks, and all the other 3D elements—as well as all the GUI elements—e.g., buttons, text fields, and labels. These objects, in turn, have components such as scripts that implement their logic and meshes and textures that define their appearance. Finally, assets encompass all resources used to build objects within the scene. These include sounds, animations, textures, and even scripts. Figure 3.2 summarizes this structure.

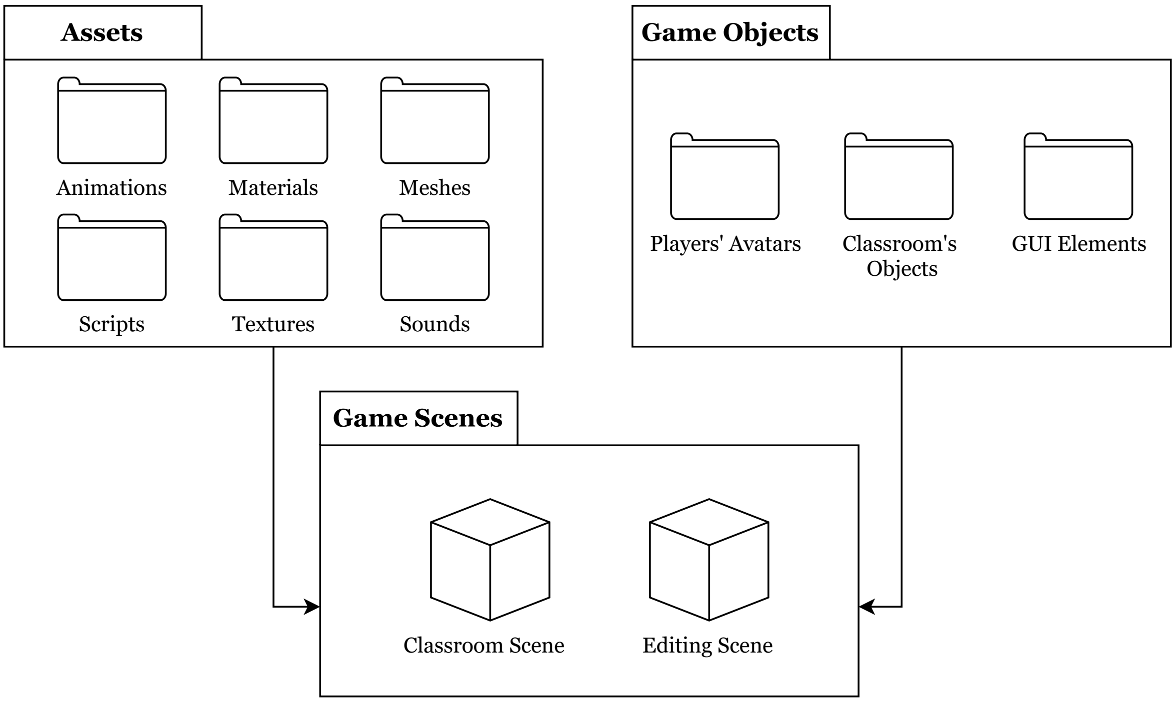


Figure 3.2: Structure of the developed application.

As mentioned earlier, the application's logic is structured into code scripts, each encapsulating specific functionalities related to a particular object or component. The underlying language in Unity3D is *C#*,[1] a multi-paradigm programming language that supports all object-oriented programming concepts. Therefore, all the code

[1]*C# documentation*: `https://learn.microsoft.com/en-us/dotnet/csharp/`

scripts have been written in this language. The scripts are not all managed by a central unit that runs them, but each script, attached to its respective component, is executed when a specific trigger event occurs. In fact, the application's logic is *event-based*, meaning a particular functionality is executed when a specific event occurs. An example is the ability to write on the whiteboard, which becomes editable only when a user approaches and interacts with it. The individual code scripts can be logically grouped into clusters representing the functionalities offered by the platform, each triggered by the occurrence of an event. The interaction flow with the application can be divided into two phases: (1) the player setup phase, where the user creates their avatar and functions in the respective scripts are triggered, and (2) the actual in-game phase, which begins when the user enters a room, where each functionality is executed when the player interacts or performs specific actions. During both phases, the networking functionalities are always running and manage the synchronization between all users and events related to the creation, access, or deletion of rooms. Figure 3.3 outlines the event and interaction flow for each functionality.

