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Figure 1: The virtual environment of the MPAI Metaverse Model implementation.

Abstract

This paper explores the MPAI Metaverse Model (MMM), a standard for creating a unified, interoperable metaverse. It outlines MMM's architecture, foundational processes, and actions, addressing challenges like platform fragmentation. The study also details a prototype implementation using Unity and Mirror, validating MMM's standards while fostering an open-source, standard-based, and scalable platform for diverse applications.

Keywords: Metaverse, reference implementation, standardization, open-source platform

Index Terms: •Software and its engineering-Software creation and management-Collaboration in software development-Open source model •Human-centered computing–Collaborative and social computing–Collaborative and social computing theory, concepts and paradigms–Social networks •Networks–Network architectures

1 Introduction

The metaverse, despite its recurring ups and downs, continues to be a highly relevant objective for both research and industry [2]. It offers the potential to transform and transition a variety of human activities [3] into virtual spaces, alleviating some of the real-world constraints and eventually increasing their impact. For the industry, the metaverse represents a transformative tool that can enhance some of its operational processes, empower human skills, and improve the environments in which individuals work and interact [2].

The widespread interest in the metaverse does not necessarily help to make it a reality. The industry tends to be stuck in addressing problems by sector instead of searching for and adopting unified approaches. This fragmentation is reflected in the plethora of metaverse definitions, where each simply emphasizes different aspects of the concept [11]. This can also be seen in practical deployments, where online gaming, for instance, has produced several successful implementations that, paradoxically, other industries – perhaps the online gaming industry itself – would hesitate to label as true "metaverses" [7]. Social networking seems to be another industry where the notion of a virtual space offers new experiences to human replicas, but some of the attempted implementations either had a hard time surviving or were simply shut down [9]. In contrast, the concept of industrial metaverse has recently gained some momentum. However, while the term metaverse evokes a broader vision, it is not clear how much it adds to the more established term "digital twin", which is defined as "*a virtual representation of a physical system (and its associated environment and processes) that is updated through the exchange of information between the physical and virtual systems*" [8].

2 Overview

The development and diffusion of the metaverse is being affected by the absence of a unifying force to harmonize needs across industries. This lack of cohesion delays the maturation of a technology that contains an immense potential for humankind. Standards have long been a proven mechanism to address these types of challenges, and the metaverse is no exception. However, there has been no shortage of ideas or initiatives aimed at establishing metaverse standards, as illustrated by the following examples:

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1. The Open Metaverse Interoperability Group[1], founded in 2021 to discover, champion, and co-create protocols for Metaverse Interoperability.

2. The Metaverse Standards Forum[2], established in June 2022 to foster interoperability standards for an open metaverse helping accelerate the mission of any industry initiative working but without developing itself specifications.

3. The Open Metaverse Alliance for Web3 (OMA3)[3], established in November 2022 as an alliance of leading innovators in Web3 that believe in one open and interconnected metaverse. It writes technical standards and runs infrastructure to fulfil this vision.

4. Focus Group on Metaverse[4], established by the —ITU in December 2022 and closed in June 2024 after developing and approving 52 Technical Specifications and Technical Reports.

5. Systems Evaluation Group (SEG 15)[5], established in December 2022 by the IEC to explore the needs of the metaverse. DEG 15 has later become a Joint SEG with ISO.

In January 2022, MPAI, an international, unaffiliated, non-profit organisation developing standards for AI-enabled data coding, identified the metaverse as a critical area for standardisation. that would integrate many of the technologies in the MPAI work plan. Over the next 15 months, MPAI published two Technical Reports where it studied some eighteen use cases from different industries, analysed a set of Functional Requirements, the state and prospects of the main enabling technologies, governance issues, a standardisation roadmap, and the use of profiles to serve different industry needs [3, 4]. Six months after releasing the second report, MPAI published the first Technical Specification: the MPAI Metaverse Model (MMM). By October 2024, the MMM specification was split in two parts: one focused on the architecture and the other on technologies. A practical implementation is a necessary step to effectively support the advancement of the outlined technical specifications.

