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# Extended Reality and Internet of Things for Hyper-Connected Metaverse Environments

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#### ABSTRACT

The Metaverse encompasses technologies related to the internet, virtual and augmented reality, and other domains toward smart interfaces that are hyper-connected, immersive, and engaging. However, Metaverse applications face inherent disconnects between virtual and physical components and interfaces. This work explores how an Extended Metaverse framework can be used to increase the seamless integration of interoperable agents between virtual and physical environments. It contributes an early theory and practice toward the synthesis of virtual and physical smart environments anticipating future designs and their potential for connected experiences.

Keywords: Metaverse, mixed reality, internet-of-things, agents.

**Index Terms:** Human-centered computing – [Mixed / augmented reality]; Human-centered computing – [Virtual reality]; Human-centered computing – [Ambient intelligence];

# **1** INTRODUCTION

The concept of the Metaverse is increasingly becoming adopted into everyday society with ubiquitous applications from common living and working scenarios, to customized forms of social activities enhancing a connectedness of experiences. The Metaverse is challenging to define, however, across multiple definitions it is often overlapped with concepts of an environment constructed by multiple and discrete virtual worlds, defined as a fully immersive, three-dimensional digital environment that reflects the totality of shared online space [15]. Lee et al. [22] consider the Metaverse as a virtual environment constructed by the Internet, Web technologies, and Extended Reality (XR) toward hybrid physical and virtual space. In this sense, XR is an expanded field of fluid space enabling the visualization of Metaverse content in both immersive virtual and hybrid environments. It is an umbrella term for Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR) of the virtuality continuum concept [24] which is a mixture of the presenting of objects from-real-to-virtual displays. XR is also a term that refers to the combination of physical and virtual (computer-generated graphic) environments that humans can interact. In particular, "X" represents the spatial computing technologies connecting virtual and physical space [16].

The Metaverse is a growing concept at this time, yet is in a state of rapid development approaching mainstream acceptance in commercial and consumer applications. However, it is often envisioned with the premise that a more mature ubiquitous Metaverse will provide many benefits for humans to connect – in various spaces and with each other, creating synchronous social engagements overcoming

physical distance and potential limitations that expend time and energy. In the most recent developments from fields of academia and industry, there is evidence to support this trend toward Metaverse research and integration. For example, in 2021, Facebook announced that they were becoming a Metaverse company [13] and rebranded itself to Meta Platforms Inc. Other major industry influencers, Roblox and ZEPETO are also representative of social platforms that have enormous users across the world and have been moving toward the adaptation of Metaverse capabilities [18]. Likewise, Nvidia has further developed its Omniverse software [9] 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.

Similarly, with the mainstream adoption of virtual reality hardware and software, users can now enter diverse Metaverse platforms of virtual spaces with stand-alone computers, mobile devices, and head-mounted VR display devices. Such devices transport users into completely virtual spaces, but challenges arise with their use. For example, with the advent of multiple virtual shared spaces, there comes a disconnect - there is significant development of virtual content within the Metaverse, but much less focus on the connections of this content within the physical space (i.e., the user's actual environment). However, regardless of how we engage with the virtual through conventional virtual reality displays, humans still rely on physical environments for basic needs to function and survive. As a consequence, if the Metaverse does not take into consideration the design to connect and maintain coherency with the physicalvirtual relation as a hybrid construct, the Metaverse will not be optimized to fully support human activities in any of these environments, co-opting a sustained and mutually exclusive distinction between physical and virtual worlds.

## 1.1 Metaverse Disconnect: A Research Opportunity

Today, Metaverse platforms in web, mobile, and VR devices have been used for various social activities, for meetings, sports and entertainment, exhibitions, conferences, gaming, tourism, and online education (see Fig. 1). However, the current Metaverse platforms are limited in their capacity to support meaningful immersion and duration for people to stay connected. Without a strong and continuous sense of connection, the reliability of a coherent Metaverse will remain a elusive, suggesting a need to consider the design for the interdependent relationship of the virtual content and world/s, to the physical world/s people inhabit.

This work proposes the following question: how can the gap between the Metaverse and the physical world be minimized to increase the dynamic engagement for smart environments with Mixed Reality and Internet-of-Things? Augmented Interaction from humancomputer interaction (HCI) research [27] highlights this issue, and the need for the right computing paradigm to support virtual and physical areas of interaction. As shown in Fig. 2, when users apply two-dimensional screen or Virtual Reality devices to enter Meta-

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Figure 1: Examples of current activities in today's metaverse applications (e.g., Horizon Worlds [10], Decentraland [3], Cryptovoxels [2], Spatial [12], Fortnite [4], HanaBank [6]).

