Designing Realistic and Interactive Avatars in Virtual Reality Environment with Embedded Serious Games: A Farm for Mental Health using Indigenous Healers and a Museum Tour for Older Adults with Cognitive Impairment

by

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Abstract

The utilization of avatars in virtual reality (VR) has emerged as a powerful tool for addressing psychological and cognitive disorders, offering unique opportunities to enhance therapeutic and rehabilitative interventions. This study focuses on the development of naturalistic avatars and their integration into two different VR environments with serious games designed to support mental health and cognitive engagement. The Oculus Rift headset was used to provide the immersive VR experience, while Unity's animation state machine ensures smooth transitions and responsive interactions within the virtual environment.

Inspiring by the Indigenous culture, the first component of this study focuses on the development of a naturalistic avatar in a VR environment to represent an individual as a "healer" or a "therapist". Leveraging VR and character creation software tools, an avatar was created based on the provided image of a current Indigenous healer, including intricate facial expressions, synchronized lip movements, and lifelike body gestures. The ultimate application is to utilize the naturalistic avatar of a healer for mental health treatments and replication of real-world therapeutic interactions. The developed avatar as a digital representation of an Indigenous healer was evaluated by 4 Indigenous individuals. The second component of this study extended the use of avatars into a virtual museum designed for cognitive stimulation amongst older adults experiencing memory challenges and/or loneliness. In this environment, a tutor avatar guides users through interactive museum exhibits, encouraging engagement, attention, and memory recall. The avatar was integrated

into the Unity environment to enable user interaction, with various scenarios developed to assess engagement and cognitive performance.

These above-mentioned two projects establish a foundation for using avatar-guided VR experiences as innovative therapeutic and cognitive tools. They demonstrate the potential of naturalistic avatars not only for mental health treatment but also for promoting cognitive well-being and social connection among diverse populations.

Keywords: Avatar, Virtual Reality (VR), Indigenous healer, Mental health, Therapeutic Interventions, Unity, Cognitive disorders.

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Dedication

*To my **loving mother**, whose endless sacrifices, strength, and unconditional love have been the foundation of all my achievements.*

*To my **beloved father**, whose greatest wish was to see me succeed — your spirit continues to guide me, and every step I take is in honor of your memory.*

*And to my **dear grandmother**, whose care, prayers, and gentle heart have always surrounded me with warmth and comfort.*

This thesis is dedicated to you all — whose love, guidance, and sacrifices have shaped every part of who I am.

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1. Chapter 1: Introduction

The utilization of virtual reality (VR) technology in mental health treatment has grabbed significant attention due to its potential as a powerful and revolutionary therapeutic tool [1]. Recent advancements in VR have facilitated its integration into psychiatric treatments, offering cost-efficient solutions and expanding access to a larger patient population [2]. By replicating real-world conditions and therapeutic environments, VR enables individuals to actively engage with their surroundings, receiving real-time responses tailored to their needs [3].

Research has demonstrated the promising results of using VR in treating in a wide range of mental health disorders, including anxiety, depression, eating disorders, and psychotic disorders [2]. While VR technology has been recognized for its potential in mental health treatment, the integration of avatars introduces a new dimension to treatment strategies[3]. Avatars, digital representations of individuals within virtual environments, has flexibility in rendering style and body visibility which allows for customization to suit users' preferences and needs, fostering immersive and engaging experiences [4]. Avatars have shown positive outcomes in various therapeutic applications, including mood improvement [3], self-conversation therapy [3], and enhancing self-compassion [5].

Studies have explored the effectiveness of avatars in facilitating mood change through embodied interactions, with participants experiencing improvements in mood when engaging with avatars representing themselves or virtual therapists [3]. Additionally, avatar-based self-conversation therapy has demonstrated the potential to facilitate self-reflection, leading to positive outcomes in resolving personal issues [6]. Furthermore, avatars have been utilized to enhance self-compassion in individuals with high levels of self-criticism, promoting psychological well-being [5].

While VR and avatar technologies hold immense potential for mental health treatment, it's essential to recognize the importance of cultural context in addressing mental health challenges. Indigenous communities have long held a deep connection to nature, plants, and the guidance of traditional healers, who play an integral role in the well-being of their tribes [7][8]. This cultural perspective emphasizes the importance of holistic approaches to mental health, rooted in the natural world and Indigenous wisdom [9].

This thesis consists of two interconnected projects that share a common foundation in the development of interactive virtual environments and realistic avatars, yet each project serves a distinct purpose. The first project, here in called “Indigenous Healer”, was inspired by the increased suicides amongst Indigenous youth and focuses on improving mental health among Indigenous youth, while the second project, here in called “Museum Tour”, is designed to support cognitive training for the elderly, particularly those experiencing memory problems or depression caused by loneliness. Despite their different applications, both projects share the goal of exploring how VR technologies and lifelike digital avatars can enhance emotional engagement, promote well-being, and create meaningful human–computer interactions in therapeutic settings.

The objective of the Indigenous Healer project is to provide future opportunities to address the mental health challenges faced by Indigenous youth and to help reduce the increasing suicide rates observed since the COVID-19 pandemic [8]. In this thesis, an interactive VR system was created featuring a digital healer who engages users in conversation and responds to their questions in real time using pre-recorded advice and comments. The healer's dialogues are grounded in Indigenous healing traditions and cultural wisdom, providing users with an authentic and culturally sensitive experience.

Although the primary goal of this digital healer is to explore its potential in supporting Indigenous youth mental health, the system's framework can easily be adapted to other contexts. Its design allows the virtual avatar to be used for new purposes—such as developing digital representations of renowned psychiatrists (e.g., Freud) or digital educators. The main novelty of this system lies in its customization to Indigenous culture and traditions, filling a gap where no similar culturally specific virtual healer currently exists.

The Museum Tour project builds upon similar interactive and immersive technologies but focuses on a different application—the development of a realistic avatar in a virtual museum environment. In this project, a naturalistic avatar functions as a guide, interacting with users as they explore paintings and exhibits in the virtual museum. The ultimate goal is to apply this environment and avatar system to cognitive therapy for the elderly, helping individuals with memory impairments or depression associated with loneliness. This project serves as a foundational step toward a larger research initiative aimed at evaluating the use of VR-based environments for cognitive improvement in older adults.

1.1 Motivation for the Indigenous Healer project

The alarming statistics highlighting the significantly high rates of suicide among Indigenous youth in Canada underscore the urgent need for focused attention and action [10]. Indigenous youth face a considerable burden of mental health challenges, with suicide emerging as the leading cause of death for individuals aged 10-29 in Indigenous communities[10]. Statistics Canada's data revealing that First Nations youth are five to seven times more likely to commit suicide than their non-Indigenous counterparts, and Inuit youth are eleven times more likely, portrays the magnitude of the issue vividly [11]. Moreover, the prevalence of suicide among Indigenous youth is exacerbated by socioeconomic factors such as living in rural communities where access to mental health services is limited, further amplifying the vulnerability of these populations [11] [10]

In addition, the COVID-19 pandemic has had a significant impact on mental health globally, with Indigenous communities in Canada being particularly affected [12]. Changes in daily life, concerns about illness, and separation from loved ones have heightened stress and uncertainty among Indigenous individuals. Recent data collection efforts, though not fully representative, provide valuable insights into the mental health challenges facing Indigenous populations during this period. Six out of ten Indigenous participants reported experiencing worsened mental well-being since the physical distancing began, reflecting broader trends of increased anxiety, stress, and depression associated with the pandemic [12]. These findings underscore the urgent need for targeted support and interventions to address the mental health needs of Indigenous communities. Moreover, a significant proportion of Indigenous participants rated their mental health as fair or poor, marking a notable departure from pre-pandemic levels. This is particularly concerning for Indigenous youth, who are grappling with disrupted routines, isolation from peers, and limited access to support services in some communities [12].

To effectively address these challenges, it is crucial to adopt culturally sensitive and community-centered approaches, recognizing the diverse experiences and strengths within Indigenous communities [9]. Prioritizing accessible and culturally relevant mental health services can help mitigate the lasting impacts of the pandemic on Indigenous mental health and promote resilience within these communities [10]. Recognizing the positive impact avatars have shown in mental health treatment, we introduce a realistic avatar in a virtual farm as a potential solution to address the mental health challenges and reduce suicide rates among Indigenous populations.

1.2 Motivation for Museum Tour project

Canada's aging population is growing rapidly, with nearly 25% of Canadians projected to be over 65 by 2030. This growth in the elderly population brings an increasing prevalence of age-related cognitive decline, including dementia and Alzheimer's disease. As of January 2025, approximately 772,000 Canadians are living with dementia—a number expected to surpass one million by 2030 [13]. Although deaths specifically attributed to Alzheimer's disease have slightly declined in recent years, the overall number of deaths due to all forms of dementia has more than tripled since 2000, highlighting a growing national health concern [14].

Alongside the challenge of cognitive decline, loneliness has emerged as a major public health concern among older Canadians [15]. As people age, social circles often diminish due to retirement, the loss of loved ones, and reduced mobility, leaving many seniors vulnerable to isolation. In Canada, loneliness affects a growing portion of the elderly population and is strongly associated with higher levels of stress, depression, and anxiety, as well as an increased risk of chronic illness, disability, and frailty. Studies show that older adults experiencing moderate to high levels of loneliness are up to 2.6 times more likely to develop frailty compared to those who remain socially connected. Beyond its physical and psychological effects, loneliness also undermines a person's sense of purpose and belonging, leading to diminished life satisfaction and motivation to engage in daily or social activities.

While various cognitive rehabilitation and treatment programs exist, traditional approaches—such as memory exercises, paper-based puzzles, and medication—often fail to maintain long-term engagement. Many seniors lose motivation when activities are repetitive or lack meaningful interaction. Research shows that adherence to cognitive therapy programs can drop to as low as 50% when participants do not feel adequately stimulated or emotionally connected to the activity [16]. To address this challenge, we introduce an interactive digital museum with a realistic avatar as a guide, designed to enhance cognitive stimulation and emotional engagement among older adults.

1.3 Thesis organization

This thesis is made up of six chapters. The following chapter is background, which serves as the foundation for understanding key concepts related to VR technology, game engines, and VR applications. It also discusses the appearance of avatars including rendering styles and body parts and their usage in various VR applications. Additionally, the chapter introduces the software tools utilized for avatar creation, including Character Creator, Mixamo, iClone, Unity, and Blender. Following the background chapter, the methodology chapter details the process of avatar creation, outlining the steps involved in generating realistic avatars using the software tools. It also discusses the features of the available game environments: the Indigenous farm and virtual museum, serving as the setting for the VR experience, along with the integration of avatars within these environments and the design of user interaction. Following the methodology chapter, the evaluation chapter presents the design and implementation of a scenario based on Indigenous culture aimed at evaluating the avatar's capabilities in various aspects such as body movements, lip synchronization, and the integration into the farm environment. It also provides the assessment of the museum performance, interactivity, and the potential for cognitive engagement. The subsequent chapter examines the challenges encountered during the avatar creation process and the museum game development and explores the potential applications of realistic avatars in different fields. Finally, the last chapter concludes the avatar creation, discusses avenues for future research and development, as well as limitations encountered during the study.

2. Chapter2: Background

Due to recent advancements in various fields of computer engineering and increased computational capabilities, virtual reality technology has made significant progress and gathered widespread attention [17]. Beyond its role as mere entertainment, VR technology has found applications in various scientific domains, particularly in psychology [17][2]. In this chapter, the definitions of VR and its related concepts are elaborated. Also, avatars and their representation are described, as well as exploring how avatars are used in various research areas like physical rehabilitation and psychology.

2.1 Virtual Reality technology

Virtual reality (VR) is a technological interface that allows users to experience computer-generated environments within a controlled setting [18]. Creation of 360-degree Murals or panoramic paintings in 19th century is the earliest endeavor at virtual reality. In 1838, Charles Wheatstone's research showed that the brain combines two-dimensional images from each eye to perceive them as a single three-dimensional object. Using a stereoscope to view two side-by-side stereoscopic images or photos gave users a feeling of depth and immersion [19]. Several inventions in 1950 and 1960 started what is known as VR now. In 1957, Morton Heilig introduced the Sensorama, a device designed to engage all the user's senses through components like smell generators and vibrating chairs, offering a comprehensive multisensory experience. the first head-mounted displays with motion tracking and dual-monitor displays were developed by the Philco Corporation in 1961. It was primarily used for military training. In 1965, Ivan Sutherland created the Ultimate display, which incorporated the first computer-generated interface, enabling users to have more interactive experiences in real-time VR environments. The term "virtual reality" was formally coined by Jaron Lanier in 1989, further solidifying the concept and leading to increased research and development in the field of VR [18].

Virtual Reality provides the user with the opportunity to immerse in the environment generated by computers. The ability to captivate users and draw them into a different world is called immersion [20]. The sense of immersion has been enhanced due to the advancement of rendering technology head-mounted displays and other interface devices[21].

