Extending the Metaverse: Exploring Generative Objects with Extended Reality Environments and Adaptive Context Awareness

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Abstract

The metaverse, with the internet, virtual and augmented reality, and other domains for an immersive environment, has been considered mainstream in recent years. However, the current metaverse platforms have a gap in the physical space, leading to reduced engagement in these applications. This thesis project explores an extended metaverse framework with generative content and the design of a seamless interface to increase the connection between the metaverse and the physical environment and create coherence and efficiency between them. The extended metaverse agent helps prevent this from happening by improving the interaction, embodiment, and agency that dynamically engage humans in mixed reality (MR) environments. This thesis project will design and prototype MR objects and environments with the research through design (RTD) and speculative design methodology, whereby future applications are imagined, assuming plausibility of smart glasses being commonplace to help users visualize the coherence of virtual and physical spaces in simultaneity. To summarize, this thesis project provides an extended metaverse framework and agent that generates from physical contexts to describe the coherence of virtual and physical environments.

Keywords: Metaverse, Virtual Reality, Augmented Reality, Mixed Reality, Internet of Things, Generative Art, Context Awareness, Research Through Design, Speculative Design.

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1 Introduction

1.1 Motivation

The concept of the metaverse is becoming increasingly adopted in everyday society with ubiquitous applications from common living and working scenarios to customized forms of social activities, enhancing people's experiences of connectedness. There are various definitions of metaverse, and it is an ongoing developing concept. For the general description of the metaverse, Lee et al. (2021) described the metaverse "as a virtual environment blending physical and digital, facilitated by the convergence between the Internet and web technologies, and Extended Reality." Metaverse applications could help people enhance the connection with the virtual environments, objects and agents, and each other as an avatar. It also has numerous benefits for society, such as reducing transportation fees and resources from the environment, enhancing people's efficiency when working and studying remotely in dynamic surroundings, and extending people's imaginations from the world of physical limitations to the virtual environment.

In the most recent developments in academia and industry, there is evidence to support this trend toward metaverse research and integration. For example, in 2021, Facebook announced that it was becoming a metaverse company[1] and rebranded itself as Meta Platforms Inc. Other major industry influencers, such as Roblox and ZEPETO, are also representatives of social platforms with enormous worldwide user bases and have been moving toward the adaptation of metaverse capabilities (Han et al., 2021). Likewise, Nvidia, a major GPU chip producer, has further

[1] https://www.theverge.com/22588022/mark-zuckerberg-facebook-ceo-metaverse-interview

developed its Omniverse software[2] for creators to simulate the constraints and details of the physical space using a digital twin 3D-connected simulation. Examples like these large-scale industry developments show how the metaverse has not only become one of the most influential trends in the marketplace. Various industries are adapting their services to provide the foundations of networked platforms for an expanded collaborative metaverse space.

Personal Motivation: I started to engage in the metaverse and decentralized community in 2019 by developing and trading land on Decentraland, which attempts to construct a metaverse infrastructure through peer-to-peer network interactions (Ordano et al., 2017). I then joined the developer team of Dragon City,[3] one of the largest communities and districts in Decentraland, to support the three-dimensional interaction development and to host events in those virtual lands. One of the fascinating features of Decentraland is that developers can stream videos in it. When I see the real-time video of myself and other people on the big screen in such a virtual space, I consider this to be the connection and communication of the physical world and the metaverse.

Nevertheless, I realize it is a one-way communication, from physical to virtual embodiment with video and sounds (see Figure 1). Additionally, such a connection is only a two-dimensional graphic display without context awareness for both virtual and physical space. These challenges prompted me to explore the embodiment and information communication between virtual and physical with MR and the internet-of-things (IoT).

[2] https://www.nvidia.com/en-us/omniverse/
[3] https://nftplazas.com/decentraland-districts/dragon-city-decentraland/

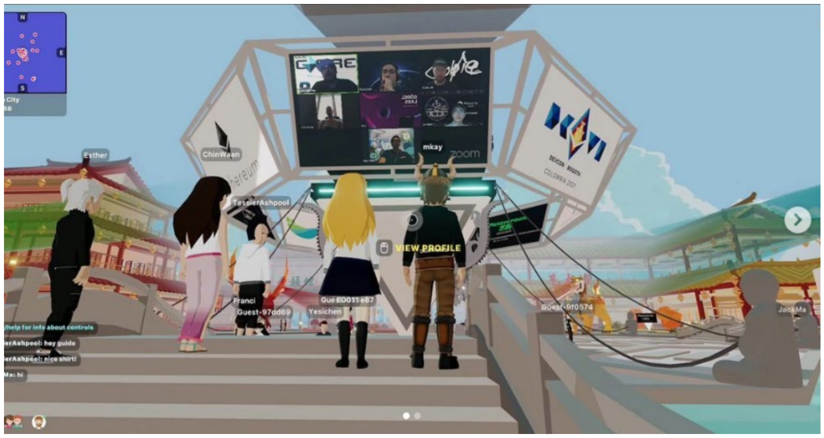


Figure 1. A round table discussion of Dragon City in Zoom and streaming in Decentraland with video and sound.

In my undergraduate capstone project[4] (see Figure 2) on cyborg plants (i.e., the combination of organisms and robots), I started to explore the coherence operation in the hybrid virtual and physical environment. The physical robot detected then followed a virtual object with its augmented eyes in the augmented reality environment. Concerning my ACE Lab[5] experiment, I started as an undergraduate research assistant in 2019 and am currently a graduate research assistant. I learned many concepts and technologies of MR and the IoT from Dr. Alexis Morris through the IoT avatar project (Morris et al., 2020; Morris et al., 2021), and now we are thinking about how we can bring the knowledge into the research and development of the metaverse (Guan et al., 2022). These experiments push me to continue exploring the connections and interactions between the virtual and the physical.

[4] https://www.youtube.com/watch?v=dGN-egL6KAE&t=35s
[5] https://www2.ocadu.ca/research/acelab/home

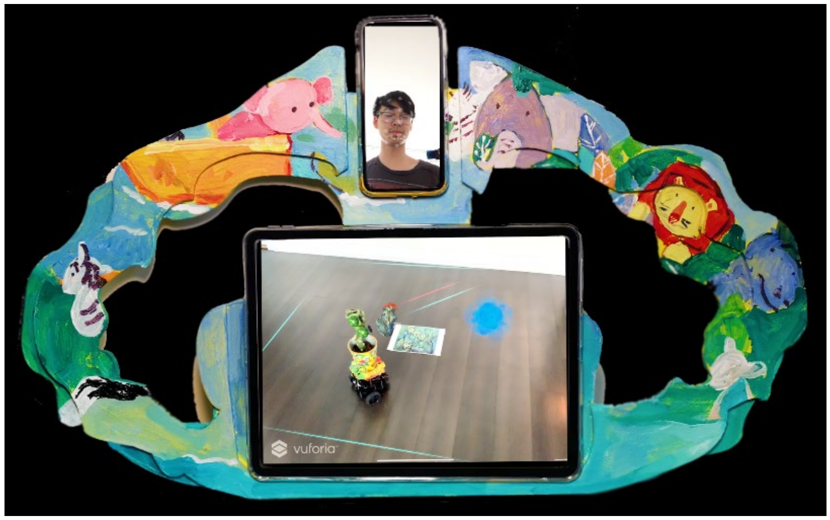


Figure 2. The author's undergraduate Capstone project, Cyborg Plant[6], presented the connection of user's face movement, a physical robot, and augmented reality (AR) objects.

1.2 Metaverse Challenge: The Disconnect Problem

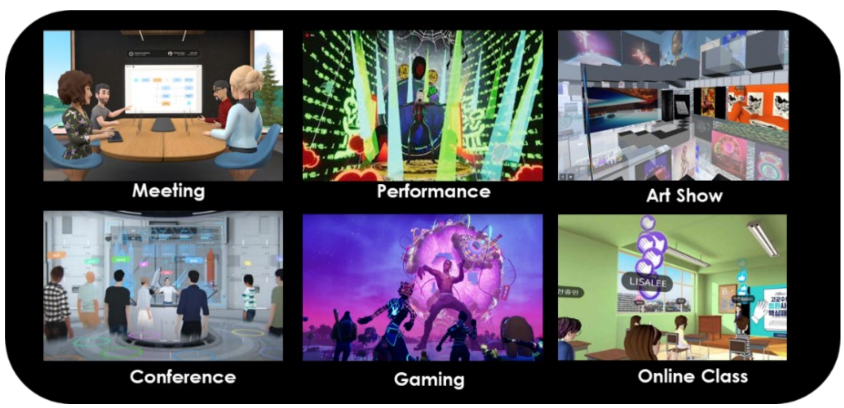


Figure 3. Examples of current activities in today's metaverse applications (e.g., Horizon Worlds, Decentraland, Cryptovoxels, Spatial, Fortnite, HanaBank) (Guan et al., 2022)

[6] https://jieguann.format.com/dynamic-cyborgian-plant-engages-in-both-physical-and-virtual-space-for-dynamic-environment

Diverse metaverse platforms and virtual spaces host various activities with standalone computers, mobile devices, and head-mounted display VR devices (see Figure 3). Most of them bring humans into complete virtual spaces, thereby focusing on the virtual content leading to the metaverse independent of the physical space (see Figure 4). However, humans must rely on physical space to gain energy, manipulate their surroundings, sleep, and so on. The incoherence of the current metaverse system will increase the "noise" of signals between physical and virtual based on the Shannon and Weaver (1964) communication model, which may result in an unpredictable and uncontrollable virtual world. On the one hand, the potential consequence of the overwhelming "noise" involved in accessing virtual and physical information is the overstimulation of senses in the psychological state causing users to become overwhelmed (Simmel, 2017). On the other hand, the current metaverse engages in various domains, such as MR, the IoT, blockchain, and artificial intelligence (Lee et al., 2021), and requires physical energy, such as electric power. Hence, the overloading of and processing information in the metaverse without rules and limitations from the physical world, or a proper design of the connection between them, may limit metaverse simulation. Consequently, if the metaverse does not have the means to maintain the coherency of the physical world (a better way for data communication, providing access and control), then the metaverse will not be a reliable place to perform human activities.

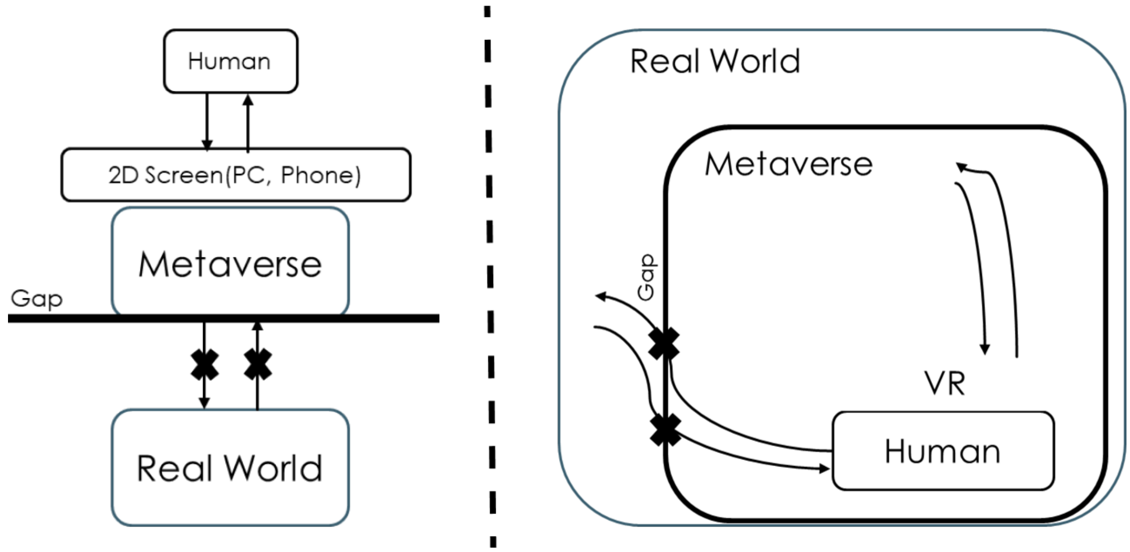


Figure 4. Current metaverse interaction and the metaverse disconnect problem (adapted from early VR explorations by Rekimoto & Nagao, 1995). There is a need to increase the strength of the link between the metaverse and the real world.

1.3 Toward a Speculative Future: An Extended Metaverse Framework

The potential future is that people will live in two spaces that concurrently exist. One is the physical world, and the other is the metaverse, which is constructed of computational graphics and simulated environments. People will live and work in such a hybrid virtual and physical world immersively with smart glasses (i.e., head-mounted displays) that will be as common as the mobile phone today. Within these speculative futures parameters, I attempt to explore an extended metaverse framework to enhance embodiment, interaction, and agency (Holz et al., 2011) that could provide a seamless interface to the physical world (see Figure 5).

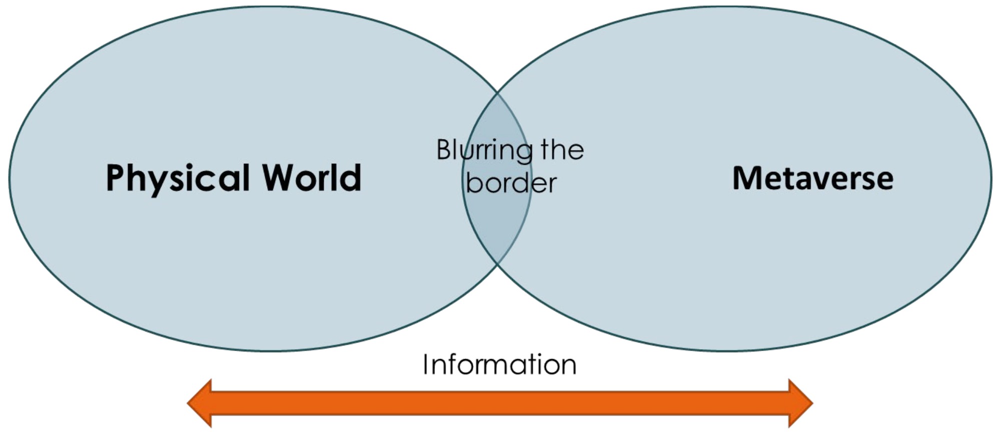


Figure 5. The concept of blurring the border of the physical world and Metaverse.

The thesis project will explore an extended metaverse framework (see Figure 6) for applying the metaverse layer in the physical spaces to increase the dynamism and interconnectedness of humans, agents, and the environment through MR and the IoT. The extended metaverse framework focuses on improving interaction, embodiment, and agency (Holz et al., 2011) in the human-in-the-loop MR space. It will contribute to the metaverse community, XR, and the IoT domains with the prototype's development with game engines and the design of the IoT framework. The context of the research will explore the history and the current state-of-the-art metaverse, XR, and the IoT as the background knowledge and their relationship to construct theories of the extended metaverse. The thesis project will design and prototype MR social place scenarios that dynamically connect humans, smart objects, and the environment. The RTD methodology will be employed to explore the literature and work related to this project, test and design the framework, develop a prototype to prove the concept, and gain knowledge through the process. The result of this project will provide an architecture to demonstrate how the system works and a prototype for users to play and test it.

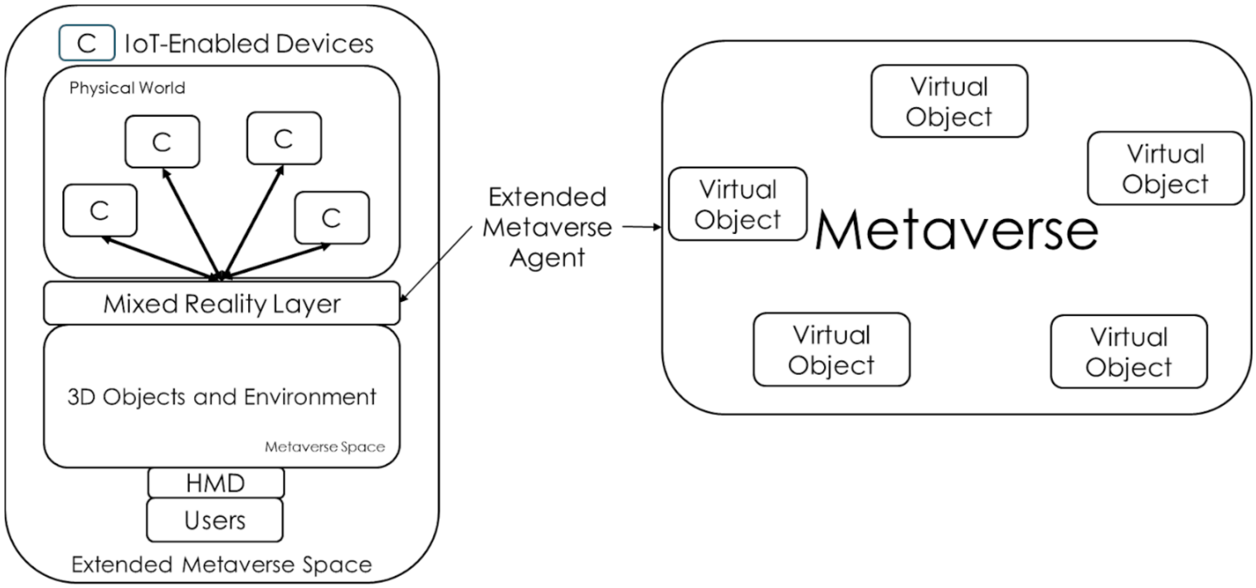


Figure 6. The framework of the extended metaverse agent, integrating the metaverse of virtual objects with XR/IoT environments through an agent controller (or set of controllers), was inspired by Rekimoto and Nagao (1995).

1.4 Research Summary

1.4.1 Problem Statement

Current metaverse platforms have an information gap for users to connect the physical space without interoperability, which prevents users from operating or accessing the physical context. The incoherence of the metaverse and the physical space caused by this gap may cause unreliability in the virtual space for users, which cannot maximize the metaverse's benefit—dynamic engagement.

1.4.2 Research Question

This thesis attempts to explore the following questions:

- How can the gap between the metaverse and the physical world be minimized to increase people's dynamic engagement with XR and the IoT?
- What technologies and design approaches could provide a useful physical-space context with which to affect virtual contexts?
- How can generative and procedural objects from computational graphics used to create dynamic metaverse environments?

1.4.3 Hypothesis

The extended metaverse framework and agent of this thesis can enhance the connection between the metaverse and the physical world and extend the dynamics and engagement of the metaverse to the physical environment with XR and the IoT. Computer vision can be used to capture context from a human-in-the-loop environment, allowing virtual content to be adaptive and generated from physical information.

1.4.4 Goal and Objectives

The goal of this thesis project is to achieve the hypothesis to improve the connection between the metaverse and physical space to make the metaverse a more reliable place for human activities than it is now. The first objective is to select the proper head-mounted MR headset to approach the immersive extended metaverse experiment. The second objective attempts to provide a method to switch between the immersive metaverse environment and the MR space, which includes the physical context. Furthermore, the projects investigate two-way communication of information between the two spaces mentioned previously and visualize metaverse content using

MR glasses or headsets to enhance human dynamic engagement in the extended metaverse environment.

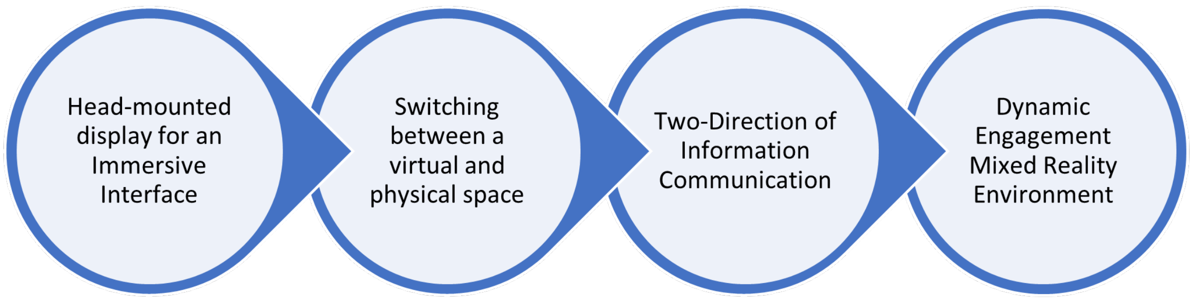


Figure 7. The objectives of this thesis project with the extended metaverse agent.

1.4.5 Project Contributions

This project will contribute to the metaverse community, XR, and IoT domains with the prototype's development with game engines and the design of the IoT framework. The contributions of my thesis project include the following:

i) the provision of an idea and proof-of-concept prototype for connecting the metaverse community to physical space, ii) an exploration of the XR and IoT theories and technologies to be used in the metaverse, iii) an MR smart and social place scenario that connects humans, agents, and environments using metaverse concepts. The problem of the current metaverse platforms has not explored the connection with the physical space, and my project would potentially flourish thinking on this trajectory.

Concerning my personal goal, my preliminary virtual space experiment results demonstrated a lack of connection between the metaverse and the physical environment, and I continued the experiment to provide a bridge between my physical and virtual computing experiments. I engage in the metaverse and blockchain communities, such as Dragon City in Decentraland, as described previously, to explore a near-future virtual space, and I hope my research will provide new knowledge about these communities to extend the current metaverse platform to the physical environment with reliable applications.

1.5 Chapter Overview

This thesis is composed of seven themed chapters, including this introductory chapter. Chapter 2 presents a literature review by laying out the background of the metaverse, the theory and technologies of XR and IoT for connecting the virtual and physical, context awareness as theory as the sensor, and generative content applying as the background for control objects. Chapter 3 discusses a range of projects (including XR-IoT) (Morris et al., 2021; Tsang & Morris, 2021) area, generative content, and metaverse-related works) to position my own research. Chapter 4 provides an overview of the use of RTD and speculative design as methodologies for this project and the theoretical works. Chapter 5 contains the details about a series of iterative prototypes with process and reflection. Chapter 6 is about the final project that combines the features of the prototypes. Chapter 7 presents the evaluation of the prototypes and their comparison with multiple tables with different methods. Finally, in Chapter 8, I conclude the thesis and provide a brief discussion about potential future research.

2 Literature Review

To discuss the thesis project of extended metaverse framework and agent, this section provides the background knowledge of the metaverse, related theory of XR and the IoT, and introduction of the context awareness and generative and procedure content concepts (see Figure 8). The background of the metaverse addresses the history and state-of-art of this concept and its possible future. XR is the method to embody the virtual and physical objects and environment while the IoT is considered to be for virtual and physical communication. Context awareness is introduced to capture and sense information in the physical environment, and procedural content is the method and rules to embody dynamic virtual objects.

Figure 8. The map of literature review.

2.1 Background of the Metaverse

2.1.1 What is the Metaverse?

As mentioned by Dionisio et al. (2013), the metaverse is a portmanteau that combines with the prefix “meta,” which means “beyond,” and the suffix “verse,” which is shorthand for “universe.” Hence, it represents a universe beyond the space we live in physically. Specifically, it is a computer-generated environment that simulates the world and distinguishes it from the metaphysical or spiritual concepts.

The concept of the metaverse, originally from the fiction novel *Snow Crash*, was developed by Neal Stephenson in 1992 (Joshua, 2017). In the novel, the metaverse was portrayed as a virtual world with humans interacting with intelligence agencies and each other as avatars in that space. It is a scenario similar to that in *Ready Player One* by Ernest Cline, where users can use any role or play as any race in a completely virtual world (Ai, 2021).

The metaverse has various definitions because it is a state-of-the-art term that is being continually explored. Dionisio et al. (2013) presented that the metaverse is constructed by multiple individual virtual worlds, defined as a fully immersive, three-dimensional digital environment that reflects the totality of shared online space. Lee et al. (2021) considered the metaverse as a virtual environment constructed by the internet, web technologies, and extended reality (XR) toward hybrid physical and virtual space.

Table 1. Comparison of papers about the metaverse.