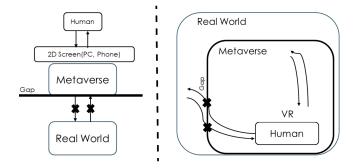


Figure 2: Current Metaverse interaction and the Metaverse disconnect problem (adapted from early explorations on VR by Rekimoto [27]). There is a need to more strongly link the Metaverse to the real-world.

verse applications or environments, they face a naturally occuring gap with the real world, as a result of the platform being used. Often, this means that, for virtual environment interactions, they can not access and manipulate the physical information found in real-world environments surrounding them. Thus the Metaverse disconnect problem is a significant hurdle for the field to overcome as it evolves toward mainstream adaptation.

This paper explores the design of an Extended Metaverse Framework to connect the physical and virtual space using Mixed Reality (MR) and the Internet-of-Things (IoT). The aim is to enhance the interconnection of the Hyper-connected smart environment. In doing so, this work describes how three-dimensional interface (virtual content) designs in MR can allow users to interact with the physical elements in a smart-environment through the IoT. This interaction allows users to switch between an immersive Metaverse environment and the MR (users can see/sense the environment they are physically inhabiting) space. On the other hand, the user could control the physical objects such as lighting fixtures by manipulating the immersive virtual interface.

This paper is presented as follows: Section 2 discusses the background related to the Metaverse and the themes involved in mixed reality and IoT. Section 3 presents the Extended Metaverse Framework and early designs of Metaverse application concepts as a proofof-concept. Section 4 provides a discussion of these techniques, and Section 5 summarizes the paper.

# 2 METAVERSE: THEORY AND BACKGROUND

The five stages of the Metaverse evolution as identified by Dionisio et al. [15] (see Fig. 3) demonstrates the increasing immersive capabilities of world-building and functionality, paralleling the technological advances in multi-user systems starting from text-based computing in the late 1970s to open-source, decentralized, co-creative platforms

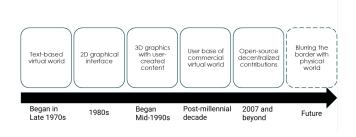


Figure 3: The Evolution of Metaverse, inspired by [15]

today. The next stage of the Metaverse may be toward a close connection with many real-life applications, producing a blurring of the border with the physical world.

Similarly, Mazurek & Gervautz [23] highlight that there are more terms to address within these VR themes, including Synthetic Experience, Virtual Worlds, Artificial Worlds and Artificial Reality. They indicate that although there are various definitions for VR, these meanings are equivalent to a simulated world that users could interact with and feel immersed. This highlights further properties of Metaverse environments; others such as within the AIP Cube [32], a taxonomy of graphic simulation systems, wherein Autonomy, Interaction, and Presence combine to describe a single interaction space: Autonomy means 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. This theory applies well to AR and MR, and hence can also be considered for the blend within the Metaverse context of physical objects and virtual environments. Further concepts related to level of agency are also relevant. In terms of the agent in Metaverse, Mixed Reality Agents (MiRAs) address an agent with virtual or physical entities embodied in a Mixed Reality environment [19]. The key concepts of MiRAs are Agency, Embodiment, and Interaction Capability within Mixed Reality Environments, divided into the three-axis agency, corporeal presence, and interactive capacity. Together, these each lend toward the concept of a blended virtual and physical environment, wherein agency is present, and where humans-in-the-loop can interact with the environment from a virtual-physical - and also agent-oriented - perspective.

## 2.1 An XR-IoT (XRI) Perspective of the Metaverse

Augmented Reality (AR) and the Internet-of-Things (IoT) are key technologies receiving significant attention, as they improve the communication between the Metaverse and physical space. 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 [20]. In [31] this concept is described as XR-IoT (XRI), representing the combination of XR-based IoT systems as well as IoT-based XR systems. A more comprehensive system of XRI is presented by [25] as those that are based on immersive, information-rich, multi-user, and agent-driven environments. The potential usability scenarios of IoT and AR have been implemented in both industrial applications and academic research. The combination of these technologies make it possible to design for improving the relationships between humans and objects, human-to-human relationships, and toward future applications for a variety of domains such as education, cyber security, and marketing [14].