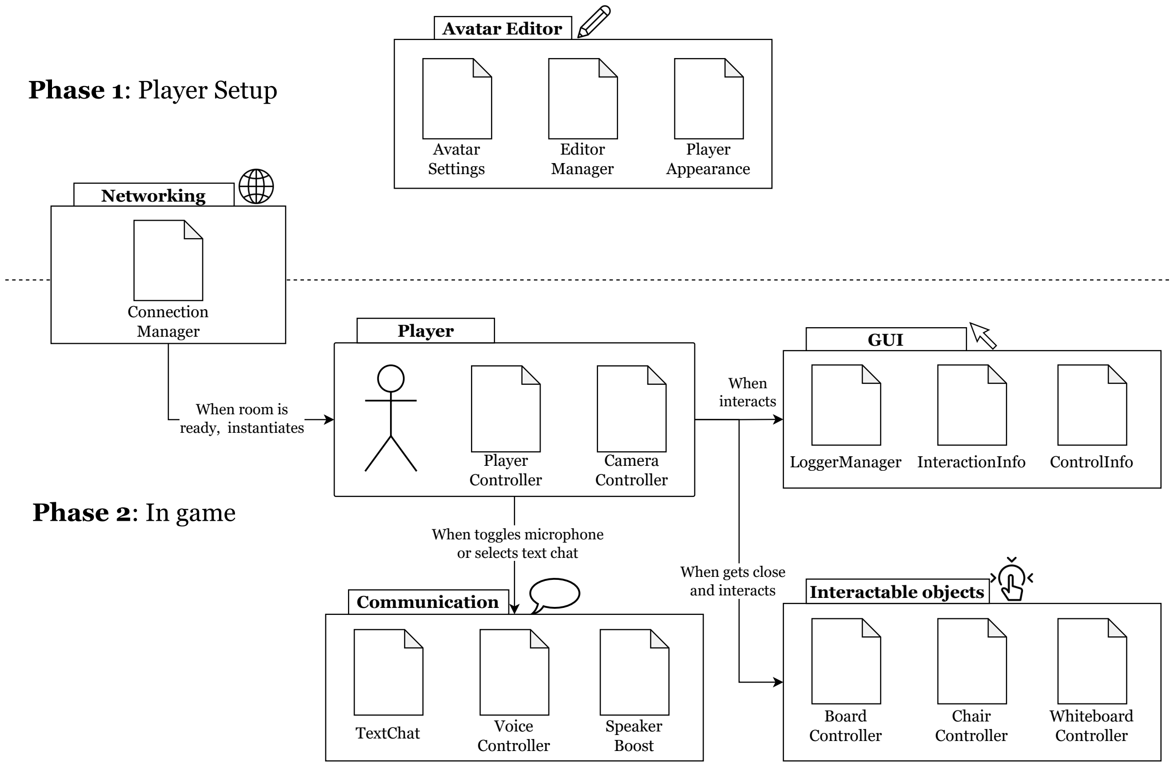


Figure 3.3: Event-based system logic.

3.4 Graphical User Interface (GUI)

This section discusses the tool's user interface and its components. It will illustrate the different screens the user encounters and the commands through which they can interact with the environment.

Figure 3.4: Starting screen of the tool.

Figure 3.4 displays the interface of the tool's startup screen. When users open the application, they encounter the main elements shown in the green squares. The enumerated components are explained below.

1. The form with login information: In the first text input area, the user enters the name they want to use for access, and in the second, the password of the room they want to join.

2. *Create* or *Connect* to room buttons: If the user is the first to connect, after entering the data, they will press the *Create* button to create the room. Otherwise, they will press *Connect*. In both cases, if this operation is successful, the user will have access to the virtual classroom.

3. The *Edit Avatar* button: This will take the user to the avatar creation screen.

4. The logger: It displays information about the application's status. If the log

shows "Connected to Master," the server connection was successful, and the user can create and access rooms.

5. The *Quit* button: It exits the application.

Figure 3.5: Avatar editing screen.

When the *Edit Avatar* button is pressed, the user is redirected to the avatar editing screen. In such a screen, as shown in Figure 3.5, the user can customize their avatar's appearance, which will then represent how other users see them within the virtual classroom. The enumerated components are explained below.

1. Editing window: The interface through which the user customizes their avatar's appearance. It is divided into sections, each controlling the color and shape of one of the customizable components: uniform, skin, lips, eyes, hair, beard, eyebrows, and accessories.

2. Avatar preview: The model that shows real-time changes to the appearance made through the editing window. It can be rotated and zoomed in to inspect it thoroughly.

3. *Load Game* button: Saves the changes and returns to the application's initial screen.

4. Info label: Informs users of the commands to control the model during the editing session.

Figure 3.6: Virtual classroom's interface.

When the user accesses a room, they will find themselves in the actual 3D virtual environment, where they will be alongside all the other users connected to the same room in real time. The virtual classroom is where the tool's experience occurs, and all the objects for interaction are present. The user sees the virtual world from a first-person perspective, much like in the real world. Their avatar's camera is positioned at head level, allowing them to view the environment and other users through it. Figure 3.6 displays the interface that the user encounters when connecting to a room. The numbered components are explained below.

1. The virtual environment and other users: The user views the virtual classroom and other users in real time through their camera. Each user's chosen avatar and their name above their head are visible. The user can also observe their real-time movement within the room and the animations they perform. Users speaking via voice chat have a megaphone-shaped icon above their name. Their voice source is emitted from their avatar, and others perceive it with varying intensity depending on their distance and position.

2. Text chat: It displays text messages written by users in the room, including the author's name and the time of sending. The on-screen chat shows the last ten text messages sent. The text input field below allows users to write messages that will be sent and displayed above.

3. *Leave* button: It returns the user to the platform's initial screen.

4. Info label: It shows various information depending on the user's status — e.g., if they are near the stage, it will indicate whether they are the presenter or not, or if they are near a chair or the whiteboard, it will indicate if it is free or occupied.

5. Voice chat info: It displays which input device has been detected for voice recording and the microphone's status — i.e., *muted* or *unmuted*.

6. Command info and *Options* button: The command info label always displays quick information for executing animations or other features on the screen. Below, the *Options* button opens a small interface where users can adjust microphone sensitivity and the application's resolution and regulate ambient audio.

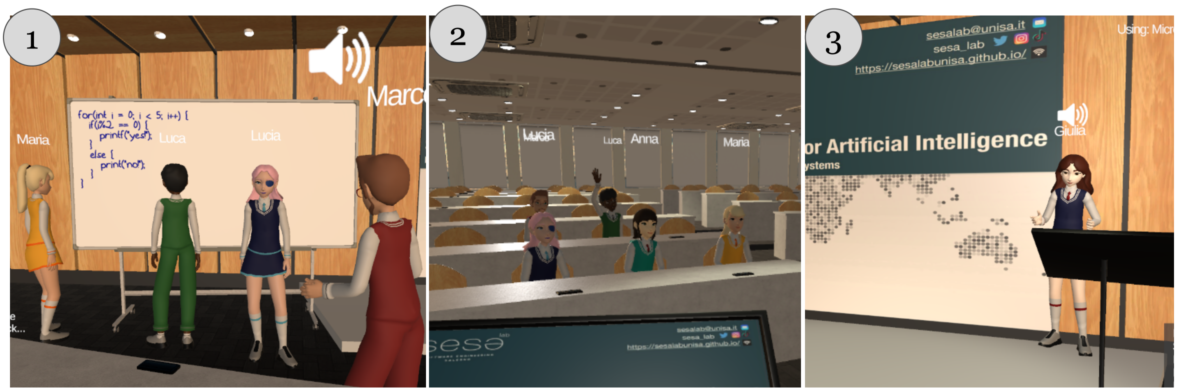


Figure 3.7: Users interacting with the virtual environment.