The level of immersion is divided into 3 groups: 1) non- immersive, 2) semi-immersive, and 3) fully immersive. Non- immersive systems consist of PC monitor, keyboard, and mouse (joystick or gamepad may substitute the mouse) [22]. Semi-immersive systems include advanced graphics and utilize larger flat surface displays. Head-mounted displays and CAVE VR systems, which consist of a cube-shaped room with projection screens, offer fully immersive experience, providing users with the highest level of immersion [23].

Immersion in a VR environment can have significant impact on sense of “presence”. Presence defined as the sense of “being there”, indicates the extent to which a virtual environment portrays real world rather than being a video watching experience. The higher-level immersion intensifies the subjective feeling of presence experienced by users [24]. However, VR can cause various health-related problems, including nausea, dizziness, cold sweats, and vomiting[25]. These issues, collectively known as motion sickness, significantly limit the interaction with VR systems and constrain the full adaptation of this technology. Motion sickness can lead to unpleasant symptoms and may pose a hazard in certain conditions, such as disorientation and vertigo[25]. According to the U.S. National Library of Medicine approximately one out of every three individuals is significantly prone to motion sickness, yet the fundamental reasons behind this condition remain unknown [26]. Consequently, despite the high level of immersion provided by VR technology, many users are unable to fully benefit from it due to the side effects of motion sickness[25].

A specific form of motion sickness that occurs exclusively within simulated or VR environments is referred to as simulator sickness[27]. While it shares many symptoms with traditional motion sickness, simulator sickness arises from the sensory conflicts unique to VR—particularly the mismatch between visual motion cues and the lack of corresponding physical movement.

Simulator sickness was first extensively observed in flight simulator training, where pilots experienced dizziness and disorientation while using stationary simulators that visually mimicked aircraft movement [27]. The sensory conflict theory is the most widely accepted explanation for this phenomenon, proposing that simulator sickness results from discrepancies between visual, vestibular, and proprioceptive inputs. When the eyes perceive motion, but the body does not, the brain interprets this conflict as a potential threat, often triggering nausea as a protective reflex. Alternative theories, such as the postural instability hypothesis, attribute sickness to difficulties maintaining balance, while the eye movement theory suggests excessive or unnatural ocular motion contributes to discomfort. However, evidence consistently supports sensory conflict as the primary cause[28].

To assess simulator sickness, researchers commonly use the Simulator Sickness Questionnaire (SSQ) developed by Kennedy and Lane, which evaluates symptoms like nausea, disorientation, and oculomotor strain [29]. While this self-report tool is widely used, it is limited by inter-individual variability and delayed symptom onset. Physiological methods, such as electrogastrography (EGG), have also been explored for detecting motion-induced disturbances with higher sensitivity [30].

Numerous strategies have been proposed to mitigate simulator sickness. Software-based approaches include maintaining low latency, consistent frame rates, static objects, and minimizing abrupt viewpoint or camera movements to reduce sensory mismatch [31] [32]. Hardware-based solutions focus on improving the synchronization between visual and vestibular cues through locomotion interfaces, such as motion chairs and omni-directional treadmills [33]. For instance, Aldaba et al. [33] compared different locomotion controllers—TiltChair, VRNChair, and treadmill systems—and found that synchronized motion cues reduced sickness and improved intuitiveness.

The degree of immersion also plays a crucial role in simulator sickness [32]. Studies comparing non-immersive, semi-immersive, and fully immersive VR systems have shown that participants using head-mounted displays (HMDs) experience the highest levels of simulator sickness, while those in less immersive setups report fewer symptoms. Interestingly, increasing the sense of presence through the inclusion of a virtual avatar has been shown to reduce sickness severity [34]. A study with 54 participants found that those interacting with an avatar experienced less cybersickness and higher levels of presence, suggesting that embodied interaction can stabilize perception and reduce sensory conflict [34].

Environmental feedback mechanisms can also help mitigate discomfort [35]. Researchers in [35] investigated airflow and seat vibration and found that airflow significantly reduced visually induced motion sickness (VIMS), while vibration alone had little effect. These results indicate that multisensory cues—particularly airflow—can enhance realism and comfort by providing consistent feedback to the vestibular system. Similarly, researchers in [36] designed a virtual reality driving simulator for individuals with advanced dementia, and they included a small fan on the car's dashboard to simulate the sensation of breeze. This simple environmental cue effectively reduced motion sickness and increased user comfort during the simulation.

2.2 Game Engines

The term "game engine" originated in the mid-1990s when it was used to describe first-person shooter games like Doom, created by id Software, which gained immense popularity. Doom was designed with a clear distinction between its fundamental software elements, including the three-dimensional graphics rendering system, collision detection system, and audio system, and the creative assets, game worlds, and gameplay rules that formed the overall gaming experience for the players [37].

The importance of this distinction became apparent when developers started licensing games and transforming them into new products by adjusting primarily to the art, world layouts, weapons, characters, vehicles, and game rules, while leaving the core "engine" software relatively unchanged[37].

Nowadays, game developers can license a game engine and reuse significant portions of its key software components to build games. While this practice still involves considerable investment in custom software engineering, it can be much more economical than developing all the core engine components in-house [37].

The current generation of computer games offers highly realistic virtual worlds with user-friendly interactions and simulations of real-world phenomena, such as gravity. Using computer games as a foundation for virtual environment development has several advantages. These games undergo rigorous testing for usability and performance, making them robust. They can be easily distributed, particularly through online communities. Many game developers also support the modification of their game environments by providing level editors and tools to edit game behavior. This enables the reuse of advanced game engine technology, including 3D rendering, 2D drawing, sound, user input, and world physics/dynamics. Consequently, computer games offer cost-effective, cutting-edge 3D virtual worlds that can be tailored to experimental requirements in a short time without extensive programming [38].

2.3 Virtual Reality Applications

Virtual reality has become the focus of different research areas such as sport [8,9,10], education [39], physical rehabilitations [40], cognitive rehabilitation [40] and psychology [2]. The key aspect of a VR program is the ability for users to interact with the virtual environment, which can be facilitated through different interfaces depending on the application.

Fig. 2-1: A) setup utilized for exercising while playing, B) The game scene of two players running [27].

2.3.1. Sport

The application of VR in sports research has encompassed various sport tasks, VR technologies, and athlete profiles. Some Studies evaluated VR technology by comparing the results of experiments using VR and real-world environment [41] and examining the effects of presence in the virtual environment [42]. Researchers in [43], examined the disparities between competitive and single player modes in virtual environments as a means to motivate individuals and enhance exercise levels, while also alleviating the monotony of exercising alone (Fig. 2-1). On the other hand, other research [44]employed VR as a tool within methodologies to explore how individuals' psychological and physiological reactions differed between self-selected and imposed exercise sessions of similar intensities and durations. In the self-selected session, participants had the ability to determine both the intensity and duration of their workout. In contrast, the imposed session aimed to match the intensity of the self-selected session by instructing participants to follow an additional virtual cyclist displayed on a monitor using CompuTrainer 3D software[44]. Physiological and psychological measurements were taken during the sessions. Analysis using a two-way analysis of variance (ANOVA) indicated no significant differences between conditions for power output, heart rate, VO2, blood lactate levels, Feeling Scale, Felt Arousal Scale, and CR100 scores. Additionally, no significant difference in scores on the Physical Activity Enjoyment Scale between the sessions was observed based on a paired t-test. The results indicated that self-selected and imposed session did not have any impact on effective responses [44].

2.3.2. Education

Many studies have been done on the effect of VR on education and training, the author in [39], investigated the effect of virtual environment combined with lecture class on student’s motivation and learning. They suggested that the integration of virtual environments with traditional classroom instruction could lead to enhanced learning outcomes and increased motivation. Other research had examined the students’ attitude towards VR [45]. They designed two virtual worlds: a virtual office, and a virtual lake. The office was furnished, and students could enter the office, navigate around it, locate and approach bookshelves, open drawers, and interact with different objects such as chairs. The virtual lake was designed and developed based on the eutrophication phenomenon for investigation of the effectiveness of virtual learning environments. Students could navigate inside or outside the lake and observe the facts and objects and investigate the process. The results indicate that students are open to the idea of incorporating VR into the educational process [45].

2.3.3. Cognitive Rehabilitation

Virtual reality offers certain advantages compared to traditional treatments. One key advantage is that patients interact with virtual elements, eliminating the risk of physical harm. Additionally, therapists have control over the stimuli presented in the virtual environment, enabling them to repeat the experience as needed [40]. Furthermore, patients' adherence and satisfaction levels are elevated when engaging with the computer-generated environment compared to conventional rehabilitation methods [46].

In recent years, the concept of "serious games" has gained increasing attention in the field of cognitive rehabilitation. Although entertainment is not their primary goal, serious games are designed to be enjoyable and engaging while serving a purpose beyond mere fun—such as training or therapy [47][48]. By combining interactive gameplay elements with therapeutic objectives, serious games provide an immersive and motivating platform for rehabilitation.

A study has been conducted in which the participants, people with learning disabilities, were required to follow a series of sounds and colors emitted by virtual objects [40]. The game offered the therapist the flexibility to customise the musical and visual elements to create different scenario for each patient [40]. The results indicated that the game was inspiring and facilitating to the learning process of patients with disabilities [40]. Furthermore, Hwang et al. [49] aimed to explore the impact of semi-immersive virtual reality-based cognitive training (VRCT) coupled with locomotor activity on cognitive function, balance, and gait ability in older adults. To achieve this, they employed a 270-degree touchable screen along with locomotor activity. Their findings confirmed that this combination of semi-immersive VRCT and locomotor activity effectively enhances cognitive function and gait ability among older adults. Another study conducted by White [50] investigated the effectiveness of an immersive VR cognitive treatment program for an individual with Alzheimer's disease focusing strengthening spatial navigation. Results indicated successful learning within the VR environment, leading to improved real-life cognitive abilities, as reported by the primary caregiver, suggesting potential benefits of VR navigation treatments for AD patients[50] [51]. Moreover, another study [52] investigated the efficacy of a 3-D virtual reality kayak program on cognitive function in elderly individuals. Results demonstrated significant improvements in cognitive function suggesting the potential of virtual reality interventions in cognitive rehabilitation for the elderly.

2.3.4. Psychology

Virtual reality has proven to be effective in treating various disorders, including anxiety, depression, eating disorders, and psychotic disorders [2]. In one study [53], authors explored how a VR-based stress management program could impact individuals with mood disorders. The program involved participants engaging in one-hour session for three days, which included a combination of psychoeducation and relaxation exercises using VR technology. The results indicated that those who successfully finished the program experienced a notable reduction in their feelings of depression[53].

VR can also help with eating behaviors and body image, as shown in research [54]. In the study [54] , they investigated the effectiveness of incorporating virtual VR technology into cognitive behavioral therapy (CBT) for treating binge-purging type eating disorders, comparing its efficacy to traditional CBT. They included six studies with randomised controlled trials (RCTs) comprising ten to fifteen sessions of VR interventions over three to six weeks [54]. The results indicated that patients who received VR-enhanced CBT experienced significantly larger reduction in the frequency of binges and body dissatisfaction compared to CBT. However, there was no difference between the frequency of purges in both groups [54].

Additionally, VR-based treatment can make a real difference for people with anxiety and paranoia from psychotic disorders; for example, a study [55] examined how virtual reality-based cognitive-behavioral therapy (VR-CBT) influences paranoid thoughts and engagement in social activities. The study comprised 16 one-hour sessions over 8-12 weeks. The results showed using VR as a therapeutic tool could bring positive changes to these patients' daily lives. By using immersive and controlled VR environments, individuals struggling with psychotic disorders reported feeling less anxious and having fewer paranoid thoughts in their day-to-day experiences. This new way of using VR has shown potential to improve well being and mental health for people facing various psychological challenges [55].

2.4 Presence of avatar in the VR

Having explored the diverse applications of VR technology from sport to neurorehabilitation and psychology, it is evident that VR's potential can go far beyond what we explained so far. In the realm of VR applications, one particularly fascinating aspect is the integration of avatars. In this section, we will explore further into the world of VR applications and avatars, exploring their impact across various domains.

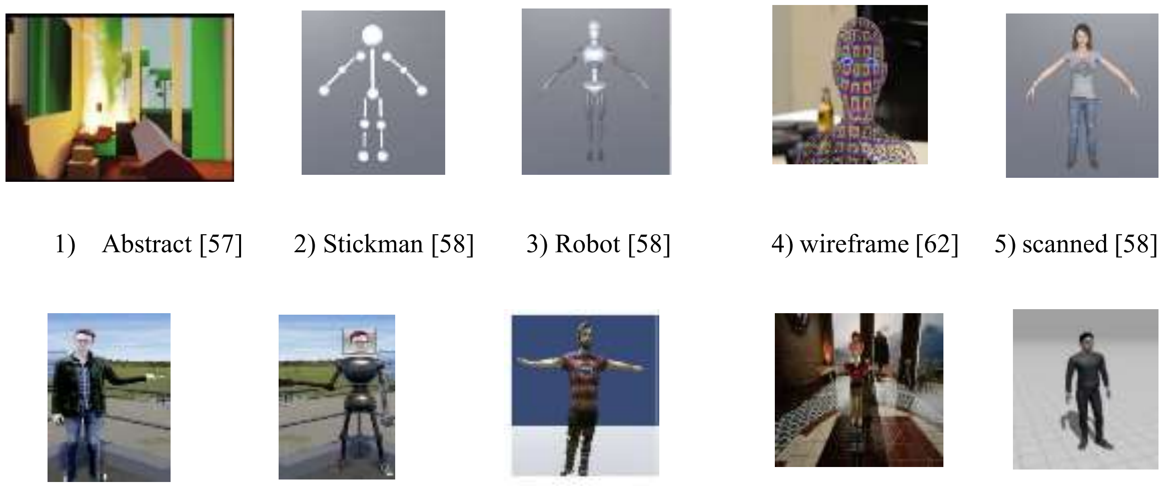
In VR environments, individuals require a form of representation to embody their being. The term "avatar" gained popularity among researchers in the field of human-computer interaction. It refers to a digital representation of a person within an online or virtual environment, such as virtual reality. Avatars and agents are being used in many virtual reality applications. While a human controls an avatar, agents are being controlled by computer algorithm [56].