Existing virtual platforms, such as Meta Horizon World, Microsoft Mesh, Roblox, and VRChat, demonstrate the growing interest in immersive environments [1]. However, these platforms often lack seamless interoperability, undermining the vision of the metaverse as a unified digital ecosystem [10].

Moving from this consideration, a more comprehensive approach that can bridge the gaps between existing virtual platforms and fulfill the requirements of a genuine metaverse instance is becoming of paramount importance. This work contributes to this effort by describing an implementation of the MMM architecture. This implementation is not intended as "just another" alternative metaverse platform but serves three critical purposes: i) validating the proposed standards through practical applications, ii) creating an open platform that can be offered to the community, and iii) acting as a source of insights and suggestions for extending the standards themselves.

In summary, the aim of this work is twofold: i) to present the core elements of the MMM to give a general overview of the technical specifications, and ii) to describe the ongoing activities aimed at developing a prototype implementation of the MMM architecture.

3 MMM Foundations

The MMM was developed bearing in mind that many successful standards have been developed specifying and then implementing a small set of functionalities and then adding more functionalities in response to user needs. Therefore, the MMM starts from an elementary, quasi-atomic architecture based on the "Processes interact with Items" notion. More details on the elements constituting the MMM Foundations are provided below.

3.1 Process

Process is a general name encompassing Devices, Services, Apps, and Users. For instance, a User is a Process representing and acting on behalf of a human. A metaverse is a society of Processes that interact using a protocol enabling a Process to request another Process to perform an Action and receive a positive or negative response with reasons. The protocol also supports a Process in a metaverse wishing to interact with a Process in another metaverse through the intermediation of the Resolution Services of the two Processes' metaverses.

3.2 Action

An action can be defined as a functionality provided by a Process. Currently, 30 Actions have been identified. The list of Actions and their definitions is available at: `https://mpai.community/standards/mpai-mmm/arc/v1-2/actions/`. As matter of example, with UM-Embed (where U stands for the universe and M for the metaverse), a User builds a metaverse replica of an object in the real world (universe) at a U-Location. With Identify, a User converts and identifies data from the universe as Items. With MM-Embed a User places an Item at an M-Location and, with MU-Embed, a User "renders" an Item at a U-Location.

3.3 Item

Item is a general term indicating any entity that a Process can perform an Action on. Currently, 65 Items have been specified by JSON syntax and semantics (more details are available at: `https://mpai.community/standards/mpai-mmm/tec/v1-0/data-types/`). There is a wide variety of Items ranging from Provenance (the history of Transactions of an Asset), 3D Model Object, to Audio-Visual Scene. The word Object attached to 3D Model indicates the combination of the data constituting the 3D Model with Qualifier, a container used to characterize, for instance, a Visual Data Type instance as using a given color space (Sub-Type), produced by an AVC codec (Format), and captured with a certain device at a certain Position and Orientation (Attributes). A Persona is the Item used by a User for rendering purposes.

3.4 Right

The metaverse society is governed by Rules that specify the Rights, a subset of which is assigned to a Process at the time a human Registers with a metaverse. A Process can grant Rights to another Process and a Process can acquire Rights from another Process.

3.5 Process Action

Process Action is the Item that enables a Process to express sufficiently articulated sentences for interactions. It is composed of a subject (Process ID), an Action (out of the current vocabulary), the Time (the sentence is issued), the Item (on which the Action is performed), and the Complements (currently, At, By, From, Into, Of, To, and With). Rights can also be expressed as Process Items together with one of the attributes: Original (at registration time), Granted (by another Process, or Acquired (through a Transaction).