Similarly, XR-IoT research on IoT Avatars was presented by the authors in a simple proof-of-concept that embodies the MR representation Avatar for a physical plant, providing mixed reality interaction

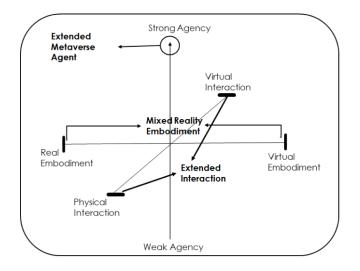


Figure 4: Criteria of Metaverse Agent (derived from the MiRAs taxonomy of [19]).

buttons to control physical servo motors and LEDs in the physical environment through IoT on the mobile phone [30]. This has been extended to explore the mixed reality framework for IoT with more interaction within an immersive Head-Mounted Display [17]. The work applied stereoscopic cameras (ZED mini) attached to an HMD (Oculus Rift) to provide a video-passthrough mixed-reality experiment and collect the real-time data of the plant's context allowing for it to adapt and respond based on the following factors: intensity of lighting, soil moisture, and the number of people in its presence. These factors informed the emotional states of a virtual plant avatar, generating a hybrid virtual-physical object with agency behaviour using fuzzy logic [26]. Other projects include "Digi-log", 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, that could apply to an augmented reality shopping scenario [21]. A further example, HoloFlows research provided a path toward direct monitoring and control of IoT applications, introducing a new Mixed Reality interaction method for end-users to manage standard IoT devices applying a visual development interface based on Node-Red [28]. These examples collectively demonstrate how the IoT and XR can integrate and exchange information and foster adaptive behaviors, interfaces, and immersive visualizations.

# **3 TOWARD AN EXTENDED METAVERSE FOR HYPER-CONNECTED SMART ENVIRONMENTS**

Based on a combination of theories including the MiRAs cube of [19], and the reality-virtuality continuum of Milgram [24], the domain of an Extended Metaverse Agent is depicted (see Fig. 4) extending along the dimensions of Mixed Reality Embodiment, Extended Interaction, and level of Agency. They represent how the virtual and physical entities can be presented on the virtual or physical space, and how they could interact with users and by other agent-objects. In this sense, the Extended Metaverse consists of one or more embodied virtual and physical objects, each having a degree of interactive properties in the virtual and physical dimension and having agent-oriented behavioral capabilities. The Extended Metaverse agent facilitates the cohesive connection – or connectedness – of these agents with their real-world counterparts.

Fig. 5 shows the landscape for designing and creating Extended Metaverse Agents. On the physical world area, C represents the IoT-enabled devices (embedded computers), while the Extended Metaverse Agent is located on the Mixed Reality layer and connects to the virtual object in the Metaverse with a head-mounted display for users.

# 3.1 Design Prototypes Toward Extending the Metaverse

Based on the Extended Metaverse framework described, there are multiple possible implementations, however, as an early proof-ofconcept, the following are described as XRI design explorations for a more hyper-connected Metaverse, namely: an XRI Lamp controller; and an XRI ambient lighting scene.

## 3.1.1 XRI Lamp Controller

The XRI Lamp Controller (see Fig. 6) is a prototype to explore a new way to control the physical object with virtual elements in Extended Reality and the possibility to switch between Virtual Reality (Metaverse Environment) and Mixed Reality space. The smart lamp is considered a shared object in Mixed Reality since it embodies both virtual and physical environments at the same position, presenting both virtual and physical properties that users are able to access. To activate the lamp, the familiar on- and off- switch nomenclature of a physical bulb is expanded to encompass either a physical or virtual action. In the virtual parameters, as the user moves a virtual bulb (virtual body presented in Virtual Reality and Mixed Reality) in and out of the physical lamp in view, the virtual interaction causes a synchronous action in both physical and virtual environments to turn the light on. The same is true in the physical parameters: as the bulb is controlled by pressing a button, the lamp is synchronized in virtual environments. In other words, the lamp object is a constant variable in both virtual and physical space, wherein the on and off function of the physical light also corresponds to control the light function in the virtual environment. Both virtual and real environments approach a two-way dual interface functionality.

The project is constructed with the physical object, the simulated virtual entities and environment, the interaction method, headmounted display (HMD) device, and data connection protocol. On the physical space, a consumer-grade IKEA lamp is transformed into a smart and IoT-enabled object with an Orbecco smart plug [1] that can connect to the Smart Life App system. The computer-simulated three-dimensional models of objects and the environment are rendered by Unity3D and visualized with Hololens 2. Meanwhile, Hololens 2 also performs hand-tracking to capture the gesture from users. The Mixed Reality Tool Kit (MRTK) [8] can use these commands to enable the interaction of the virtual elements, presented as moving the virtual bulb in this prototype. The IFTTT [5] was considered as the connection service for data communication in the project since it provides a direct way to connect the Smart Life system and Webhook, which can be commanded from Unity with HTTP Request.