Within the virtual environment, users can interact with various elements to access different features provided by the tool. Figure 3.7 displays the following elements that users can interact with, namely: (1) the whiteboard, where they can write as an editable text area shared by all users in the room; (2) desks and chairs where users can sit and observe, as well as interact with the presenter; (3) the stage and projector, where the presenter can display and control slides for other users to see, and view them themselves while speaking, thanks to the synchronized display in front of the projector.

3.5 Installation and How to Use

The developed platform is publicly available on its GitHub repository.[2] The repository contains both the Unity3D project with the source code and the already built application for Windows and MacOS.

If a user wants to install the application on their device, it is necessary to download the build corresponding to its operating system and follow the steps outlined in the guide available on the repository. Once successfully installed, the user can open the application to start using it, and they will find the starting screen shown previously in Figure 3.4.

If developers want to view or contribute to the source code, they can open the platform's project by importing it into their own Unity3D. In this case, they should follow the guide on the repository for installing the entire Unity3D project with the specified version. By doing so, they will have access to all the resources and assets used for development.

[2] *Metaverse Classroom Github Repository*: `https://github.com/vipenti/Metaverse_Classroom`

CHAPTER 4

RITE and Usability Evaluation

After its development, the tool was evaluated to assess its usability. The goal was to immerse the tool in its intended practical context, such as the academic environment, gather participants interested in trying it out for collaboration and educational tasks, and then evaluate its usability and user satisfaction. The Rapid Iterative Testing and Evaluation (RITE) approach was employed for this phase. This section will provide an overview of the RITE approach, followed by a description of how this approach was applied to evaluate the tool and the results obtained.

4.1 The RITE Methodology

The Rapid Iterative Testing and Evaluation method, known as RITE, was chosen to assess the usability of the developed tool. Medlock et al. [15, 16] first introduced the RITE approach while developing a video game. Specifically, the approach was used to identify and rectify usability issues in the tutorial of Age of Empires II.[1] In practice, applying the RITE method involves evaluating the tool's usability using an iterative approach, meaning that the experiment is repeated multiple times with participants. Any identified bugs and issues are addressed between each interaction.

[1] *Age of Empires II website*: `https://www.ageofempires.com`

More importantly, each subsequent iteration cannot start if the provided issues or bugs are not properly resolved. It shares the same principles of usability testing outlined by Dumas and Redish [44], specifically:

- The goal is to improve the product.
- The participants are real users.
- The participants do real tasks.
- The researchers observe and record what participants do and say.

Concretely, each iteration consists of two phases: (1) a tool testing experiment, which involves recruiting a set of potential users to complete tasks using the tool, and (2) collecting feedback from the experiment and participants and promptly addressing identified issues and bugs. Subsequently, a new iteration will be performed with the corrected version of the tool. The process stops when saturation is reached, meaning that between iterations, no significant issues preventing the successful completion of tasks are encountered, and there are no further improvements to be made to the tool.

This approach was chosen for evaluating the tool due to its several advantages. At the core of RITE, there are two philosophical principles: (1) *"Once you find a problem, solve it as soon as you can."* and (2) *"Make the decision-makers part of the research team."* [15, 16]. This entails applying a fast yet targeted approach to problem resolution, aiming for rapid and effective tool improvement even after the initial iterations. Furthermore, the iterative nature allows for identifying new bugs resulting from the implemented corrections and addressing them accordingly. All these characteristics make RITE different from typical usability tests because it is based on continuous product testing and modification based on the results obtained. This makes it a robust and practical approach, albeit at the expense of more significant effort compared to other usability testing approaches.

4.2 Experiment Design

The conducted experiment aimed to assess the usability of the developed tool and its features using the RITE approach. Specifically, the tool's usability was evaluated in terms of three well-known metrics in the field of usability testing [45], stated below.

- *Learnability*, i.e., the measure that represents how easy it is for users to learn how to use the tool.
- *Efficiency*, i.e., the trade-off between the resource used—expressed in terms of completion time, mental, and communication effort—and accuracy and completeness with which the users achieve their goals.
- *Satisfaction*, i.e., the user's satisfaction when using a tool in a specific context.

In light of the considerations made so far, experiments were designed to evaluate the tool based on the abovementioned metrics, following the RITE approach guidelines. The tool was then tested by recruiting participants from the academic context, specifically students and researchers from the Department of Computer Science at the University of Salerno. In this context, participants were asked to participate in activities conducted using the tool, during which they were required to complete a series of tasks. Such tasks were defined based on the platform's main functionalities, encompassing various interactions that could be common among the various conducted activities for the experiment. Indeed, during each of the iterations performed, each user participating in the organized activity was asked to perform all or a subset of these tasks. Table 4.1 shows the designated tasks.

For each iteration during which participants had to perform the described tasks, an activity was scheduled that invoked scenarios from real-world situations and practical contexts in which the tool would actually be used, as indicated by the RITE approach guidelines. The experiment reached saturation after three iterations, so in the end, there were three scheduled activities in which participants took part.

1. *Remote seminar*: The first group of participants was asked to participate in a seminar within the Metaverse platform. One of these was the researcher who had to deliver the seminar, while all the others were students and researchers

Table 4.1: Tasks performed for RITE evaluation.