There are two factors influencing the avatars' representation: rendering style and body parts. Rendering style refers to the avatars visualisation and body parts refers to the different part of body being displayed [4]. They are explained in below sections.

2.4.1. Rendering style

Avatars has been used with different rendering styles such as abstract, stickman, robot, cartoon, video avatar, point cloud, wireframe, and hybrid design (Fig. 2-2) [4]. In the abstract design, one or a few geometric shapes such as a cuboid are used [57][58]. In stickman design, spheres and cylinders represent extremities and main body joints [45]. Robot visualization represents the human body with a robot look [58][59]. Cartoon design includes exaggerated body parts such as nose and ears [60]. Video avatar is another design in which a person's body is recorded and appears as a 3D mesh [59]. Point cloud design is used to represent a human with a cloud of single dots. The more dots are being used, the more realistic the avatar looks [61]. Wireframe humanoid design is a visualisation in which a detailed 3D model used but is transparent [62]. Hybrid design used in [40], utilized the robot's body and the video of a person's head.

Realistic avatars are divided into three groups: 1) generic; 2) scanned; and 3) personalized [4]. Generic realistic style represents detailed human body and clothing with texture. In scanned design, photogrammetry cameras are being used to resemble the real user. The personalized realistic style achieves a comparable level of detail and accuracy as the generic realistic approach but is specifically tailored to the individual participant. This style is created by capturing images of the participants using cameras and merging these scans with preexisting 3D models [4].



1) Abstract [57]   2) Stickman [58]   3) Robot [58]   4) wireframe [62]   5) scanned [58]

6) Video [59]   7) Hybrid [59]   8) Point cloud [61]   9) Cartoon [60]   10) generic [63]

Fig. 2-2: Avatar rendering style.

2.4.2. Body part

Apart from variations in rendering style, the visual representation of avatars also exhibits diversity in terms of the extent to which different parts of the avatar's body are made visible [4]. Within various studies, different levels of body visualization have been employed. Some investigations chose not to display any parts of the body, while others opted to show specific body parts such as hands alone, hands and arms, hands and feet, hands and head, head and torso, hands and torso, head and hands and torso, hands and head and torso, hands and arms and legs, hands and head and feet, hands and forearms, hands and feet and head and arms, head-to-knee body depiction, feet only, and the complete full-body representation [4]. It's important to note that most of these studies incorporated a full-body configuration in at least one experimental condition, indicating its prevalence as a choice in avatar visualization.

In a study [4], they examined the impacts of various avatar or agent representations in VR, with a particular emphasis on HMD-based setups. They offered an overview of 72 articles from 2015 to 2022. The results showed that almost always full-body configuration and realistic avatar and agent had significant advantages over other body configurations and rendering styles [4].

2.5 Avatar measures

Apart from presence and immersion discussed above, *affinity*, and *agency* are important factor for a game to be engaging. Affinity is the sense of connection and attachment that the user of the VR game experience [64]. On the other hand, the user's ability to interact with characters in VR environment is referred as agency [64].

Much research has been conducted on using avatars and agents with different body parts and rendering styles in the VR-based games to investigate presence [64], immersion, and agency [64], and affinity [64]. To investigate presence, a study [65] used four types of visual presentation (as shown in Fig. 2-3). In the VR game that the participants were encouraged to pass a wall, they observed the participant's behaviour and the moment in which they pass the wall. Results indicated that realistic full body avatar increase sense of presence [65]. In another study [20], immersion was measured through questionnaires, task performance time and eye movements. It was reported that the level of immersion was higher in immersive condition than non-immersive environments [20].

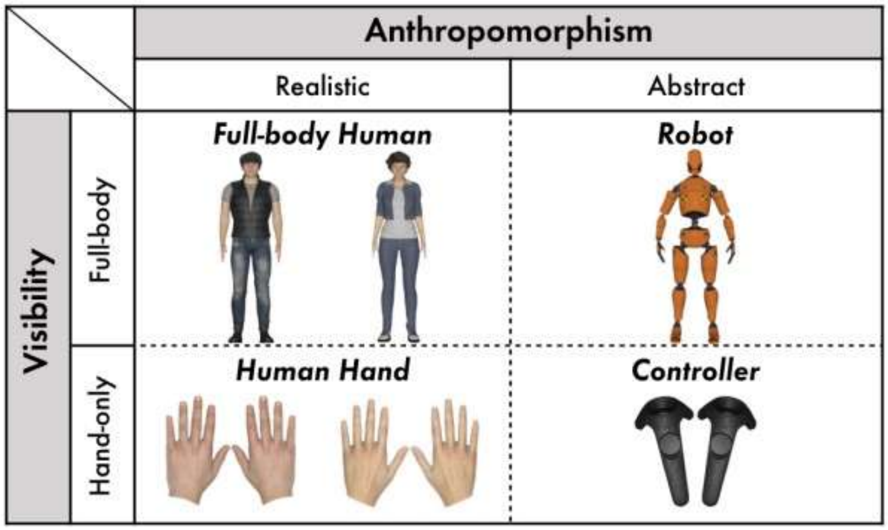


Fig. 2-3: Four different types of avatars used in the experiments [65] where the participant is supposed to pass a wall.

Authors in [64] created a VR game in which the user was instructed to read the words written on the front and back of a created character. The character had 3 different rendering styles: 1) realistic, 2) Toon CG, 3) Toon shaded as shown in Fig. 2-4. They used questionnaires to investigate the use of realistic character on presence, agency, and affinity. The result showed that realistic full body agent enhanced agency, sense of presence and affinity [64].

Fig. 2-4: three avatars with different rendering styles used in [64] to investigate presence, agency, and affinity.

2.6 Usage of Avatar in VR applications

Avatars and agents are being used in many different research areas such as education [66], social communication [67], physical rehabilitation [68], and psychology [3]. Researchers have been investigating whether the use of avatar is effective or not.

2.6.1. Education

It has been a topic of discussion if education system can be revolutionized by VR. VR can be utilized for simulation-based learning, allowing students to practice new skills in a controlled environment that allows for correction, repetition, and safe experimentation. Additionally, VR offers the opportunity to interact with costly or distant environments that would otherwise be inaccessible. With the introduction of new version of HMD which is more accessible to the public, and provides better quality, the hope of widely use of VR has increased [69]. A new method of teaching in VR is using pedagogical agent [66].

A pedagogical agent refers to a virtual avatar, powered by artificial intelligence (AI), that employs different teaching approaches within an interactive educational environment to assists students in their learning process [70].

Social agency theory, a widely employed framework in multimedia learning, explains the use of pedagogical agents. According to this theory, incorporating social cues within multimedia lessons can evoke a sense of social presence among learners, resulting in enhanced cognitive processing and improved learning outcomes. Social presence refers to a psychological state where virtual social actors are perceived as real individuals, either through sensory or non-sensory modalities. The theory posits that individuals are attentive to social cues when interacting with computerized agents, which can elicit a feeling of engaging with another social being [66].

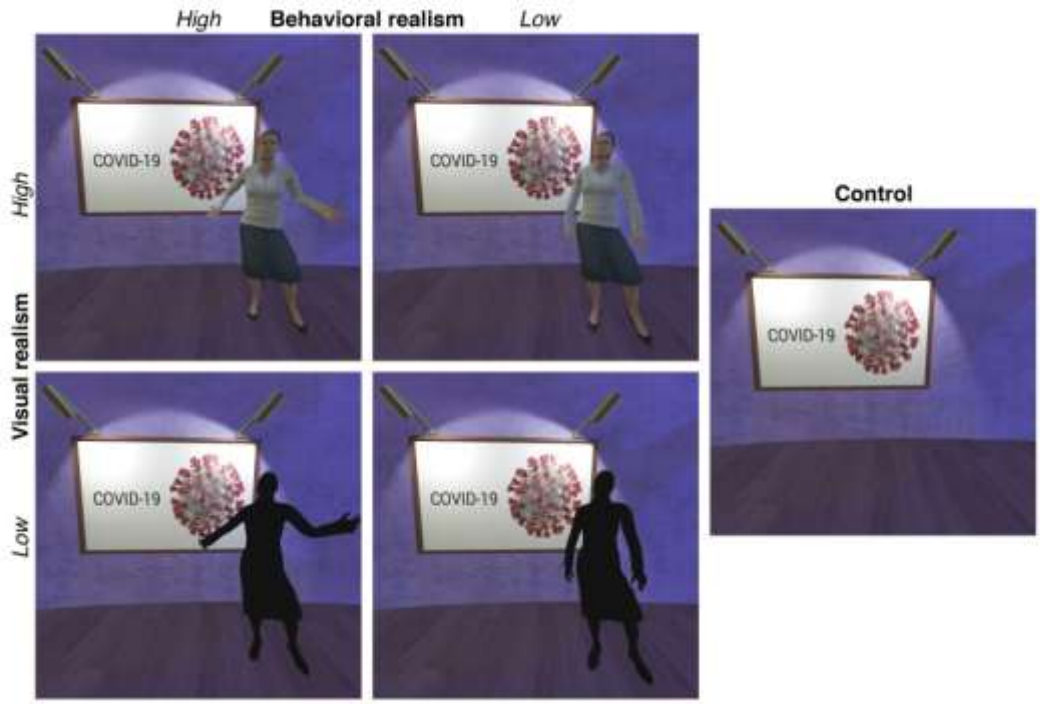


Fig. 2-5: Experimental design of the study. High behavioral realism including eye contact, gesturing, lip sync, and natural movements (left). High visual realism entailed rendering the agent as a human (top) rather than in monochrome (bottom). The control group experienced the simulation without a pedagogical agent (far right) [66].

To investigate the effect of agents on participants learning in an exhibition centred around viruses, [66] controlled the behavioural and visual aspect of a virtual museum guide in 4 different experiments (Fig. 2-5). Before beginning the game, participants were required to complete a knowledge test. After a brief introduction at the beginning of the game, participants could walk freely and follow the tour guide. At the end, identical knowledge test was completed by the participants. They concluded that pedagogical agent is useful for conceptual learning and has negative impact on factual learning.

The impact of agent on boys and girls was examined by [71]. They used 2 pedagogical agents, Marie which was a humanoid character and drone which is a hovering robot (Fig. 2-6). The results indicated that boys learn better with drone, and girls learn better with Marie. As boys felt higher presence with Marie and learned better with drone, it can be assumed that boys pay less attention to lessons in Marie's presence. They concluded that gender matching is an important factor in learning process [62].

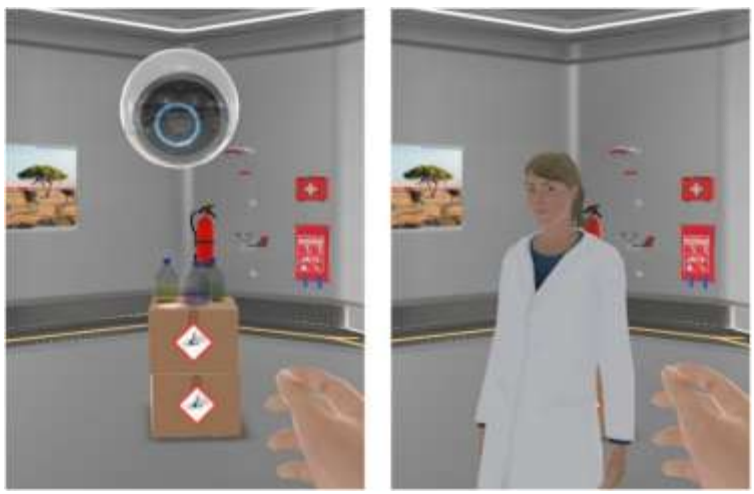


Fig. 2-6: pictures of the immersive VR lab safety simulation displaying the two pedagogical agents: Left: Hovering robot (The drone). Right: Female, humanoid assistant (Marie) [71].

2.6.2. Social communication

To have successful social communication, people need to consider perspective in visual, conceptual, and emotional domains[67]. In a study [49], they tried to find out the effect of the presence of an avatar in performing taking tasks. They placed a table in the room with chair alone or an avatar sitting on it at the right, left or the center position. a broken ring with a crack in one of eight directions (0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°) was presented on the table with quick or slow time interval (Fig. 2-7). The study found that presence of a human avatar helps us determine the direction of visual stimuli from a different viewpoint [67].