Literature	Definition of Metaverse Terms	Purpose	Proposed/Framework/ Prototype/Outcome	Application Domain
Metaverse Theory (Ai, 2021)	The metaverse is a sci-fi world from *Snow Crash* that enables people to do similar activities as in *Ready Player One* (Cline, 2011).	Guide the development of future blockchain games to be the metaverse.	The metaverse theory proposed the theorem of the condition of becoming a metaverse, including market diversification, bidirectional demands, and an entropy-increasing world.	Blockchain game
3D Virtual Worlds and the Metaverse (Dionisio et al., 2013)	Metaverse refers to a fully immersive, three-dimensional digital environment constructed by the interconnection of individual virtual worlds.	The paper presented a survey and history of the metaverse.	The features of the metaverse should have realism, ubiquity, interoperability, and scalability for future possibilities.	3D virtual world
Escaping the Gilded Cage (Ondrejka, 2004)	They considered the metaverse an online environment that is real for users, which can interact with each other similar to the real world.	This article shows the proper economic and legal decisions to maximize the power of player creativity for the metaverse.	The paper supported the value of user-creating content and the importance of virtual marketplace and ownership.	Virtual economic, user-created content
Higher Education in the Metaverse CHRIS (Collins, 2008)	The concept of the metaverse is beyond the vision of Stephenson's immersive 3D virtual world, to include the aspects of physical world objects that are virtually-enhanced physical and physically persistent virtual space.	Address the problem of higher education to use the metaverse platform for teaching and the potential direction.	Virtual worlds (metaverse) technologies are changing the way of learning, and the author predicts that a higher education institution should have a virtual world presence like the web presence today.	Education

A content service deployment plan for metaverse museum (Choi & Kim, 2017)	The metaverse includes AR and simulation as one of the fundamental axes (lines), and another is internal and external elements. The key elements of the metaverse include AR, virtual worlds, lifelogging, and mirror worlds.	Provide a metaverse exhibition experience service that allows users to journey back and forth between real and virtual spaces.	Discuss the possibilities of deploying experiential content for museum exhibition space with head-mounted display and beacons toward a metaverse exhibition.	Museum
Distributed Metaverse (Ryskeldiev et al., 2018)	The metaverse is a persistent and constant collection of MR space mapped into different geospatial locations.	Decrease the computational costs for mobile MR applications and expand available interactive space.	They proposed a decentralized platform that represents spaces as blocks with related information with the blockchain-based peer-to-peer model in MR with mobile devices.	Blockchain, MR
All One Needs to Know about the Metaverse (Lee, Braud, et al., 2021)	They considered the metaverse as a virtual space that blends the digital and physical world with the internet, web, and extended reality (XR) technologies.	Provides a survey to offer a comprehensive view of the metaverse in both technology and ecosystem.	The article demonstrated 14 focused areas of the metaverse and their reflection of them.	XR, IoT, AI, blockchain, etc
When Creators Meet the Metaverse (Lee, Lin, et al., 2021)	Cyberspaces of enormous and open 3D virtual spaces for unlimited users to perform various activities.	To illustrate the relationship between artworks and the metaverse.	They pinpointed vital topics and the research agenda for supporting the artistic metaverse's computational arts and technological infrastructures.	Computational art

2.1.2 History of the Metaverse

The metaverse evolved from virtual worlds, and Dionisio et al. divided its history into five phases (see Figure 9). The initial phase began in the late 1970s with the text-based virtual world, including multi-user dungeons (the role-playing game that users involved in creation) and multi-user shared hallucinations (collaborative creation.). The next phase incorporated a 2D graphical interface. Habitat[7] represented this period, first introducing the term avatar for the virtual world (Dionisio et al., 2013). The development of the third phase began in the mid-1990s. It brings full three-dimensional graphics to the users because of the improvement of the Graph Card. Meanwhile, it also provides the ability for users to create content to personalize their virtual environment (Dionisio et al., 2013). The fourth phase revolved around the user base of commercial virtual worlds. For example, Second Life[8] had improved creator tools for users and major institutions from the physical world engaging in it. The fifth phase of development began in 2007 and is still ongoing. The main features of this period are open source and engaging with decentralized contributions. To the potential future, the metaverse should not only live in the virtual space but should blur the border with the physical world.

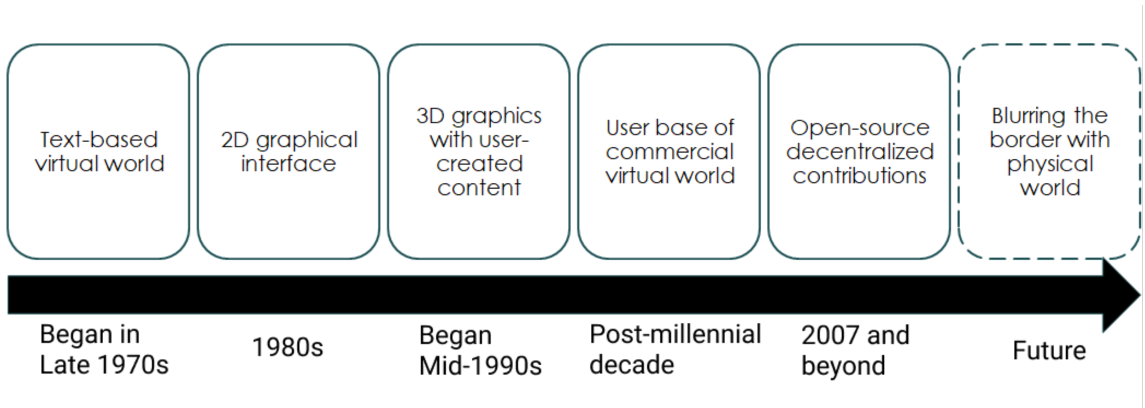


Figure 9. The Evolution of Metaverse, inspired by Dionisio et al. (2013).

[7] https://web.stanford.edu/class/history34q/readings/Virtual_Worlds/LucasfilmHabitat.html
[8] https://secondlife.com/

2.1.3 State-of-the-Art Applications and Platforms of the Metaverse

They are many applications and platforms for the metaverse today. Understanding their features and limitations will provide a better direction for this thesis project. Digital ownership is a big problem in the metaverse, and blockchain is implicated in some platforms to deal with it, such as Decentraland[9], Cryptovoxels[10], and Somnium Space[11] (see Figure 10). Decentraland attempts to be a virtual reality platform based on the Ethereum blockchain, where users own the creation's property entirely when they purchase the "land." The land is a non-fungible token (NFT), a digital asset stored as an Ethereum smart contract that users can create (Ordano et al., 2017). Cryptovoxels and Somnium Space also have a similar approach to defining the ownership of digital assets. Although Decentraland's VR feature is still in development, Cryptovoxels's origin city is available to be visited through VR in other VR worlds like VRChat[12], NeosVR[13], and Substrata[14]. Meanwhile, Somnium Space even provides its desktop version that could connect to the SteamVR supported VR headset[15]. A highly comprehensive table (see Table 2) is presented to compare different metaverse platforms that are popular and represent the industry of XR and blockchain.

[9] https://decentraland.org/
[10] https://www.cryptovoxels.com/
[11] https://somniumspace.com/
[12] https://hello.vrchat.com/
[13] https://store.steampowered.com/app/740250/Neos_VR/
[14] https://substrata.info/
[15] https://store.steampowered.com/app/875480/Somnium_Space_VR/

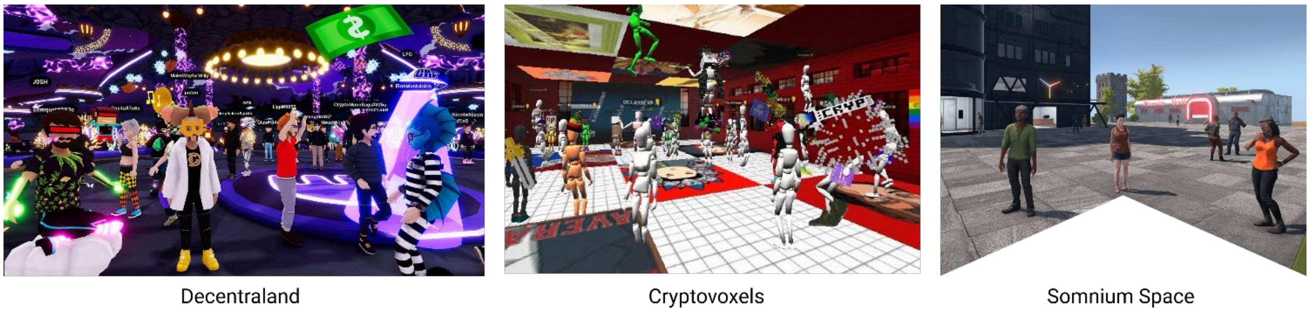


Figure 10. The Metaverse platforms with blockchain implement.

Table 2. A comparison of selected Metaverse platforms that represent their related industry domain.

	Platforms	Output Devices	Graphic Quality	Can it be developed by users?	Interconnection with other Platform	Is it a Decentralized platform?	Why do users use it?
Decentraland	Web	Standalone PC	Low-poly model, Cartoon	Yes, provide builder and SDK for creating content.	Yes, the NFT token based on Ethereum can interact with other platforms. IoT-Enable with WebSocket and REST API that can send and receive information from outside agents	Yes, based on Ethereum	Live Performance, Art Exhibition, Game Play
Cryptovoxels	Web, WebXR	Standalone PC, Mobile Device, Oculus Quest, Oculus Rift, HTC Vive	Voxel Style	Yes, users can edit the scene by dragging and dropping objects and scripting inside the platform if they own the land.	Yes, the NFT token based on Ethereum can interact with other platforms. The origin City can be viewed in VRChat, NeosVR, and Substrata	Yes, based on Ethereum	Art Exhibition, Live Performance
Somnium Space	Windows app, VR app, web	Standalone PC, Mobile Device, Oculus Quest, Oculus Rift, HTC Vive	Realism Graphics Style	Yes, Unity SDK for creating avatar and builder for developing the scene.	Yes, tradable land on the decentralized marketplaces	Yes, a blockchain VR metaverse	Performance, virtual party, game playing, art exhibition

Fortnite	Windows app, mobile app, game console app	Standalone PC, Game Console(PlayStation, Xbox, Nintendo Switch, Android	Stylized graphic(between realistic and Cartoon)	Yes, create a mode for players to design an experience that could be published and shared with others.	Yes, although Roblox is not provide	No	Gameplay, live performance
Roblox	Windows app, mobile app, game console app	Standalone PC, Mobile Devices, Game Console (Xbox)	Cartoon	Yes, Roblox studio for creating and developer hub to the public the game.	No	No	Gameplay
Horizon (Meta)	Virtual reality app	Oculus Quest, Oculus Rift	Cartoon	Yes, users can create their room and rules.	No	No	Game Play, Meeting
Microsoft Mesh	MR app, VR app, PC app, mobile app	HoloLens, Standalone PC, Mobile Phone, VR Headsets	Cartoon, Realism	Yes, provide SDK for developers.	No	No	Training, Collaborate Remotely, Get Remote expertise, Design Together

2.2 Mixed Reality Agent

The mixed reality agent (MiRAs) is a taxonomy for classification in three-axis, agency, corporeal presence, interactive capacity developed by Holz et al. (2011). The key concepts of MiRAs are agent, embodiment, and MR environment, that defined as an agent with virtual or physical entities embodied in an MR environment. Wooldridge and Jennings (1995) defined an agent as an entity in hardware or software with autonomy, social ability, reactivity, and pro-activity. To be considered as having strong agency, a MiRA cube should incorporate mentalistic notions such as beliefs, emotions, and desires (Wooldridge & Jennings, 1995). Applying MiRA to this thesis provided the researcher with three dimensions to consider when developing the prototype and was used as the criteria for evaluating the works.

2.2.1 Embodiment and XR

In the MiRAs, embodiment represents the degree of virtual or physical visual representation (Holz et al., 2011). Then the concept of XR provides the theory and technologies for the visualization of MiRAs in the MR environment "X" as the mathematical variable in "eXtended Reality" means the degree of MR. It was firstly introduced in Charles Wyckoff's "XR" film in 1961 (Mann et al., 2018). Then the device was embodied by Mann and Wyckoff in 1991, and Sony used "X-Reality" as the brand for their mobile AR that attempts to extend human sensory perception. Although XR/X-reality has at least three definitions, they are all based on the use of the "X-axis" to define the number line across the "reality" and "virtuality" along a one-dimensional path (see Figure 11).

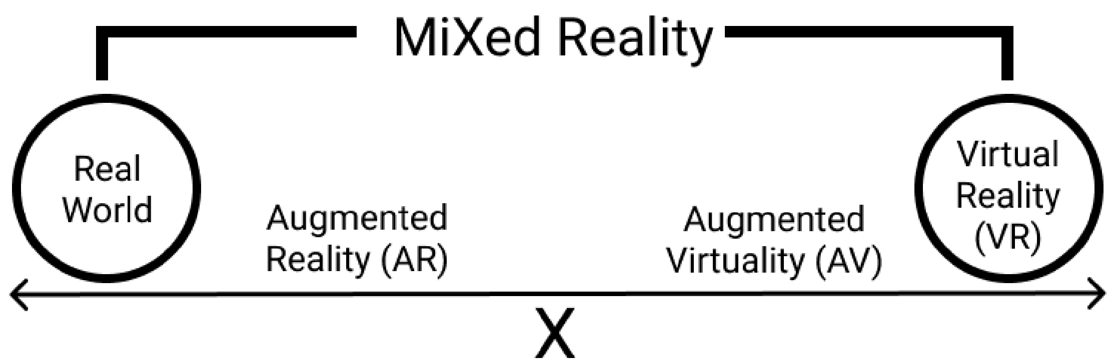


Figure 11. X-axis from Reality to Virtuality adapted from Mann et al. (2018).

XR is an umbrella term for VR, AR, and MR of Milgram and Kishino's (1994) concept of "virtuality continuum," which is a mixture of the presenting objects from-real-to-virtual on screen. XR is also a term that refers to the combination of physical and virtual (computer-generated graphic) environments in that humans can interact. Specifically, the X represents the spatial computing technologies connecting virtual and physical space (Greenwold, 2016).

2.2.1.1 VR

VR Theories: One of the suggested features of the extended metaverse agent in this thesis is switching between VR and MR, and background knowledge about VR is needed. VR is defined as completely virtual immersive environments, where the "virtual" is referred to as the computer-synthesized world that is not artificial but provides a really "real" feeling to the participant (Milgram & Kishino, 1994). Brooks (1999) addressed that Virtual Reality is a window to look into a virtual world instead of a screen. It effectively immerses the users into a responsive virtual world that looks real, sounds real, and even feels real. Participants are vital during the VR experience because VR interaction is tightly coupled to human senses, and instead of human interfacing with the technology, VR interaction should finally interface with humans (Machover & Tice, 1994). VR as a whole new branch of technology refreshed how we look at the area of human interaction, including user interface design, flight and visual simulation, and telepresence technologies. Mazuryk and Gervautz (1996) stated that there are addition terms needed to address VR, including synthetic experience, virtual worlds, artificial worlds, and artificial reality. They indicated that although various definitions for VR, these meanings are equivalent to a simulated world in which users could interact and feel immersed, as Zeltzer (1992) mentioned of the AIP Cube (see Figure 12). Zeltzer (1992) demonstrated a taxonomy of graphic simulation systems, with autonomy, interaction, and presence dimensions. Autonomy involves how well the virtual agent reacts to the simulated environment, interaction defines the degree of users manipulating the simulated parameters, and the Presence axis measures users' perceiving system of the available sensory input and output channels. Heeter (1992) mentioned that there are various dimensions of presence, including personal presence, social presence, environmental presence. Slater & Wilbur (1997) addressed that immersion is the illusion of reality to the senses that human feel immersive with the computer displays, and presence is the consciousness of being in the virtual environment. In other words, presence in VR is the illusion of being in the virtual world though the users know they are not (Slater, 2018).

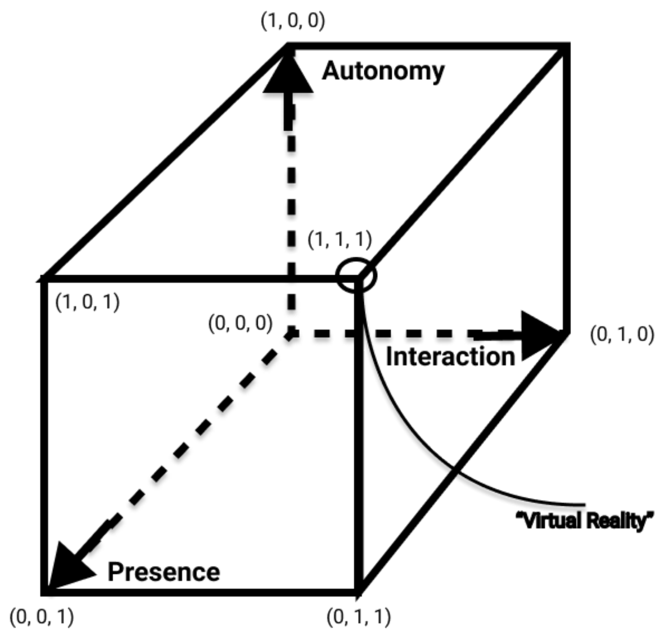


Figure 12. Autonomy, Interaction, Presence (AIP) Cube in an immersive Virtual Reality experience (adapted from Zeltzer, 1992).

Applications of VR: In recent years, VR has been used to develop many applications in various domains, including the education and training, tourism, fitness and sports, and social domains. There were many VR military training scenarios in VR, Liu et al. (2018) introduced the possibility of VR for military training, such as driving an aviation flight, being familiar with the battlefield environment, and increasing the efficiency of design and development of the weapon.

There were also VR education applications in the healthcare field, such as the simulation of surgery in VR could enhance surgical education (Pulijala et al., 2017). VR training provides immersive experiences for users to engage in a fun manner of repeating practice with serious games to gain required skills without causing any damage to the patient. Pulijala et al. (2017) presented a demo of combining a pre-recorded stereoscopic 3D video of the surgery process and interactive models of the patient's anatomy model implemented with Oculus Rift and Leap Motion (for hand tracking). Castro and Orosa (2018) showed how VR could be used in tourism to allow tourists to experience the desired place closely, either for fun, distraction, or professional purposes. They presented a demonstration of a virtual touristic application to promote the tourist sites in the Republic of Ecuador. It can be used to visualize the 3D map of the original terrain features in both mobile applications and VR devices (Gear VR and HTC VIVE) on that location and use the AIP REST system to request the real-time weather state and update it in the virtual environment. Neumann et al. (2018) defined that when VR is applied to the sport, it represents individuals mentally or physically present and interact with the computer-simulated environment immersively when engaging in sport. They addressed that a sports VR system should include two components, the VR environment and the sport, because they are linked closely with examples, including cycling, walking, golf, running, and rowing. Facebook launched its new virtual world Horizon, a creative space for makers to build a new world together, during the Oculus Connect 6 conference (Johnson, 2019). Horizon has been designed as a social platform for the audience to create art, education, and beyond collaboratively.

2.2.1.2 AR

The early AR exploration tracked back to 1968, as Sutherland (1968) demonstrated the Sword of Damocles for AR head-mounted display (HMD) system. Then in 1992, Caudell and Mizell

(1992) addressed compared to full VR, the “augmented reality” concept only responds to rendering a part of the graphical objects for users, instead of generating every pixel. AR represents the real environment being “augmented” by virtual objects (generated by computer graphics), and the essence of this technology is that videos and images of real scenes are enhanced using computer-generated graphics (Milgram & Kishino, 1994). Azuma et al. (2001) considered that the features of AR systems should be more than visually coexisting virtual and physical objects in the same spaces and supplemented with interactively in real-time and aligning the real and virtual objects. These three characteristics are also required for approaching the AR system technically, including displaying virtual and physical images, interactive graphics, and the tracking system (Billinghurst et al., 2014).

Billinghurst et al. (2014) indicated that the current handheld computing devices are powerful enough to process the AR system in visualization and interaction. Hence, smartphones and tablet computers are adopted to run AR applications widely, and Morris et al. (2020) addressed that they dominate the AR space. To efficiently operate the AR system, virtual objects should be anchored to the real space to enhance immersion for users (Brito & Stoyanova, 2018), which could be approached by two techniques, marker-based and markerless methods (Oufqir et al., 2020). On the one hand, the planar marker system (QR code or image) is widely used, such as positioning certain information (Hirzer, 2008), because it can easily perform recognition and tracking with low-power devices (Oufqir et al., 2020). On the other hand, the markerless method projects the virtual objects onto the scenes without registering beforehand. Today’s applications increasingly implement this method because of the rapid advances in technology. Mobile phones have provided a stable platform for many applications and have been part of our daily lives. AR gaming and social applications are popular on smartphones, including Pokemon GO[16] and WallaMe,[17] which could enable users to leave virtual messages in the real locations in the world (Morris et al., 2020), Snapchat,[18] or Messenger[19] filter of AR, and the IKEA[20] catalog (Oufqir et al., 2020).

2.2.1.3 MR

Speicher et al. (2019) conducted a survey of what MR is, and most of the papers they found used Milgram and Kishimo's (1994) paper to provide the definition of MR. They described that the MR environment could be viewed in a straightforward way that presents the real and virtual world together within a single display, and it is anywhere between the extrema of the virtuality continuum (see Figure 13), including AR and augmented virtuality (AV). MR is a kind of VR but a concept that goes beyond AR, enhancing the virtual environment with the physical data about the real world that AV represents (Tamura et al., 2001). MR is one of the paradigms to integrate a group of computational devices into the real environment by overlaying digital objects to approach the concept of "Ubiquitous Computing" (Costanza et al., 2009).

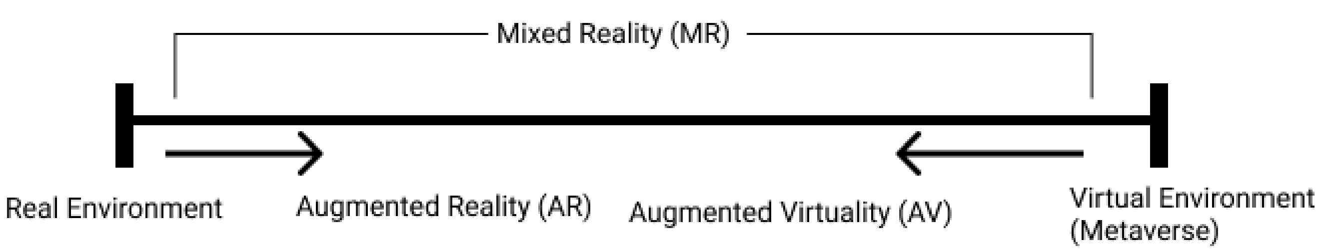


Figure 13. Reality–Virtuality Continuum adapted from Milgram & Kishimo (1994).

[16] https://pokemongolive-com.translate.goog/?_x_tr_sl=en&_x_tr_tl=zh-CN&_x_tr_hl=zh-CN&_x_tr_pto=sc
[17] https://test-wallame-campaign-manager.youandemili.com/accountview/login?ReturnUrl=%2F
[18] https://www.snapchat.com/create
[19] https://mashable.com/article/facebook-messenger-ar-effects
[20] https://www.ikea.com/au/en/customer-service/mobile-apps/say-hej-to-ikea-place-pub1f8af050

Costanza et al. (2009) addressed that the display is one of the technical challenges of MR to render high-quality virtual objects with two solutions, semi-transparent mirrors as optical display and video passthrough with a camera attached. MR devices with transparent screens (glasses) displayed in front of the eyes have been made and developed significantly, such as Google Glass,[21] Vuzix Blade,[22] and Epson Moverio[23] (Y. Liu et al., 2018). Microsoft Hololens[24] is the state-of-art MR HMD that enables users to interact with the simulated surrounding through holograms (Park et al., 2021). The second version (Hololens 2[25]) has a wider Field of View that could enhance the immersive experience for users. Additionally, Magic Leap[26] and Nreal[27] are alternative MR devices that are cheaper and lighter than Hololens 2 but require plugging into a computational unit. Billinghurst et al. (2014) indicated that in most cases, the see-through video method is attached to the video camera on the back. StereoLabs provides an extended depth camera (ZED Mini[28]) for the common VR head-mount devices, and Morris et al. (2020) attached it to the Oculus Rift to explore their IoT Avatar in a more immersive MR environment. More recent devices have built-in cameras to capture the real environment, such as Varjo XR-3[29] that could provide the most immersive MR experience and photorealistic virtual fidelity, LYNX R-1[30] is an affordable and versatile head-mounted device to access MR, and Oculus Quest 2[31] from

[21] https://www.google.com/glass/start/
[22] https://www.vuzix.com/products/vuzix-blade-smart-glasses-upgraded
[23] https://epson.com/moverio-augmented-reality
[24] https://www.microsoft.com/en-us/hololens
[25] https://www.microsoft.com/en-us/hololens/hardware
[26] https://www.magicleap.com/en-us
[27] https://www.nreal.ai/
[28] https://www.stereolabs.com/zed-mini/
[29] https://varjo.com/products/xr-3/
[30] https://www.lynx-r.com/collections/frontpage
[31] https://developer.oculus.com/blog/mixed-reality-with-passthrough/

Facebook also provide the SDK for the developer to access their camera to enable MR in black and white on the VR headset.

Table 3. A comparison of VR and MR devices, using data adapted from VRcompare[32].