ID	Task Description
T1	Creating an avatar using the built-in editor
T2	Performing the login in the application
T3	Using the projector and associated tools to share and present slides
T4	Sitting on chairs in the room
T5	Communicating performing an avatar's emote
T6	Communicating using the built-in voice system
T7	Communicating using the built-in textual chat
T8	Writing something on the whiteboard
T9	Writing something on the notes' tablet

interested in the topic, participating as attendees. The speaker was asked to prepare slides to show during the lesson and present them to the attendees during the seminar; the attendees were asked to sit in the virtual classroom and participate in the seminar, actively engaging.

2. *Exam presentation*: The second group of participants was asked to deliver a presentation for an exam within the Metaverse platform. The course from which the students were recruited required them to present a project to the professor using slides. Therefore, the students who agreed to participate had to take turns in the role of presenter and discuss their project, while the professor participated as an attendee and had to listen and provide feedback to the students.

3. *Collaborative group activity*: The third group of participants was asked to access the Metaverse platform to collaborate and perform a group activity. Each student group assigned to collaborate had to enter the virtual classroom and find a space to work as isolated groups, sharing the available resources —i.e., the projector and the whiteboard. They were required to communicate and

cooperate to complete the educational activity. The professor had to be there too, helping all the groups in their activity.

It is important to highlight that all the described scenarios were real activities that had to be performed; this means that the participants performed the above-mentioned tasks in a completely real context rather than a simulation.

4.3 Survey Design

At the end of each iteration, a survey was created to be administered to the participants after each activity to gather feedback and information regarding issues and bugs encountered. The survey was created and distributed via Google Forms: it was an anonymous survey consisting of 18 questions aimed at (1) evaluating their experience, (2) assessing the tool's usability, and (3) collecting follow-up feedback. Specifics regarding the questions asked in the survey are provided in Table 4.2. In the table, the range of possible answers is indicated for each of the questions. For questions with a 5-point Likert scale, the range specifying the minimum and maximum values for the scale is provided; for multiple-choice questions, the possible values are indicated within curly brackets.

The selection of survey questions was a result of a collaborative effort. Such an activity was conducted during three meetings, each involving researchers with at least three years of experience in survey design and survey-based research. Each question underwent thorough discussion in these meetings until a consensus was reached. Subsequently, the initial survey design was validated through a pilot study involving three researchers who were neither involved in the tool's development nor the experiments. Adhering to the guidelines outlined by Flanigan et al. [46], a deliberate decision was made to maintain anonymity in the survey, ensuring that the influence of the authors on respondents' answers was minimized. At the end of this process, the survey was created using Google Forms[2] , and the completion time was estimated to be around 10 minutes.

The resulting survey is structured into four sections. The first section consists of

[2]*Google Forms website*: `https://www.google.com/forms/about/`

Table 4.2: Evaluation survey questions.

ID	Question	Type	Metric
Q1	What gender do you identify with?	Open-ended question	Demographic
Q2	What is your academic role?	{Student, Researcher}	Demographic
Q3	How many years of experience do you have?	Numeric	Demographic
Q4	Were you a presenter or a listener?	{Presenter, Listener}	-
Q5	How satisfied are you with the overall usability of the tool?	[Very dissatisfied - Very satisfied]	Satisfaction
Q6	How easily did you learn to use the tool for your presentation?	[Very difficult - Very easy]	Learnability
Q7	How would you rate the presentation modality provided by the tool?	[Very bad - Very good]	Efficiency
Q8	How easy is to control your presentation and your avatar during the exposition?	[Very difficult - Very easy]	Learnability
Q9	How easy is to interact with your listeners and answer their questions?	[Very difficult - Very easy]	Efficiency
Q10	How would you rate the quality of communication channels?	[Very bad - Very good]	Satisfaction
Q11	How likely are you to use this tool compared to online communication platforms (e.g., Teams, Zoom, Meets...) to give your presentations?	[Not at all likely - Very much likely]	Satisfaction
Q12	How engaged did you feel while experiencing the presentation?	[Not engaged at all - Very engaged]	Satisfaction
Q13	How easily did you learn to control and position your avatar?	[Very difficultly - Very easily]	Learnability
Q14	How satisfied were you with the interaction capabilities with the presenter and other participants during the presentation	[Not satisfied at all - Very satisfies]	Satisfaction
Q15	How well were you able to view and read the presentation?	[Very difficult to see and read - Very easy to see and read]	Efficiency
Q16	How well were you able to listen to the presenter?	[Very difficult to listen - Very easy to listen]	Efficiency
Q17	How likely are you to use this tool compared to online communication platforms (e.g., Teams, Zoom, Meets...) to attend to presentations and seminars?	[Not at all likely - Very much likely]	Satisfaction
Q18	Please share any additional feedback or suggestions you have regarding the tool's features, usability, or any improvements you would like to see.	Open-ended question, Optional	Learnability, Efficiency, Satisfaction

demographic questions for statistical purposes, including gender, role, and years of experience of the participant. It's important to emphasize that the survey is anonymous, and no identifying information is required. At the end of this first section, there is a question about whether the participant acted as a presenter, using presentation and content projection features during the activity, or solely as an attendee, meaning they watched someone else's presentations or did not utilize that specific functionality—e.g., students and researchers who participated in the *remote seminar*. Depending on the response to this last question, the user is directed to the second section if they were a presenter; otherwise, they will be redirected to the third section. In the first case, after completing the second section, they will also be redirected to the third section. These sections contain closed-ended questions to obtain feedback on the tool's usability according to the previously defined metrics: satisfaction, learnability, and efficiency. All questions require a 5-point Likert scale answer, with 1 representing the lowest satisfaction and 5 the highest. Finally, the fourth section included an optional open-ended question. Here, participants were asked to provide open feedback, report any bugs and issues encountered, and suggest future improvements for the platform. It was made optional to refrain from collecting uninformative data from participants who did not wish to add anything extra. This ensured that responses remained informative.