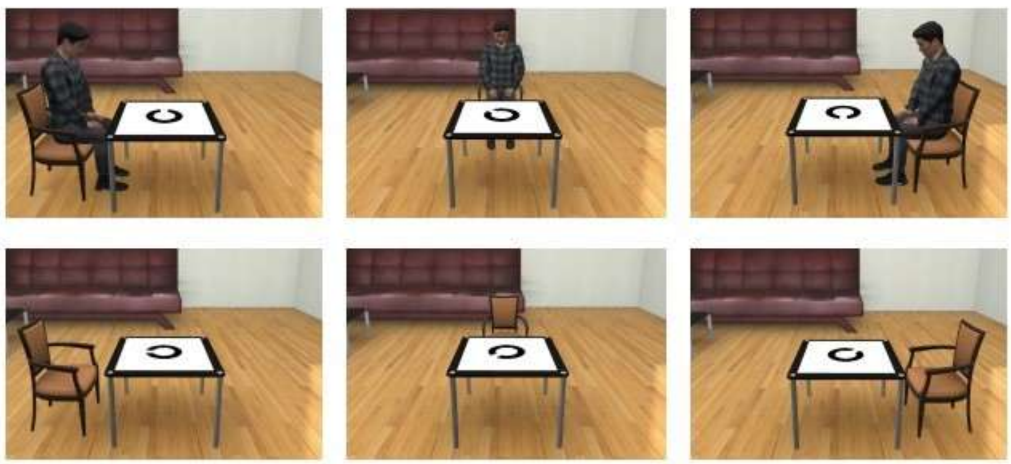


Fig. 2-7: Experimental design for preforming taking task. Top pictures show the stimuli in presence of an avatar, Bottom pictures show the stimuli in absence of avatar[67].

2.6.3. Physical Rehabilitation

Rehabilitation is another application where using avatar is beneficial[68]. During the process of rehabilitating lower limb function, patients are assigned with purposeful and functional tasks, such as walking and stepping over objects[68]. In a hospital environment, these activities are typically conducted under the supervision of physiotherapists or who offer feedback to patients and adjust their training regimen accordingly[68]. However, once patients are outside the clinic, they often lack sufficient guidance for their exercise routine.

As a result, patients may lose motivation or perform exercises incorrectly in the absence of direct supervision from a physiotherapist. The study [68]was conducted to examine the ability of healthy individuals to accurately synchronize their movements with a virtual avatar. The study involved measuring the participants' step tempo and the degree of asynchrony between their steps and the movements of the avatar. Participants were instructed to synchronize their steps with the avatar at two different inter-step intervals: a fast interval and a slow interval. The research has shown that virtual reality humanoid cues can be utilized as exercise cues for entrainment. Participants were able to match and adjust the timing of their movements to synchronize with the avatar (Fig. 2-8). It is crucial to note that this successful synchronization was only possible with the addition of footstep sounds [68].

Fig. 2-8: The participants' visual perspective of the avatar while performing the stepping task [68].

2.6.4. Psychology

One of the applications of avatars is treating psychological disorders. In a study [3], they investigated the effect of using avatar in mood change. The participants experienced embodiment in two different body representatives. One representation closely resembled their own body, and the other representation embodied Dr. Sigmund Freud as shown in Fig. 2-9. In one scenario of the experiment in which virtual body resembled participants, they described a personal issue. In the other scenario, the virtual body portrayed Dr. Sigmund Freud, and the participants provide themselves with advice. The participants alternated between these two roles throughout the experiment. It was observed that participants experienced an improvement in their mood when they interacted with a counselor who resembled Freud, as opposed to when they interacted with a counselor representing themselves[3].

The previous experiment [3] did not provide a conclusive answer regarding the significance of body swapping itself or whether the results were influenced solely by participants discussing their issues with a virtual therapist[6]. Therefore, authors in [6] designed an experiment to investigate if self-conversation through embodied perspective taking (body swapping) could play a role in assisting participants in resolving personal problems, or if the findings observed in the previous paper [3] were solely a result of participants discussing their issues.

They designed two methods of counselling: Scripted and Self-Conversation[6]. Participants in the Scripted group engaged in a conversation with a virtual representation of Sigmund Freud, during which they explained their problem. The virtual Freud character actively participated in the dialogue by asking questions and providing comments.

Those in the Self-Conversation group followed a similar process, explaining their problem to Freud, and then engaging in body-swapping between the virtual Freud and their own virtual body. They maintained a conversation with themselves from two different perspectives [6].

Fig. 2-9. The virtual scenario. (A) An overview of the scene from just behind the viewpoint of the participant who can see himself in the mirror and the virtual Freud across the table. (B) From the virtual body of Freud, the participant can see the refection of the Freud body in the mirror and the representation of himself across the table[3].

In both scenarios, the participants underwent digital scanning before entering the VR environment to ensure that their virtual bodies closely resembled their actual appearances. The results indicated that Self-Conversation method has a positive influence compared to the Scripted method[6].

Falconer [72] designed a situation to explore how virtual embodiment could enhance self-compassion in individuals with high self-criticism. In the first part, participants interacted kindly with a virtual crying child while inhabiting the virtual body of an adult. In the second part, one group of participants switched to embodying the virtual child's body and could observe a recording of their own compassionate actions and words from the perspective of the child. By allowing participants to be in both adult and child bodies, the scenario enabled self-directed compassionate communication. As expected, this setup led to a significant increase in self-compassion compared to a control group where participants saw and heard the same compassionate actions and words, but from an external, third-person viewpoint. Both groups experienced a decrease in self-criticism. Then they decided to apply the same method to people with depression. The results indicate significant reductions in the severity of depression and self-criticism, along with substantial improvement in self-compassion [5].

2.7 Methodological background

The presence of avatars in VR environments is facilitated and enhanced by the utilization of various software tools focused to avatar creation, animation, and integration.

These tools, including iClone[73], Character Creator[74], Blender[75], and Unity[76], play a crucial role in shaping the visual representation and behavior of avatars, ultimately contributing to the overall immersive experience in VR applications.

2.7.1. Character creator:

Our journey to develop realistic avatars within the virtual reality landscape begins with the indispensable tool known as Character Creator (Fig. 2-10). Character creator software is a specialized application designed to meet the needs of artists, game developers, animators, and designers. It empowers these professionals to meticulously design and personalize digital characters or avatars for a variety of purposes, such as video games, virtual reality simulations and animations. This software plays a vital role in bringing virtual beings to existence with a high level of precision and creativity, offering a comprehensive set of tools and functions to facilitate the process.

Character sculpting capabilities allow users to meticulously shape every aspect of a character's physique, spanning from their body to facial attributes. This is achieved through the utilization of digital sculpting tools and brushes that closely resemble those found in specialized sculpting software. Texturing and material editing functionalities facilitate the application of textures, colors, and materials onto the character's surfaces, resulting in a realistic portrayal of skin, attire, and accessories. Rigging tools are of paramount importance in establishing the character's skeletal framework and articulation points, which are essential prerequisites for animating a wide spectrum of movements, including subtle facial expressions and intricate actions.

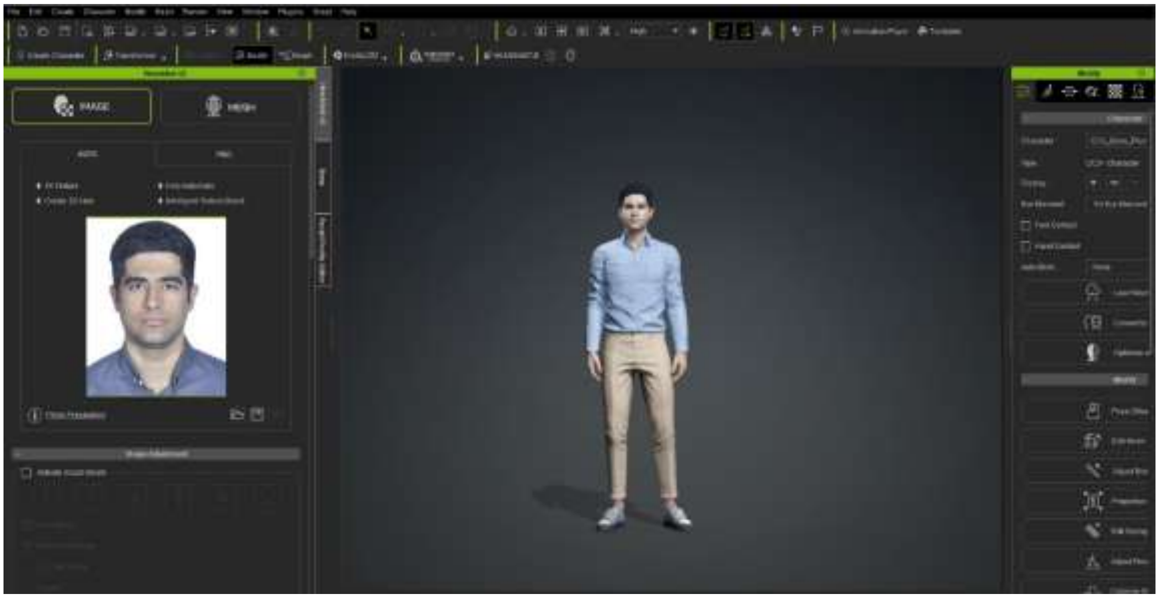


Fig. 2-10. Character Creator enables users to design their desired avatar, and it offers various customization options allowing the users to finely sculpt every aspect of avatars body.

The available animation features encompass a spectrum ranging from fundamental gestures and facial expressions to elaborate animations that are integral for narrative storytelling or interactive gameplay. Additionally, character creator software facilitates clothing and accessory customization, empowering users to personalize the character's attire and style. Precise control over facial expressions, including eyes, brows, mouth, and more, is achievable through facial expression editing tools. These software packages offer diverse export options compatible with various platforms, game engines, and 3D software, streamlining the integration of created characters into a wide range of projects.

Furthermore, seamless integration with other 3D modeling, animation, and game development software enhances professionals' workflow, while content libraries featuring pre-made assets expedite character creation. To enhance visual appeal, character creator software often incorporates rendering engines capable of producing realistic, high-quality visuals, culminating in a comprehensive suite of tools to elevate character design and animation [74].

To achieve a high degree of realism in our interactive avatars, we used the 'Headshot' plugin integrated into Character Creator 4. The 'Headshot' plugin is a powerful tool that allows for the precise recreation of human facial features based on reference headshots. By leveraging this technology, we were able to capture the subtleties of human expressions and accurately translate them into our avatar designs. This level of detail not only enhances the visual fidelity of our avatars but also plays a crucial role in establishing a genuine connection between users and the virtual characters they interact with. The 'Headshot' plugin, combined with the broader capabilities of Character Creator 4, forms the foundation of our approach to creating lifelike and engaging interactive avatars for our research [77].

2.7.2. Mixamo

Moving forward in our project to create realistic avatars, we turn our attention to Mixamo[78]. Mixamo is a cutting-edge online platform and animation technology developed by Adobe that revolutionizes the process of character animation for 3D projects (Fig. 2-11). It caters to a wide range of users, from game developers and filmmakers to designers and animators. What sets Mixamo apart is its ability to simplify and expedite the often complex and time-consuming task of character rigging and animation[78].

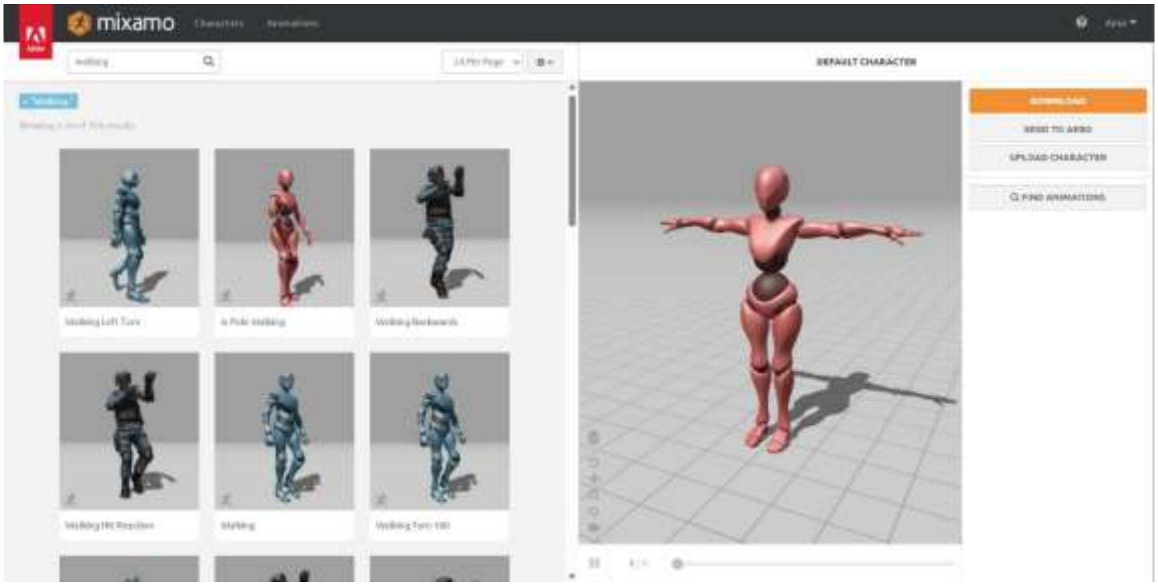


Fig. 2-11. Mixamo provides users with pre-made 3D character animations including walking, running, etc [78].