Devices	Year	Type	Display	Resolution	Field of View	Tracking	Interaction
Oculus Quest 2	2020	VR and MR (Black and White) Standalone	Screen-based and video passthrough	1,832 * 1,920	89°	6 DoF with inside-out cameras	Hand tracking and 2 controllers
Oculus Quest	2019	VR Standalone	Screen-based	1,440 * 1,600	94°	6 DoF with inside-out cameras	Hand tracking and 2 controllers
Oculus Rift S	2019	VR PC-powerd	Screen-based	1,280 * 1,440	87°	6 DoF with inside-out cameras	2 controllers
Oculus Rift	2016	VR PC-powerd	Screen-based	1,280 * 800	87°	6 DoF with 2 base statetions	2 controllers
HTC Vive	2015	VR PC-Powerd	Screen-based	1,080 * 1,200	108°	6 DoF with at lease 2 base stations	2 controller
Nreal	2020	MR Phone-powered	Optical display	1,920 * 1,080	52°	6 DoF inside-out through 2 cameras	Hand tracking
Magic Leap	2018	MR Standalone	Optical display	1,280 * 920	50°	6 DoF inside-out	Hand and eye tracking and controller
Hololens 2	2019	MR Standalone	Optical display	1,440 * 936	52°	6 DoF inside-out with	Hand and eye tracking

[32] https://vr-compare.com/

						4 cameras	
Varjo XR-3	2020	VR and MR PC-powered	Screen-Based and Video Passthrough	2,880 * 2,720	115°	6 DoF	Hand and eye tracking
LYN R-1	2020	VR and MR Standalone	Screen-Based and Video-Passthrough	1,600 * 1,600	90	6 DoF inside-out with 2 cameras	Hand tracking
KURA[33]	Unlisted	MR	Optical display	8,000	150°	6 DoF with cameras	Hand and eye tracking

2.2.2 Interaction in XR Through the IoT

Holz et al. (2011) introduced that the interactive capacity of MiRA can be represented by their sensing and acting capabilities in both virtual and physical domains. In human-in-the-loop scenarios for MiRAs, Rekimoto and Nagao (1995) presented the comparison of human-computer interaction style (see Figure 14), and the augmented interaction is the method that supports interaction with virtual and physical areas. Tan and Wang (2010) consider IoT could bring a new communication for ubiquitous computing. Such information connection could also enhance the augmented interaction in the hybrid virtual and physical (XR) environment.

[33] https://www.kura.tech/

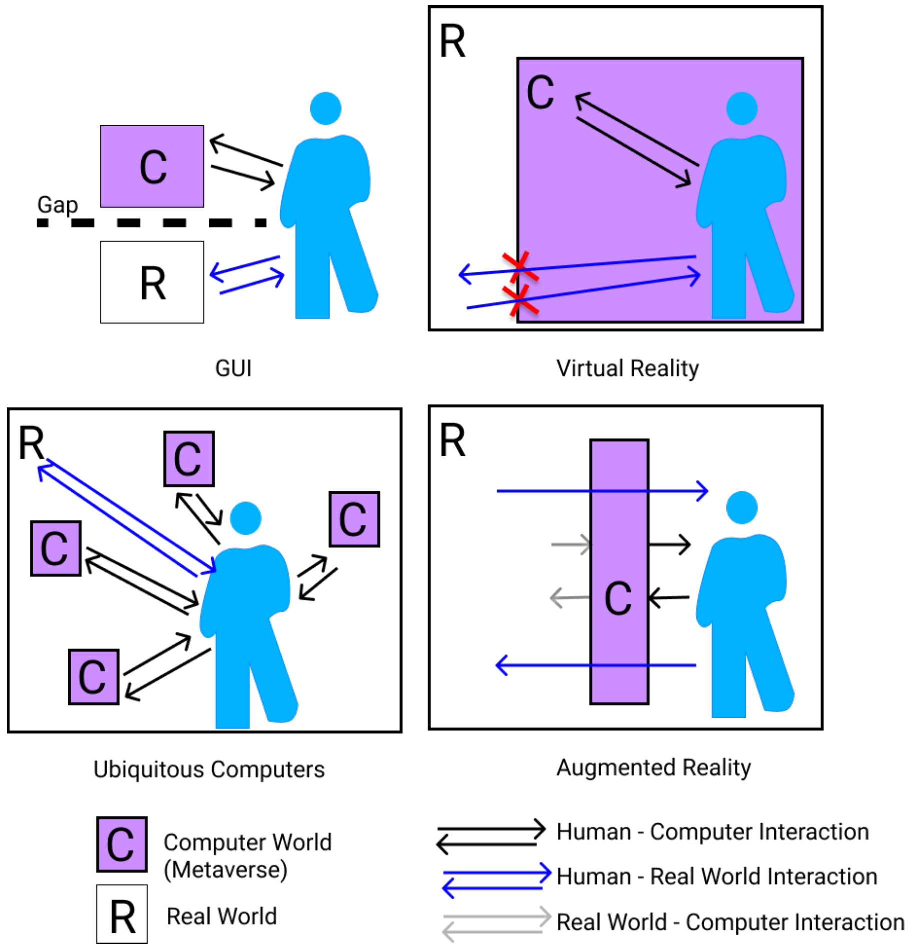


Figure 14. A comparison of HCI style adapted from Rekimoto and Nagao (1995).

2.2.2.1 IoT and the Interaction

Living in the modern day has used ubiquitous sensing which is enabled by the wireless sensor network in various aspects. The communication network between these devices that connect the sensors and actuators seamlessly creates the IoT (Gubbi et al., 2013). Asthon (2010) was the first one to introduce the term IoT when linking radio frequency identification to the supply chain. The IoT has been covered across a range of domains and applications, such as intelligence building, retail management, transportation (Sundmaeker et al., 2010), personal and home service in the monitoring system, and controlling air conditioners, washing machines, and the like (Gubbi et al., 2013). In recent years, IoT technologies have become the infrastructure of smart city development that involves sustainable energy and the environment to use power efficiently (Nižetić et al., 2020).

2.2.2.2 The Connection Between XR and the IoT

XR-IoT Theory: This paragraph will address the theory of XR and IoT, which provides the method for designing the XR-IoT metaverse system. AR and IoT are the key technologies that received significant attention recently. AR is the interactive medium that provides computer augmented elements to the view of the real world while IoT refers to the networking of physical objects with computing devices for sensing and communication (Jo & Kim, 2019a). Tsang & Morris (2021) refers to this concept as XR-IoT (XRI), which represents the combination of XR-based IoT systems as well as IoT-based XR systems. A more comprehensive system of XRI is presented by Morris et al. (2021) that engages in immersive, information-rich, multi-user, and agent-driven systems. The potential usability scenarios of IoT and AR have been implemented in both industrial applications and academic work. The combination of these technologies can reduce the distance between humans and objects, human and human, and future applications that can be used in education, cyber security, and marketing (Andrade & Bastos, 2019).

XR-IoT Applications: In this section, I provide some information about applications related to the XRI domain and prototype ideas for this thesis work. IoT Avatar was started with a simple proof of concept that embodies the MR representation Avatar for the plant and provides buttons to control the physical servo motor and LED through IoT on the mobile phone (Shao et al., 2019). It has been extended to explore the MR framework for IoT with more interaction with

HMD (Guan et al., 2020). The work used ZED Mini plus Oculus Rift to approach the video-passthrough MR experiment and collect the real-time data of the context (intensity of the lighting, the soil moisture of the plant, the number of people in front of the plant) to control the emotional states of the virtual plant avatar through fuzzy logic (Morris et al., 2020). “Digi-log” is a seamless and scalable AR service and experiment for IoT-ready products, such as data visualization based on object position, the mechanism for accessing, controlling, and interacting with objects, and content exchanging interoperability. An augmented reality shopping scenario using IoT-enabled products in a “digital-analog” shopping style (Jo & Kim, 2019b). Seiger et al. (2021) mentioned direct monitoring and control of IoT applications are limited due to the interconnectedness of today’s smart devices, and they presented HoloFlows, a new MR interaction method for end-users to manage standard IoT devices without coding. In conclusion, there are various studies and prototypes related to XR and IoT, and these experiences could apply to the development of extended metaverse agent prototypes and applications for this thesis work.

2.3 Context Awareness

Context awareness can be considered to be the source of information from the physical environment in the extended metaverse agent. The traditional computing interaction method is users providing mechanism input to the computer that will lead to the computer being unable to take full advantage of context. Hence, context-aware computing should make interaction easier by collecting contextual information through automated means (Abowd et al., 1999).

2.3.1 What is Context?

Abowd et al. (1999) addressed that "context" from the previous definition is related to the location and identity of the nearby people and objects and the situation of the environment around the users, such as the time of a day, season, and temperature. They also provided a more recent definition below.

> Context is any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves. (Abowd et al., 1999)

They think their definition makes the developer understand the context of the application scenario, if the information is related to the interaction situation for the users, and such information is context.

2.3.2 What is Context Awareness?

Concerning context awareness, the first definition was restricted to applications adapting themselves from the context (Abowd et al., 1999). Harter and Hopper (1994) presented a location awareness system of people and equipment for the active office. Schilit and Theimer (1994) considered context-aware computing and extended the communication of the location-based information mobile users with active maps. It has been developed to become related to other terms, adaptive, reactive, responsive, situated, context-sensitive, and environment-directed. These earlier definitions fall into two categories, how applications use the context and how it could be adapted with the context. Abowd et al. (1999) also provided their definition of context awareness, "A system is context-aware if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user's task." This definition is more specific for the "adapting to context" category that applications react to be modified by the context. Perera et al. (2014) and Pascoe (1998) both considered the abilities of a context-aware system to be sensing environment-related information, automatically interacting with and adapting to the context, reacting to commands from users and the environment, and displaying relevant information to users. Based on their presentation, Abowd et al. (1999) proposed three major categories of context-aware features, presenting the information, automatic execution, and tagging context information.

Baldauf et al. (2007) considered the active badge location system (Want et al., 1992) to be the first context-aware application for determining the people's current location and forwarding phone calls to the closest user in an office environment. Abowd et al. (1998) addressed that the application of context awareness had been involved in wearable computing, mobile computing, and ubiquitous computing domains. They presented three prototypes of context-aware application, cyberguide to use the location of mobile devices as context, CyberDesk for using context to aid desktop and network service, and improving the voice interaction application through informational context. Context-aware computing has become popular with ubiquitous computing. With the large number of sensors deployed, the IoT is one way to connect information (Perera et al., 2014). CA4IOT architecture highlighted the importance of IoT as middleware to connect the sensors and users in the context-aware system, and it has been designed as a detailed scenario in the agriculture domain (Perera et al., 2012).

2.4 Generative and Procedural Virtual Objects and Contents

To construct an extended metaverse agent, actuators are vital to performing the behaviors. The generative and algorithmic virtual objects and contents provide performance and logic movement control in the extended metaverse agent.

2.4.1 The Background of Generative Art

The term “generative art” is used in the artistic community, meaning artists provide a set of rules, and computers take over some of the decision-making. Instead of the step-by-step algorithm approach, with unpredictable results, the computer artists use specified rules or constraints based on their experience and “feel” to fully control the computer (Boden & Edmonds, 2009). Galanter (2016) discussed various generative art communities, from electronic music, computer animations to open source digital art and social media. The typical features of “generative art” include randomization, evolving forms, constant change, and creation by running code. Galanter (2016) addressed that generative art has 70,000 years of history, and it is as old as art. Through mathematical operations, computer programs, chemical processes, and so on, artists cede some of their controls over artwork to the functional autonomous system.

2.4.1.1 L-system

L-system is one of the most popular methods for generating virtual creatures simulating the virtual plant cells and modeling from a biology perspective (Lindenmayer, 1968a; Lindenmayer, 1968b). Regarding the ability of computer graphics to represent the virtual plant in pictures, an ordered triplet $G = (V, \omega, P)$ is presented to construct the generative graphic system (Prusinkiewicz, 1986). The V is the alphabet represented as symbols for containing elements in both variables (can be replaced) and constants (cannot be replaced), where ω is the axiom to define the initial state of the system and P is the production rules to define the how the variables are replaced by others.

The L-system was used to illustrate a virtual tree that can be interacted by the users in MR. E-Tree is an emotional driving art that presents the growth of a virtual tree attached to a marker in AR that can be influenced by the emotional response from spectators with a dimensional model of affect (Gilroy et al., 2008). The system captures speech and video of users to analyze the emotional speech feature, the sequences of words, and the facial geometries. These affective inputs are communicated with the affective interpretation modules through UDP or TCP to provide pleasure, arousal, and dominance values to modify the visual appearance of the virtual E-tree based on the L-system. Chen and Lee (2018) created a somatosensory edutainment system based on the L-system for users to interact with the virtual plant. With the implementation using Kinect 2, the system can detect the motion of the users to control how the three-dimensional virtual tree grows and animates. The graphic can be viewed in HTC Vive (VR) immersively to provide users with an experience of scene ambiance.

The L-system can provide the rules for growing trees and be used to design other objects. It has also been used for various applications such as pattern design, music composition, neural network modeling, and robotics (Fridenfalk, 2015). Fridenfalk used it to design 3D objects and immersive worlds that could generate a virtual reality environment in cyberspace with the game engine. Lawrence et al. (2017) presented a procedural virtual city that generates fills on real space based on the spatial awareness in MR with HoloLens. Specifically, the generation of the road in the virtual city is constructed by L-system based on Parish and Müller's (2001) *Procedural Modeling of Cities*, and the building of this generative city is based on the Perlin noise in the Unity engine. For metaverse applications, L-system could be potentially used for generative various objects and environments and a visualization method for representing the information from the physical space.

2.4.1.2 Particle Swarm Behaviors

The particle swarm behaviors are the background knowledge of how to consider and develop the movement of objects in the metaverse application through the algorithm. The particle system is useful for simulating fuzzy objects such as clouds, smoke, water, and fire, with a group of simple particles with their movement and states (Reeves, 1983). The key concept of a particle system is how the collection of individual particles as entities constructs a fuzzy object together, with their algorithmic interaction with each other by determining attributes, including position, velocity, size, color, transparency, shape, and lifetime.

Reynolds (1987) thought efficient, robust, and reliable group motion systems for flock animation are needed instead of scripting flock. Hence, he presented an approach of simulated individual birds' behaviors interactive with each other in a flocking group, with collision avoidance, velocity matching, flock centering. Similarly, Heppner and Grenander (1990) presented a nonlinear bird flocking system with computer simulation to approach the natural flocks. Reynolds was intrigued by the aesthetics of bird flocking while Heppner focused on the underlying rules of individual bird behavior related to others in a group with large numbers of entities (Kennedy & Eberhart, 1995). Kennedy and Eberhart (1995) addressed that particle swarm optimizer algorithm is probably the best to simulate the unpredictable choreography of birds flock.

Despite the particles system theory used widely in simulating artificial life, it is also applicable for many other mathematical and computer modeling areas. Schaefer et al. (1998) presented a model for traffic simulation of vehicles and pedestrians' behavior as individual entities. Moreover, it has been used to estimate the collision risk for the air traffic when the distance of at least two aircraft is smaller than the aircraft size (Prandini et al., 2011).

3 Related Work

3.1 XR and IoT (XRI) related projects

3.1.1 The Last Cyborg Plant

The Last Cyborg Plant (see Figure 15) is an interactive installation capstone project from the author's undergraduate study that explored virtual content, human, machine, and networking. The project attempted to extend the cyborg concept from Haraway et al. (2017) (combining the organism and robot body) into the hybrid virtual and physical body with AR. On the visual side, two virtual eyes were attached to the physical plant and followed its movement to construct a Unity hybrid object. Additionally, a virtual cell and a water parter were presented to interact with the hybrid plant body. On the physical side, a simple robot with wheels was used to perform the movement as the actuator, and a mobile phone captured the user's face as a sensor. With the sensing and controlling capacities of the system, it could provide two-way communication of virtual and physical objects.

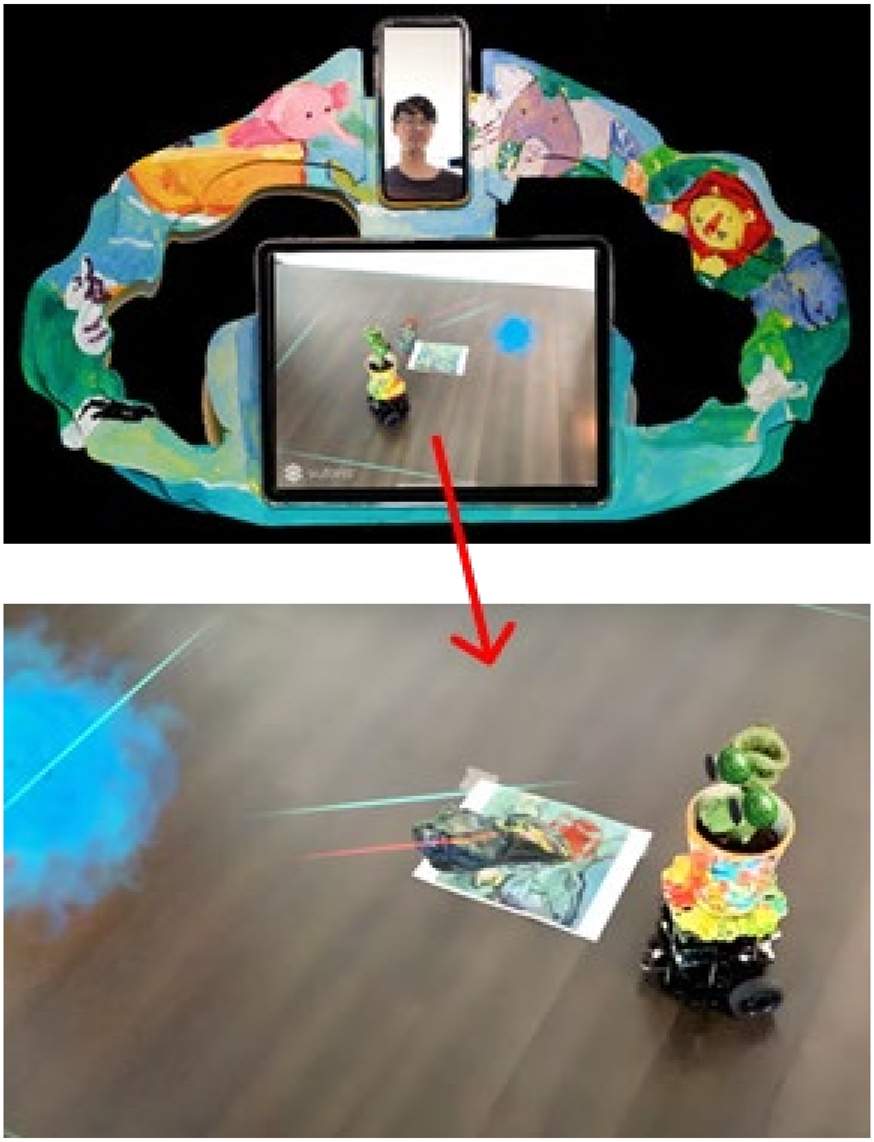


Figure 15. The Last Cyborg Plant from the author's undergraduate Capstone project (2020),[34] with facial movement, a physical robot, and AR content interactions.

[34] https://jieguann.format.com/dynamic-cyborgian-plant-engages-in-both-physical-and-virtual-space-for-dynamic-environment

3.1.2 IoT Avatar Projects Series

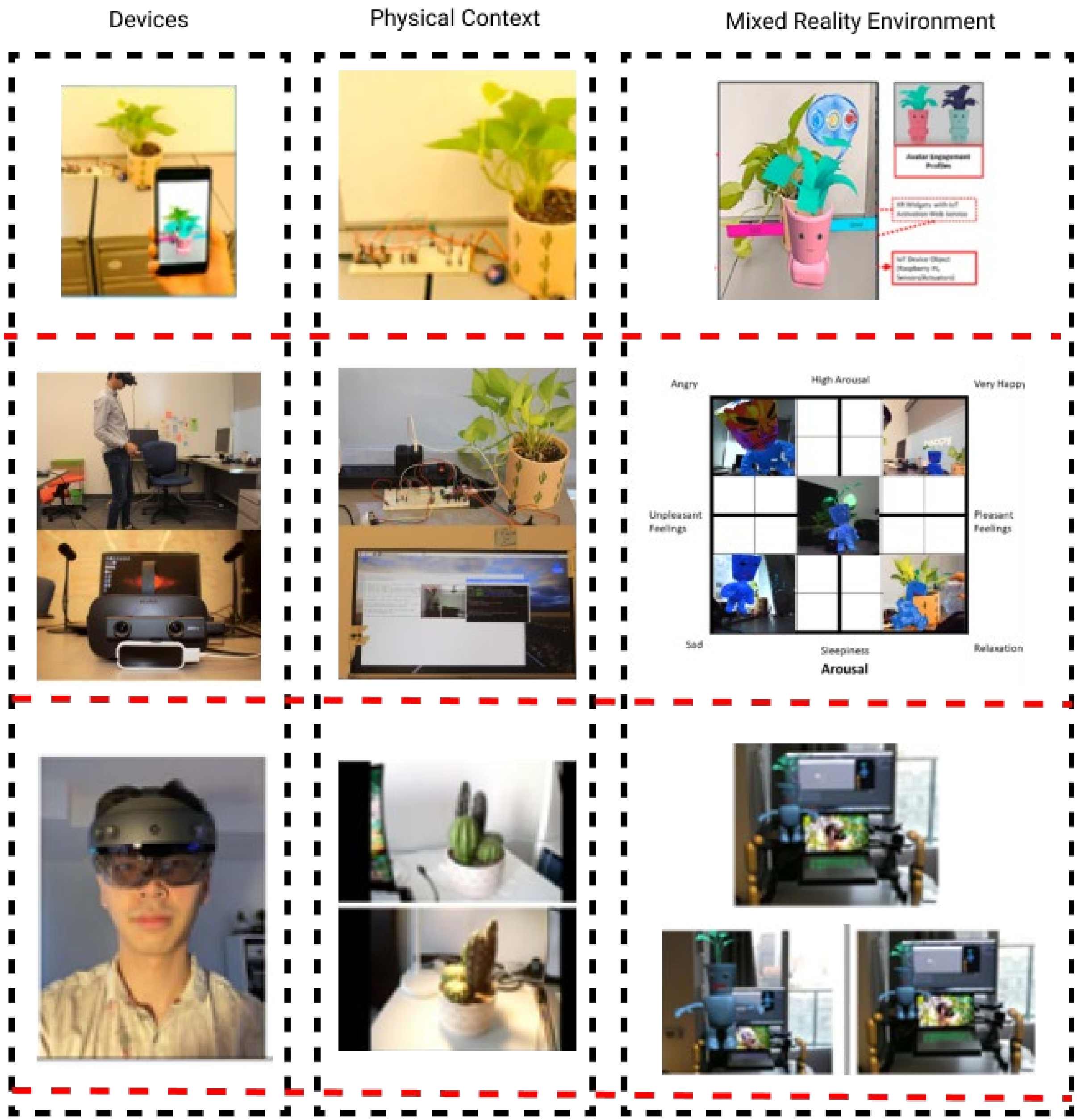
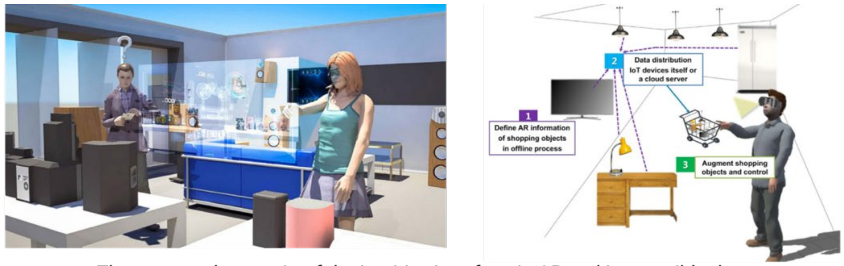


Figure 16. IoT Avatar projects series adapted from Shao et al. (2019), Guan et al. (2020), Morris et al. (2020), and Morris et al. (2021).

IoT Avatar is a series of research and projects (the author participated in some of them) (see Figure 16) from the ACE Lab directed by Dr. Alexis Morris at OCAD University. The research was started from the CoRe (contextual reality) architecture (Morris & Lessio, 2018), which proposed ambient intelligence with IoT and MR visualization elements. The first prototype connected AR and the IoT presented in Shao et al. (2019) with mobile phones visualization of the plant avatar and 2D buttons interaction that could toggle the physical servo motor and LED light. The mobile phone approach of AR (MR) has low levels of immersion and engagement among users. The interaction is limited in a one-way communication from virtual to physical. The next prototype (Guan et al., 2020; Morris et al., 2020) adopted Oculus Rift and a depth camera (ZED mini) for a more immersive MR experiment in the video-passthrough method. Additionally, this project considered using sensors to detect the light intensity and soil moisture and a webcam to run a computer vision model for capturing the number of people presented in the environment. These physical pieces of information are used to decide the emotional states of the virtual plant avatar with different animations, textures, and particle effects through a fuzzy logic system. The HMD MR devices used in this project provide an immersive experiment for the user to see the virtual objects. Interaction is another way of communication that from physical to virtual. A more recent prototype is presented in Morris et al. (2021) with Hololens 2 that attempt to approach a better MR environment with optical see-through.[35]

[35] Due to the impacts of COVID-19 on this project, it was an at-home setup of the plant avatar and simplified the detecting physical information method with only computer vision from the self-trained model from the teachable machine.

3.1.3 "Digi-log" Shopping Experience



The proposed scenario of the intuitive interface in AR and its possible data configuration diagram.

The example of using a mobile device in AR connects to IoT-enabled products.

An AR interaction example presents the operating of an IoT lamp in AR.