The prototype provides two-way data compatibility from virtual to physical commands, activating the lighting by moving the virtual bulb in and out of the constant lamp object. This method provides a novel way to reconsider design functions, and whether it is necessary to use buttons to turn on and off the smart objects in the Extended Metaverse environment. It also encourages designers, engineers, and users to explore how the relation with objects and virtual elements can be expanded in a new interactive dynamic ontology. The switching between Virtual Reality and Mixed Reality environments provides a bridge for users to see the physical space. However, as the current Virtual Reality headset system immerses the user into the completely computer-generated environment, it impairs the sense of vision for users to access and navigate the physical context.

# 3.1.2 XRI Ambient Lighting

Another Prototype (see Fig. 7) explores a more dynamic way to control the physical light from Mixed Reality by changing the colour instead of only turning it on and off, namely the Mixed Reality Color

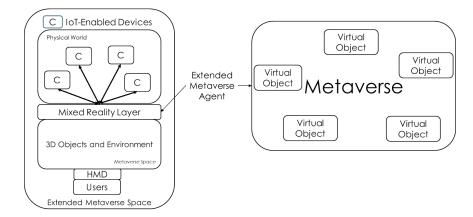


Figure 5: Framework of Extended Metaverse Agent, integrating the Metaverse of virtual objects with XR-IoT environments through an agent controller (or set of controllers), inspired by [27].

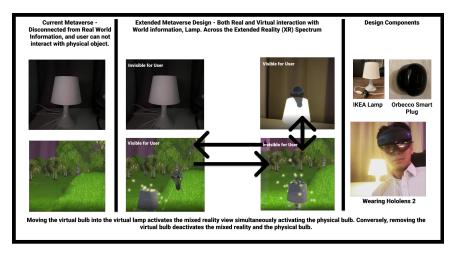


Figure 6: Design of an XRI Lamp Controller - In the extended metaverse, virtual representations adapt physical behaviors (lamp and bulb controller interface when fully immersed). Similar mixed reality interactions take place, for controlling the virtual when in physical environment.

Picker. When wearing the Mixed Reality headset (Hololens 2), the users are able to see some virtual planets with different colours and shapes moving around a virtual sun. The goal of the galaxy setting is to immerse the users into a Mixed Reality universe space with their everyday surroundings to transform the living room into a more dynamic and engaging space. On the physical side, four smart bulbs with colour-changing features are installed that can provide an ambience colour effect to the environment. In terms of interaction, the users can move a virtual rocket around space by air tapping and holding it with hand-tracking in the Hololens 2. If the rocket collides with the planets, it will change its colour into the colour of the planet, simultaneously changing the ambient lighting in the physical environment accordingly with the smart bulbs.

The Mixed Reality 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 to a Rotator script onto the sun entity, making it the parent object of other planets. The colours of the planets are defined by their textures, while the rocket is considered as a colour picker to select the RGB value of colour; when it is moved the rocket enters into the planet with an "OnTriggerEnter" function. In terms of the physical environment lighting, it is created with the Phillips Hue White and Color Ambiance Kit [11] and their Developer Kit [7].

Current Mixed Reality applications do not provide the capacity

for users to manipulate the physical agent with the Mixed Reality Interface, and users still need to access and control the physical environment in the traditional way - 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 APP, Shao et al. [30] indicates that the current IoT dashboard design is widget-based with a 2d graphic User interface and faces scaling challenges to address a large number of devices. Hence, a Mixed Reality Interface design of connect-ness to virtual elements and the physical space is identified as a critical aspect of the design process to produce dynamic, engaging, and cohesive interactive experiences. The physical ambient lighting effect provides an enhanced immersive Mixed Reality environment while combining the virtual galaxy in this prototype, as the dynamic interaction of the virtual planets and the rocket colour picker synchronously ties physical lighting colour with the virtual texture content. As this prototype presents, the ambient colour of the physical environment will change based on the planets' interaction with the rocket in the virtual realm, prompting users to connect the visual atmospheric properties as a "landing" cue on the selected planet. The user's surrounding physical atmosphere adapts to the appearance of that planet. In other words, coherence and continuity between physical and virtual spaces are hyper-connected with an extended immersive environment produced by the synchronous shared content.