Mixamo offers an extensive library of pre-made 3D character animations, including walking, running, dancing, and more, as well as an impressive collection of customizable 3D characters. Users can easily apply these animations to their own 3D characters, saving valuable time and effort. Additionally, Mixamo provides an online Auto-Rigger tool that automates the character rigging process, which is essential for character movement and articulation. This tool eliminates the need for manual rigging, a process that traditionally demands expertise and significant time investment. With Mixamo, users can rapidly create and animate 3D characters for their projects, making it an invaluable resource in the world of 3D animation and game development [78].

2.7.3. iclone

iClone is a robust and versatile 3D animation software developed by Reallusion[73], designed to meet the needs of a diverse community of animators, filmmakers, game developers, and content creators. With its user-friendly interface and a wide range of features, iClone provides a powerful platform for creating high-quality 3D animations and renderings (Fig. 2-12). One of its standout features is its real-time animation capabilities, allowing users to shape and control 3D characters and scenes in real-time, providing instant feedback and facilitating smooth adjustments during the animation process.

The software features an impressive character creation system allowing users to design and personalize 3D characters with precision. This includes modifying character appearances, clothing, and accessories, or importing characters from other 3D modeling tools. Additionally, iClone seamlessly integrates motion capture technology to capture real-world movements and apply them to 3D characters, offering a library of pre-made motion capture animations for added convenience. Motion Director, another notable feature within iClone, allows users to record and edit custom animations for their 3D avatars. With Motion Director, users can control the movement of their avatars in real-time, adjusting speed, direction, and timing to create dynamic and realistic animations. Additionally, Motion Director provides tools for fine-tuning animations, such as adjusting joint movements and refining motion curves, ensuring smooth and natural movement in the final animation sequences. For accurate and expressive character animation, iClone incorporates AccuLip, a feature that simplifies the lip-sync process. AccuLip enables automatic lip-syncing, synchronizing character lip movements with audio dialogues, enhancing the realism and expressiveness of characters' speech. This not only streamlines the animation process but also ensures that characters convey emotions and effectively engage the audience.

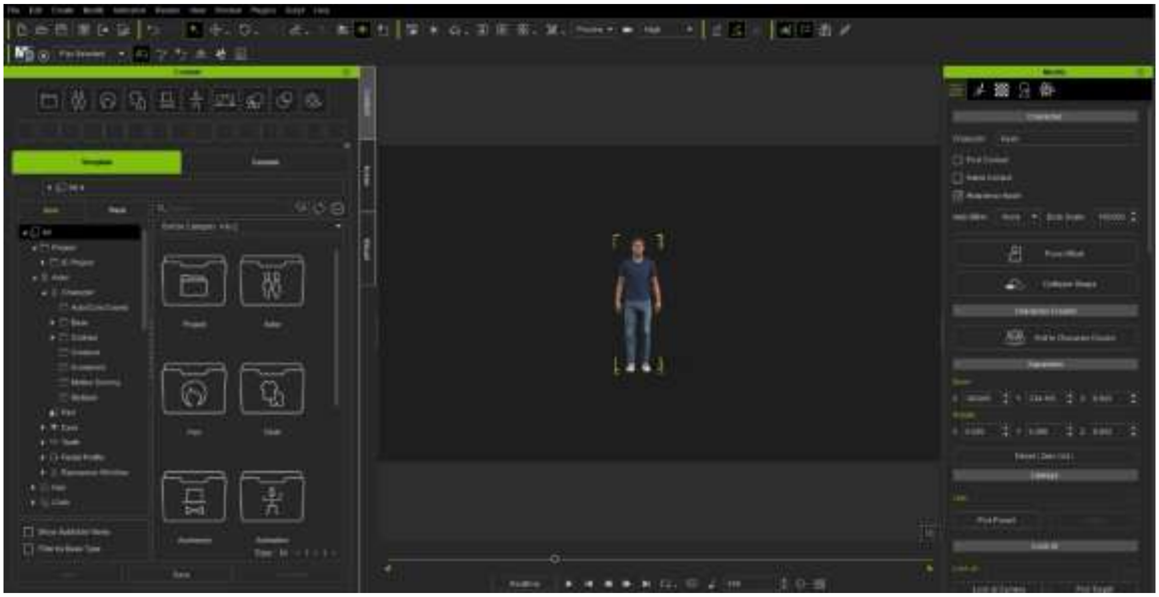


Fig. 2-12. iClone enables users to create and add animations to avatars. With features like AccuLip, iClone facilitates realistic lip movement and allows for the expression of a wide range of facial expressions.

Beyond character animation, iClone provides tools for scene and set design, offering a library of 3D environments, props, and assets that can be customized or used in its current state. Its timeline-based animation system grants users' precise control over character movements and actions, ideal for creating detailed animations and sequences. The software also offers rendering options, including real-time rendering and ray tracing, to generate visually stunning 3D animations and scenes. iClone's compatibility with various 3D modeling and animation software further enhances its versatility, making it an excellent choice for integration into professional workflows. Suitable for a wide range of applications, from filmmaking to game development, virtual production, educational content creation, and interactive presentations, iClone serves as an inclusive platform. It is further enriched by an extensive content marketplace, offering a vast selection of 3D assets, characters, animations, and more, enabling users to broaden their creative horizons. In summary, iClone simplifies the 3D animation and rendering process, making it accessible to users at all levels, from beginners to experienced professionals. Its real-time capabilities, along with a comprehensive feature set, enhance the creation of immersive 3D animations and content while incorporating the convenient and efficient AccuLip feature for improved character lip-sync[73].

2.7.4. Unity

The Unity 3D game engine is primarily used to build interactive environments, especially for the creation of video games. The initial release of Unity occurred in 2005, with the aim of creating a set of tools that simplify game development. These tools were designed to cater to both novice game developers and those who couldn't afford expensive game development software [79].

Unity incorporates collision physics, visual elements, sound synthesis systems, and advanced graphical features including noise reduction filter and realistic lighting effects that enhance user interactions and significantly elevate the immersion level of VR systems [27][38]. Furthermore, Unity's source codes are composed of managed code, which is written in a high-level language, such as C# in the case of Unity 3D. These codes undergo a compilation process, resulting in intermediate language files [80]. During the runtime process, these intermediate files are converted into binary machine language [80]. While this compilation process incurs some communication overhead, it allows the runtime language to automatically handle memory management and security considerations. In contrast, when using languages like C/C++ to write computer programs, programmers are responsible for managing memory and addressing security concerns [80].

Unity has the capability to arrange multiple animations using a single avatar, thanks to a state machine (Fig. 2-13). In simple terms, a state machine acts like a storage unit that keeps track of what condition something is in at a particular moment – in this context, it monitors the state of the Avatar. When it receives input, it responds based on the current state, possibly transitioning to a different state. Typically, Unity employs the state machine to link an animation to a character's condition, like whether the character is running or jumping, and then assigns the appropriate animation accordingly[81].

Therefore, the state machine is an ideal tool for arranging the different animations required for a transition. our state machine consists of various states such as idle, talking, walking, and sitting. The idle state represents the basic animation when there are no ongoing actions, whereas the other states are utilized when there are ongoing actions. When it receives the required animations, it allocates each animation to the relevant states in a specific sequence. It also establishes a rule that as one state's animation concludes, it automatically transitions to the next stage[81].

Unity offers a functionality known as "ExitTime" within each state. This feature serves as an additional condition that instructs the system when to switch states, in this case, to progress to the next state. When this condition is activated, Unity initiates the next animation when approximately 75% of the current animation has played, which is the default setting. With both animations running concurrently, Unity orchestrates the transition from one animation to the other. This transition operates by comparing the positions and rotations of each bone in the skeleton from both animations and aligning the values of the first animation with those of the second. This feature ensures that the first animation doesn't abruptly stop but smoothly transitions to the second [81].

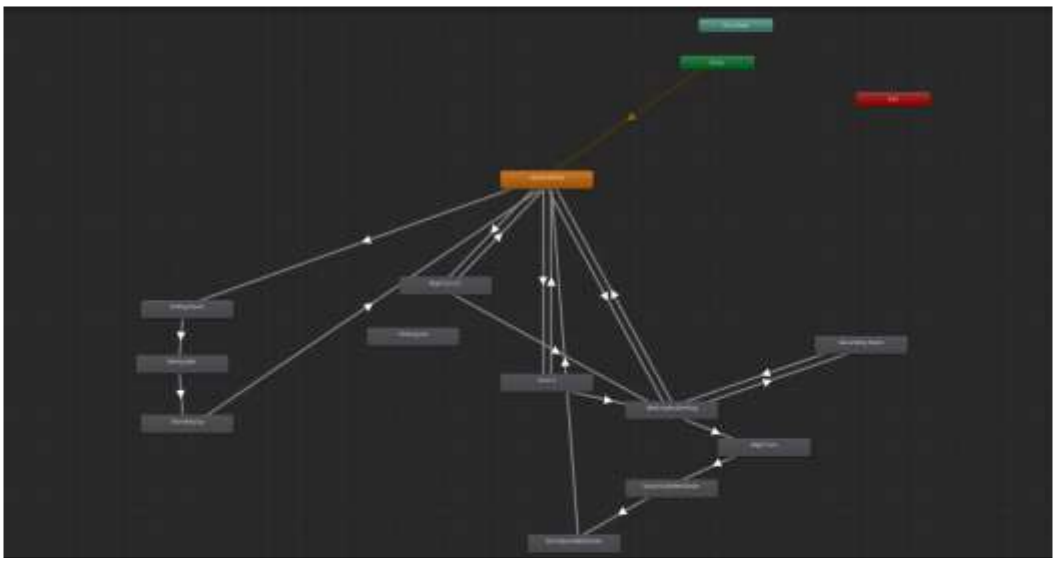


Fig. 2-13. Using the state machine for smooth coordination of multiple avatar animations allows us to smoothly navigate through states like idle, talking, walking, and sitting.

2.7.5. Blender

Blender is an open-source 3D computer graphics software that holds a prominent place in the realm of digital content creation [75]. It serves as a powerful and versatile tool for a wide range of creative activities, including 3D modeling, animation, rendering, and even game development (Fig. 2-14). What makes Blender particularly appealing is its status as free and open-source software, which has active community of users and developers. They provide frequent updates, plugins, and add-ons, making Blender a valuable asset for any project [75].

One of Blender's primary strengths lies in its robust 3D modeling capabilities, which form the foundation for creating avatars. It offers a comprehensive suite of tools and techniques for modeling, including everything from polygon modeling for precise geometry control to sculpting for organic and fluid shapes [52, 53]. Blender's capabilities expand beyond modeling into the realm of texturing and material creation which is a crucial aspect of crafting lifelike avatars. With Blender, we can seamlessly apply textures and materials to the 3D models, enhancing their visual appeal and realism. Furthermore, Blender simplifies the process of UV mapping, ensuring that textures adhere smoothly to the avatar's surface. This capability is particularly advantageous when striving for realistic skin textures, intricate clothing designs, and other visual details that contribute to the overall believability of avatars [75].

Fig. 2-14. In the domain of 3D graphics, animation, and game development, Blender stands as a crucial player, in shaping immersive avatars and dynamic virtual landscapes. Leveraging its cutting-edge rigging and animation tools, we sculpt avatars with subtle expressions and movements, enriching the depth of our immersive digital experience.

Blender offers robust tools for rigging and animation. Rigging involves creating skeletal structures, or armatures, that enable avatars to move realistically. Blender's armature system allows for precise control over joint movements, deformations, and expressions, ensuring that avatars can convey emotions and gestures effectively. By combining Blender’s animation capabilities including keyframe animation and Graph Editor for fine-tuning motion, we can bring avatars to life [75].

2.8 Summary

This chapter provided an overview of the essential details and foundational aspects related to the design and utilization of VR environments. We discussed applications of virtual reality in different research areas such as education, neurorehabilitation, and psychology. Furthermore, avatar and its visualisation consisting of rendering style and body part were introduced. We presented different factors such as affinity, presence, and agency that are important for a game to be engaging. In addition, a literature associated with various usage of avatar in VR applications such sport, education, and psychology were overviewed. Finally, we discussed various software tools commonly employed for creating avatars in virtual reality environments.

3. Chapter 3: Methodology

In this section, we outline the methodology employed in the creation and integration of avatars within two Unity-based environments: a farm featuring Indigenous culture and a museum. We used a combination of software tools, including iClone, Character Creator, Blender, and Unity, to develop realistic and interactive avatars for both projects. Moreover, this section provides an explanation of the gameplay and the design of the virtual environments.