Figure 17. Digi-log - an augmented reality shopping experiment from Jo and Kim (2019b)

Jo and Kim (2016) are pioneers of connecting AR and the IoT. They presented an ARIoT framework to foster an IoT environment with basic information objects (Jo & Kim, 2016). Then they presented a survey of how AR could be used to visualize and interact with IoT data and IoT as the infrastructure of data management for AR (Jo & Kim, 2019a). A proof-of-concept implementation is applied with "digital-analog" style shopping (Jo & Kim, 2019b) (see Figure

17) to support a seamless AR service with IoT-ready products. The prototype was started by scenario design of an intuitive interface with AR glass and a framework design of data communication flow through IoT. One of the prototype features is to visualize the IoT data in AR, and a Raspberry Pi implemented it to send the product information of clocks to the AR client, which users hold. Another interaction is operating the IoT lamp with a virtual On/OFF button in AR on a mobile device.

3.2 Generative Objects in XR

3.2.1 World Language Tectonics

A mobile device recorded an Augmented Reality scene at Eaton Centre in Toronto.

Conceptual rendering of the question and the four sentiment rings with related colour

Figure 18. World Language Tectonics (2021)[36] by Jie Guan and Connor YS Matla.

[36] https://github.com/jieguann/World-Language-Tectonics

World Language Tectonics (see Figure 18) is a mobile MR experiment created by Connor YS Matla and author in 2021, which attempts to use text to construct a collaborative virtual landmark form in the public space with a mobile MR experiment. Users will collectively create a digital monument composed of an ongoing accumulation of text inputs, with each person responding to the same open question, “what’s your message to this WORLD?” The collected data will be used to collaboratively create a structural archetype of texts, each of which will be randomly translated into a different language and semantically classified by a deep learning language model (GPT-3) to fuse the text within one of four sentiment. Each revolving and gravitating around a central core and each with its own distinct color (a white spherical structure composed with the word “WORLD” written in different languages).

As a virtual construct object, the textual architecture is amidst somewhere between physical and virtual space, experienced through the lenses of MR. The experiment is unique to users in different environments with distinct times and surroundings. This project’s server and client framework setup provides the connection for edge-end devices that enable data communication between users. On the server-side, the API of Google Translate and GPT-3 (from OpenAI) is running for processing the message sent by the user. The AR app client of this project is created with Unity 3D for two functionalities. On the one hand, it provides a simple UI for input and sending the message to the server. On the other hand, the most crucial part is collecting the accumulation of messages from the server through HTTP requests for the visualization and 3D embodiment.

The project aims to provide a platform in AR for people to express, communicate, and connect in this information age that allows individuals for expressions. The virtual construction from the text can be considered as a metaverse object that can connect individuals without limitation.

3.2.2 E-tree: Emotionally driven augmented reality art

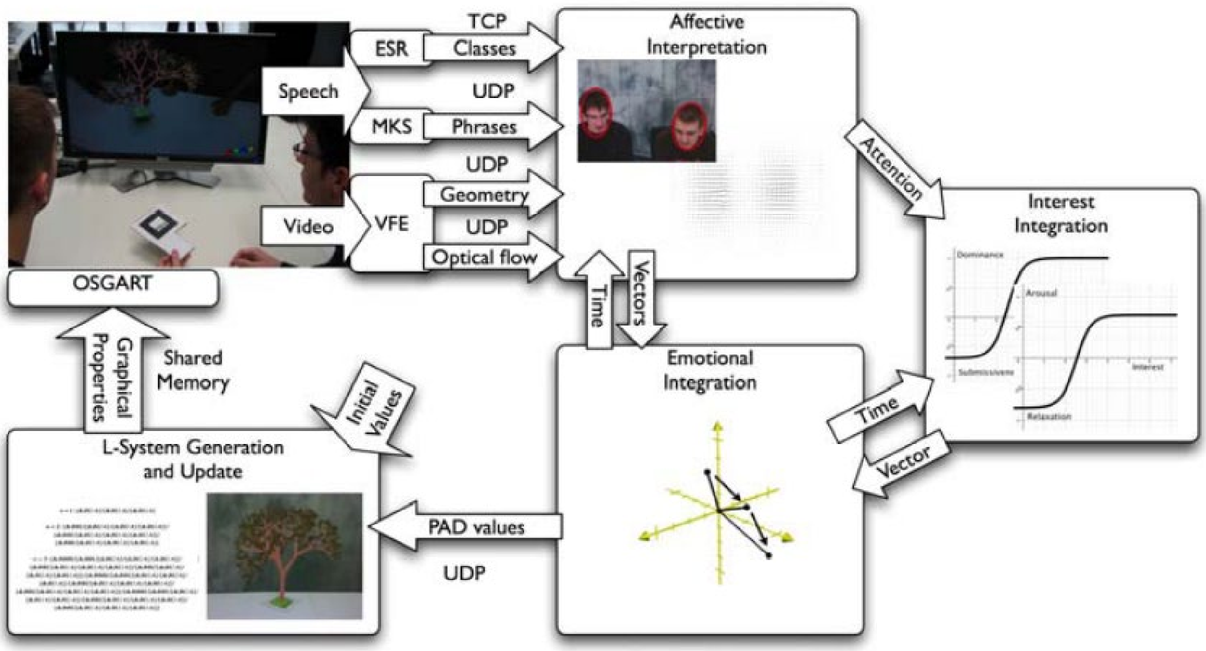


Figure 19. E-tree system architecture (Gilroy et al., 2008)

The emotional tree (E-tree) (Gilroy et al., 2008) is an example of generating a virtual object from physical context information with AR and the IoT. The appearance of the E-tree is generated by the naturalistic structure of the L-system, which was mentioned in Section 2.4. A speech and facial expression from the user is captured and fed into a pleasure-arousal-dominance model to produce affective inputs and transfer from physical to virtual through TCP or UDP to provide in the L-system to generate the E-tree. Because of the limitations of AR technologies when this project was implemented, the researcher considered using a desktop with a monitor to display the virtual object and anchor it with a market-driven approach that enables users to manipulate it with the marker.

3.2.3 Plant Growth Simulation of L-system

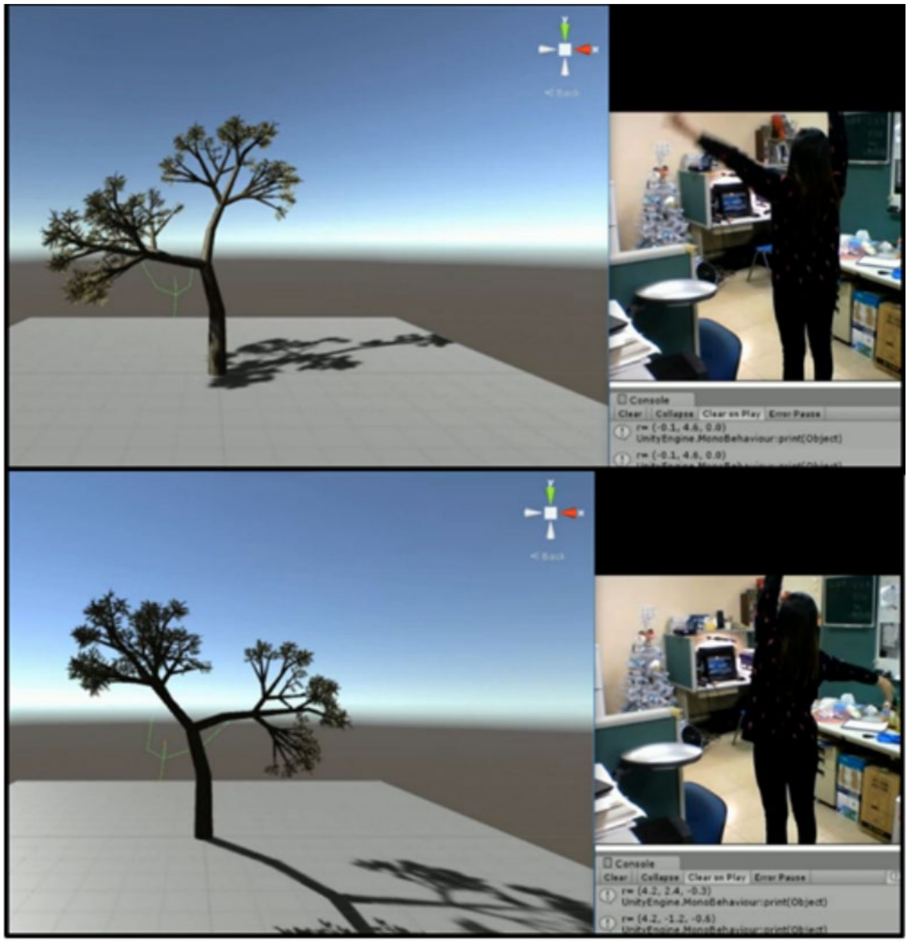


Figure 20. The L-system simulation interfaces with Kinect in Unity from Chen and Lee (2018).

Similar to in the previous project, Chen and Lee (2018) presented an L-system generated plant with the motion-capture technique of Kinect 2 to capture the movement from the user. The virtual tree is grown based on the predefined grammar and rules that are the height of tree would be defined by the user's height, the tree species is selected by users of the initial string, and render the tree based on Turtle Graphics in 3D. The somatosensory interaction is implemented with the motion detection of flat hands, hold hands, and waving hands to affect the branch growth and rotation of the tree. This project is only available for watching the tree in VR with HTC Vive and enabling interaction with the growing tree in VR is ongoing work.

3.3 Metaverse

3.3.1 Holograktor–Metaverse on Wheel by Wayray

Figure 21. Holograktor[37] - Metaverse on the wheel from WayRay[38]

Holograktor (see Figure 2119) is the first car from WayRay designed with AR technology that seamlessly connects the real and virtual worlds with safety, comfort, services, and entertainment for the metaverse on Wheel. It could also be considered the first metaverse wheels device for

[37] https://holograktor.com/
[38] https://wayray.com/

driving conventionally or by VR remote control. With their true AR displays with holography technology, users are no longer needed to wear AR glasses or headgear but still can access the vivid 3D rendering.

4 Methodology

4.1 Research Through Design (RTD)

I used RTD as the method by iteratively developing prototypes. The main focus of RTD is practice-based research, emphasizing the development of design methods, artifact-led, conceptual frameworks, experiential, hands-on prototyping and theories, and products (Gaver, 2012). The RTD practice gains new knowledge by prototyping the concept to understand better the complex process of the design, prototyping, and product. Zimmerman et al. (2010) suggest that rigorous documentation of the progress and evolution of the prototyping in RTD is needed. It should cover the process from framing the problem and idealizing the preferred state to the outcome.

The first five prototypes were designed to explore and prove the concept of my thesis separately, and the last one is a combination of them as a complete experiment (see Figure 22). My design and development process was an attempt to provide the user with an immersive experiment in the extended metaverse environment. Hence, the prototype of considering using an MR headset (HoloLens 2) for the user to wear. The change from the immersive metaverse (VR environment) to the MR environment, the virtual and physical states of IoT data and communication, and the shared object concept were addressed and embodied in Prototype 1. Continuing the extending virtual data to the physical environment, Prototype 2 tested a dynamic color control of physical ambient lighting with a virtual rocket and galaxy system. In addition, Prototypes 3 and 4 were designed to explore the context awareness of physical information through computer vision and brainwaves for sending data from physical to virtual. The Prototype 5 combine some of the feartures and presented a two-way communication and computer vision for context awareness. Through the RTD process, I will document the design process, the problem I would face, and the knowledge I learn from the prototypes. The last prototype would be the final project of my thesis to prove my concept and provide a more accessible experiment for people to play.

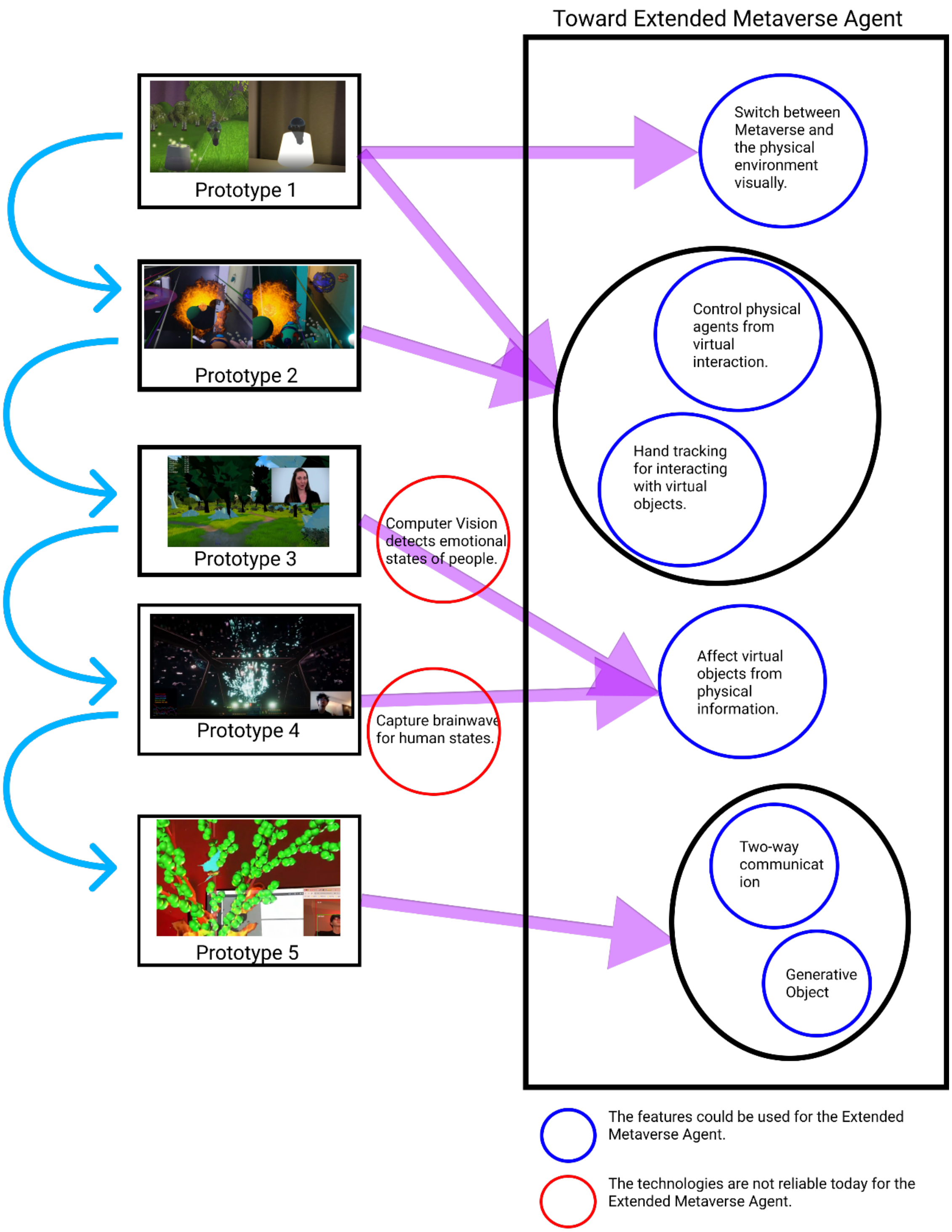


Figure 22. The map of RTD of the thesis prototypes.

4.2 Speculative Design

The consideration of speculative design is for thinking the prototypes for the speculative and foresight possible scenarios. Dunne and Raby (2013) addressed that speculative design considers design as a method of speculating the possibilities of things, to foster new perspectives. They considered the possible future a s tools, starting from what-if questions and forming fictional scenarios to better understand the present of what people want and do not want. Figure 23 demonstrates the potential futures with cones expanding from present to future, representing a different level of likelihood.

Probable: Things that are likely to happen without extreme upheaval and most design processes toward this space

Plausible: A scenario of what could reasonably happen with planning and foresight. It could help organizations explore alternative economic and political futures for preparing to thrive in different futures.

Possible: The suggested scientifically possible scenarios; anything could happen within limits, even entirely fictional, with a bridge between where we are today and those scenarios.

Preferable: It is an intersection between probable and plausible to open the discussion for all sorts of possibilities that can be discussed to define a preferable future for a given group of people.

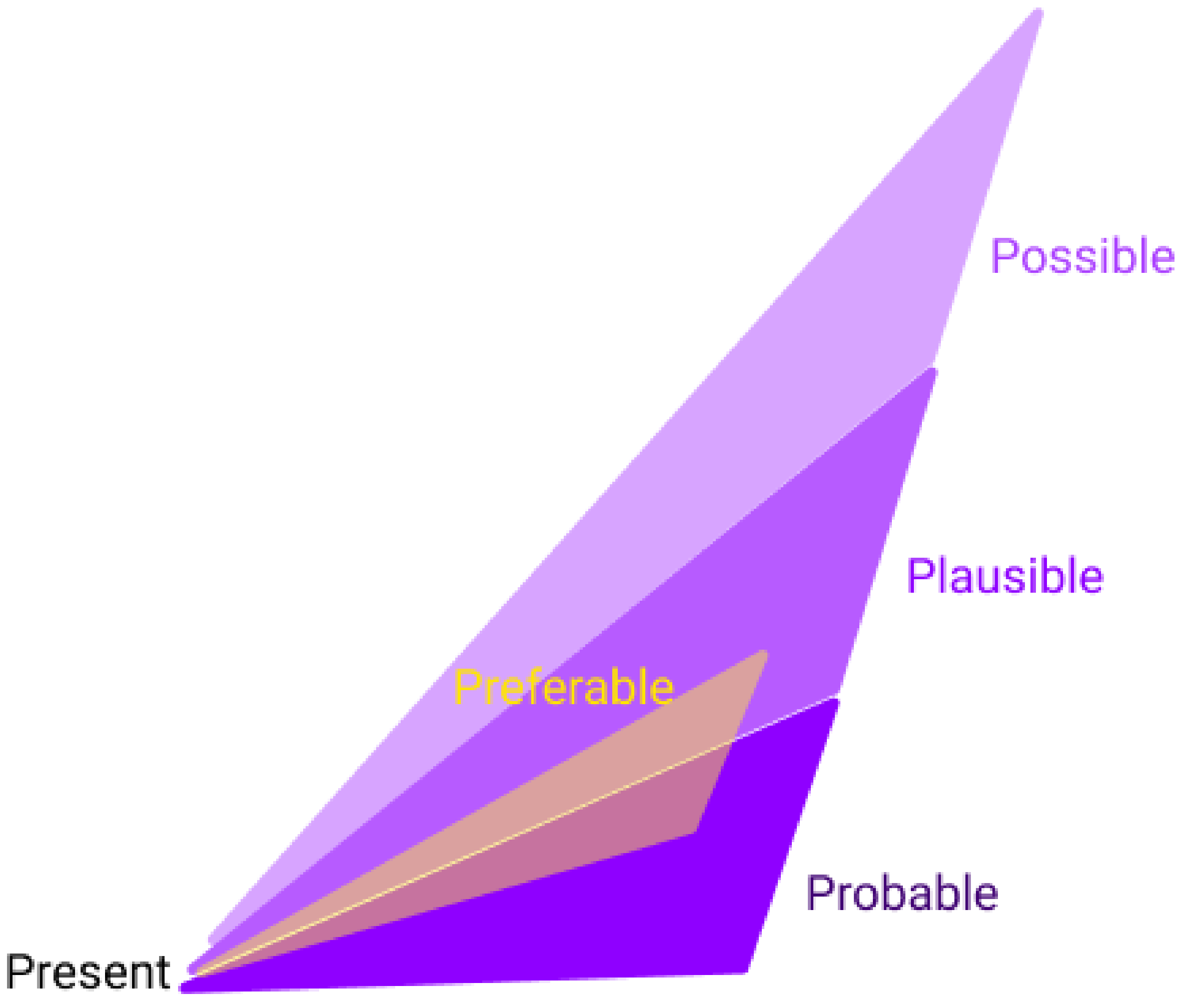


Figure 23. Cones of different kinds of potential futures (adapted from Dunne & Raby, 2013)

4.3 Theoretical Design of the Extended Metaverse Agent

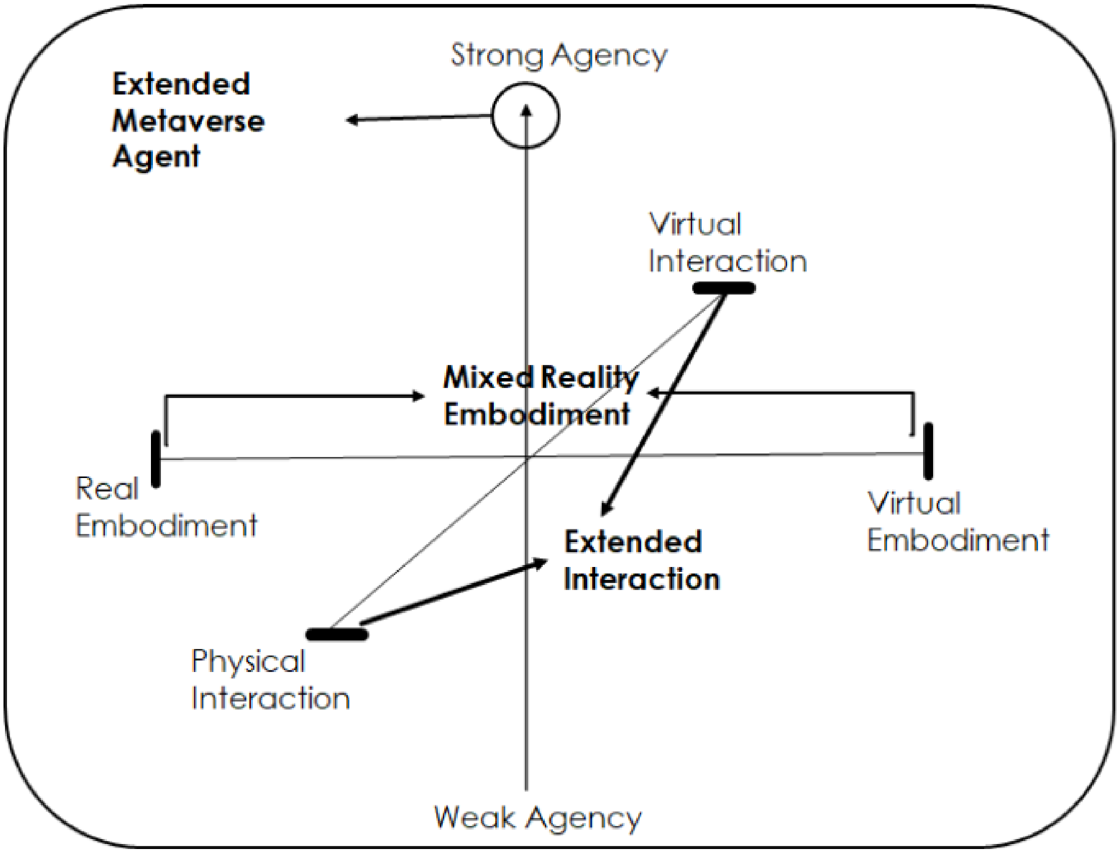


Figure 24. Criteria of metaverse agent with dimensions in interaction, embodiment, and agency, derived from the MiRA taxonomy (Holz et al., 2011).

Figure 25, Figure 26 , and Figure 27 are the early framework design of the extended metaverse of communication and embodiment. The first image (see Figure 25) is a simple two-way connection between the metaverse and physical space, which include human avatar, virtual agent avatar, and physical agents of smart light and mobile phone. Furthermore, Figure 26 is the design of a decentralized network between individual agents for interconnection in both the metaverse and physical space. Finally, Figure 27 addressed the mix-body (including mixed-human, mixed-agent, and mixed-embodiment) embodiment with both virtual and physical body in the extended metaverse space, which is on the intersection between the metaverse and physical space.