4.4 Participants

Following the experiment's design and its associated activities, as well as the survey to be administered at the end of each, the focus shifted towards participant recruitment. These participants needed to be affiliated with the academic context for which the tool was intended, and they had to be individuals capable of genuinely representing users who would use the platform. Initially, a convenience sampling approach was employed, a non-probability sampling method drawn from a readily accessible group of individuals [47]. This approach was chosen due to the immediate accessibility of participants within the University where the tool was developed. However, it was acknowledged that this strategy may yield results of limited generalizability [47]. A set of predetermined criteria was established to mitigate this limitation, delineating the requirements participants should satisfy. Firstly, participants for the experiment were recruited among students and researchers possessing experience in Human-Computer Interaction. Such a choice was motivated by the aim of collecting feedback underpinned by a theoretical knowledge base. Furthermore, individuals with knowledge or experience concerning the Metaverse were selected to elicit insights informed by various experiences. These were the only criteria considered, and more stringent filters were established to prevent bias in the results, intentionally keeping the participants' group as heterogeneous as possible.

In the end, 28 participants were recruited, comprising 5 researchers and 23 students at the master's and Ph.D. levels. As previously specified, each was already meant to participate in the activities later scheduled within the Metaverse. Consequently, students for each activity were selected from the pool of participants available, aiming to align with the criteria mentioned before. 13 participants participated in the first activity —*remote seminar*—, 5 participants in the second —*exam presentation*—, and 10 participants in the third activity —*group activity*. Table 4.3 summarizes the recruited participants and the activity they participated in.

4.5 Procedure

Each of the three activities followed the same procedure, with slight variations due to the nature of each activity.

Firstly, at least 24 hours before the experiment, the participants were sent the platform prototype to install on their devices. This was done to (1) address any technical issues before the experiment, (2) ensuring the participation of everyone, and (3) gather initial feedback on the installation procedure itself. The experiment organizers assisted participants in resolving any problems and launching the application. None of the three iterations encountered issues that prevented individual participation in the experiment.

Participants and organizers were physically present at the University on the day of the experiments. Each participant was separated into small groups—ranging from 1 to 3 individuals—and physically scattered to ensure that communication with the various groups occurred remotely. Furthermore, individuals within the physically

Table 4.3: Participants characteristics.

ID	Gender	Role	Expirience's years	Iteration
P1	Female	Researcher	27	1
P2	Male	Researcher	25	1
P3	Male	Researcher	22	1
P4	Female	Student	7	1
P5	Male	Student	7	1
P6	Male	Student	6	1
P7	Male	Student	8	1
P8	Female	Student	8	1
P9	Female	Student	5	1
P10	Male	Student	6	1
P11	Male	Student	4	1
P12	Male	Student	4	1
P13	Male	Student	4	1
P14	Male	Researcher	6	2
P15	Male	Student	5	2
P16	Male	Student	5	2
P17	Female	Student	5	2
P18	Male	Student	5	2
P19	Male	Researcher	5	3
P20	Male	Student	4	3
P21	Female	Student	4	3
P22	Male	Student	4	3
P23	Male	Student	3	3
P24	Female	Student	3	3
P25	Female	Student	3	3
P26	Female	Student	3	3
P27	Male	Student	3	3
P28	Male	Student	3	3

present groups were positioned as far apart as possible to ensure that communication within the same group could only occur through the platform. This was done to create a more controlled environment for the experiment and to ensure that each organizer was physically present with the participants to guide and assist in the process. The division was carried out so that participants could interact exclusively through the platform. An example of this happened during the third iteration (i.e., *the group activity*), where members of the same group that had to collaborate within the platform were physically in different rooms during the experiment.

Once everything was set up, one of the organizers accessed the platform first, choosing a password for the room where all the participants would connect. The password was communicated, and gradually, the participants created their avatars and gained access to the platform. Before starting the actual activity, 10 minutes of free exploration of the platform were allowed. This was done to (1) provide a time window to ensure everyone was connected and ready and (2) allow participants to become familiar with the interface and controls before beginning the experiment. During this phase, participants could also test various features and attempt to perform the previously listed tasks. After these 10 minutes, the organizers addressed the participants and explained the guidelines for carrying out the activity. For example, in the case of the *exam presentation*, they indicated the methods for presenting the project to the students, or during the *group activity*, they explained how the collaborative tasks would be carried out (they instructed the students to disperse themselves throughout the 3D environment virtually). Then, the activity starts.

Each activity had a total duration of 45 minutes. During this time, observations were already made regarding the platform's behavior and the various technical bugs and issues. In the iterations following the first one, organizers paid particular attention to verifying whether the previously highlighted problems had been adequately resolved.

The activity concluded at the end of the 45 minutes, and participants could disconnect from the platform. At that point, they were asked to remain for 10 minutes to administer the evaluation survey. Once the survey was completed, the session ended, and participants could leave the experiment location.

Table 4.4: Survey's results after the first iteration.

	Mean	Standard Deviation
Satisfaction	3.29	0.96
Learnability	4.26	0.92
Efficiency	3.67	1.28

4.6 Analysis of the Results

This section will present the results obtained at the end of the experiment. The problems and bugs encountered will be described for each iteration, and how each iteration addressed the issues identified in the previous one will be explained. As mentioned earlier, the experiment stopped at the third iteration of the RITE since no significant issues that would hinder the correct completion of the tasks and activities were encountered at the end of it.

4.6.1 First Iteration

The activity carried out in the first iteration was the *remote seminar*, in which one of the participants played the presenter role, and the others acted as attendees, intervening and communicating with the presenter during the session. There were 13 participants, marking the first real test of the platform with multiple users connected in a single room. Table 4.4 displays the mean and standard deviation of the survey responses obtained after the activity for the three analyzed metrics.

In this initial test, the majority of technical and interface issues with the platform surfaced, some of which posed significant challenges to the proper execution of the activity. The identified issues are listed and described in Table 4.5. Such issues were identified by observing the platform's behavior during the activity and from the feedback received through the questionnaire. As an example, participants P12 and P5 provided the feedback showed below.