[1]The World Wide Web Consortium; Open Metaverse Interoperability Group: `https://www.w3.org/community/metaverse-interop/`

[2]The Metaverse Standards Forum: `https://metaverse-standards.org/`

[3]The Open Metaverse Alliance for Web3: `https://www.oma3.org/`

[4]International Telecommunication Union; Focus Group on Metaverse: `https://www.itu.int/en/ITU-T/focusgroups/mv/Pages/default.aspx`

[5]IEC; Standardization Evaluation Groups 15 - Joint SEG with ISO – Metaverse: `https://tinyurl.com/ymfuru6m`

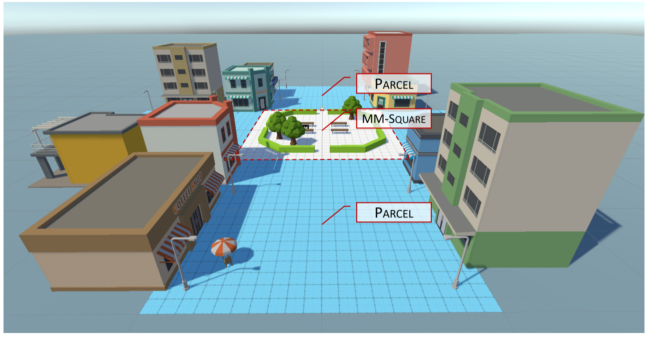

Figure 2: Elements constituting the virtual environment: MM-square and the surrounding parcels.

3.6 Use cases

A first test of the viability of the specification has been performed on several use cases covering lectures, meetings, hybrid working (in presence and remote), eSports, virtual performance, AR tourist guide, virtual car showroom, and the use of the metaverse scene representation as communication format between connected autonomous vehicles [5, 6]. The conclusion was that the MMM-defined Actions and Data Types enable the complete description of the use cases considered using the Process Actions referring to the specified Actions and Items.

4 Reference Implementation

As anticipated, this paper also aims to report on the advancements of the ongoing work focused on developing the prototype implementation of the MMM (shown in Fig. 1). The implementation serves the following purposes: i) ensuring compliance with the established standard, enabling validation of its effectiveness in real-world applications; ii) facilitating the creation of an open-source platform that can be shared with the community, thus promoting collaboration, innovation, and broader accessibility; iii) acting as a valuable source of feedback for enhancing and extending the current standard, as practical implementation often reveals areas for improvement or additional features. Moving from the above considerations, a simplified use case, referred to as phase 0, was designed.

4.1 Phase 0 Use Case

The phase 0 use case does not support all MMM functionalities. This choice was made to streamline the implementation and facilitate initial testing and validation. In some cases, restricting the supported actions to a given subset was necessary because certain parts of the standard are still under discussion and development.

A possible workflow supported by the phase 0 use case is reported below.

4.1.1 User registration

A Human can start registration to the platform through the Registration Service using the Register action and providing their Personal Profile. The Registration Service creates an Account which includes Personal Profile, Device and User details, and a Persona (i.e., the 3D model of the avatar associated with the user).

4.1.2 Navigation in the virtual environment

The User places its Persona (through the MM-Embed action) at an initial M-Location of the metaverse. This location, in the following referred to as MM-Square, is a flat land composed of a central square surrounded by parcels that may include buildings, as shown in Fig. 2. The User then displays (MU-Embed) its Persona by MM-Sending the Personal to the Device, which then displays it (MU-Actuate). The Human controls the Persona through the User, which requests the Device to capture (MU-Capture) their movements. Once Human's motion stream has been converted to an Item (Identify), the User can start animating the Persona with an MM-Animate Action. To enjoy a social life on the metaverse, the User sends (MM-Send) a message to the Activity Service notifying the system of its presence. After receiving an acknowledgment, the User interacts with the metaverse environment by strolling around (i.e., by MM-Embedding its Persona at various locations).

4.1.3 Parcels and Rooms management

While moving around the MM-Square, User views and selects a parcel from one on offer by the Parcel Service (no Transactions in the current version) by embedding the Persona on the selected parcel. This "ownership transfer" is implemented by the Parcel Service by updating (Change) and sending (MM-Send) its Rights to the parcel to the User. The User can also purchase a Rooms from the Author Service with a Rights transfer like the one effected by the Parcel Service. The User them MM-Embeds the Room at a particular place on the parcel. The User performs these operations by MM-Embedding the Persona in the Parcel Service and Author Service, selecting the parcel and room, and obtaining Rights to the parcel and room.