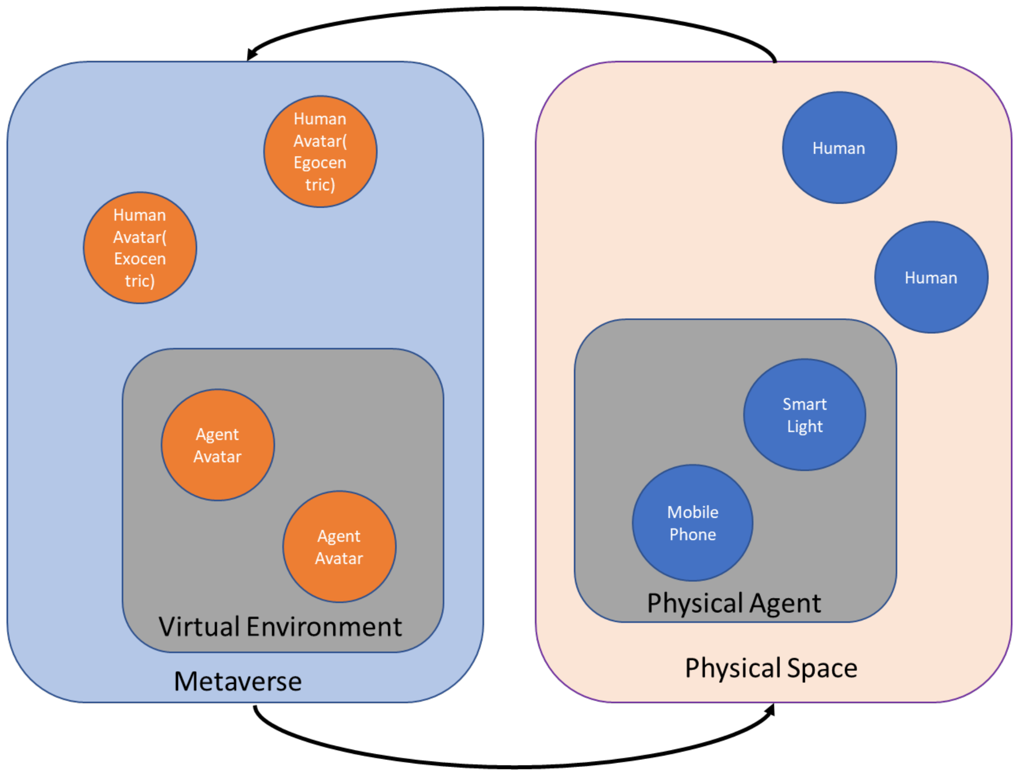


Figure 25. Design of two-way communication between the metaverse and physical space, with information communication between each other.

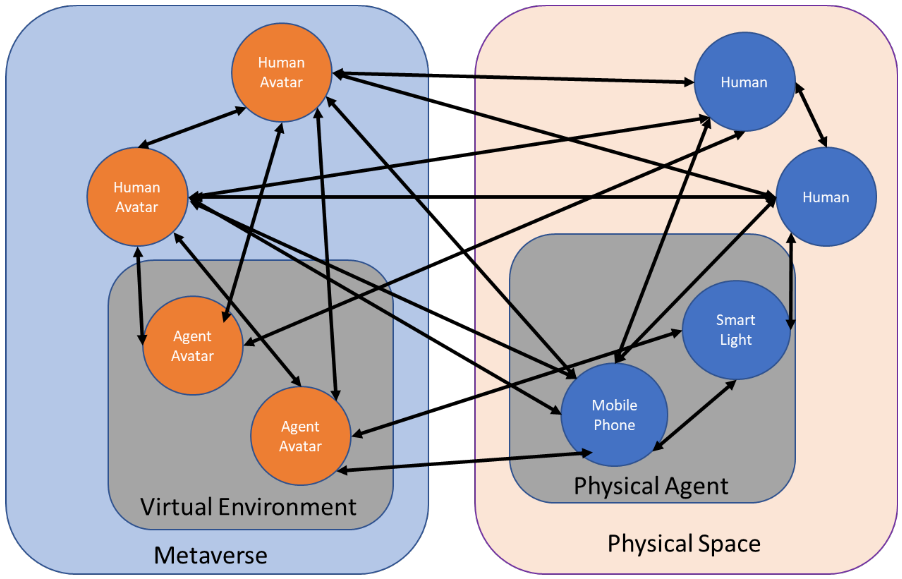


Figure 26. The design of decentralized interconnection of agents in the metaverse and physical space that agents could connect to each other individually.

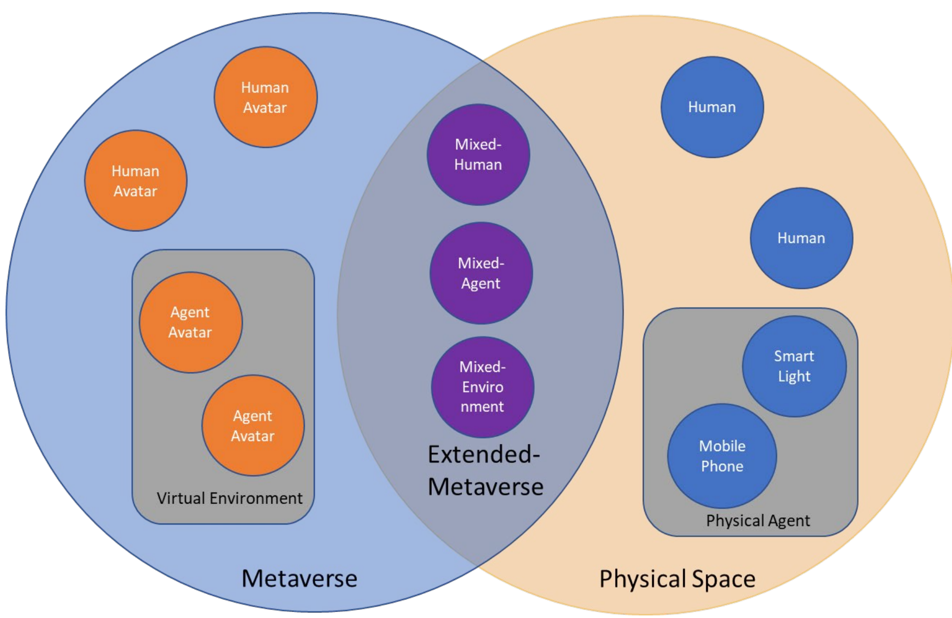


Figure 27. The design of potential extended metaverse agents, with the hybrid virtual and physical embodiment across the metaverse and physical space.

An early framework of a smart home scenario for the extended metaverse design is presented in Figure , demonstrating that humans could access both completely virtual space and MR. The physical context has the brainwave from a human, temperature, power, and lighting intensity as the environmental data and information live on the internet space. These data would be collected as history on a local or cloud server and sent to the virtual area to control the virtual elements. The agent embodiment would adapt the algorithm art concept to generate the virtual objects based on rules and the physical data in the metaverse.

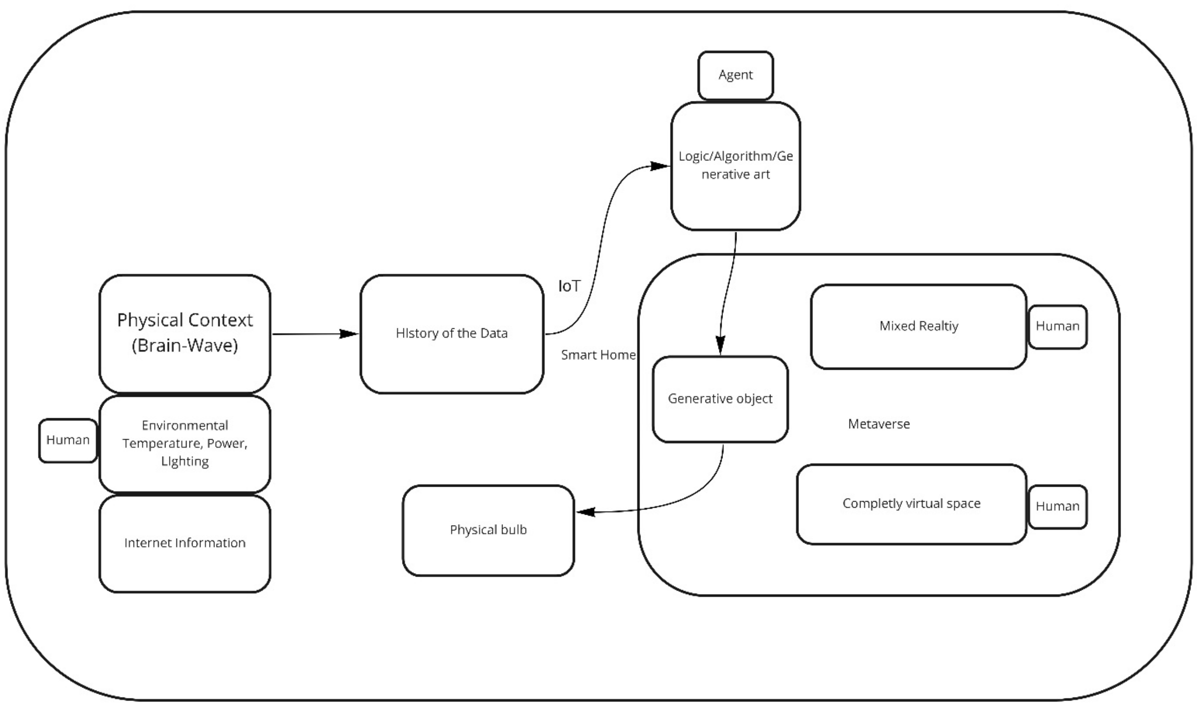


Figure 28. Early framework design of extended metaverse in a smart home scenario, with physical context input and a collection of data history, to generate virtual objects and controls the physical bulb.

The more complete and integrated framework design for an extended metaverse agent is presented in Figure 29. To provide users with an immersive extended metaverse experiment visually, an HMD headset is considered to be worn by them. The design includes two areas: the metaverse represents the virtual reality environment, and the other is the MR environment with the physical environment and metaverse content. The system enables users to switch between these two spaces, as shown by the red arrow. The physical environment has smart agents perform as actuators (smart light as an example) and sensors, and a computer to operate the system. With the IoT communication of the information (shown as the blue arrow) between physical and virtual agents, the agents could be affected by each other. Similar to the previous design, the generative objects of the metaverse content are based on the physical context information. There is also a block showing a 3D user interface that is a new perspective of users interacting with virtual content in MR that different from the traditional 2D interface on screen-based devices.

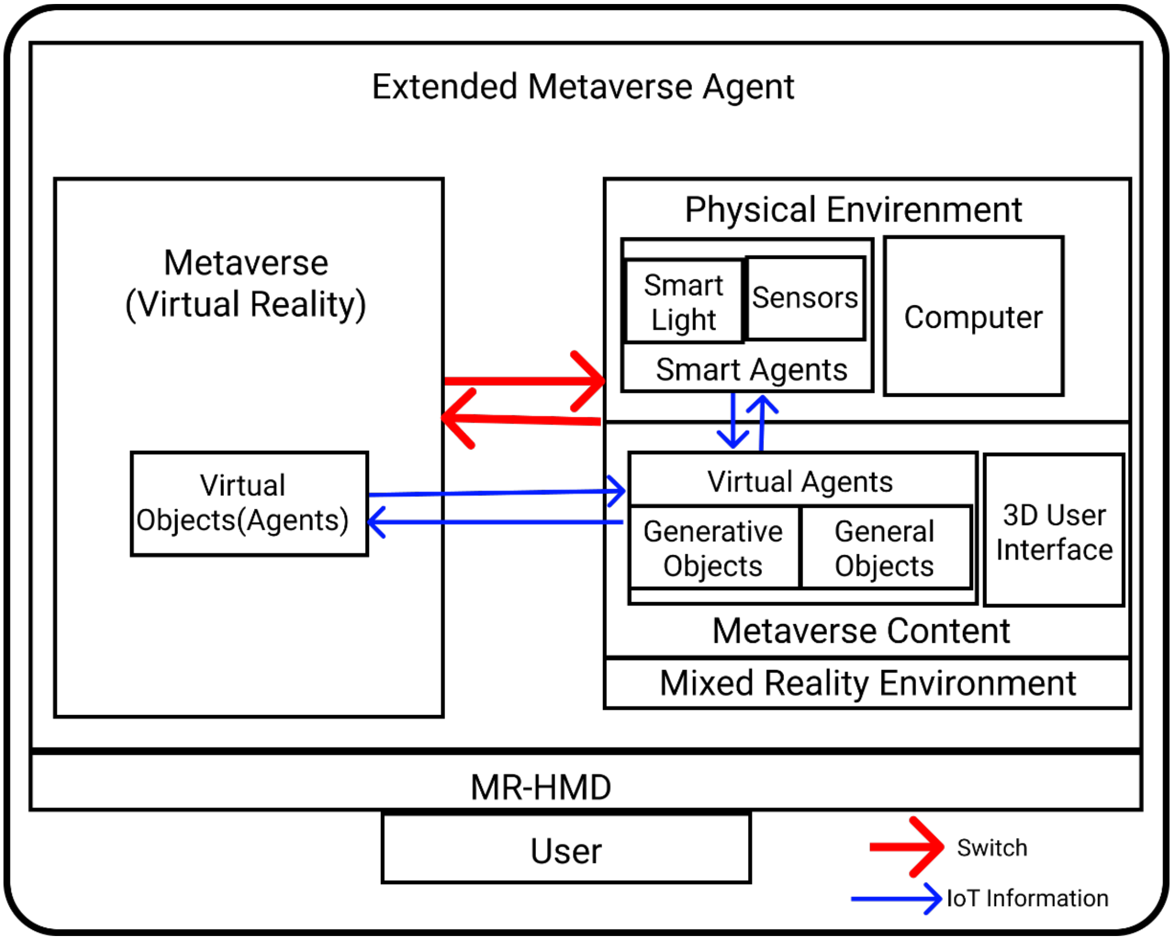


Figure 29. Conceptual framework of the extended metaverse agent

5 Iterative Prototyping

5.1 Early Work

The early design begins in a small smart home scenario, with an everyday object, a light bulb, to explore the connection between virtual embodiment and physical object. The consideration of choosing the bulb as the object is that it is easy to access and operatable. The early sketch (see Figure 30) presented the first anthropomorphic visual design of the virtual bulb with two eyes. The bulb's design was embodied into the Unity engine that could develop into MR. Moreover, the sketch demonstrated a simple scenario design of how the virtual elements interact with the physical light with off, white mode, and rainbow mode states. The user on the design is wearing an HMD MR headset and holding a colorful virtual particles effect that could be manipulated through the hands. When the virtual particles collide with the physical bulb, it transforms into a yellow and transparent sphere, and the physical light is on with white color. The third interaction design is that when the virtual content is above the physical bulb, the virtual firework starts to play, and the physical bulb changes color in the rainbow model.

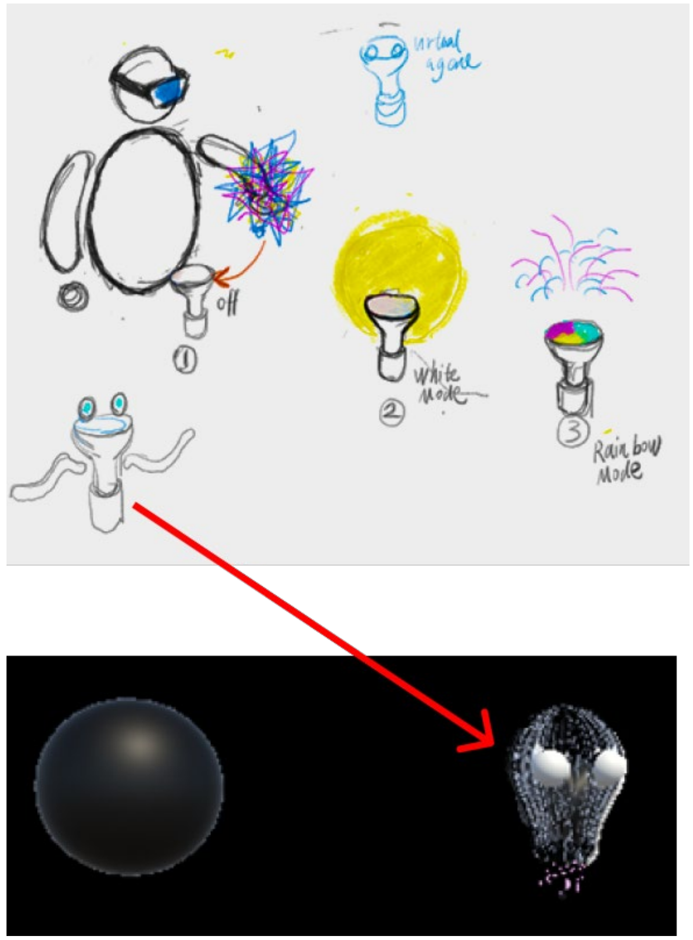
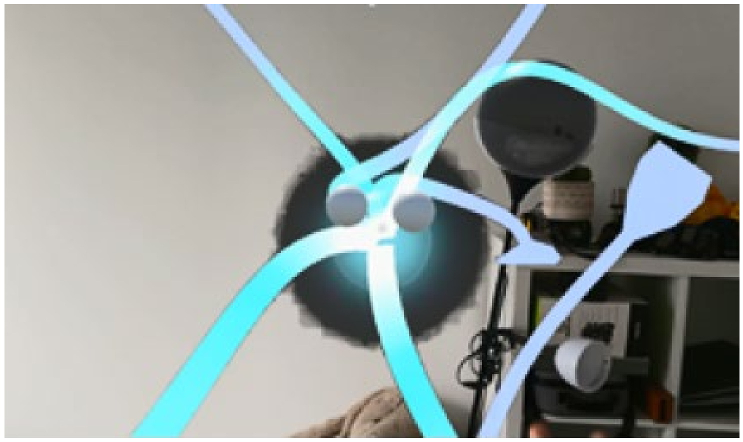


Figure 30. Early scenario and visual design sketch, and embodiment in Unity with 3D model.

Figure 31 presented an early prototype that implemented some of the functionality from the sketch scenario design. The original application in Unity has a virtual bulb entity, but when it was running in MR, it was not displaying properly with a transparent and a black effect around it, as shown in the image. This prototype embodied the virtual bulb with particle effect surrounding and provided the proof of concept of connection virtual and physical agents with the IoT.



When the virtual bulb is outside the physical lamp, the physical light is off.

When the virtual bulb is inside the physical lamp, the physical light is on.

Figure 31. An early prototype of controlling physical light with a virtual bulb that presented in Hololens 2.

5.2 Prototype 1: Shared Smart Lamp in Virtual and Physical Space

5.2.1 Description

The Shared Smart Lamp[39] (see Figure 32) is a prototype attempt to explore a new way to control physical objects with virtual elements in XR and the possibility to switch between VR and MR. The smart lamp is considered to be a shared object in MR because it embodies both virtual and physical environments at the same position, with both virtual and physical entities presented, that users can access. On the one hand, instead of using the traditional way to switch on and off a physical bulb by pressing a physical or virtual button, this prototype moves the virtual bulb (virtual body presented in VR and MR) in and out of the shared lamp to approach the function. On the other hand, the shared lamp (representing the lighting) is the affordance in both virtual and physical space, the physical light is also controlled using the enable and disable buttons in the virtual environment.

The users are required to wear the HoloLens 2 to access the MR environment. The system's initial state is a completely virtual space in the headset with green trees and mountains as the background, as well as a lamp and a bulb as interactable objects to approach a VR space, and the physical side with the light off. Users can move the bulb around the space with the ray attached to their hands. Once the virtual bulb is moved into the lamp, the physical light is turned on, and the virtual background is invisible, so the users enter the MR environment.

[39] https://github.com/jieguann/Shared-SmartBulb-Thesis-Prototype1

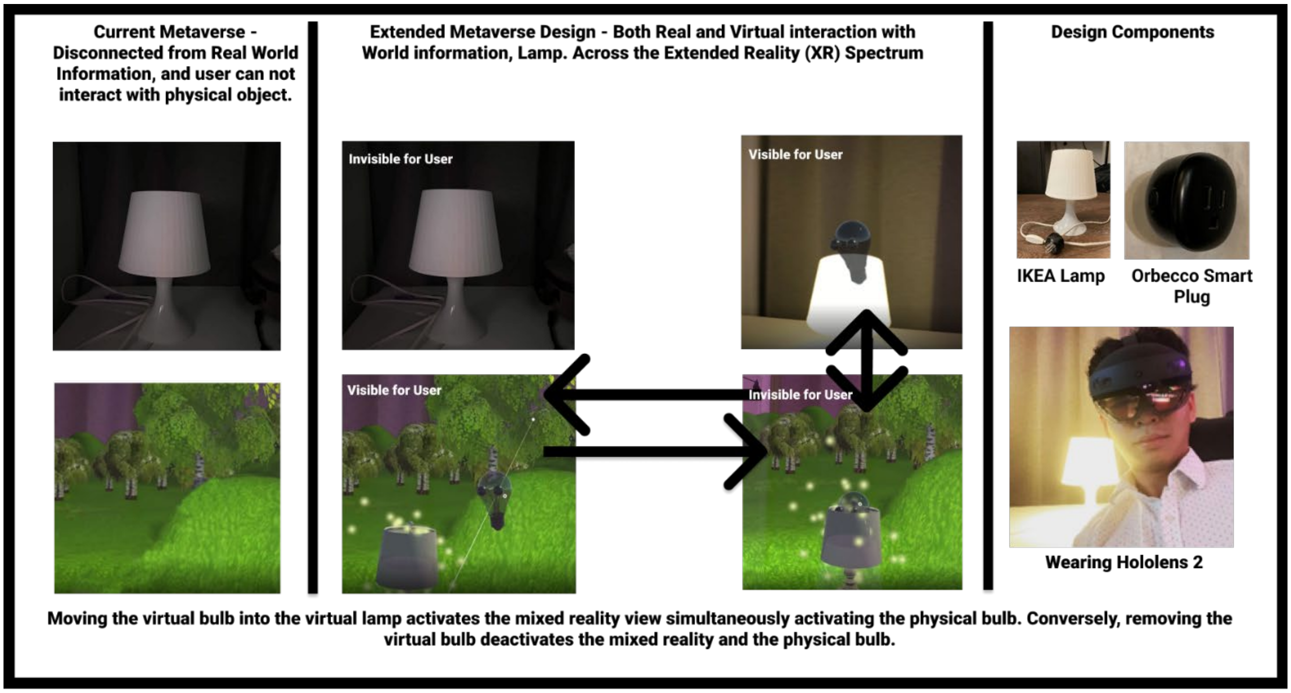


Figure 32. Prototype 1[40] - Design of an XRI Lamp Controller[41] - In the extended metaverse, virtual representations adapt physical behaviors (lamp and bulb controller interface when fully immersed). Similar MR interactions take place for controlling the virtual when in the physical environment.

5.2.2 Process

The project included a physical object, simulated virtual entities and environments, the interaction method, an HMD device, and data connection protocol. In the physical space, a traditional lamp from IKEA was transformed into a smart and IoT-enabled object with an Orbecco smart plug that can connect to the Smart Life app system. The computer-simulated 3D models of objects and the environment are rendered by Unity3D and visualized to the users with

[40] https://www.youtube.com/watch?v=byGyiOgM2iU
[41] Published in IEEEVR2022 Metabuild Workshop (Guan et al., 2022)

HoloLens 2. Meanwhile, HoloLens 2 also perform hand tracking to capture the gesture from users. The Mixed Reality Tool Kit (MRTK) can use these commands to enable the interaction of the virtual elements, presented as moving the virtual bulb in this prototype. The IFTTT[42] was used as the connection service for data communication in the project because it provides a direct way to connect the Smart Life system and Webhook, which can be commanded from Unity with HTTP Request.

5.2.3 Reflections and Limitations

The prototype provides a one-way data communication, from virtual to physical command, to switch the lighting by moving the virtual bulb in and out of the lamp. This switching method provides a new way to think about whether it is necessary to use buttons to turn on and off of the smart objects in the MR environment and encourages people to explore how to expand the dynamic interaction with objects with virtual elements. The switching between VR and MR environments provides a bridge for users to see the physical space. Although the current VR headset system indeed immerses the users into the completely computer-generated environment, it blocks one of the most important senses (vision) of users to access the physical context. As humans living in the physical realm, we cannot separate from it to completely enter the virtual space. Some people may argue that they can move off the VR headset from their eyes to come back to the physical area, but I would like to say this project is considering the futurist scenarios,

[42] https://ifttt.com/explore

where the smart glasses (or VR headset) become a part of human life like the mobile phone we use today and even a part of the human body.

The feedback I got from other peers and professors is that I need to think about more specific scenarios of how people should use it. One of the interesting suggestions is that I can consider the virtual bulb as a virtual pet because I create eyes to make it like a creature's appearance. The virtual pet can be like the natural pet to provide companionship for humans, so the virtual agent can have more dynamic animation and even have high agency to understand humans and the context. Some people also argue that switching on/off a light with a virtual bulb in MR is unnecessary because they can just press the physical button. I think this is a futurist scenario in which people are living in an MR space normally with smart glasses. The virtual interaction with physical agents is worth exploring. Another suggestion also helps me think of this further. For specific users, it may help disabled people approach some of the physical events with virtual interaction, like what this prototype presents with the switching of the light.

The limitation of this project is obvious because the HoloLens 2 technologies are not able to provide a fully immersive virtual environment with see-through holographic lenses (waveguides) and a 54-degree diagonal field of view. The see-through holographic lenses cannot visualize the virtual content like the traditional screen, and users will still see the blended physical background of the environment. The presentation of the virtual elements in this approach is also obviously influenced by the lighting of the surroundings. The intensity of illumination is high, or at daytime, the opacity levels of the virtual contents on HoloLens 2 become low while with a low-intensity lighting environment such as a room closing the curtains, turning off the light at night, the HoloLens 2 will provide a better experiment for the users to see the computer-generated elements. Another issue with this technology on the MR headset I used is that the contents with black color cannot be visualized properly. Concerning the low degree of the field of view, the viewers can see the boundary of the screen from the physical background, especially with a fully virtual environment present on the lenses. Hence, the video-passthrough MR headset is a better choice for better experiments.