"I found the tool very interesting. There are some software corrections to be made, for example: not all participants were sitting, if someone sits in front of me, I

Table 4.5: Issues found after the first iteration.

ID	Name	Description
I1	Possession bug	When a new user accessed the platform, they began controlling an avatar that wasn't theirs due to bad synchronization among network objects
I2	Bad visibility	The visibility of the slides from the farthest seats from the projector was poor, and the names of the other avatars sitting in front covered parts of the presentation
I3	Animation lag	The animation synchronization was slow and laggy, causing many avatars to appear standing even though they were actually seated
I4	Bad tablet interaction	The interaction with the tablet for taking notes was found to be not very usable and useful
I5	Lack of interaction	Users would have liked to have other non-verbal interactions, such as applause that they could use at the end of a presentation

have difficulty reading the slides because the name placed on the 'head' of the avatar covers the view. However, the experience was very interesting; there is always a bit of a lack of immersion, that is, I don't have full control over what happens (as in reality), but it is undoubtedly a huge step forward. I would like to highlight one peculiarity: with these tools, there is always the idea that it's a game, so the possibility of conducting lessons or similar activities is still challenging. However, I think it's normal; there's always the "hype" effect when it comes to new technologies."

"It could be useful to improve the presentation mode as often the view of the slides was not optimal."

After analyzing the collected data, solutions were implemented for the identified issues in the conclusive step of the first iteration. Below are listed the proposed solutions for each of the issues.

Table 4.6: Survey's results after the second iteration.

	Mean	Standard Deviation
Satisfacton	4.0	0.72
Learnability	4.53	0.74
Efficiency	4.16	0.76

- *I1*: The synchronization logic between clients and how the platform handles new accesses has been improved, so connection overlaps and avatar control issues will no longer occur.
- *I2*: The option to zoom the camera has been added, allowing users to zoom in or out at any time. The option to temporarily hide other users' names from above their avatars' heads has also been added to avoid visibility issues.
- *I3*: The animation trigger mechanism has been improved, preventing avatars from standing when they should be sitting.
- *I4*: The note-taking functionality on the tablet available to each user has been removed as it was considered less valuable and usable.
- *I5*: The ability to applaud and wave with the hand through one's avatar has been added.

After making the changes and improvements mentioned above, the first iteration of the RITE process was concluded.

4.6.2 Second Iteration

The activity conducted in the second iteration was the *exam presentation*, in which a group of 4 students presented their exam project to a professor using the platform, resulting in a total of 5 participants. Table 4.6 displays the mean and standard deviation of the survey responses obtained after the activity for the three analyzed metrics.

Table 4.7: Issues found after the second iteration.

ID	Name	Description
I6	Low voice volume	Users found it difficult to hear each other using voice chat unless they were very close to each other
I7	No chat history	The history of the text chat was lost, and there was no way to read previous messages beyond the 10 displayed on the screen

Unlike the previous iteration, no issues similar to the ones encountered before were observed, and there was an increase in the average values of each of the three metrics. However, without the significant issues that were previously present, new issues and suggestions emerged from this iteration, as shown in Table 4.7. Examples of this are the received feedback provided by participants P15 and P14.

> "*Improve the volume level, and the chat features (the history is lost).*"

> "*The general volume of the room is very good, but probably a bit low when people are far apart. I understand that it is a question of audio depth, but i would amplify just a little to improve the overall quality of the meeting.*"

In light of the newly emerged issues and suggestions, solutions were implemented to address them. Below are listed the proposed solutions for each of the issues.

- *I6*: The overall volume of the voice chat has been increased; additionally, the spatial audio blending has been slightly reduced, allowing two users to hear each other better even if they are virtually distant in the classroom.
- *I7*: A text chat log feature has been implemented, saving a history of all messages on the user's device, which can be accessed even after the session ends.

After making the changes and improvements mentioned above, the second iteration of the RITE process was concluded.

Table 4.8: Survey's results after the third iteration.

	Mean	Standard Deviation
Satisfacton	4.31	0.61
Learnability	4.59	0.49
Efficiency	4.53	0.66

Table 4.9: Issues found after the third iteration.

ID	Name	Description
I8	Limited choice in avatar customization	Users requested a greater variety of cosmetics during the avatar customization phase

4.6.3 Third Iteration

The activity conducted in the third iteration was the *group activity*, where three groups of three students connected to the platform to collaborate on a project. The professor was also present to support the students, totaling 10 participants. Table 4.8 displays the mean and standard deviation of the survey responses obtained after the activity for the three analyzed metrics.

No significant issues hindered or made the activity difficult to complete this time. The various groups could discuss and collaborate without problems, sharing resources—e.g., the projector and the whiteboard. The tuning of the voice chat volume proved successful, as the different groups could communicate effectively within their group, just like in a real classroom. Therefore, the feedback received reflects this overall picture, focusing more on suggestions for future developments than on actual issues that hindered the correct execution of the experience. Examples of feedback received by participants P22 and P28 are provided below. Nonetheless, one specific issue was considered based on this feedback, as shown in Table 4.9.

"I'd like more personalization for the avatars."

"Add a few more options in avatar creation."