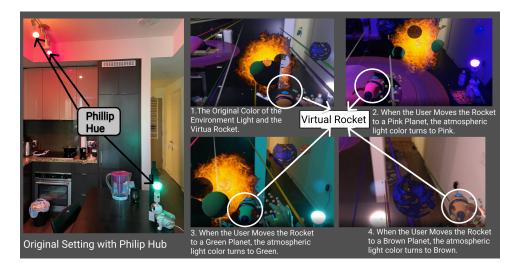


Figure 7: Design of an XRI Ambient Lighting Capability

The preceding design prototypes demonstrate but one approach to connect the user experience in the virtual environment of the Metaverse in a tandem relationship to their physical environment, regardless of whether this ranges from full virtual reality, to mixed reality, to non-VR applications.

# 4 DISCUSSION AND FUTURE WORK

This research has highlighted a gap in between the integration of real and virtual dimensions within the Metaverse. It proposes the following concern of a disconnect in information between the virtual and physical environments: if the Metaverse and the corresponding physical space/s are not communicating in interoperable coherence (e.g. constant objects in the physical world and the Metaverse are not compatible; or full VR immersion impairs and blocks out navigation in physical space), the "noise" of incongruous signals between them would potentially become overwhelming or irrelevant, perhaps eventually resulting in forms of cognitive overload for the user, from both physical and virtual domains at the same time. This situation may be a mere nuisance to the user, but as the Metaverse applications increase in prevalence and utility, such a disconnect in non-compatibility may impact important or critical application scenarios as well.

"Noise" as defined by Shannon & Weaver [29] is specific to the engineering problem of data as signals, however the definition is relevant to today's engineering challenges of the Metaverse. These challenges include incongruous agents that limit coherent interoperability, as well as excessive inputs in environments that limit clarity of the communications between them [e.g. cues from shared environments are inconsistent]. "Noise reduction" could support the theory of reducing the gap between the Metaverse and the physical world through the design of interoperable interfaces. Designing for noise reduction would potentially have multiple benefits which span across the variety of agent interaction relationships below:

- Human-to-Human Metaverse Relationships: increased efficiency with communications and tasks without the demands of attention divided in the physical and virtual world. Shared interfaces within human-to-human environment contexts foster and encourage co-creative engagement and community.
- Environment-to-Human Metaverse Relationships: as smart home and smart work environments develop with integrated IoT technology, physical environments can adapt and change to fit the needs of user or community profiles through AI and

generative approaches of machine learning. Filtered data from external sensors (e.g. weather and environmental systems, transportation, social news feeds) would become naturalized elements of the explicit and implicit habitable environment.

Object-agent to object-agent Metaverse Relationships: Dialogue between two or more objects may interact to inform users and participants of shared Metaverse spaces of collective activity or sentiment; e.g. XRI Ambient lighting conveys participant engagement, collective sentiment of community. Similarly, non-human agent-objects having presence and agency via sensors would afford communication of unseen states e.g. plants [30], gaseous detection or mold, pets, etc.

As the research and development of such interfaces between agents and humans are explored, the integration of appropriate filters and controls would support the continuity and end goals of the Extended Metaverse. An Extended Metaverse Agent as proposed would help to prevent such disconnects, reducing cognitively demanding uses of Metaverse applications by improving the interaction, embodiment, and coherence of multiple Metaverse spaces, while designing for the human as a part of a dynamic system seamlessly connected across Mixed Reality Environments.

In terms future work, through the development of new test scenarios, the authors plan to continue these explorations to consider how the integration of the Metaverse with the actual environment can be achieved. This offers multiple promising directions toward the following:

- Toward a more contextually driven usage of the user's physical and psychological contexts in the representation of the metaverse content and behavior.
- Toward a procedural and generative design approach for representing metaverse informational objects (this may apply generative tools like L-system representations, or others to evolve the virtual representation of the metaverse object).
- Toward embedding richer levels of agency into the extended metaverse designs to enable the metaverse environment's adaptive system behaviors, more autonomously across physical and virtual domains.

## 5 SUMMARY

This work has presented a design perspective on the Metaverse, highlighting the essential need to create approaches that synchronize and connect the Metaverse more concretely to the physical world to streamline user interaction. The theoretical foundations of the Metaverse, XR, and IoT are identified, and a new Extended Metaverse framework is discussed as a means toward facilitating this strong connection. Two early-stage design projects are presented, showing how stronger connections can be made in this domain, leading to interactive and embodied Metaverse applications that adapt in both the physical and virtual realities. It is hoped that this contribution will help further the design considerations within the Metaverse research and development community as the technology moves toward mainstream acceptance and use.

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