The IFTTT for data communication works fine in this project to connect the Smart Life protocol and Unity with Webhook, but it is still not the best choice for the IoT connection in the prototype stage. Firstly, although it provides three free connection events for users to test, it is still a paid service with a month-by-month subscription to unlock unlimited connection events and more features. Additionally, we cannot access the server without a developer account, which means we do not have control of what it is processing on the server site. Hence, we can only process the command predefined by the IFTTT and their partner, such as the simple switch without custom control. Moreover, we do not know whether the data process on this third-party cloud server could provide privacy. Based on my experiment, anyone with the hyperlink they provide from the Webhook could control my light from anywhere (by entering the link on their Brower). Lastly, the server checks the update of the local devices' state in 10 seconds with a free account and three seconds with a pro account in Webhook. Thus, it has a significant delay to process the command sent from MR, which reduces the real-time feedback for users.

5.3 Prototype 2: MR Color Picker

5.3.1 Description

The second prototype[43] (see Figure 33) explores a more dynamic way to control the physical light from MR by changing the color instead of only turning it on and off. When wearing the MR headset, users can see some virtual planets with different colors and shapes moving around a virtual sun. The goal of the galaxy setting is to immerse the users into an MR universe space with their everyday surroundings to transform the living room into a dynamic and engaging space. On the physical side, four smart bulbs with color-changing features are installed that can provide an ambient color effect to the environment. Regarding interaction, the users can move a virtual rocket around space by air tapping and holding[44] it with hand tracking in HoloLens 2. If the rocket collides with the planets, then it will change its color into the color of the planet while the ambient lighting will also change to this color with the smart bulbs changing.

[43] https://github.com/jieguann/MR-Color-Picker-thesis-prototype2

[44] https://docs.microsoft.com/en-us/dynamics365/mixed-reality/guides/authoring-gestures-hl2

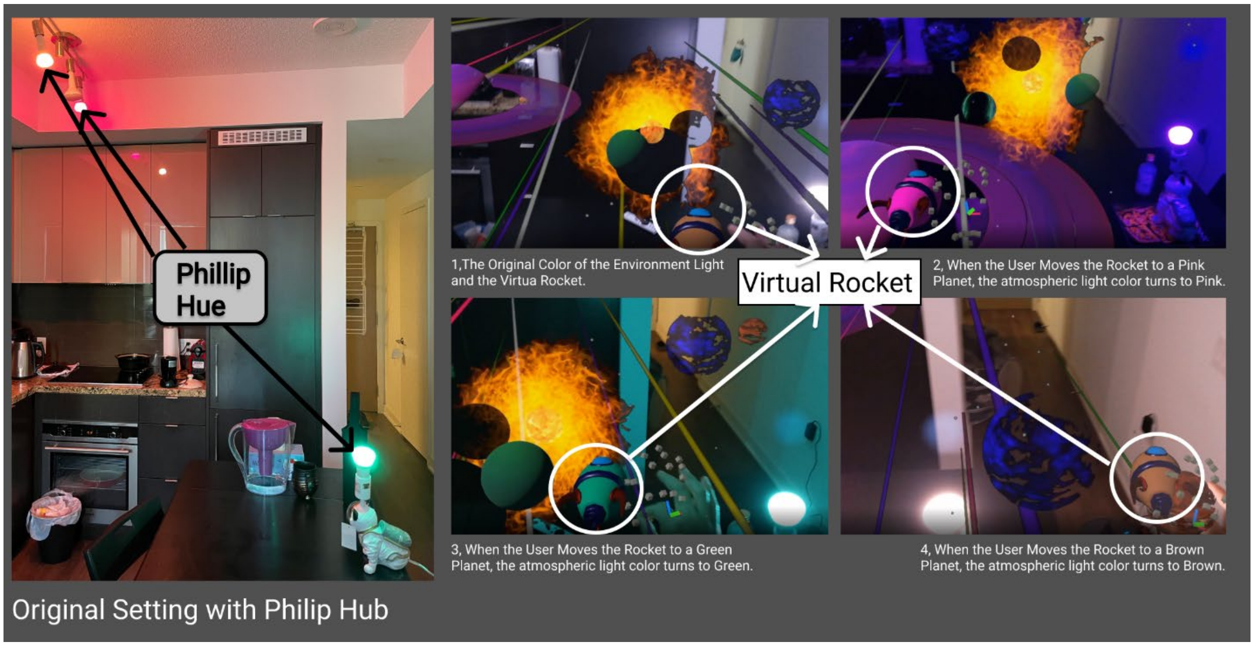


Figure 33. Prototype 2[45]–Design of an XRI Ambient Lighting Capability, with a virtual rocket to collide the planets to change the physical light to the corresponding color[46].

5.3.2 Process

The MR environment visualization and interaction are also made with Unity and MRTK in this prototype. The rotation of the planets (with various directions) around the sun is simply attached a Rotator script onto the sun entity, making it the parent object of other planets. The colors of the planets are defined by their textures while the rocket is considered to be an RGB color picker when it enters a planet with an "OnTriggerEnter" function. Concerning physical environment lighting, it is created using the Phillip Hue of the White and Color Ambiance Kit[47] and their Developer Kit[48]. The first step to making the Phillip Hue in developer mode is to get the local IP

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[45] https://www.youtube.com/watch?v=eHkH5pgXA9E
[46] Published in IEEEVR2022 Metabuild Workshop (Guan et al., 2022)
[47] https://www.philips-hue.com/en-us/products/smart-light-starter-kits
[48] https://developers.meethue.com/develop/get-started-2/

address of the Phillip hub, which is the bridge of the bulbs to connect the local network. With the HTTP GET method, it can require the bulbs' ID and its states (e.g., on or off, saturation, brightness, and hue) with JSON format. The HTTP PUT method (call from Unity on this prototype) is for controlling the states of the bulbs, and this project focuses on changing the color. The color of Phillip Hue is quantified by CIE color space[49] with X and Y values, so it must convert the RGB values getting from Unity to XY of CIE. The whole process of conversion is from RGB to XYZ on CIE, and then XYZ to XY of the CIE color space. A Unity plugin (pb_ColorUti[50]) is provided to easily process the RGB into XYZ, and the calculation from XYZ to XY is processed with the formula $X = \mathrm{X}/(\mathrm{X}+\mathrm{Y}+\mathrm{Z})$ and $Y = \mathrm{X}/(\mathrm{X}+\mathrm{Y}+\mathrm{Z})$ (Kerr, 2010) to be implemented in Unity.

5.3.3 Reflections

The current MR applications do not provide the capacity for users to manipulate the physical objects with the MR interface, and users still need to access and control the physical environment in the traditional way—through physical touch. Meanwhile, although the exploration of the smart home system provides the users to monitor and control their physical IoT-enabled devices in their mobile phone application, Shao et al. (2019) indicated that the current IoT dashboard design is widget-based with a 2d graphic user interface and face scale challenges to deal with a large number of devices. Hence, an MR interface method of connecting the virtual elements and the physical space is needed for a more dynamic engagement and efficient interaction. In my opinion, the physical ambiance lighting provides a highly immersive MR environment while combining the virtual galaxy in this prototype, especially the color picker interaction that affects

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[49] http://hyperphysics.phy-astr.gsu.edu/hbase/vision/cie.html
[50] https://github.com/jieguann/pb_ColorUtil

the physical lighting color with the virtual planets and rocket. In addition, ambient lighting can also be used to enhance user immersion into the MR environment because it changes the atmosphere of the users' surrounding that links to the virtual environment. As presented in Prototype 2, the ambient color of the physical environment will change based on the planets on the interaction with the rocket in the virtual realm, that users will feel they are landing on that planet because their ambient lighting is changing to the color of that planet.

5.4 Prototype 3: Emotional Interaction

5.4.1 Description

Prototype 3[51] (see Figure 34) attempts to explore the relationship between human emotion and color, with a virtual environment that reflects the human's emotional state through color changing. Based on the deep networks for the facial expression recognition model (Barsoum et al., 2016) and the example in Unity of EmotionFerPlus[52] from Keijiro Takahashi, the system can recognize the human emotional state from video resources or real-time video. This project uses an online video source of decoding facial expressions[53] as the input to visualize how the color changing is related to the facial emotion. The computer vision emotion analysis model can provide seven states of the emotion with scores (neutral, happiness, surprise, sadness, anger, disgust, fear, contempt) that can be mapped into the color that developed based on Jamet's emotion color wheel (see Figure 35).

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[51] https://github.com/jieguann/Emotion-Effect-Thesis-Prototype3
[52] https://github.com/keijiro/EmotionFerPlus
[53] https://www.youtube.com/watch?v=B0ouAnmsO1Y

Figure 34. The image shows a screenshot of Prototype 3[54], with a video playing and computer vision model to capture the Emotions to affect the color of the virtual trees and grasses.

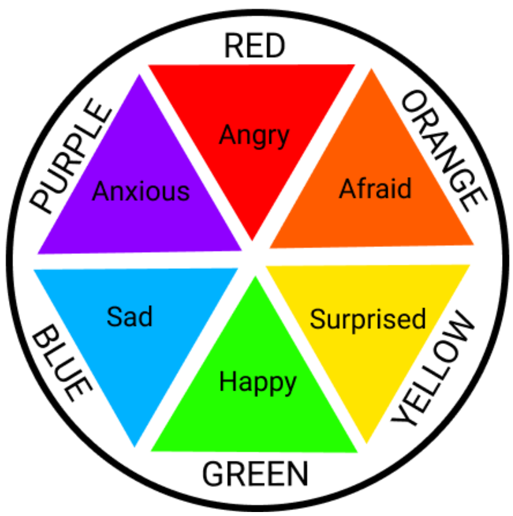

Figure 35. Jamet's Emotion Color Wheel[55]

[54] https://www.youtube.com/watch?v=HpYXZP1bDPc&t=42s
[55] https://blossomireland.ie/body-maps-and-emotions-colour-wheel/

5.4.2 Process

The emotion recognition part should be supported by computer vision and deep learning, and this project is used the example project from Keijiro Takahashi as previously mentioned. Various models could be chosen to reflect the emotion in color (Conte & Nijdam, 2009), and the project starts with the simple one - Jamet's emotion color wheel. The color of objects, such as the grasses, leaves, branches, in the virtual natural environment is affected by the emotional state of the input video source. The computer vision model detected emotional levels for happy, surprised, afraid, angry, anxious, or sad based on the video and provided a value to change the degree of green, yellow, orange, red, purple, and blue that link to the material of the virtual objects. Figure 36 shows the Shader Graph[56] in Unity to implicate the logic. Each color is

[56] https://unity.com/shader-graph

multiplied by a float value linked to emotional state and level. The output color degrees are added together to construct the objects' color.

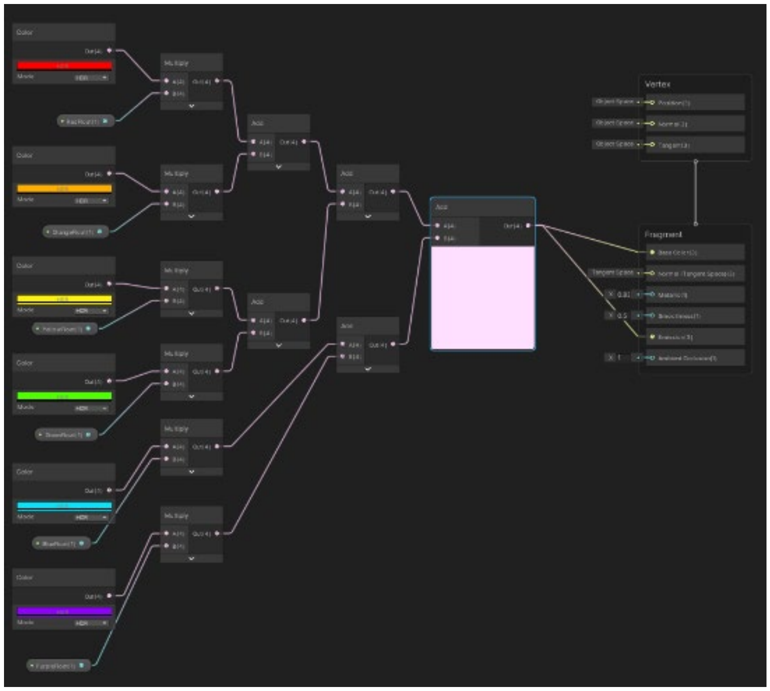

Figure 36. Unity Visual Graph to implicate the logic of changing color. It indicates the relationship between the input values and the representation of the virtual environment.

5.4.3 Reflection

This prototype attempts to explore how physical context, especially the human state, can directly affect the computer-generated graphic. Unlike the previous two prototypes of virtual to physical interaction, it includes control over the virtual world based on physical context information, especially human emotional states. Although this project chose an online pre-recode video to be monitored the emotional states and control the emotional value, it can be transformed into real-time video input with a webcam to capture human facial expressions easily. Based on the reliable rules study and design, like the color wheel used in this project, I am able to create the feedback loop from physical to virtual interaction logically and dynamically. For example, when the computer vision model detects the person in the video showing happy emotion, the virtual environment shows green. The feedback loop of the interaction between physical and virtual is a key element of this project consideration, as it means connecting the physical and virtual world. It enables the user to intuitively be aware of and interact with the rules of the system.

5.5 Prototype 4

5.5.1 Description

Because I was aware that the computer vision method is not able to capture the human emotion from faces when wearing the HMD MR headset, Prototype 4[57] (see Figure 37) explored how the human brainwave could affect the moving and color of particles and used the virtual universe as the background. It embodies the effects of the brain activities that represent emotional statuses. The Muse 2 system[58] can capture the human brainwave that reflects the status through Gamma, Beta, Alpha, Theta, and Delta waves. The human status would provide the influence of the universe background, as well as particle speed, force, and color, which are the visualization methods of physical information of humans in the metaverse environment.

[57] https://github.com/jieguann/BrainWave-Universe-Movement-Thesis-Prototype4
[58] https://choosemuse.com/muse-2/

Figure 37. Prototype 4[59] shows the universe background and particle effect movement based on the brainwave from user status.

5.5.2 Process

The brainwave frequency links to different human states, and each has characteristics (Marzbani et al., 2016). The author of the article from the Muse website shows the meaning of each brainwave frequency (*A Deep Dive Into Brainwaves: Brainwave Frequencies Explained*, 2018). Figure 38 presents the framework, processes, and tools used in this project, along with the meaning of the brainwave, and how they affect the virtual elements. As the previous part mentions, Muse 2 is used to capture the brainwave from the human brain. With Bluetooth connected to the mobile phone, the Mind Monitor app can send data to Unity through OSC streaming for visualization, through Visual Effect Graph (see Figure 39) for generative particles,

[59] https://www.youtube.com/watch?v=uzkjSNrsjTk&t=30s

and through Shader Graph (see Figure 40) for background. Rules of the particle and universe background performance are present below with *A Deep Dive Into Brainwaves: Brainwave Frequencies Explained* (2018):

1. Gamma means solving problems and reasoning brain activities. Thus, its value controls the speed of the particles. If the Gamma frequency is higher, then the moving speed of the particle is faster.
2. The Theta frequency is used to demonstrate the deep states and dreams of the human mind. In this project, its value has been used to affect the size of noise texture on universe background and drag force of particles.
3. The Beta signal is generated when the brain is thinking and excited, and it is linked to the Red degree of color for particles.
4. Delta is the bodily awareness signal, and it controls how much the universe texture is presenting on the scene and the particles' Green value.
5. Alpha is related to the relaxed state of the human brain, and it controls the Blue value of the particle color.

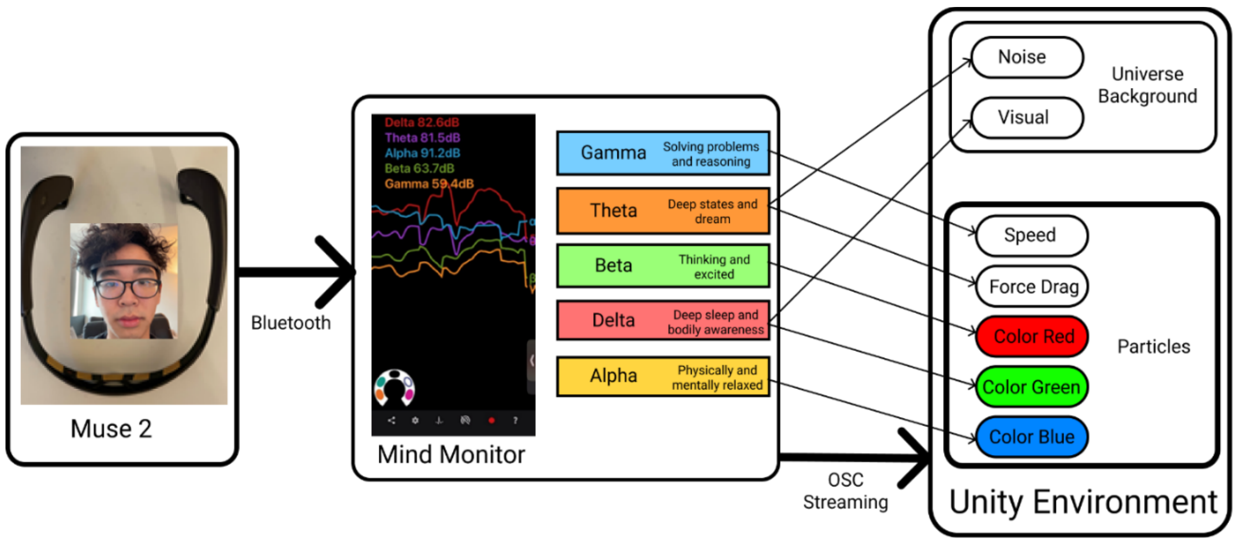

Figure 38. The framework of Prototype 4

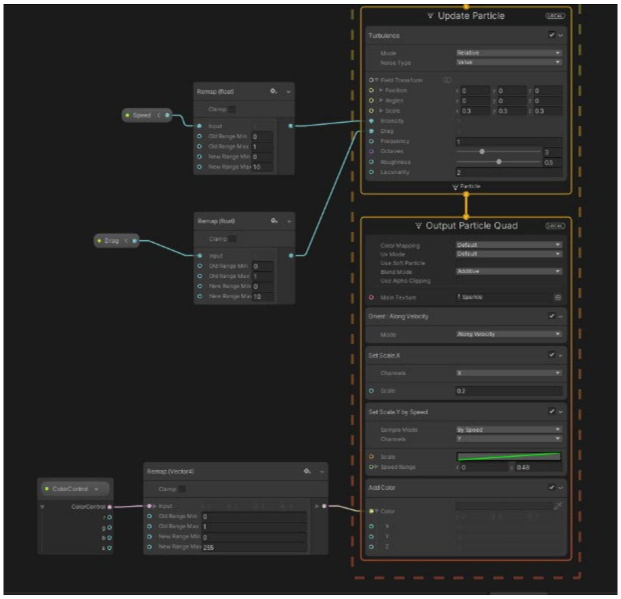

Figure 39. Visual Effect Graph for generating particles

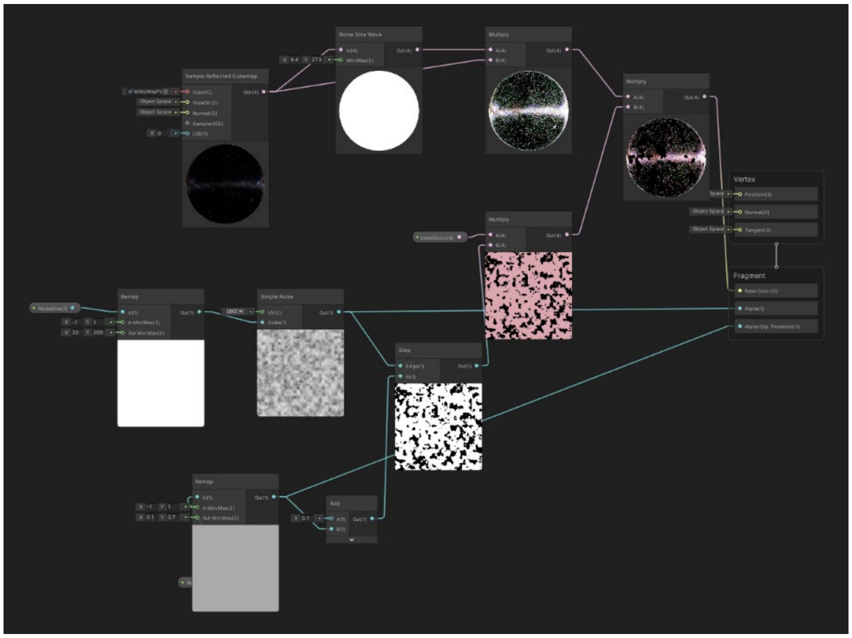

Figure 40. Shader Graph for Universe Background

5.5.3 Reflection

This project continues exploring the physical context that affects the virtual elements. Instead of using computer vision to detect emotion, it considers a physical device worn on the head to capture the brainwave. The device is then connected to the mobile phones to process the signals, and the human states are calculated through the brainwave. The novelty of this project is about combining affective computing to explore the possibility to include brainwaves (representing human states) as context for designing the future human and computer interface. Although this prototype chose a physical device to replace the computer vision method, it is still implemented in one-way interaction from physical to virtual and showing on a 2D screen, and directly affecting the information.

Additionally, the brain-computer interface is one of the most important techniques to explore MR and the metaverse that can control the virtual objects through "thinking." If we have the brain interface and immersive MR glass, then we can see the virtual world and interact with it through our minds.

5.6 Prototype 5: Adaptive MetaPlant

5.6.1 Description

The goal of this prototype is to illustrate a more complex extended metaverse agent scenario with a generative object and context awareness approach in a smart space. This prototype (see Figure 41) uses location (computer vision detect a user in front of desktop) and timing (the time of user sits in front of the computer) as context to affect the shape, effect, and growth of the MetaPlant (the virtual plant from the metaverse) and the color of ambient light, as well as when using a mobile phone, will attract a virtual butterfly to fly around the head of the user. This project aims to build an immersive and dynamic "clock" to provide a ten-minute block alarm to prevent users from sitting too long in front of computers and the distraction of virtual butterflies flying around when the user uses a cellphone at work. It is a kind of data visualization project that represents the time as the virtual tree grows and turns the minutes to the iteration of the L-system. This project provides two-way communication (information connection from virtual to physical and vice versa) between the metaverse and physical space by applying the light control from Prototype 2 and expanding into prototypes 3 and 4 with context detection by computer vision. In addition, it is a proof-of-concept prototype that demonstrates how the generative and procedural virtual object through the L-system and flocking algorithm could enhance the dynamic of the extended metaverse environment. As demonstrated in Figure 41, a Philip Hub ambient light is presented as an actuator by changing color in the physical space. At the same time, a webcam can be used as a sensor in a computer vision model through a web browser to detect whether the user is in front of the computer. In this scenario, the user is wearing a HoloLens 2 to enter an extended metaverse space that could see the virtual embodiment of the plant agent and butterfly. The virtual plant has eight states, with iterations growing with L-system with timing and the size of the fire and physical lighting color after six minutes.

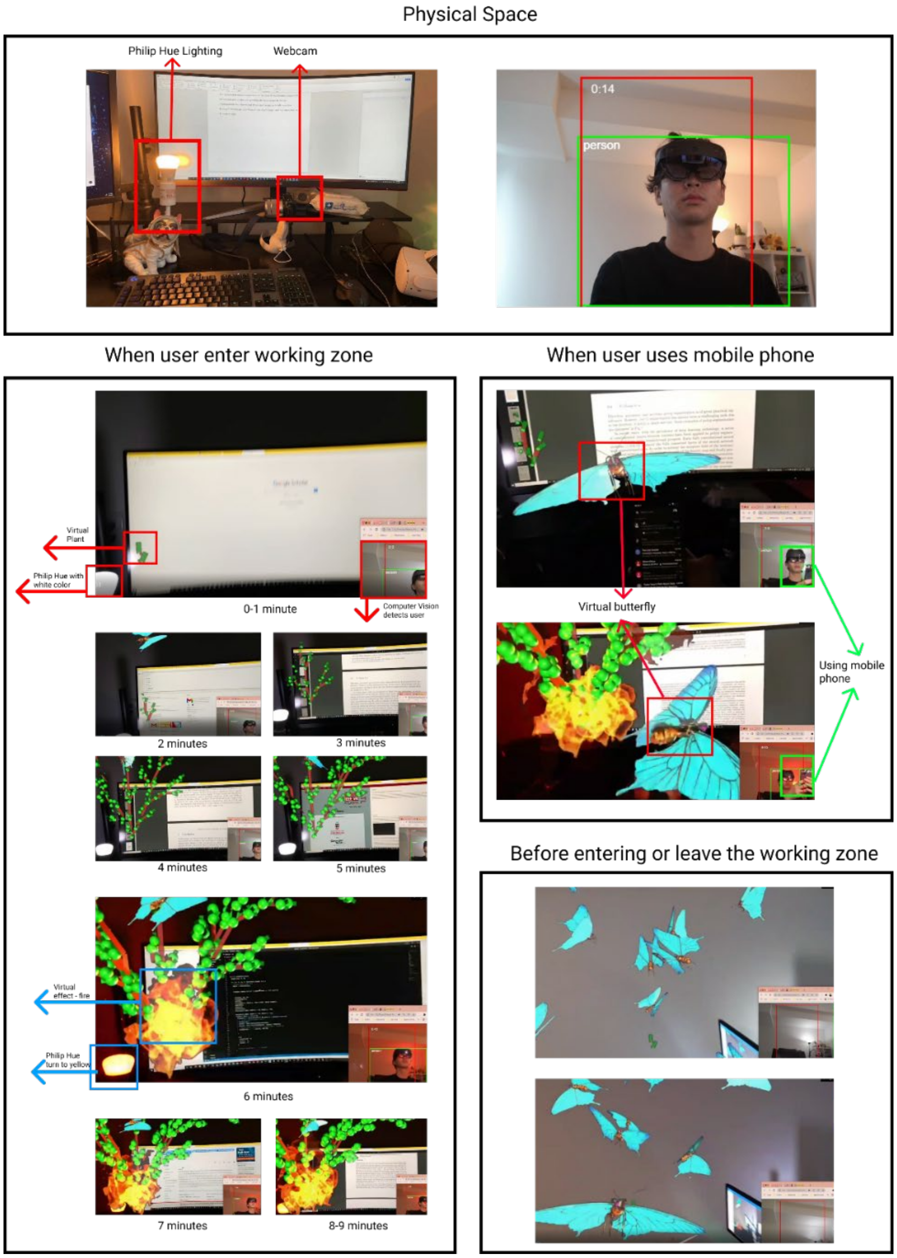

Figure 41. The events happen in Prototype 5[60], with a tree growing, particles effect shows, and physical light changing color based on the time of the user sitting in front of the working zone, and the butterfly moving around the user when playing mobile phone.