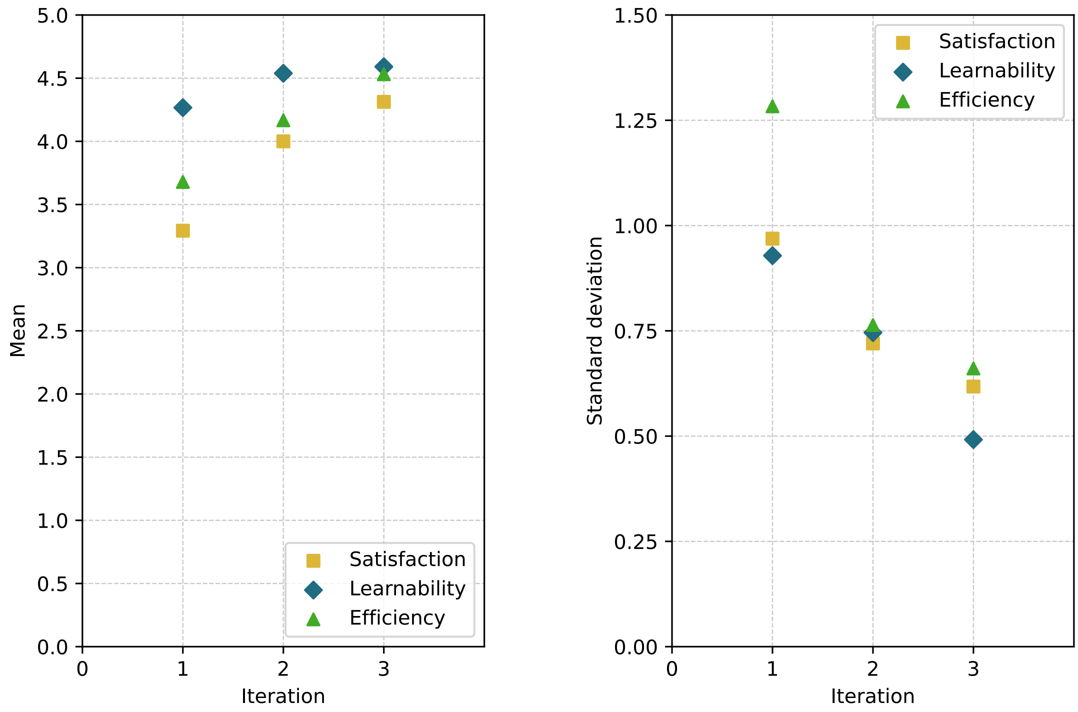
It was decided to conclude the RITE with this third iteration, as the state of the platform was deemed acceptable since (1) the activity was conducted without significant issues and (2) the feedback ulterior increased respect to the previous iteration. Nevertheless, all the feedback collected will be considered for future platform developments.

4.6.4 Final Results

The evaluation of the tool using the RITE method concluded after three iterations. Between each iteration, the collected and analyzed results showed a constant improvement in all evaluation metrics and a significant decrease in the number of issues encountered. In fact, in the first iteration, most of the bugs surfaced, even hindering the proper conduct of the activity. However, by the end of the third iteration, the platform was fully functional, allowing participants to provide feedback of a more subjective nature rather than at the technical or usability level.

The data collected during all three iterations were compared and summarized in a single graph. Figure 4.1 depicts the changes in the mean and standard deviation of survey responses, grouped by the metric considered, throughout the various iterations. In all phases, it can be observed that there is (1) an increase in the average responses for all categories and (2) a decrease in the standard deviation, indicating that the responses were converging more towards higher values.

Following the same trend of the metrics discussed above, **there was a consistent decrease in the number of issues identified between the iterations**, as shown in Figure 4.2. Such a diminution reflects the nature of RITE itself, which entails implementing solutions immediately after each iteration to mitigate the identified problems. Therefore, the solutions implemented proved to be effective and allowed subsequent iterations to focus on different aspects of the platform, accommodating all feedback in the evaluative survey. In the third iteration, user-provided feedback was still categorized as an issue, indicating that the platform had yet to reach an optimal state. However, it was deemed appropriate to conclude the evaluative iterations of the tool, as **no more critical issues were encountered that required immediate intervention**.



(a) Mean of survey's answers across iterations. **(b)** SD of survey's answers across iterations.

Figure 4.1: Mean and SD of survey's answers across iterations.

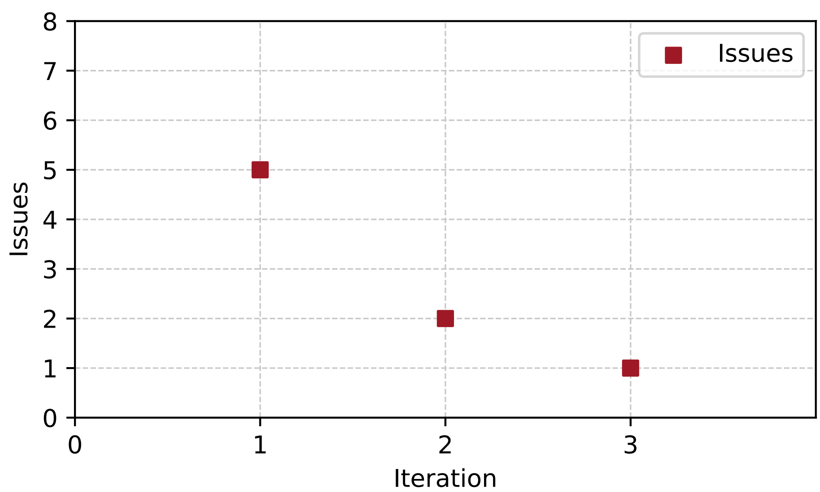


Figure 4.2: Number of found issues across iterations.

In conclusion, the Rapid Iterative Testing and Evaluation (RITE) method has been a valuable approach to refining the usability of the developed tool. Through three iterative cycles, **the platform saw significant improvements in technical stability and user experience**. The decrease in identified issues, coupled with the increasing mean of survey answers, underscores the effectiveness of this method in shaping a functional and user-friendly tool. While room for further enhancements remains, the platform's overall usability reached an acceptable level, prompting the conclusion of the evaluative iterations. The collected feedback will continue to inform future developments and refinements.

Summary of the results

The platform proved to be easily usable and intuitive, despite its interaction being different from typical 2D platforms. Similarly, the tool achieved high efficiency and satisfaction metrics scores, resulting in an immersive and engaging experience, despite the absence of more advanced technologies such as HMDs. Overall, The experiment demonstrated a positive reception of the tool. At the end of the usability evaluation iterations, an excellent state was achieved for each of the three analyzed metrics.