4.1.4 Social interaction

Once in the Room, User (in the following referred to as User1) may wish to communicate with other Users. In the devised use case, User1 MM-Sends a message, such as "Is User2 on MMM?" to the Activity Service which responds with a confirmation that is shown on the Device through the MU-Embed Action. User1 then sends an invitation message such as "Come see me at Room1" to User2 (MM-Send). User2 responds "Ok" (MM-Send), and the message is displayed on the User1's device (MU-Embeds). Then User1 Changes Rights to User2 who is now allowed to join User1 in Room1. After embedding the Persona of User2 in the Room (MM-Embeds), both User1 and User2 move their avatars by embedding their Personae at different M-Locations in Room1. When User2 leaves Room1 (by embedding its Persona at an M-Location outside the room), User1 Changes User2 Rights in order to prevent it from re-joining Room1.

4.2 Implemented architecture

To accommodate the requirements of the phase 0 use case and ensure a scalable and flexible foundation for future enhancements, the architecture depicted in Fig. 3 has been designed. Several alternative solutions were considered, but the final selection was made based on their ability to meet the project's goals efficiently. As shown in the figure, open-source solutions were preferred in line with the objectives of this work, i.e., fostering an open-source, standard-based, and scalable platform. The overall architecture includes: a Metaverse Server, MMM Clients, Services and Rooms.

4.2.1 Metaverse Server

The architecture enables multiple MMM clients, each corresponding to a different User, to connect to a Metaverse server. The Metaverse Server implements the MMM logic and keeps track of all the Actions performed by Users on Items. It is implemented using the Unity game engine (editor version 2022.3.47f). The 3D models leveraged in the current implementation to populate the virtual environment are those included in the Simple-Poly City - Low Poly Unity assets, that is free and available at: https://tinyurl.com/3jw67are.

The server-clients connection is established over a Wi-Fi network and implemented using Mirror, a free and open-source

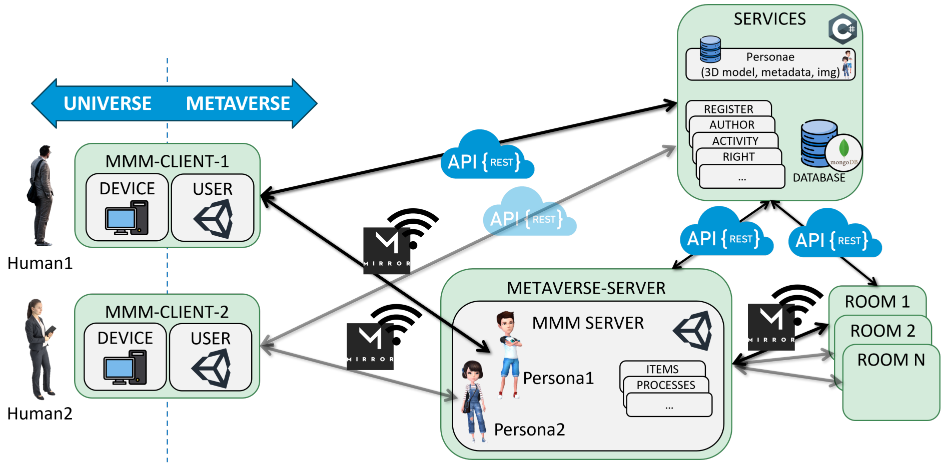

Figure 3: Overall architecture of the phase 0 use case implementation.

game networking library for Unity. (https://github.com/MirrorNetworking/Mirror).

4.2.2 MMM Clients

As shown in Fig. 3, Humans have access to the metaverse using a software application running on their Devices. The client application is responsible for transmitting the operations performed by the local user to the Metaverse Server, thus making them visible to other remote Users. The client application is also in charge of elaborating and rendering/actuating the information received from the Metaverse Server. In the current implementation, Devices are desktop computers running the client application, developed with the Unity game engine. The traditional character controller technique based on WASD keyboard keys and mouse movements is used to move the Persona within the environment. However, in the future, the flexibility of the MMM technical specifications makes it possible to replace desktop computers and traditional 2D interfaces with alternatives. For instance, natural user interfaces, (e.g., based on Microsoft Kinect) or Virtual Reality (VR) systems (such as Oculus Meta Quest 3 or HTC Vive XR Elite) using headsets and VR controllers can be leveraged to improve immersion, interaction, and overall experience by providing more intuitive and engaging ways to navigate and interact within the environment.