3.1 Avatar creation process

An interactive avatar involves a multi-step process that begins with capturing a high-quality headshot of a person, which serves as the foundation for generating the avatar's facial features. A headshot plugin within a character creator application uses advanced computer vision and 3D modeling techniques to create a 3D representation of the face based on a 2D headshot photograph (Fig. 3-1). This 3D model can then be customized extensively, allowing for the modification of individual facial features such as the jaw, nose, and eyes. The addition of a 3D body and clothing options further enhances the avatar's appearance, providing opportunities for personalization. We can modify different body parts such as hand, chest, etc., to make the avatar thin, fat, muscular, etc. (Fig. 3-2). To further enhance the avatar's overall appearance and functionality, a crucial step involves rigging, where a skeletal system is added to the avatar. This rigging enables the avatar to move and animate realistically, with the ability to express emotions and interact within a digital environment. Once the avatar is ready, it's exported in FBX format to ensure compatibility with various 3D software and game engines.

After creating the avatar, the next step is to make the animation which brings the avatar to life and allow it to interact within various scenarios. Animations for the avatar can be obtained from platforms like Mixamo, which provides pre-made motions, and iClone. In Mixamo, we have access to a vast library of animations covering various styles and categories, such as walking, running, dancing, and more. Once we have chosen an animation that suits our project, the customization process begins. Mixamo offers options for adjusting animation parameters like duration and rig settings. Importantly, Mixamo provides the flexibility to retarget animations to different types of rigs, allowing us to adapt them to our specific avatar (Fig. 3-3). In iClone, we are presented with a variety of options for animation creation. we may choose to utilize pre-made animations or opt for the more customizable approach of recording animations via the Motion Director tool. Within Motion Director, we can guide the avatar through movement at three distinct speeds, capturing and transforming these movements into animated sequences. After customizing the animation to our liking, we can proceed to download it in FBX format.


Fig. 3-1. 3D model creation of the body based on a Colin's headshot using Character Creator software. Permission was obtained from the individual shown, Colin Mousseau.

The next step involves importing both our customized avatar and the downloaded FBX animation into iClone a real-time 3D animation software known for its character customization capabilities. iClone's animation tools and features facilitate the application of the animation to our avatar. To ensure a seamless integration, it's essential to associate the animation's skeletal rig with our avatar's rig. As customized animations are limited on Mixamo, users often need to combine multiple animations to achieve desired sequences. iClone offers the capability to seamlessly blend different animations. For instance, users may wish to transition an avatar from an idle stance to pointing to the right and back to idle. To achieve this, we need to combine the pointing and idle animation. iClone allows us to fine-tune and refine animations by providing precise control over joint movements and deformation, ensuring animations align seamlessly with the avatar's proportions and movements (Fig. 3-4).

Fig. 3-2. The above pictures show the flexibility inherit in the Character Creator software. It enables the smooth transformation of characters, allowing for the manipulation of body, from thin and heavy to muscular.

In addition to body animations, facial expressions, and lip synchronization can be added to the avatar in iClone to make the avatar more realistic. Facial expressions, a crucial aspect of avatar realism, are created in iClone, offering detailed control over individual facial muscles and features. In addition to the facial expression, which is a remarkable capability of the iClone, lip synchronization can take realism to the next level. In order to achieve precise lip synchronization with audio, this platform provides a specialized tool called AccuLip. It operates by uploading an audio file and detecting words based on a predefined dictionary, generating accurate lip movements for each word. Customization options within AccuLip, such as controlling smoothness and adapting lip movements to various emotions, provide the flexibility needed for believable expressions.

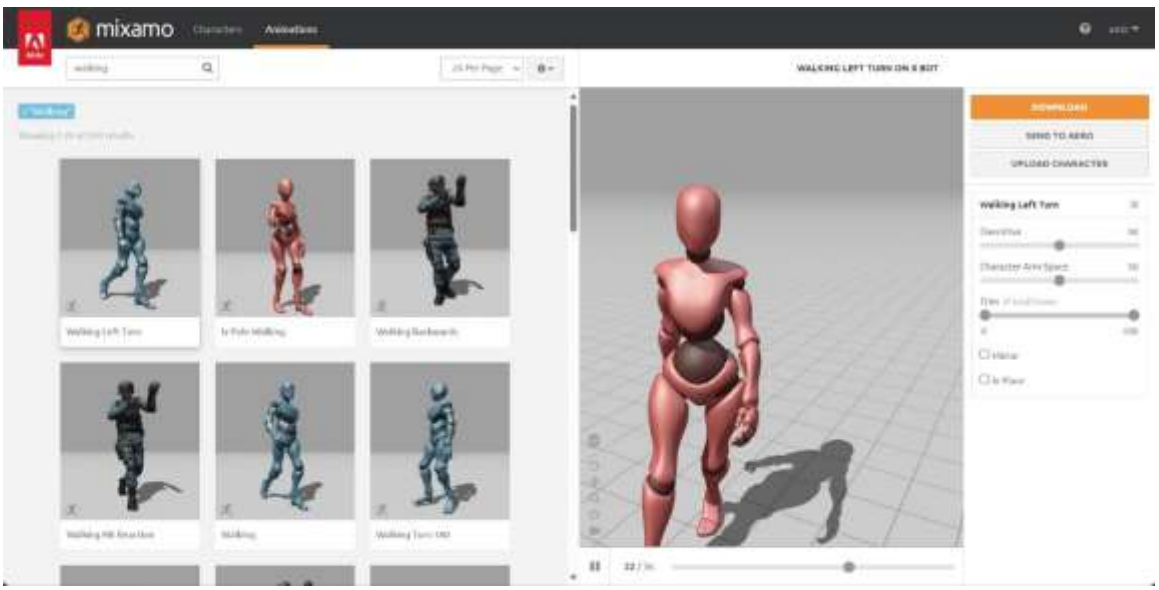


Fig. 3-3. Mixamo offers options for adjusting animation parameters like duration and rig settings. As the picture shows Mixamo provides the flexibility to retarget animations to different types of rigs, allowing you to adapt them to your specific avatar.

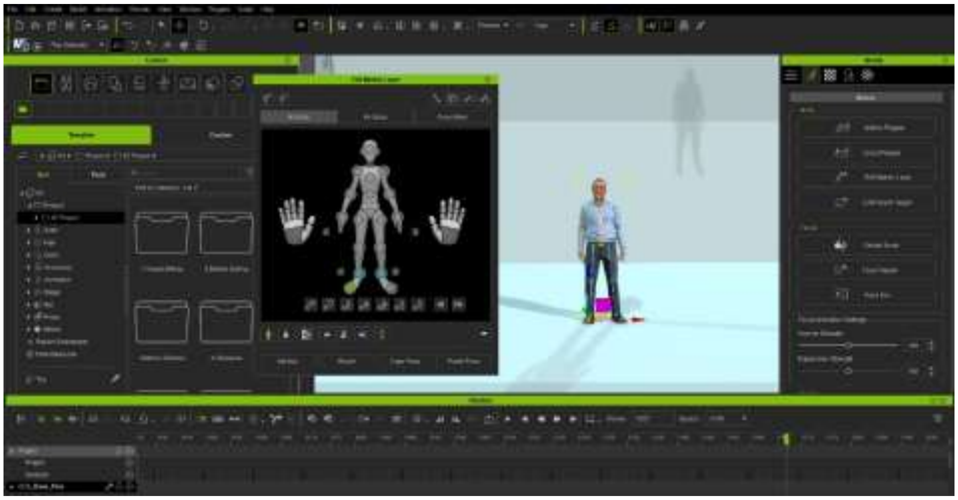


Fig. 3-4. iClone enables the user to fine-tune animations. it provides precise control over joint movements and deformation, ensuring animations align seamlessly with the avatar's proportions and movements.

Once the avatar is fully customized with body movements, facial expressions, and lip synchronization, it’s ready for export in FBX format and integration into a game environment such as Unity, a versatile game engine. Unity provides tools for optimizing 3D models and textures to ensure optimal real-time performance.

Unity's Animation State Machine enables the creation of complex animation sequences, defining states and transitions that manage how animations play in response to triggers or conditions. Avatar masks within Unity offer granular control over animations, allowing for the blending of facial expressions, body movements, and specifying which parts of the avatar are affected by particular animations. We have created different masks for body and face to have better control over face and body movements. In order for the lip movement to be realistic, it should be sync with the playing audio. Audio integration is facilitated through Unity's audio sources, which enable the play-back of audio clips attached to objects in the game world, including the avatar. Synchronization between audio playback and animations is achieved by triggering events at specific points in an animation, ensuring precise alignment of lip movements with spoken words. Finally, in the game environment, the avatar is scripted and designed to respond to player input or events. Various movements, such as walking, sitting, standing, and turning, require detailed animation rigs and scripts to handle different states and transitions smoothly. The ability to add and use additional body and lip movements enhances the avatar's adaptability, making it responsive to dynamic scenarios or user interactions.

Having crafted our avatars with precision and care, the next crucial step was to immerse them within our chosen settings. In order to achieve a harmonious integration between avatars and environment, it was necessary to meticulously design and develop the game environment.

3.2 Farm environment

In our pursuit of creating an engaging and culturally sensitive virtual reality (VR) experience, we introduce the Indigenous farm (designed by BSDXR), a meticulously designed digital landscape where innovation meets tradition. This immersive environment is not only a farm; it is a bridge between technology and Indigenous healing culture. It is a serious game, a novel approach that may have the potential to be used in addressing and treating mental health challenges, including depression and suicidal thoughts, among Indigenous youth. The user, an Indigenous youth, will be given the VR farm of the wild rice to take care of it, plant, water, and eventually harvest.

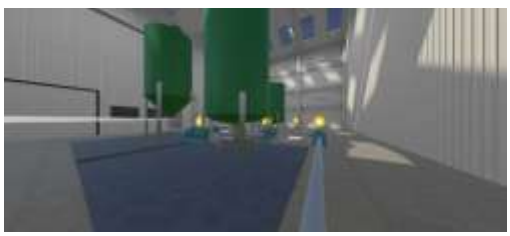
In this virtual farm environment, the users will navigate through ten distinct scenes (Fig. 3-5), each offering a unique aspect of agricultural and cultural immersion. From the central 'Home' hub, users will move into 'Crop Fields' and 'Rice Farms' to cultivate crops, while 'Fish Farms' and 'Fish Nurseries' introduce them to aquatic life management. 'Fish Waste Handling' and 'Fish Water Filtration' are about keeping the environment clean. 'Large Greenhouses' and 'POD Botanical' foster a connection to Indigenous healing culture through plant cultivation. Meanwhile, 'PPE' emphasizes safety, and 'Straw Filter Production' teaches sustainability practices.

1) Field crop

2) Home Scene

3) PPE scene

4) Fish nursery scene



5) Fish waste handling scene

6) Fish water filtration scene

7) Greenhouse scene

8) Straw filter production scene

9) Home scene

10) Rice farm scene

Fig. 3-5. Virtual farm designed based on Indigenous culture.

A realistic digital avatar is integrated into this virtual environment to enhance the user's sense of presence and engagement. Careful spatial placement, proportional scaling, and naturalistic animation ensure that the avatar feels lifelike and contextually grounded. The avatar can walk, sit, turn, point, wave, and display facial expressions and lip synchronization during conversations, creating an impression of a living guide. Built using the Unity engine, the avatar's interactions with the environment and objects are scripted to respond naturally to user actions, consequently reinforcing the realism and coherence of the overall experience. (Fig. 3-6).

From a technical perspective, integration required scripting and coding to define the avatar's behavior and responses. Unity's game engine played a central role in implementing avatar integration, allowing for precise control over the avatar's interactions with the environment, objects, and user inputs. The avatar's ability to navigate and move within the VR farm environment was another essential aspect of integration. The avatar's movements are controlled smoothly, whether it's walking through crop fields, exploring fish farms, or moving between different sections of the farm.

User interaction within the virtual farm is designed to be intuitive, meaningful, and culturally resonant. Participants engage with the avatar and the environment through natural actions such as planting, watering, feeding fish, or cleaning filtration systems (Fig. 3-7). These interactions promote a sense of responsibility and mindfulness while mirroring the healing connection to nature central to Indigenous traditions. The avatar communicates through pre-recorded dialogues and reacts to user actions, ensuring a two-way interaction that deepens engagement and emotional connection. Together, these elements create a cohesive and immersive therapeutic experience that blends cultural authenticity with modern VR design.