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[60] https://www.youtube.com/watch?v=8-mS2F5Q5aM

The architecture (see Figure 42) of Prototype 5 presented MQTT Broker is the IoT protocol hosting on the cloud to connect the computer vision model and the Unity environment. The COCO[61] pre-trained model, which is a large-scale dataset of object detection, is considered and running with Tensorflow.js[62] through a browser to detect human presented as time and mobile phone presented, and publish this context information to the MQTT Broker with Minutes and Cell Phone Presented topics. Unity is the visualization and interaction engine used to subscribe to these topics and use these data to generate a virtual plant with L-system and operate the butterfly movement. Regarding the physical implementation, a Philip Hue was considered in Prototype 2 to change a physical agent that presented the two-way communication between the metaverse and physical space.

[61] https://www.tensorflow.org/datasets/catalog/coco
[62] https://master.d3leejw38swymm.amplifyapp.com/about

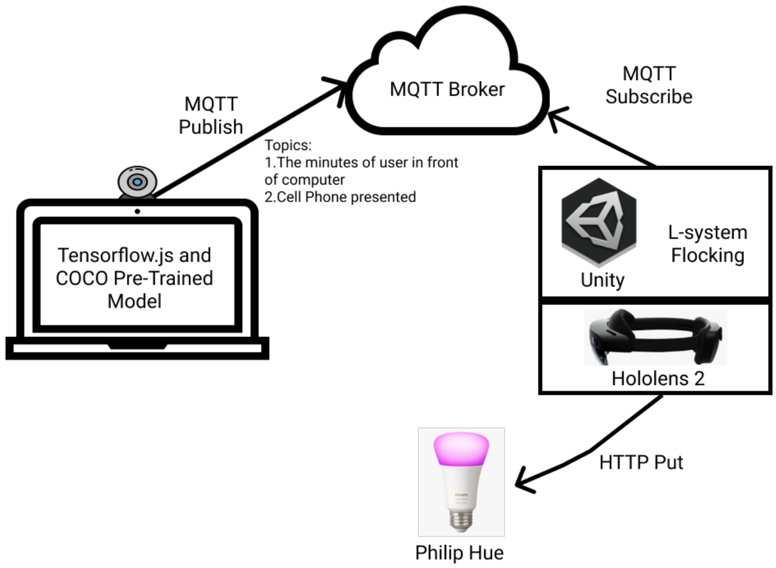

Figure 42. The architecture of Prototype 5 with the IoT (MQTT and HTTP protocol) connection between physical (computer vision model detect environment context) and virtual (Unity visualization with Hololen 2) environment.

5.6.2 Process

This prototype started by designing the framework (see Figure 43) of the interaction between physical space with computer vision detection and the extended metaverse space with visualization in HoloLens 2 through MR. As previously mentioned, the computer vision model will detect whether the user and the mobile phone are inside the box. Moreover, the virtual presentation is the butterfly behavior and the growing of a virtual tree that links the context of physical space.

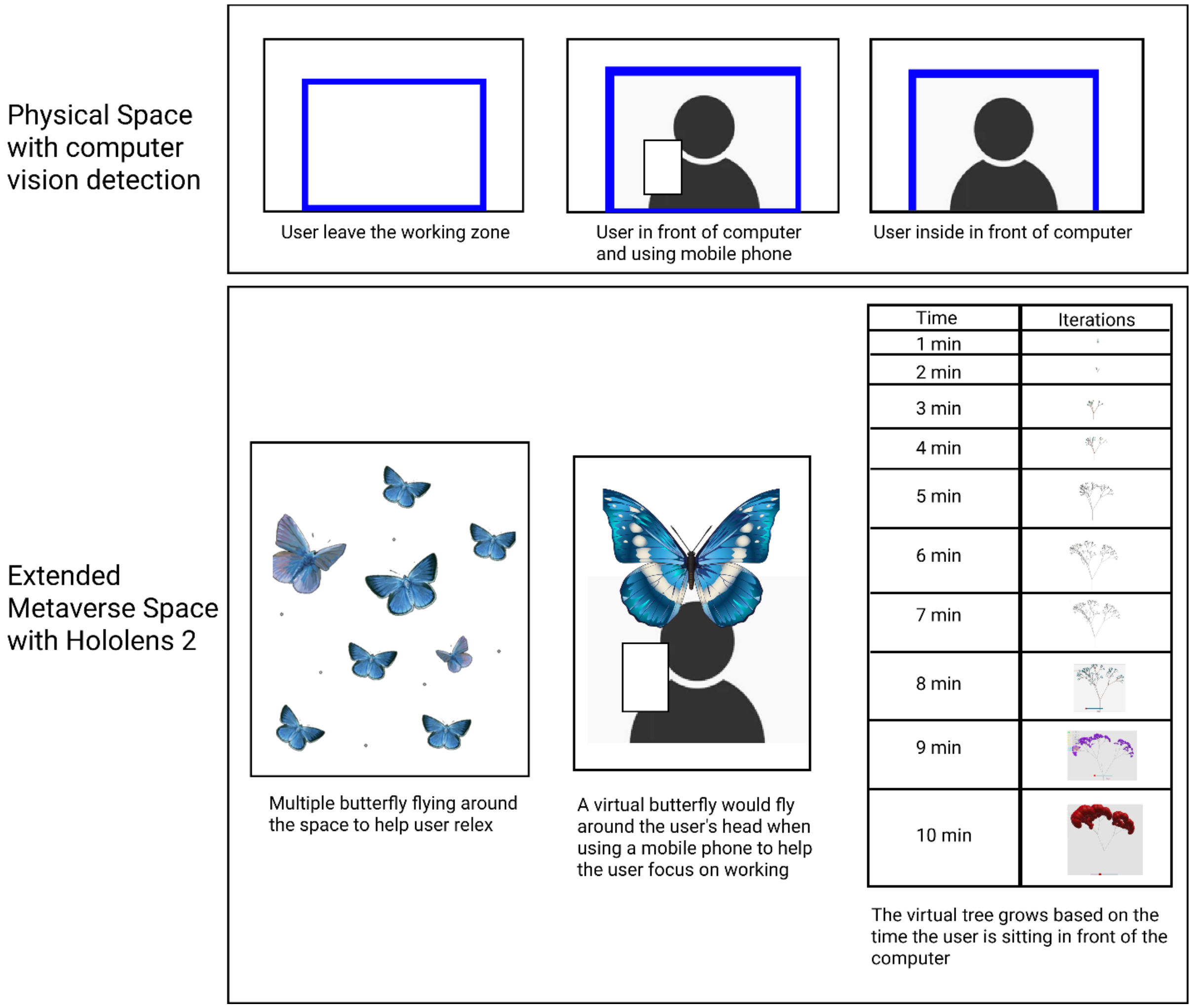

Figure 43. Framework Design of Prototype 5 of working zone detection for the user, the interaction of the butterfly, and the growing of the tree based on time.

The development process starts with learning a course from Daniel Shiffman[63] with ml5.js[64]of object detection with the COCO-SSD.[65] Then it was adapted only to detect when the label is

[63] https://thecodingtrain.com/learning/ml5/1.3-object-detection.html
[64] https://ml5js.org/
[65] https://github.com/tensorflow/tfjs-models/tree/master/coco-ssd

equal to "person," and the timing of minutes will start. The code is also present when the label is equal to "cell phone," and the timing of the cell phone presented also will start. For IoT communication, the detection agent connects and publishes this context information as topics to the cloud MQTT Broker with MQTT.js[66] through WebSocket. The script is presented below:

```
if(object.label == "person"){
    if(object.x < widthC/4+widthC/4 && object.x > widthC/4-widthC/4){
     // console.log(performance.now());
     totalSecond++;
     minutes = Math.floor(totalSecond/3600);
     seconds = Math.floor((totalSecond - minutes *3600)/60);
     // milliseconds = totalSecond - (minutes*3600 + seconds*60);
     text(minutes + ":" + seconds, 190,50);

    }
    else{
     totalSecond = 0;
     minutes = 0;
     seconds = 0;
    }
    //console.log(minutes + ":" + seconds);
   }
   //control cell phone value
   if(object.label == "cell phone"){
    totalCellPhoneSecond = 0;
   }
   else{
    if(CellPhoneSeconds<3){
     totalCellPhoneSecond++;
    }
   }

client.publish('jieThesis/MetaPlant/seconds', seconds.toString(), { qos:
0,retain: false });

client.publish('jieThesis/MetaPlant/minutes', minutes.toString(), { qos: 0,
retain: false });
```

[66] https://github.com/mqttjs/MQTT.js

```
client.publish('jieThesis/MetaPlant/totalSecond', totalSecond.toString(), { qos: 0, retain: false });

client.publish('jieThesis/MetaPlant/CellPhoneSeconds',CellPhoneSeconds.toString(), { qos: 0, retain: false });
```

The cloud communication protocol initially attempted to use the public MQTT Brokers, such as Eclipse[67], Mosquitto[68], and HiveMQ[69]. However, after testing many times, I realized they were not working properly and have little security. Then I decided to host a private broker with Mosquito[70] installed on DigitalOcean[71] (see Figure 44) and enabled the WebSockets connection[72] for the web-based computer vision model to connect. DigitalOcean is an online platform with an easy-to-use user interface to host cloud services, and the affordable and scalable price plan has benefits for students and small prototypes. With the web-based command prompt, users can manipulate the virtual cloud machine on their local computer. Monitoring the data and topics with MQTT Explorer[73] in MQTT brokers (see Figure 45) could enhance the development process of the IoT connection. With MQTT Explorer, as a developer, I could test the self-host broker by public topic and monitor the data transmitted in real-time.

[67] mqtt.eclipse.org
[68] test.mosquitto.org
[69] broker.hivemq.com
[70] https://mosquitto.org/download/
[71] https://www.digitalocean.com/
[72] https://gist.github.com/smoofit/dafa493aec8d41ea057370dbfde3f3fc
[73] http://mqtt-explorer.com/

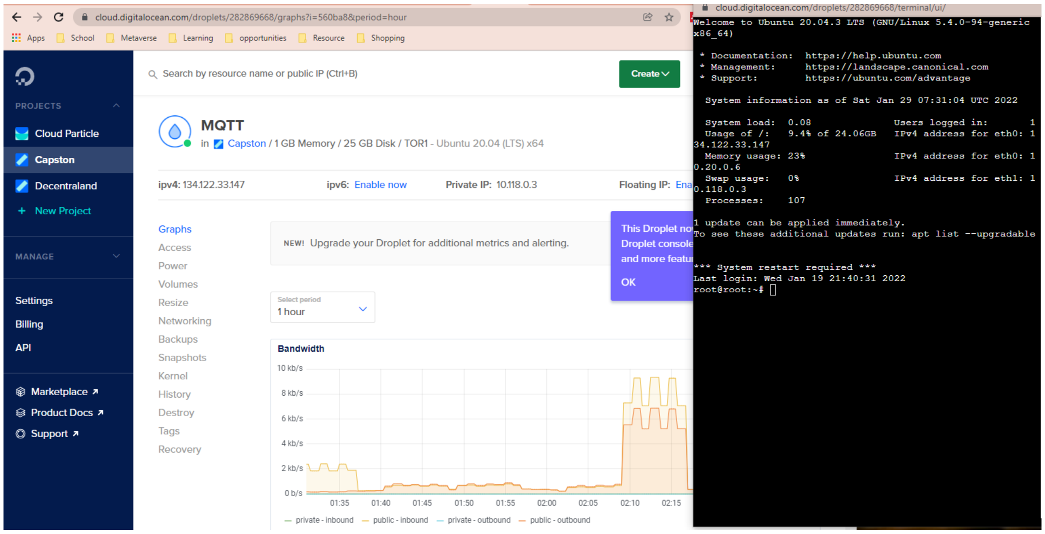

Figure 44. DigitalOcean

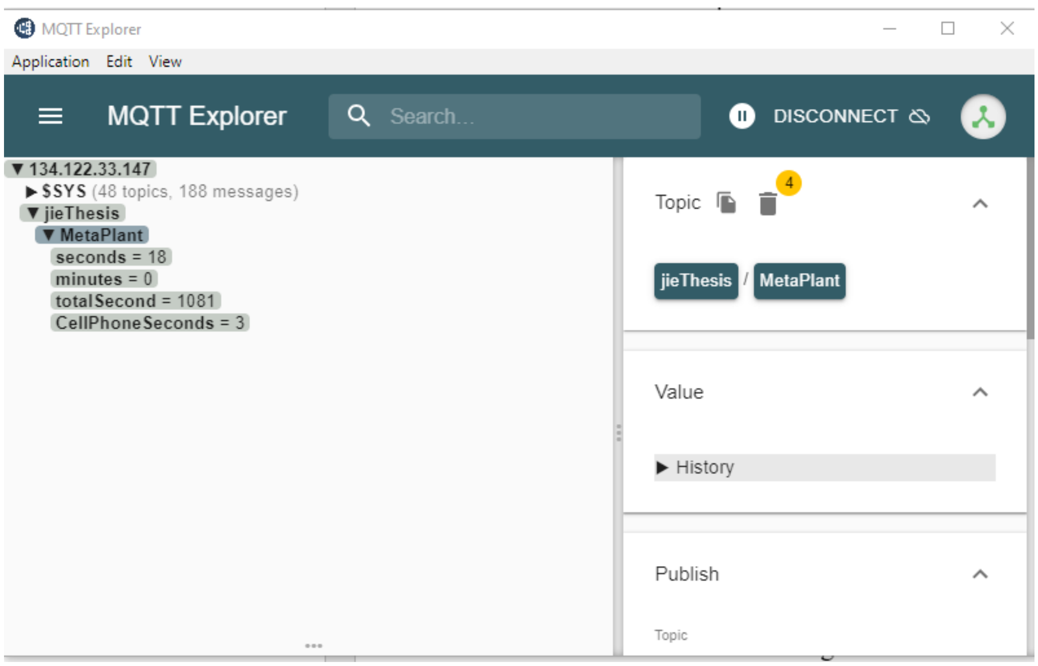

Figure 45. MQTT Explorer

Concerning the visualization of the virtual content in HoloLens 2 with Unity, the major development is the L-system for generating the virtual plant with iterations and the flocking behaviors of the butterfly (see Figure 46). The L-system implication started with the project from Pejoph[74] with the pre-set of alphabets (as mentioned in Section 2.4.1.1L-system) to indicate the growing shape of the virtual tree in different iterations. As shown in Figure 47, manipulating the leaf shape (adding a green sphere) and adding fire particle effect to the virtual tree growing process could enhance the dynamic of the experiment. The butterfly's movement is controlled by flocking, and the tool from Cloud Fine[75] is considered. For butterfly movement between the head of the user and the virtual plant, the queue behavior is considered. Based on the MR headset position, which presents the head's location in the extended metaverse space, the invisible target can be switched between these two positions in different conditions. Finally, as 5.3 Prototype 2: MR Color Picker presented, the physical light (Philip Hue) is controlled by sending HTTP Put with the JSON data format.

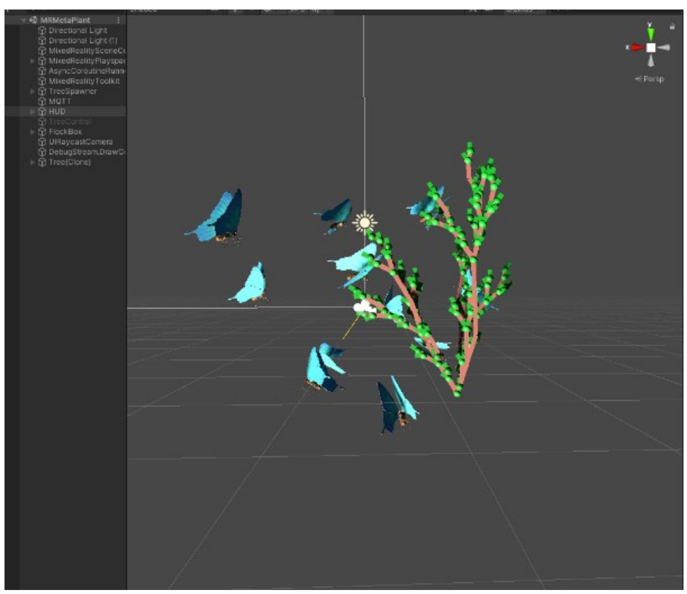

Figure 46. Unity Scene

[74] https://github.com/pejoph/L-Systems
[75] https://assetstore.unity.com/packages/tools/ai/flock-box-dots-155028

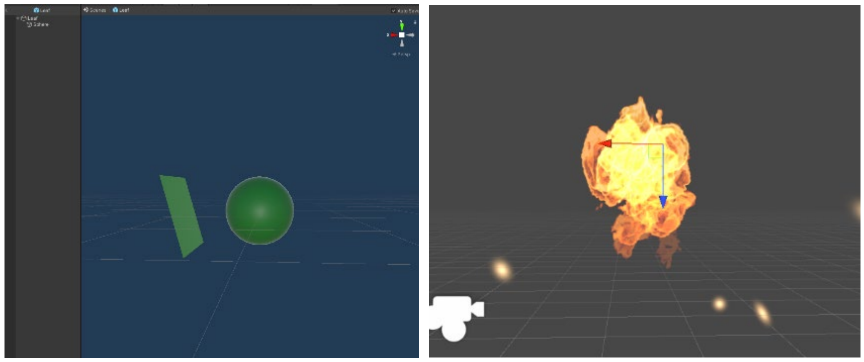

Figure 47. Green Sphere in the Leaf Prefab and the Fire Particle Effect

5.6.3 Reflection

Because the technologies of computer vision detect emotion from the face and use sensors to capture brainwaves for human states, prototypes 3 and 4 are not suitable for wearing MR headsets, and the data are not reliable and accurate, this prototype simplifies the detection of context, by capturing human and mobile phone present in front of the computer. By combining the color control of the light from Prototype 2, it can perform two-way communication between metaverse content and the physical agent. With the generative object of virtual plant, the system indeed enhances the users' dynamic and engageable MR. However, although the original idea for this project was to provide an agent for timing and help users focus on working with the computer, the visualization of virtual graphics in MR could distract the users from seeing the screen. Moreover, it can still not anchor the virtual object on the ideal physical location, such as the virtual plant should position on the plane of the desk, but it is floating on air currently. The marker-based or image-based MR method should be considered for the future prototype to connect the virtual and physical location. One of the future directions is to provide a method to allow users to customize the timing. This prototype has proved that the computer vision model is a simple way to capture uncomplex the physical context and could provide accurate results. It also tested the generative tree could work properly in the Unity engine and could grow virtually based on the physical information.

6 Final Prototype

6.1 Description

The goal of the final prototype is to combine the previous experiment with a more accessible way with a low-cost Oculus Quest 2[76] device. Because the previous project does not have the solution of positioning the virtual object to the physical environment, this approach uses the keyboard (with Apple Magic Keyboard[77]) (see Figure 49) as the marker to anchor the virtual object to the desired position that is related to the physical environment.

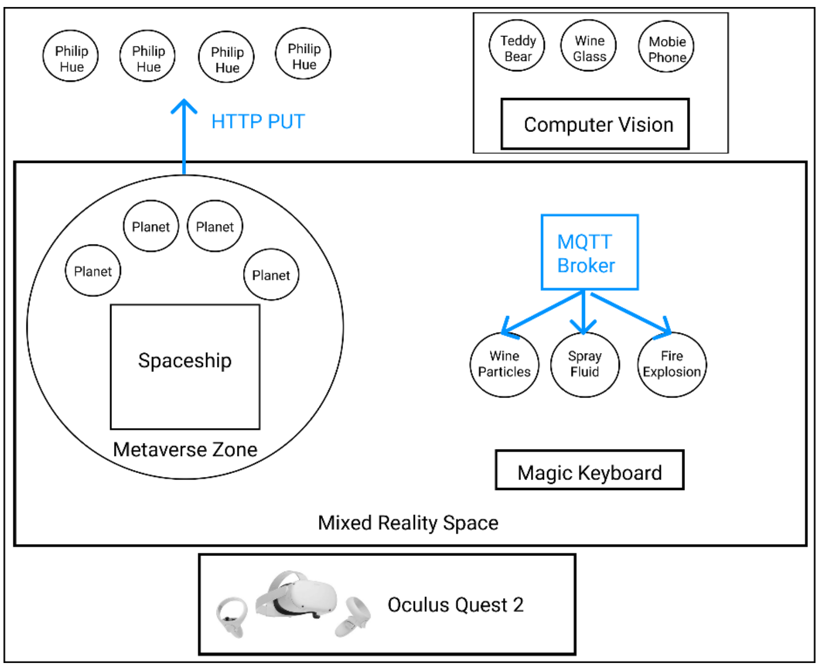

Figure 48. The framework design for the final project, with a metaverse zone and mixed reality space present in Oculus Quest 2, could connect to the Philip Hue that represents physical objects.

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[76] https://www.oculus.com/quest-2/
[77] https://www.apple.com/shop/product/MK2A3LL/A/magic-keyboard-us-english?fnode=19843616d15903564d495321c4994fd7c81545d9285bc82622c9d092fbdc96b4cd4b3f492e75878bca17e737b7e7abeeaf56d9462dea7a7154f0a85045ca9ee5134a12ee441a207f1698c7b3f560bdf7a412d8f3a0db1cfaf9e5f29b7929ad45

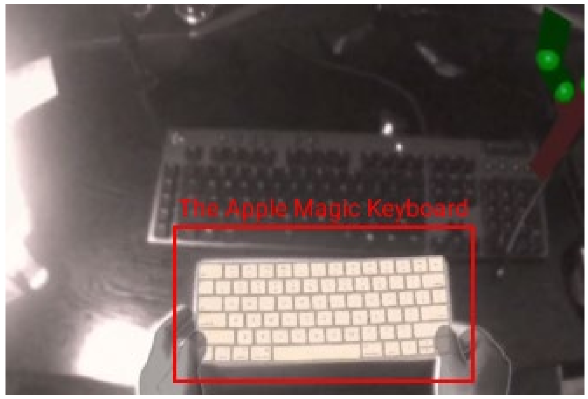


Figure 49. View of the Apple Magic Keyboard used in Oculus Quest 2 to anchor the virtual objects and environment.

This approach involved designing a metaverse zone (see Figure 50) in the physical space by combining Prototype 1's switching capacity between two spaces. The virtual environment (a spaceship and universe background from Prototype 4) would appear immersive when users enter the area. One of the new features of this prototype of entering the metaverse is the virtual environment is embodying gradually by changing the alpha of the virtual spaceship based on the distance between the users and the metaverse zone. The virtual bulb is also a shared object of the metaverse and MR environment. The user could switch the physical light by moving in/out in a specific area in the MR space and need to bring it to the metaverse zone and to control the spaceship movement in the virtual universe. In the virtual environment, the bulb should attach to the virtual joystick to control the movement of the spaceship in the universe. The two-way communication tested in Prototype 5, from virtual to physical and from physical to virtual, was also implicated in this project. On the one hand, switching on and off the physical light using a virtual bulb is one of the interactions from virtual to physical communication.