4.2.3 Services

As reported in Section 4, the phase 0 use case takes into consideration three main services: i) Registration service that enables Humans to deploy Devices and Users in MMM, ii) Activity service that manages User presence in the MMM, and iii) Parcel and Author Services enabling User to own lands and rooms.

The three services are made available to the Users through RESTful APIs. This approach promises to bring numerous benefits such as scalability, interoperability, and flexibility. For instance, the platform-agnostic nature of REST APIs will enable seamless communication across diverse clients, such as web, mobile, and IoT devices. Furthermore, REST APIs support multiple data formats that adhere to widely accepted HTTP standards. This capability would enable easy extension of the implemented functionalities without disrupting existing ones. Finally, REST APIs are optimized for web communication, thus providing efficient and rapid mechanisms to exchange data using standard HTTP methods. Currently, all the services are hosted on the same web server, however, in the future, it would be possible to distribute them to increase the scalability of the devised architecture.

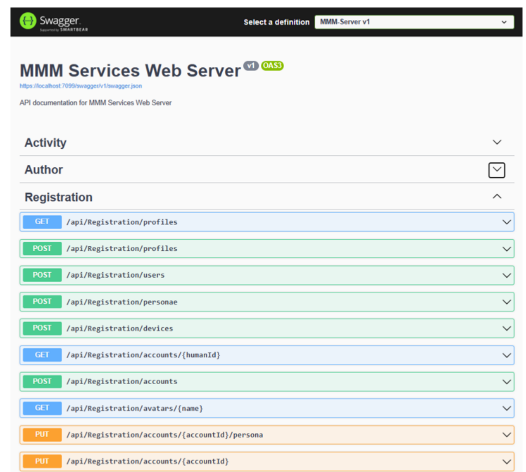

Figure 4: The web interface based on Swagger is used to test the REST APIs to implement the services.

The open-source framework named Swagger (https://swagger.io/) is used for designing, documenting, and testing the RESTful APIs. This tool enables a structured and standardized way when working with REST APIs. Fig. 4 shows the web-based Swagger interface that can be used to test the REST APIs of the services.

Besides exposing services, the Web server also hosts a database aimed at memorizing all the data produced by the Users when interacting with the Metaverse Server. The database was implemented with MongoDB. Being a NoSQL database, MongoDB provides flexibility in handling unstructured or semi-structured data. These kinds of data are particularly useful in those scenarios characterized by rapidly changing data schema. The scalability of MongoDB also makes it possible to easily distribute data across multiple servers, facilitating growth as the current implementation scales. Finally, MongoDB's document-based structure offers an efficient solution for data storage and retrieval, thus making it ideal for scenarios requiring the handling of large volumes of data with minimal overhead. Users and their associated metadata are stored on the web server as well ensuring efficient access to and management of the assets. For the current implementation, sample Personae were generated using Ready Player Me (https://readyplayer.me/).

The web server implements CRUD for both the data memorized in the database and the Users, through the REST API. This ensures reliable and up-to-date data. The web server was implemented using the C# programming language.

4.2.4 Rooms

To manage Rooms and ensure the scalability of the devised solution, it was decided to handle them as disconnected virtual spaces that are synchronized by means of the Mirror library. In this way, the network traffic generated by the Users connected to the Rooms can be dissociated from Users located in the MM-square, as different servers are assigned to handle separate Rooms.

5 Conclusion

This work presented the foundation of the MMM, which may represent a viable solution to address the challenges related to the interoperability of metaverse platforms. The foundation of the MMM was outlined by providing details of the MPAI technical specifications involved in the standardization process. Building on these technical specifications, a prototypical implementation of the MMM was described to validate the proposed standards, establish a versatile open-source platform, and provide feedback for future refinements.