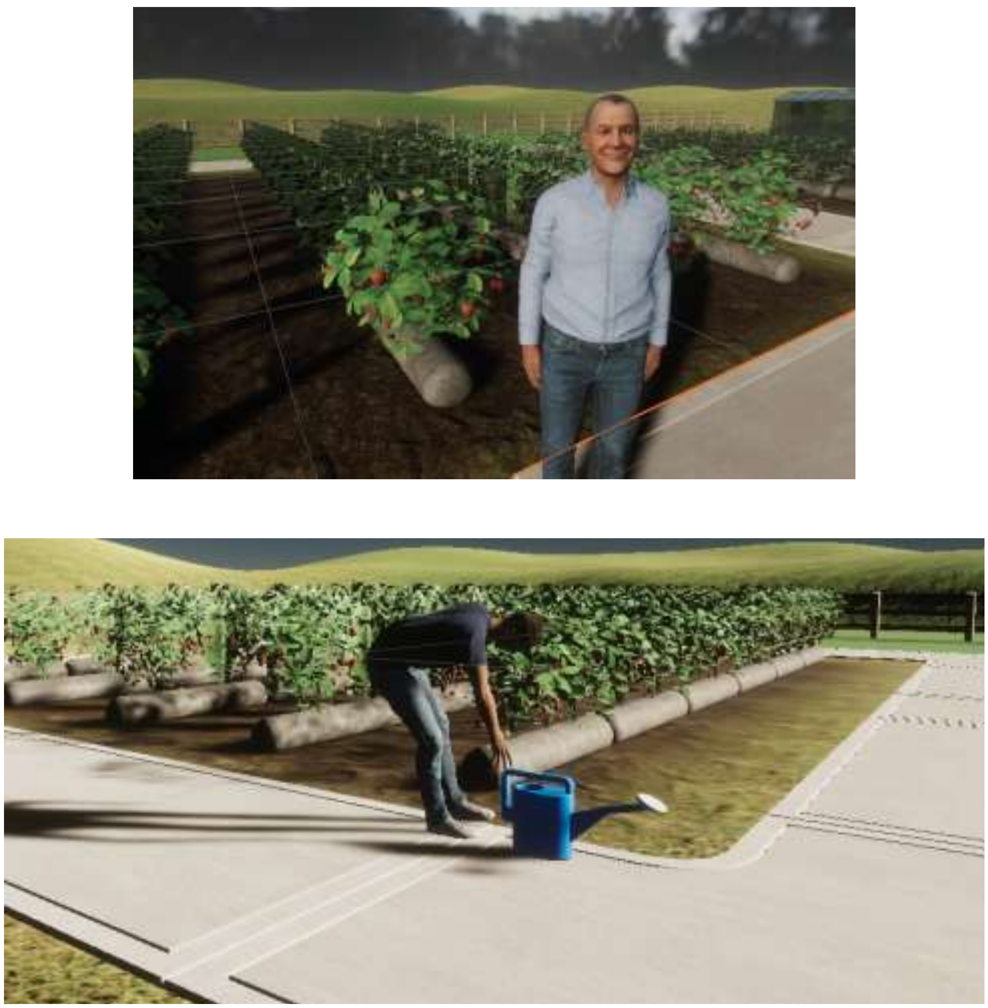


Fig. 3-6. Addressing spatial placement, realistic interactions, and user-centered design for a smooth integration of the Avatar, nurturing profound engagement in the virtual farm environment.

Fig. 3-7. User actively participate in virtual farming activities, from washing hands to harvesting and planting, fostering an immersive learning experience.

In addition to the virtual farm, a second environment—the Virtual Museum—was developed to explore memory and cognitive engagement through interactive learning and spatial navigation tasks.

3.3 Museum Tour

The Museum tour program was designed as a serious game aimed at promoting cognitive engagement and spatial learning through immersive exploration and guided interaction. It consists of two main components: the gameplay scenarios, which define how users explore and interact with the museum, and the data logging and scoring system framework, which records user behavior and performance throughout the experience. Although a full scoring system has not yet been developed, the logged data will provide the foundation for designing such a system in the future. These elements are described in detail in the following subsections.

3.3.1. Museum Gameplay

The Virtual Museum Environment was developed by Edit Point company to simulate a realistic art gallery, allowing users to freely explore and interact within a calm and visually engaging setting. The museum consists of three connected rooms, each displaying a selection of paintings arranged with careful attention to spacing and lighting (Fig. 3-8). This layout was intentionally designed to encourage natural navigation and to provide users with a smooth and intuitive sense of movement between rooms. Subtle ambient sounds and realistic lighting effects further enhance the sense of immersion, creating an atmosphere similar to a real-world gallery visit.

To make the environment more dynamic and socially engaging, virtual audience avatars were added to the museum. These avatars move autonomously using a NavMesh-based navigation system, allowing them to walk intelligently between artworks, stop to observe paintings, and avoid obstacles (Fig. 3-9). Their presence contributes to a lively atmosphere, helping users feel as though they are part of a shared, social experience rather than exploring a static virtual space.

Fig. 3-8. Layout of the Virtual Museum Environment showcasing three interconnected rooms, each designed with a distinct selection of paintings.

Fig. 3-9. Virtual audience avatars autonomously navigating the museum space.

The museum includes two main game scenarios, each designed to create a distinct mode of interaction and engagement. In the Exploration Scenario, users can navigate the museum freely at their own pace, observing artworks either alone or alongside the audience avatars. This mode promotes curiosity and self-directed exploration, encouraging users to develop familiarity with the environment and the displayed paintings.

In the Guided Scenario, users are accompanied by a tutor avatar who provides prerecorded audio instructions and leads them through a structured learning process. The tutor first introduces a specific painting and discusses its details before guiding the user to a separate testing room. The testing phase is divided into two parts. In the first phase, the user is asked to identify the painting previously discussed. All paintings are displayed sequentially on the screen, allowing the user to browse through and select the one they recognize. In the second phase, the user answers a set of multiple-choice questions about the painting, such as its artist and year, using a simple on-screen interface (Fig. 3-10).

After the testing phase, the user and the tutor return to the main museum area, where the user is tasked with locating and guiding the tutor to the same painting that was discussed earlier. This second phase serves as a navigation test, designed to evaluate the user's spatial memory and sense of orientation within the virtual environment. To assist users who may experience difficulty recalling the painting's exact location, the system can provide directional hints indicating which direction they should move to find the correct artwork. These hints are displayed contextually on the screen to guide users without disrupting immersion. Throughout the guided experience, users interact with the tutor avatar by clicking on on-screen buttons to advance dialogue, confirm actions, or respond to prompts.

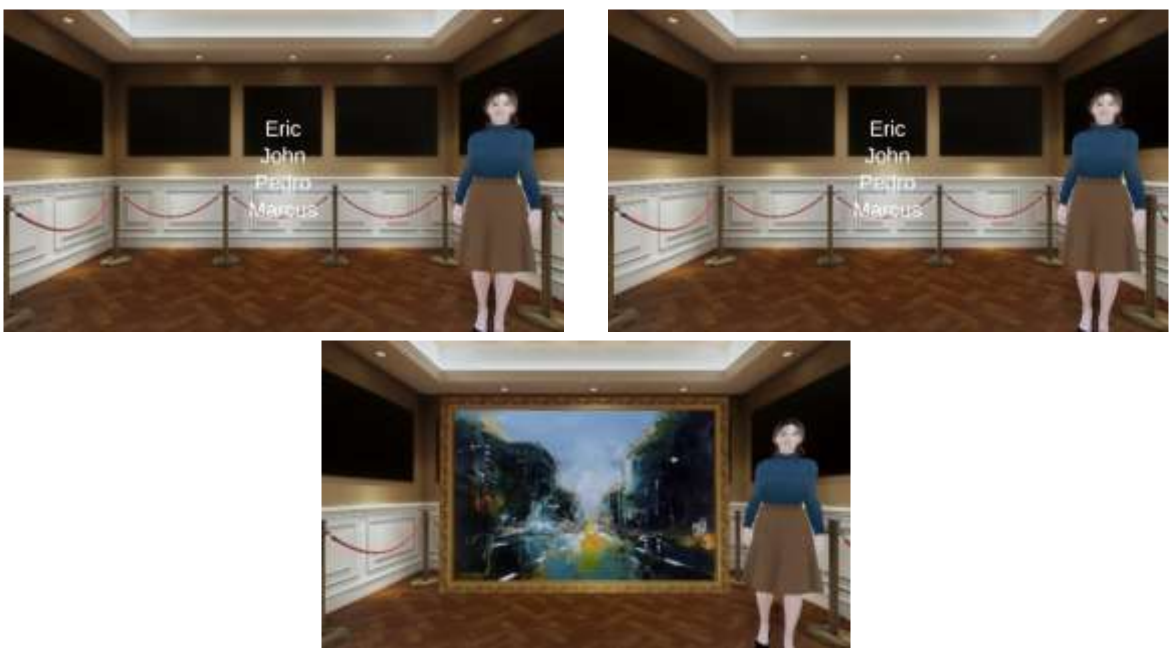


Fig. 3-10. Museum testing phase including multiple-choice interface for identifying the artist and year of a previously discussed painting, and painting selection screen where users browse and choose the correct artwork.

3.3.2. Data Logging and Scoring in the Museum Gameplay

The user's performance is recorded at each step, involving the tracking of movements and responses to assess cognitive function and engagement. Checkpoints are placed to log user movements, time spent at each exhibit, and interactions. In addition, this detailed logging includes recording the user's responses to avatar questions, the time taken to complete tasks, accuracy in recalling information, and the number of hints provided to the user.

Developing a scoring standard is crucial for evaluating user performance comprehensively. The scoring criteria include accuracy in responses to the avatar's questions, successful task completion with minimal errors, time efficiency, recall ability without hints, and overall engagement with exhibits. Points are awarded based on these criteria, with penalties for errors, excessive time, and reliance on hints. A cumulative score reflects the user's overall performance, providing a clear measure of their cognitive abilities.

Similar methods have been used in other studies. For example, in the Virtual Reality Driving Simulator (VRDS) cognitive training program [82], researchers developed a spatial learning score using logged information such as direction errors and failures to stop at traffic lights or stop signs. The total number of errors was compared to the maximum possible errors for each level, and scores were adjusted based on difficulty. In another study [83], participants received a score for accurately identifying the location of a target room.

During each trial, the system logged the participant's trajectory, visited rooms, total distance traveled, and time taken to find the target. Three main variables were analyzed: navigation duration, navigation distance, and an Error Score. The Error Score was calculated as a weighted sum of errors, including unsuccessful trials, incorrect navigation strategies, and mistakes in identifying the direction, position, or floor of the target room. This measure proved to be a reliable and sensitive indicator of age-related spatial decline.

In the same way, the data collected in this study—such as movement, timing, and accuracy—can be used to define a performance or error score suited to the specific goals of the VR environment. This score provides a meaningful way to measure user progress, cognitive engagement, and the overall effectiveness of the training experience.

In general, a game scoring system that is designed heuristically through pilot data must later undergo statistical validation against cognitive status or other intended outcome measures. Such validation requires a large experimental dataset. For example, in the VRN project [22], the researchers proposed an error score formula that was later validated by Omid Ranjbar et al. [83] in a study involving over 400 participants, demonstrating its correlation with MoCA scores for spatial cognition assessment. Similarly, in the VRDS study [82], the researchers suggested a scoring formula based on experiential observations of participants' driving performance; however, that formula has not yet been statistically validated for its relationship to cognitive status.

3.4 Summary

In this section, we presented a detailed description of the step-by-step process employed to create and smoothly integrate a virtual avatar into the farm and the museum environments. Our toolkit included diverse software tools, namely iClone, Character Creator, Blender, and Unity. The process began with avatar design, followed by animation, rigging, and integration into the respective virtual environments. Each stage involved careful attention to avatar realism, environmental placement, and interactive functionality. The final stage highlighted gameplay, user engagement, data logging and scoring system, providing a comprehensive overview of the methodology used to develop, integrate, and facilitate interaction with avatars in immersive VR experiences.

4. Chapter 4: Evaluation

The evaluation of the avatar's performance in interactive scenarios serves as a crucial component in assessing its effectiveness in engaging users and conveying information. This chapter presents the design and implementation of a scenario based on Indigenous culture aimed at evaluating the avatar's capabilities in various aspects such as body movements, lip synchronization, and integration into the VR environment. Additionally, feedback from four Indigenous participants is included in the results, showcasing their comments and experiences.

4.1 Indigenous Healer

4.1.1. Scenario description

The scenario take place in a virtual environment where users encounter the avatar of a healer, situated in a home scene decorated with cultural artifacts. Upon entering the scene, users are greeted by the avatar, who introduces themselves and extends an invitation to explore the surrounding area. The avatar, rendered with realistic body movements and facial expressions, establishes a sense of presence and connection with the users.

As the interaction progresses, the avatar initiates a dialogue with the users, presenting them with the option to learn about special leaves including sweetgrass, cedar bough, white sage, and tabacco. Upon expressing interest by selecting the options on the UI menu, users are guided to a nearby table where the avatar provides explanations about the significance and stories behind each leaf selected by the user (Fig 4-1).

Subsequently, the avatar suggests a visit to the crop field, where users are transported to an agricultural landscape featuring rows of crops. The avatar leads the users through the field, showcasing sections dedicated to the cultivation of strawberries and purple potatoes. Through engaging dialogue and descriptive narratives, the avatar shares knowledge about the cultural significance and insights associated with each crop.