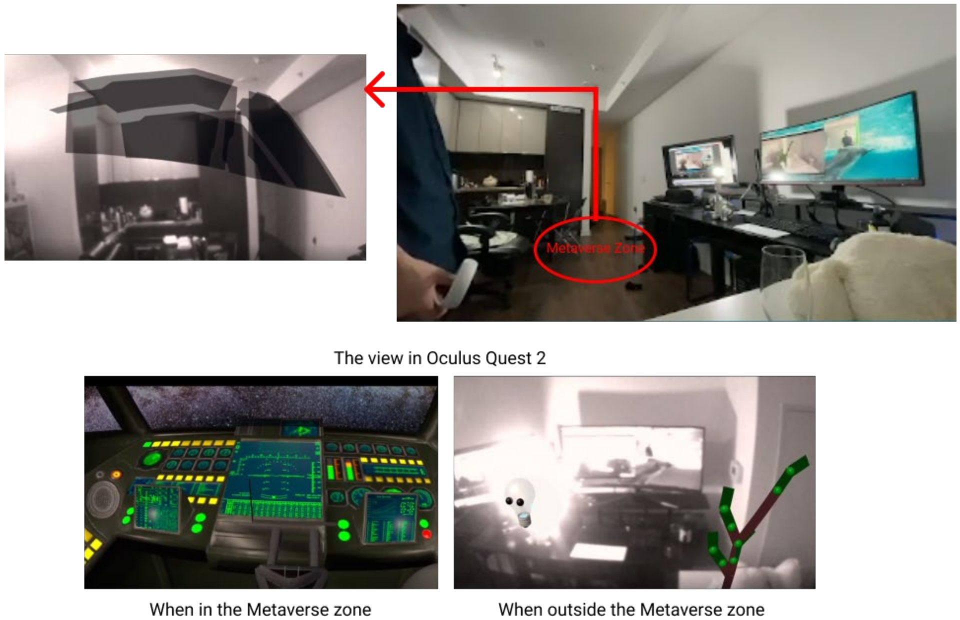


Figure 50. The design of the Metaverse zone location is related to the physical environment and views in and out of the Metaverse zone[78].

Additionally, when driving the spaceship in the metaverse, there are many planets moving toward the users. Users can move the spaceship by manipulating the virtual joystick to avoid or collide with the planets. If the spaceship hits a planet, then the physical ambient light will change the color to the planet's color (the user can not be aware of this because the physical environment in Oculus Quest 2 is black and white) (see Figure 51).

[78] https://www.youtube.com/watch?v=BuaRgL45GTs

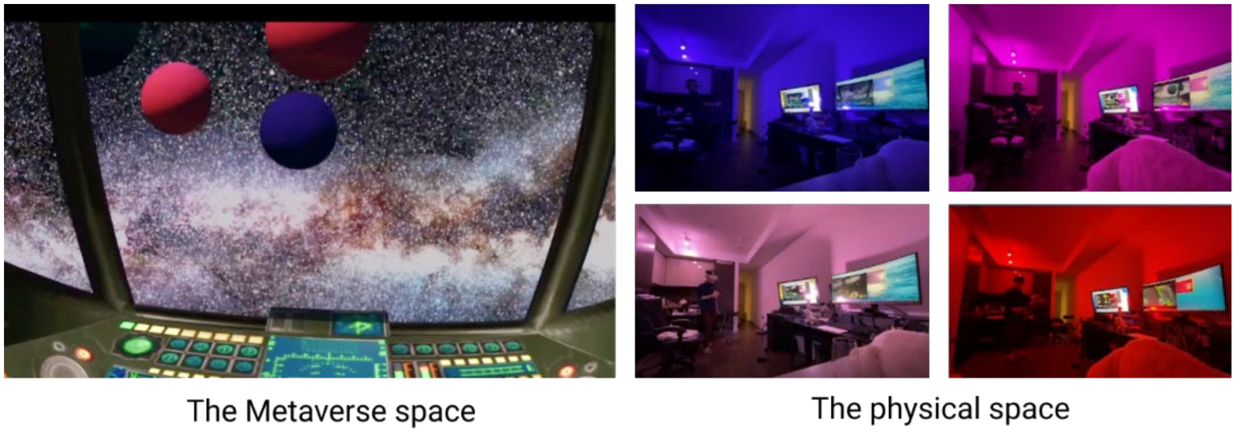


Figure 51. The view on the virtual environment when spaceship hits the planet and physical environment will change to the related color.

On the other hand, similar to Prototype 5, the from physical to virtual interaction use a computer vision to aware the physical context. The generative tree based on the user's time in front of the work zone is also incorporated into this project, plus object detection to affect the virtual presentation. When the computer vision model detects wine glass, teddy bear, and phone, the MR environment will relatively display flowing wine particles, spray fluid, and fire explosion (see Figure 52).

Figure 52. The computer vision detects a wine glass, a teddy bear, and a mobile phone and presents flowing wine particles, spray fluid, and fire explosion.

6.2 Process

The first step of this project is to set up the passthrough API for the Oculus Quest 2, and although it has strong documentation, it still requires much time to figure out the setting. In Unity, it needs to attach the OVR Passthrough Layer for the OVRCameraRig and change the camera background to transparent. To use hand tracking and keyboard tracking, the setting in the OVRCameraRig need to enable these features. Other settings for building on the device are ARM64, IL2CPP, and linear color rendering. The same protocol was used from prototypes 2 and 5 with Phillip Hue to interact with the physical light in the project with HTTP PUT to switch and change the ambient lighting color. Concerning context awareness in computer vision and communication with Unity, the same methods from Prototype 5 are considered.

6.3 Reflection and Limitation

The final project has combined the previous experiment into a more complex extended metaverse agent prototype in an MR smart space. The consideration of using the Oculus Quest 2 as the headset could provide a more accessible way for the design because the price is reasonable, compared to the high price of the HoloLens 2, which is only sold to businesses. This device could also provide a more immersive experiment through the video passthrough and have a better solution by anchoring virtual objects to the physical with a trackable keyboard. However, it has limitations on the visualization of the physical space and tracking with hand. The embodiment of the MR from the video passthrough could only provide black and white because of the built-in camera limitation. Moreover, hand tracking can not work properly in a dark environment, and once the light are turned off, the tracking will not work. Hence, this project still considers using the controller for the interaction with the virtual objects.

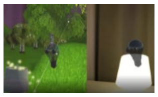
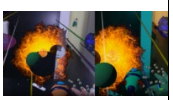
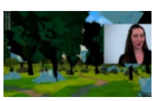
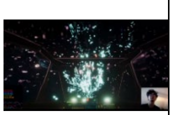
7 Discussion and Evaluations

This section discusses and evaluates the iterative prototypes and the final project. Firstly, it will present a comparison table (see Table 4) of the prototypes with questions, problems, features, benefits and limitations. Then, a subjective table (see Table 5) and radar plot (see Figure 53) will show the score of the prototypes in nine parameters for demonstrating how to develop a better extended metaverse agent. Lastly, a table (see Table 6) will present a speculative and foresight scenario of a smart environment with preferable and possible future, near term and far term.

7.1 Evaluation of the Iterative Prototypes

Table 4 below is an evaluation table to compare the iterative prototypes. Each prototype starts with a question and problem to explore and solve. The features and controls present what the users could do with the related prototype and what function they could trigger. The benefits and outcomes column shows the achievement of the prototypes, and the limitation is what is still needed to improve in the next prototype. Table 5 is a subjective evaluation of the extended metaverse prototypes, and each of them has scored from 1 to 5 based on the parameters Jovanović & Milosavljević (2022) (Metaverse agent), Holz et al. (2011), and Milgram (2011). And a radar plot illustrates the visualization of the score to compare the strengths and weaknesses of each prototype.

Table 4. The comparison of prototypes through the RTD method.

Prototype	Question	Problem	Features and Controls	Benefits and Outcomes	Limitation
 Prototype 1	How do users access and operate the physical devices in an immersive metaverse environment?	When immersive in the virtual environment, the player is not able to access information from physical space.	Able to switch between MR and immersive metaverse environment,	Have the freedom to access and operate information of the physical space.	The controlling from virtual to physical only perform on and off states with one-way communication.
 Prototype 2	How to make the control of physical agents dynamic and engaging with metaverse elements?	Users cannot control the physical devices with the current virtual interface in MR.	Users can pick up colors from the virtual galaxy to change the physical lighting color dynamically.	Provide the ability for the users to control the physical lighting with the virtual elements in MR.	It is still one-way communication from virtual to physical.
 Prototype 3	How can computer vision be used to capture emotional states from users in a physical context to affect the metaverse environment?	Current metaverse platforms are not aware of the physical context.	The computer vision model can detect the users' emotional states in front of the webcam, affecting the colors of the metaverse environment.	Provide a method to connect the physical context to the metaverse environment.	This method is not able to detect human emotion when they are wearing HMD headsets.
 Prototype 4	How to capture the human states when users are wearing smart glasses without relying on	The computer vision model can not provide reliable results when users wear an HMD that covers their faces.	With a brainwave sensor (Muse 2), the system could capture the human states	It uses a sensor to detect the states of users that represent the physical	The data from the brainwave sensor (Muse 2) is not reliable and can not

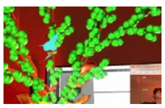
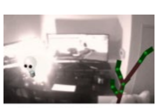
	computer vision?		and affects the color and movement in the metaverse environment.	information and affect the metaverse elements.	represent the human states correctly.
 Prototype 5	How to use the non-emotional method to represent the user's states and generated objects to increase the environment's dynamics?	Firstly, using computer vision for emotion detection and sensor to capture brainwaves is not the proper way to acquire human states. Moreover, the previous prototypes only provide one-way communication between the metaverse and physical context. Lastly, the current metaverse objects are predefined, which has less dynamic and engagement.	The computer vision model could detect whether the user is presented to represent the human state in front of the computer. Based on the time user presented, the system will generate a virtual plant and illustrate the effect in MR and affect the color of the physical light.	Experience a generative metaverse object with physical information and a two-way communication method between the metaverse and physical agents.	The system does not allow controlling from remote metaverse space.
 Final Project	How to bring the previous features to the final projects and make the project more accessible?	The device (HoloLens 2) from the previous projects is hard to access for the public, and the anchor of the virtual content to physical still does not have a reliable solution.	This project combines the previous prototypes of light control, tree growing, and computer vision detection.	It used a low-cost device for more access to the public to experience and a keyboard for anchoring.	The MR background is black and white.

Table 5. Subjective evaluation of extended metaverse prototypes with scores of 1 to 5 (super low, low, medium, high, super high) (Inspired from Jovanović & Milosavljević (2022) (Metaverse agent), Holz et al. (2011), and Milgram (2011))

	Prototype 1	Prototype 2	Prototype 3	Prototype 4	Prototype 5	Final Project
Embodiment	3	2	3	3	4	4
User Interaction	3	3	3	3	5	5
Agency	1	1	3	2	5	5
Virtual Realiy	4	2	1	1	2	4
Real Environment	4	3	1	1	3	4
Mixed Reality	5	5	1	1	5	5
Scene Design	3	3	2	2	4	4
Content Generation	1	2	2	3	4	4
Connectedness	3	2	3	3	5	5

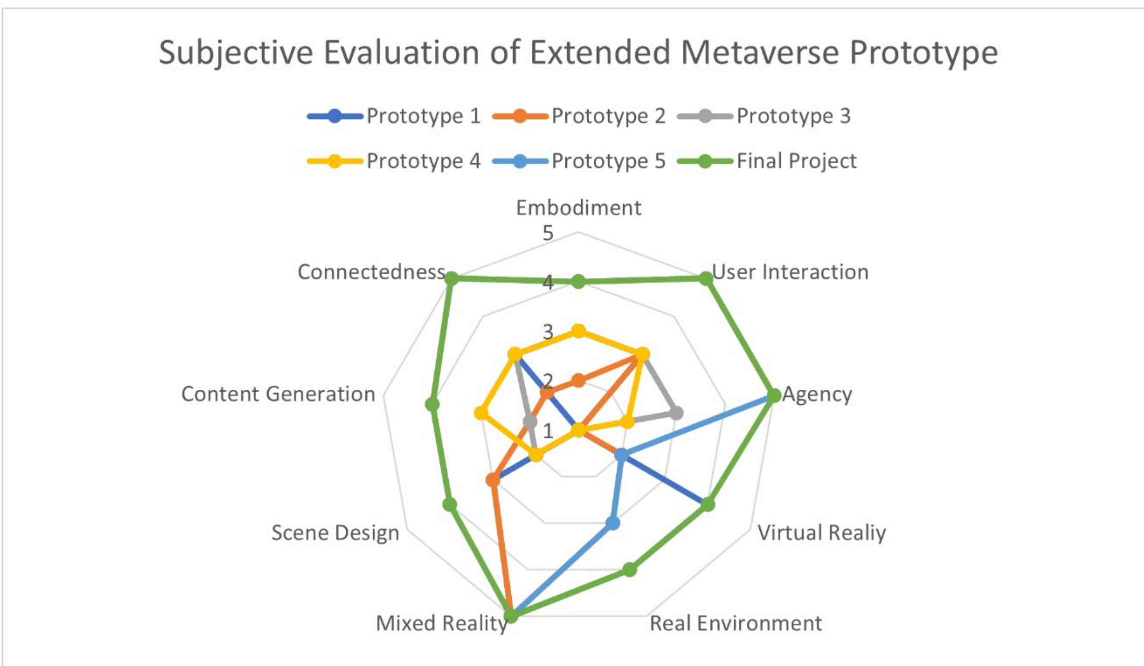


Figure 53. Radar plot of the Evaluation of the extended metaverse prototypes to visualize the comparison of the parameters for each prototype.

To conclude the comparison of the prototypes, the final prototype rated is so much better than the others. The reason is that i) it has two-way communication features from virtual to physical and vice versa through MQTT and HTTP PUT, ii) it has a better embodiment and is more immersive for users of the virtual objects and environment with Oculus Quest 2, iii)it has a better scenario design for interaction with the virtual objects and physical agents. Moreover, these tables and charts are limited since the rating is subjective, with my personal feeling.

7.2 Speculative and Foresight for Future Scenarios

By combining the speculative design, the three horizons model[79], and the human factor model from Kim Vicente (modified version) (Kozey, 2016), a speculative and foreign table of how the extended metaverse agent could be used in different scenarios are presented below. The table below is my perspective of how the extended metaverse agent could work for the futurist scenario and compare the preferable and possible future in the near and far terms.

[79] Three Horizons Framework (Available at: http://training.itcilo.org/delta/Foresight/3-Horizons.pdf)

Table 6. Speculative and Foreign for a Scenario - Manipulate the smart objects physically and virtually in the future using an extended metaverse agent in a smart environment.

	Preferable	**Preferable**	**Preferable**	**Possible**
	Individual (Physical and Psychological)	Team (small team or large group)	Organization/ Political	General
Near Term with mobile AR (2022–2029)	Manipulate a virtual personification bulb to interact with the physical light with a mobile device when they lay on the bed	A family may want the virtual decoration of their light in MR and a funny interaction to turn on the light.	A corporation may want to use the virtual bulb system to organize its lighting system.	With XR glasses, users can switch the physical light and monitor the physical environment state in a virtual environment.
Far Term (2037 and beyond)	The lighting and the virtual elements that are attached to the light could be adaptive based on the users' states and the context information.	The lighting and virtual contents in the MR entertainment (e.g., concert, disco) space could be adjusted by decentralizing the performer and the audience.	The government may want to control large numbers of physical lights and the digital twin in the MR smart city.	The extended metaverse agent could capture the human and the context information to adjust the physical and virtual lighting for individuals in smart homes and facilities in smart cities.

7.3 Conclusion of this section

The evaluation section showed the comparison of the iterative prototypes with tables and a chart that could help answer how each prototype related to the research questions and the objectives of this thesis. The iterative prototypes shown in the tables show that the connection between the metaverse and physical space increases gradually, with dynamic engagement interaction with the three-dimensional interface.

Based on the hypothesis in the research summary, I think the extended metaverse framework and agent could enhance the connection of metaverse space and the physical environment, XR and

IoT could extend the dynamic engagement to the physical space with metaverse content, and computer vision could acquire physical context for adaptive and generated virtual objects. However, this thesis project is not fully tested, and it is a proof-of-concept work which requires more testing in future work. The current research is subjective qualitative, and it needs significant participants for testing for approaching the quantitative research. Further testing should require user experience to measure the level of connectedness, immersion, interaction, and agency of the system.

In terms of the research questions, I will also provide subjective answers to how well the prototypes meet them. For the first question, I think the prototypes provide virtual embodiment overlaying the physical environment through XR technologies and use IoT to connect the metaverse and physical world with two-way communication. These approaches indeed reduce the gap between the two spaces and increase the user's engagement in the environment with dynamic metaverse objects. Considering the prototypes of chosen computer vision to capture information from physical context and recognize the objects to affect the virtual environment could answer the second question. The answer to the final question is using the L-system to generate a virtual plant, as the virtualization of timing in some prototypes could increase the dynamic of the metaverse environments.

8 Conclusion, Limitation and Future Work

8.1 Conclusion

The motivation of this thesis is a gap between the current metaverse platforms and the physical space that users could not access and control physical information while they are in the metaverse. This thesis project explores the possibility of extending the metaverse to physical space with XR and the IoT, to create a seamless connection between them toward an extended metaverse agent. Through the literature review, this thesis provides the background knowledge about what the metaverse is, the theory and implementation of XR and the IoT through the MiRAs framework, the context awareness concept as the sensor for input, and generative and procedural content as the actuator for output in the extended metaverse agent. With the iterative prototypes, the project provides a series of proof-of-concept works on reducing the gap between the metaverse and physical space and using metaverse elements to enhance the dynamic and engagement of the physical space, through an immersive experience with HMD headset, two-way IoT communication between virtual and physical, computer vision to capture the states of users and generative virtual plant with L-system.

8.2 Limitation

As the state-of-art of virtual reality and mixed reality devices, they have various limitations to achieving the goal of extended metaverse agent. The device, Hololens 2, used for prototypes 1 to 5, is hard to access and expensive since it is only for corporations or research institutes to purchase with over four thousands dollar. In addition, it still can not provide a fully immersive mixed reality experience since the size of the screen limitation. Although the device (Oculus

Quest 2) used in the final project is easy to access with a low price and more immersive with a video-passthrough present, it only provides black and white for the physical environment due to the limitation of its camera. Another limitation of this thesis study is the evaluation is subjectively and not tested on human participants, and it only represents my perspective.

8.3 Directions for Future Work

8.3.1 Complex Smart Environment with Extended Metaverse Agent

One of the suggestions of this thesis is to position it into a more specific scenario, smart home for indoor setup, smart car for driving experience, and smart city for a bigger scale. These proposed scenarios could bring the extended metaverse agent into people's normal lives experience and possibly enhance the living quality with the virtual objects and environment that are connected to their physical life.

8.3.2 Blockchain for Non-human Virtual Identity

Blockchain is one of the important domains of the metaverse, and it could be used for thinking of the identity of not only a human agent in the extended metaverse environment but also non-human agents (including virtual and physical agents). The question starts from is it possible for AI as the agent to hold a part of the token, to make the decision with a human agent. For example, a plant avatar holds the tokens of a DAO (Decentralized Autonomous Organization), a blockchain-based system for agents to coordinate decentralized through self-executing rules that are deployed on the public blockchain (Hassan & De Filippi, 2021), and a human agent also holds some of the tokens. The human agent wants to vote to add water to the physical plant, but the plant agent (which has a sensor to detect the soil) thinks it does not need water and votes to reject the suggestions.

8.4 Final Remarks

The extended metaverse agent has many future possibilities to bring the current metaverse into a more complex and reliable system to connect the physical space that could change human life. Although smart glasses have become one of the common devices in our lives, the extended metaverse agent could bring dynamic engagement to our physical environment.

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Appendices

Appendix A. Source Code

Prototype 1

The code below shows how the virtual bulb triggers the IFTTT event to control the physical light.

lightTrigger.cs

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using UnityEngine.Networking;
public class lightTrigger: MonoBehaviour
{
 // Start is called before the first frame update
 public GameObject VirtualEnvironment;
 public GameObject VirtualLight;

 private void OnTriggerEnter(Collider other)
{ triggerLight("https://maker.ifttt.com/trigger/Light/with/key/mSl1498NtCACZrYh8eAbtz9ZgfAdFtowYUZPsDmyPhb");
 //Disable Environment
 VirtualEnvironment.SetActive(false);
 VirtualLight.SetActive(false);
 }

 private void OnTriggerExit(Collider other)
 {
 Debug.Log("Exit");
 VirtualEnvironment.SetActive(true);
 VirtualLight.SetActive(true);

triggerLight("https://maker.ifttt.com/trigger/turnOffLight/with/key/mSl1498NtCACZrYh8eAbtz9ZgfAdFtowYUZPsDmyPhb");
 }

 void triggerLight(string url)
 {
 WWWForm form = new WWWForm();
 form.AddField("myField," "myData");

 UnityWebRequest www = UnityWebRequest.Post(url, form);
 www.SendWebRequest();
 }
}
```

Prototype 2

The code below shows how the virtual rocket and planets could change the colour of the Phillip Hue through HTTP PUT.

LightControl.cs

```
Public IEnumerator HttpPutLight(float x, float y)
    {
            lightControl.xy[0] = x;
            lightControl.xy[1] = y;
            lightControl.bri = 100;
            updateLight();
            //picker.b = false;

            yield return null;
    }

   private void updateLight()
    {
        httpPostLight("http://192.168.2.49/api/zx9NNIegikmyEgZZOQmR-
FTTzTomumRr4nzjyoWc/lights/4/state");
        httpPostLight("http://192.168.2.49/api/zx9NNIegikmyEgZZOQmR-
FTTzTomumRr4nzjyoWc/lights/3/state");
        httpPostLight("http://192.168.2.49/api/zx9NNIegikmyEgZZOQmR-
FTTzTomumRr4nzjyoWc/lights/2/state");
        httpPostLight("http://192.168.2.49/api/zx9NNIegikmyEgZZOQmR-
FTTzTomumRr4nzjyoWc/lights/1/state");

    }

    private void httpPostLight(string url)
    {
        var client = new HttpClient();
        string json = JsonUtility.ToJson(lightControl);
        var content = new StringContent(json, System.Text.Encoding.UTF8,
"application/json");
        client.Put(new Uri(url), content, HttpCompletionOption.AllResponseContent, r =>
        {   // This callback is raised when the request completes
            if (r.IsSuccessStatusCode)
            {    // Read the response content as a string if the server returned a
success status code
                string responseData = r.ReadAsString();
                //print(responseData);
            }
        });
    }
```

The code below shows how to convert the RGB value to the CIE value that could be used in Philip Hue.

ColorPicker.js

```
private void OnTriggerEnter(Collider other)
    {

        if(TriggerBool == true)
        {
            picker.GetComponent<Renderer>().material.color =
other.GetComponent<Renderer>().material.color;
            col = other.GetComponent<Renderer>().material.color;
            pb_XYZ_Color xyz = pb_XYZ_Color.FromRGB(col);
            pb_CIE_Lab_Color lab = pb_CIE_Lab_Color.FromXYZ(xyz);
            //Calculate the xy values from the XYZ values

            //float x = X / (X + Y + Z); float y = Y / (X + Y + Z);

//https://github.com/johnciech/PhilipsHueSDK/blob/master/ApplicationDesignNotes/RGB%20t
o%20xy%20Color%20conversion.md
            x = xyz.x / (xyz.x + xyz.y + xyz.z);
            y = xyz.y / (xyz.x + xyz.y + xyz.z);
            //b =  true;
            StartCoroutine(control.HttpPutLight(x, y));
            //control.controlLight(x, y);
            //control.controlLight(x, y);
            //print(col);
            print(x + " " + y);
            //print(y);

            TriggerBool = false;
        }



    }
```

Prototype 5

The code below shows how to use MQTT to connect the computer vision model by subscribing to the topic.

MQTTTest.cs

```
protected override void DecodeMessage(string topic, byte[] message)
        {
            string msg = System.Text.Encoding.UTF8.GetString(message);

            StoreMessage(msg);
            //Data = JsonMapper.ToObject(msg);

            if (topic == "jieThesis/MetaPlant/seconds")
            {
                //print("1: " + Single.Parse(msg));
                //print(msg.GetType());
                seconds = Single.Parse(msg);
                print("seconds: "+ seconds);
            }

            if (topic == "jieThesis/MetaPlant/minutes")
            {
                //print("1: " + Single.Parse(msg));
                //print(msg.GetType());
                minutes = Single.Parse(msg);
                print("minutes: " + minutes);
            }

            if (topic == "jieThesis/MetaPlant/totalSecond")
            {
                //print("1: " + Single.Parse(msg));
                //print(msg.GetType());
                totalSeconds = Single.Parse(msg);
                print("totalSecond: " + totalSeconds);
            }

            if (topic == "jieThesis/MetaPlant/CellPhoneSeconds")
            {
                //print("1: " + Single.Parse(msg));
                //print(msg.GetType());
                cellPhoneSeconds = Single.Parse(msg);
                print("CellPhoneSeconds: " + cellPhoneSeconds);
            }

        }
```