Despite the potential of the MMM and the benefits its implementation could bring to the community, it is important to note that this work also presents some limitations in its current state. More specifically, potential issues due to the concurrent user interactions with MongoDB through the REST APIs and the adoption of Mirror, which is mainly designed for smaller multiplayer instances, represent a risk to system performance and user experience as the number of participants and complexity of interactions scale up. To cope with this limitation, alternative solutions, e.g., Photon Unity Network, could be integrated. It is worth noting that, at this stage, such solutions have been discarded due to their typically paid nature, which contrasts with the project's commitment to an open-source direction. Additionally, potential issues related to data privacy could arise from the use of Mirror, which relies on WebSockets and REST APIs, which are inherently vulnerable to unauthorized data access. These aspects were not addressed in the prototypal implementation, as they are outside the scope of the MMM technical specifications. Security mechanisms are not enforced by the standard, which leaves developers full freedom to integrate any solution to enhance data security and privacy.

As a work-in-progress, no experiments have yet been conducted to assess the effectiveness of the design choices. Aspects such as usability, user experience, and accessibility would benefit from comprehensive evaluations and user feedback to refine the implementation and ensure that the platform meets diverse user needs. Additionally, testing from a technical perspective will be crucial to assess the performance, scalability, and reliability of the platform, helping to identify any areas for improvement before integrating the subsequent components of the technical specifications, making the platform fully compliant with the standard. Finally, performance optimization and scalability under real-world conditions remain areas requiring further investigation and validation through extensive testing.

Although phase 0 is a functional use case, it also represents a simplified scenario, limiting its applicability. Therefore, the integration of advanced functionalities targeting more complex scenarios and a broader range of devices is considered critical - and will be addressed in future work - for fully realizing the MMM's potential as a unified and interoperable solution.

Future work will address these limitations by expanding the MMM's scope, improving cross-platform interoperability, and distributing services across multiple servers to enhance scalability. Moreover, as outlined among the main objectives guiding the implementation of the MMM, the prototype will serve as a fundamental step in collecting feedback and identifying potential improvements to the standard. For this reason, it is planned to gather opinions from domain experts to revise the MPAI technical specifications. Finally, deeper integration of advanced AI capabilities and the exploration of blockchain-based mechanisms for digital asset management could further enhance the robustness and user experience of the MMM's implementation. To this end, different standards proposed by the MPAI group could be integrated.

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References

[1] R. Cheng, N. Wu, M. Varvello, S. Chen, and B. Han. Are we ready for metaverse? a measurement study of social virtual reality platforms. In *Proceedings of the 22nd ACM internet measurement conference*, pp. 504–518, 2022. 2

[2] M. E. Latino, M. C. De Lorenzi, A. Corallo, and A. M. Petruzzelli. The impact of metaverse for business model innovation: A review, novel insights and research directions. *Technological Forecasting and Social Change*, 206:123571, 2024. 1

[3] MPAI. Technical report: Mpai metaverse model (mpai-mmm) – functionalities (mmm-fnc); chapter 4 – use cases. 1, 2

[4] MPAI. Technical report: Mpai metaverse model (mpai-mmm) – functionality profiles (mmm-fnc); chapter 4 – use cases. 2

[5] MPAI. Technical specification: Connected autonomous vehicle (mpai-cav) – architecture (cav-arc) v1.1;. 3

[6] MPAI. Technical specification: Connected autonomous vehicle (mpai-cav) – architecture (cav-tec). 3

[7] M. Sparkes. What is a metaverse. *New Scientist*, 251(3348):18, 2021. doi: 10.1016/S0262-4079(21)01450-0 1

[8] E. VanDerHorn and S. Mahadevan. Digital twin: Generalization, characterization and implementation. *Decision support systems*, 145:113524, 2021. 1

[9] A. Visconti, D. Calandra, and F. Lamberti. Comparing technologies for conveying emotions through realistic avatars in virtual reality-based metaverse experiences. *Computer Animation and Virtual Worlds*, 34(3-4):e2188, 2023. 1

[10] M. Weinberger and D. Gross. A comparison of virtual worlds based on the metaverse maturity model. *ITU J. Futur. Evol. Technol*, 4:537–548, 2023. 2

[11] Z. Zhou, Z. Chen, and X.-L. Jin. A review of the literature on the metaverse: definition, technologies, and user behaviors. *Internet Research*, 34(1):129–148, 2024. 1