4.1.2. Result

The game underwent evaluation by four Indigenous participants, who provided significant insights into various aspects of the experience (Fig. 4-2). They believed that the avatar showed high level of realism, emphasizing its appearance and movements. Additionally, they noted seamless synchronization between audio, lip movement, and body gestures, enhancing the authenticity of the Indigenous healer avatar. While all participants expressed optimism about the potential therapeutic applications of the program, one of the participant highlighted the naturalistic feel of the experience and her readiness to engage with the program for support if necessary. All participants experienced smooth and immersive movements within the virtual farm environment, highlighting the absence of motion sickness or headaches. Overall, they concluded that the avatar demonstrated high level of realism, and it is ready to be utilized in a clinical trial to explore the opportunities it may have in helping to address mental health issues.

Fig. 4-1: The top right image shows the simple UI used to interact with the avatar in the home scene. The top left image displays different leaves on the table to select. The bottom right image shows the avatar pointing to the purple potatoes while explaining them. The bottom left image the avatar is pointing to the crops behind it.

Fig. 4-2: The top image shows the Indigenous male participant playing the game. The bottom image illustrates the Indigenous female participant playing the game.

4.2 Museum Tour

The virtual museum provides an interactive environment for exploring artworks, guided by a tutor avatar. The tutor avatar provides engaging explanations about the museum's artworks and environment, offering interesting facts and details to capture the user's attention and inspire curiosity. Predefined dialogue and scripted interactions function reliably, ensuring smooth communication between the user and the system. Gestures, facial expressions, and synchronized lip movements contribute to a human-like experience, enhancing the sense of presence even in a non-immersive setup.

From a technical perspective, the museum game performs well in terms of stability and responsiveness. The environment loads efficiently, and transitions between rooms and interactions occur without noticeable lag. The low movement speed, stationary artworks, and absence of sudden camera shifts reduce the risk of simulator sickness. Additionally, the ability to adjust movement speed provides accessibility for users with varying sensitivity levels.

The museum layout and content were designed to support cognitive engagement and mental stimulation. The tutor avatar guides users through the environment, presenting information and prompting interaction to encourage attention, memory recall, and engagement with the virtual space. This design shows potential for applications in cognitive rehabilitation or support for individuals with cognitive impairments, providing a safe and interactive setting to stimulate mental activity.

Overall, the virtual museum achieves its objectives of providing a comfortable, interactive, and cognitively stimulating environment. While user testing is required to quantify its impact on cognitive outcomes and engagement, the current evaluation indicates that the system functions reliably and has the potential to serve as a foundation for future therapeutic studies.

5. Chapter 5: Discussion

An important consideration in VR development is the potential for simulator sickness, which can significantly affect user comfort, engagement, and overall usability. Previous studies have emphasized that motion-induced discomfort primarily arises from conflicts between visual and vestibular cues [27] [28]. To address this issue, various strategies have been proposed, such as adjusting movement speed, limiting camera acceleration, and providing stable visual references [32]. In designing the museum tour game, several of these principles were implemented to minimize simulator sickness.

Consistent with recommendations by Stanney et al. [32], movement speed within our environment was intentionally kept low and made adjustable to accommodate individual user comfort levels. This adaptive control facilitates smoother navigation and reduces sensory conflict, a factor known to reduce visually induced motion sickness (VIMS). Furthermore, all paintings and key visual elements in the environment remain stationary, maintaining visual stability and minimizing disorientation—an approach supported by studies showing that fixed environmental anchors improve user comfort and spatial awareness [31].

Another strategy employed was presenting the virtual museum experience on a standard screen rather than through a head-mounted display (HMD). While HMDs can enhance immersion, they are also associated with a higher incidence of cybersickness due to visual–vestibular discrepancies [32]. Researchers in [32] reported that non-immersive or semi-immersive systems significantly reduce symptoms of nausea and dizziness, making them particularly suitable for older adults or therapeutic applications. Our design follows this evidence-based practice, prioritizing accessibility and comfort over maximum immersion.

The inclusion of avatars within the VR environment also serves as a stabilizing visual reference. Previous research indicates that the presence of human-like figures in virtual spaces can anchor users' perception of self-motion and reduce discomfort [34]. In our environments, an avatar functions as a tutor or therapist to enhance comfort, spatial coherence, and engagement during interaction.

The creation of realistic avatars represents another crucial aspect of our VR design. Prior work in VR therapy and training environments has highlighted the importance of avatar realism for promoting user identification and engagement [4] [67] . Using Character Creator's Headshot plugin, we generated avatars that closely resembled individual facial features, enabling greater personalization and naturalistic interaction. This approach parallels findings by Latoschik et al. [57], who demonstrated that personalized avatars increase user immersion and perceived presence.

Researchers in [3] and [81] utilized motion capture suits to create realistic animations for avatar movements within virtual environments, enabling precise replication of human motion. In contrast, due to the unavailability of a motion capture system in our project, we adopted an alternative approach by combining predefined animations in iClone. This method allowed the creation of customized and realistic avatar movements, achieving natural transitions and expressive gestures despite hardware limitations. Moreover, this approach proved to be a cost-effective and flexible solution compared to motion-capture-based systems, supporting future scalability in similar therapeutic VR projects.

These findings align with research showing that avatars can serve as effective virtual therapists [5], coaches [68], or educators [66]. For example, Falconer et al. [5] demonstrated that virtual therapists improve engagement and adherence in mental health interventions, while other studies have employed avatars as rehabilitation agents to guide cognitive or physical recovery [68]. Similarly, educational studies have shown that virtual teachers or historical avatars enhance comprehension and motivation among learners [66]. In parallel, existing literature emphasizes the important role of traditional healers in supporting mental health and well-being within Indigenous communities [7][8]. Consistent with these findings and based on the feedback provided by our participants, the avatar of an Indigenous healer demonstrates potential as a culturally grounded therapeutic tool to explore the opportunities it might have in helping address mental health challenges among Indigenous youth.

Overall, the design strategies implemented in this project reflect best practices identified in prior VR research while extending them through the integration of personalized avatars and adaptable user comfort controls. By prioritizing user well-being, accessibility, and cultural relevance, the developed system contributes to ongoing efforts to create human-centered VR environments for cognitive and emotional rehabilitation.

6. Chapter 6: Conclusion, Limitations, and Future work

This chapter presents the conclusion of the development of two VR projects designed to support cognitive impairment and potential mental health interventions. The first project focused on the development of a naturalistic avatar within a virtual farm, inspired by an Indigenous healer, while the second project involved the creation of a virtual museum featuring a tutor avatar as a guide to facilitate cognitive stimulation through interactive exploration. It includes a detailed overview of the avatar's creation process, its integration into immersive VR environments, and the anticipated impact on therapeutic interventions. Following the conclusion, a discussion on the limitations encountered during the project and directions for future research are explored. By addressing these aspects, this section aims to provide a comprehensive understanding of the project's achievements, challenges, and directions for further exploration in this developing field.

6.1 Conclusion

This study included two VR projects aimed at enhancing cognitive engagement and supporting mental health interventions. The first project focused on the development of a naturalistic avatar in a virtual farm, inspired by an Indigenous healer. The second project involved the creation of a virtual museum, where a tutor avatar serves as a guide to facilitate cognitive stimulation through interactive exploration of artworks. Both projects were designed to utilize avatars to create immersive, engaging, and supportive virtual environments.

In the virtual healer project, the Indigenous healer avatar was developed with intricate facial expressions, synchronized lip movements, and lifelike body gestures. It was evaluated by four Indigenous participants and demonstrated potential for research applications, particularly in mental health treatments. This avatar aims to replicate real-world therapeutic interactions, aligning with prior findings where avatars have been shown to improve mood, enhance self-compassion, and reduce the severity of depressive symptoms.

The virtual museum project extends this work by creating an environment designed for cognitive engagement. The tutor avatar guides users through artworks, prompting interaction, attention, and memory recall within a visually comfortable setup. This demonstrates the broader potential of avatar-guided VR experiences beyond therapy, highlighting their use in cognitive engagement and support.

The process of avatar creation in both projects involved capturing high-quality headshots, generating realistic 3D faces using Character Creator, and implementing rigging, animation, facial expressions, and lip synchronization with iClone's AccuLip tool. In Unity, the avatars were scripted to respond to user input and seamlessly transition between movements, ensuring a naturalistic experience.

These two VR applications contribute to the growing field of avatar-based interventions, offering innovative platforms for mental health treatment and cognitive stimulation. Future research and clinical trials will be essential to validate their efficacy and explore their impact across diverse populations. Together, the virtual farm and museum projects open new avenues for the intersection of technology, cognitive engagement, and mental health care.

6.2 Limitations and Future Work

While this project successfully demonstrated the potential of combining an interactive avatar with a virtual game environment, it also faced several limitations that shaped its final outcomes. Some of these challenges were due to software and hardware restrictions, while others were related to design choices made to keep the system functional and accessible within the available resources. Recognizing these limitations is important for understanding the scope of this work and for guiding future improvements toward creating more realistic, adaptive, and engaging virtual experiences. The following sections discuss the main limitations encountered in both the avatar creation process and the museum game development.

6.2.1. Avatar creation

In the process of developing a realistic and interactive avatar for virtual reality applications, a range of software tools—including iClone, Character Creator, AccuLip, motion capture features, and the Headshot plugin—were employed. While these technologies provided an effective foundation for creating animated and expressive avatars, several limitations were encountered during implementation.

One notable constraint originates from the restricted range of character customization options and animation presets available in iClone and Character Creator. Although these tools offer robust design capabilities, their limited preset libraries may reduce the visual diversity and animation richness of avatars, potentially impacting realism and user engagement. Future research could focus on expanding the available customization assets or developing additional plugins to enable greater artistic flexibility. Collaborations with 3D modeling experts may further enhance the variety and quality of avatar features.

Another limitation was associated with the AccuLip tool used for lip-syncing. Since AccuLip supports only the English language and limits animations to 30-second segments, the avatar's dialogue was restricted to short English interactions. This limitation reduces the system's adaptability for multilingual users and longer conversational exchanges. To address this issue, future work could integrate multilingual lip-sync solutions or explore alternative AI-based synchronization tools capable of handling extended speech durations.

The absence of motion capture suits also represented a key limitation. Motion capture technology provides highly realistic animations by tracking human movements, and its absence may have resulted in less natural avatar motions. Incorporating motion capture into future iterations would enhance the avatar's physical realism and overall sense of presence.

In addition, while the Headshot plugin allowed facial modeling from reference photos, it did not always generate 3D heads that closely resembled the source images. This limitation affected the visual fidelity and expressiveness of avatars. Future improvements could include refining facial recognition algorithms or leveraging advanced AI-driven modeling to achieve greater likeness and detail.

Finally, the inability to produce a fully accurate 3D model of the avatar's body based on real-world references limited the realism of body proportions and postures. This constraint could reduce immersion in VR environments. Integrating body scanning or advanced 3D modeling techniques in future work could yield more precise and lifelike representations of human figures.

6.2.2. Museum environment

The virtual museum game component of this project also presented several limitations that influenced the interactivity, adaptability, and assessment depth of the game experience. First, interactions between the user and the tutor avatar were driven by prerecorded audio and predefined scripts, restricting the system's ability to dynamically respond to user behaviors. Similarly, the audience avatars followed automated navigation paths and lacked adaptive social interactions, which may have reduce the sense of realism and immersion within the environment. Future developments could involve integrating AI-driven dialogue systems and behavioral models to support dynamic and context-sensitive interactions.

Another limitation was the absence of adjustable difficulty levels in the gameplay. All participants experienced identical tasks and questions regardless of their prior game experience or in-session performance. This uniformity may have affected engagement and learning outcomes. Implementing adaptive difficulty systems in future iterations could customize challenges to each user's ability, therefore enhancing both motivation and cognitive benefit.

Additionally, the exclusive use of multiple-choice questions during the testing phase constrained the depth of cognitive evaluation. Without open-ended or verbal response formats, participants had limited opportunity to demonstrate reasoning, recall, and critical thinking. Future versions could incorporate voice or text-based input to assess higher-order cognitive skills more effectively.

Moreover, participants with neurological or cognitive impairments were not included in this study, restricting the conclusions that can be drawn about the system's therapeutic potential for clinical populations. Future research should involve participants with varying cognitive profiles to better evaluate the system's broader applicability.

Looking ahead, future iterations of the game will introduce several improvements to address these limitations. Users will be able to choose which paintings to explore, guided dynamically by the tutor avatar. The number of paintings per room will vary by difficulty level, encouraging memory-based challenges. The tutor avatar could be generated in real time based on a photo of someone familiar to the user, enhancing emotional connection and presence. AI-based speech recognition will allow the system to capture and analyze verbal responses, encourage more naturalistic learning interactions. Finally, to systematically evaluate user comfort and identify potential issues related to simulator sickness, the Simulator Sickness Questionnaire (SSQ) will be used.

Overall, while the current system successfully demonstrated the feasibility of integrating avatar-driven interaction and interactive elements within a virtual museum, both the avatar creation process and the museum experience demonstrated technical and methodological constraints. Addressing these limitations through advanced animation techniques, adaptive game design, AI-driven dialogue, and inclusive participant recruitment will be crucial for achieving more immersive, personalized, and cognitively engaging virtual environments in future studies.

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