CHAPTER 5

Conclusions and Future Work

This chapter summarizes the objectives that have been set and the work done to achieve them. It will provide a general and conclusive overview of the results obtained and then discuss how the work could be expanded and evolved through potential future work.

This work aimed to develop and experiment with a Metaverse platform in an academic and educational context to harness the potential benefits that this type of application can bring to such environments. By analyzing the state of the art and the main prototypes found in the literature [12, 13, 14], critical aspects and strengths were identified, using them as a basis for the design of the proposed platform. The developed tool considers the key characteristics that define a Metaverse [2, 3], previous work in the field, and the specific requirements of the intended context. The Metaverse classroom was thus developed using Unity3D to be a collaborative and immersive platform for its users. It presents itself as a 3D environment designed to resemble a real classroom, with recognizable and interactive elements that enhance the realism of the experience. Inside it, users can explore, interact, and communicate in real-time through their customized avatars, using the platform for collaborative and educational tasks. The platform is open-source and publicly available in its GitHub repository.

The developed prototype was then evaluated in terms of usability, specifically focusing on three well-established metrics in the usability testing field: learnability, efficiency, and satisfaction [45]. The RITE approach was employed to achieve this, which involves performing multiple testing iterations, addressing identified issues immediately at the end of each iteration, and proceeding with a new iteration until no more issues arise [15, 16]. RITE was applied by testing the platform in the intended academic context. Researchers and students were recruited as participants to carry out actual activities within the Metaverse platform, and they provided feedback through an evaluative questionnaire at the end. Usability testing reached saturation after three iterations, as no further issues obstructed the proper execution of tasks, and excellent scores were achieved for all three mentioned metrics.

Developing and experimenting with the proposed platform has revealed intriguing findings in the context of potential Metaverse applications. Indeed, despite its distinct interface and modes of interaction compared to more well-known remote communication platforms like Microsoft Teams[1] or Google Meet,[2] the results obtained from the evaluative survey have indicated a positive reception and appreciation for this type of platform compared to the former. As an example of this, participant P1 wrote what follows.

> *"As a presenter, I can say that I would prefer the platform over Teams because I have the ability to simultaneously view the slides I am presenting and the chat status, who has raised their hand, and who is joining the room (with Teams, you can only view the slides in full screen, and you cannot simultaneously see the chat). Seeing avatars instead of black windows during the call, in my opinion, can help mitigate an undesirable effect of remote learning, which is alienation and loneliness. Regarding the usability of the tool, I believe that everything is straightforward, and one can become familiar with the platform quickly."*

As highlighted by the feedback above, the tool has proven capable of addressing fundamental limitations that posed a hurdle to traditional remote learning, as discussed in Subsection 2.1.4. The realistic and collaborative 3D environment has allowed

[1] *Microsoft Teams website*: `https://www.microsoft.com/en-us/microsoft-teams/`

[2] *Google Meet website*: `https://meet.google.com/`

for a greater sense of presence and engagement compared to typical 2D solutions. However, it is essential to consider the effect and enthusiasm for the novelty of the experience, as underscored by participant P1 in the feedback reported in Subsection 4.6.1. Therefore, it will be necessary to continue paying attention to these types of solutions and their interaction design to evaluate how they will adapt to user needs over time. Nevertheless, the conducted evaluation experiment has undoubtedly shown a significantly high level of approval in using a similar platform, reaching a final mean for the satisfaction metrics of 4.31/5. Such a result represents a starting point that can drive further research in this direction to evolve and design new solutions and promote the adoption of the Metaverse to harness its potential fully.

Currently, the tool is a relatively small-scale prototype, which can be further developed to become a more comprehensive platform both from an educational and academic perspective and as a true Metaverse. In light of this, the need to consider and evolve some of the tool's limitations in potential future scenarios arises. Among the initial limitations to address will be the addition of the ability to create and upload multimedia materials within the platform itself, which is currently absent, and the projector currently displays only pre-loaded content before running the platform. Furthermore, it will be essential to reconsider and refine the note-taking capability via the tablet, initially present but later removed during the tool evaluation. As a final concern, the limitation that emerged during the last iteration of the RITE —i.e., to increase the avatar customization options—will be addressed to improve and promote inclusivity within the platform.

Regarding broader future enhancements, there is the potential to integrate Virtual Reality (VR) technologies into the platform. This integration would significantly enhance the overall realism and immersion of the user experience. This goal can be readily achieved thanks to Unity3D's provision of Application Programming Interfaces (APIs) for synchronizing the platform with a wide range of VR head-mounted display (HMD) devices. Integrating VR technologies would enable users to engage with the platform in a fully immersive VR environment. Furthermore, consideration can be given to implementing mechanisms focused on persistence and security. Adding such mechanisms would make the platform more robust and reliable, and persistence would allow for the retention of user data and interactions across multiple sessions, enhancing the continuity of the experience. Simultaneously, security measures would safeguard user information and create a secure environment for all interactions conducted within the platform. This aspect is especially critical, mainly when the platform is employed for educational or collaborative purposes. Lastly, exploring the potential integration of digital twins into the platform is worthwhile, facilitating the synchronization between the virtual platform and physical academic spaces. Such synchronization would establish a seamless bridge between the digital and physical worlds. For instance, users could access their educational materials, notes, or collaborative workspaces within the platform, and these resources would remain consistently synchronized with their physical counterparts. This integration could effectively could blend virtual and real-world academic experiences, fostering a more comprehensive and interconnected learning environment.

In conclusion, the presented work represents the beginning of a journey towards more immersive, interactive, and connected educational experiences. By addressing the evolving needs of users, staying attuned to technological advancements, and maintaining a commitment to usability and security, the tool has the potential to become a comprehensive and robust platform, representing a significant step in the research of Metaverse solutions for education.

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