Moving Picture, Audio and Data Coding
by Artificial Intelligence
www.mpai.community

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This document is a draft Technical Report of the MPAI Metaverse Model published for Community Comments.
Anybody can send comments to the MPAI Secretariat about the MMM until 2023/01/23T15 UTC.
This text is also available online.
MPAI plans on approving and publishing MMM Version 1 as a Technical Report on 2023/01/25.

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MPAI Technical Report

MPAI Metaverse Model
MPAI-MMM

WD0.5

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Technical Report
MPAI Metaverse Model
V1 (Under development)

1 Introduction

The MPAI Metaverse Model (MMM) is a project designed to facilitate the establishment of standards promoting Metaverse Interoperability. The industry is showing a growing interest in the Metaverse that is expected to create new jobs, opportunities, and experiences with transformational impacts on virtually all sectors of human interaction.

Standards and Artificial Intelligence are widely recognised as two of the main drivers for the development of the Metaverse. MPAI – Moving Picture, Audio, and Data Coding by Artificial Intelligence – plays a role in both thanks to its status of international, unaffiliated, non-profit organisation developing standards for AI-based data coding with clear Intellectual Property Rights licensing frameworks.

The MMM project and this document are organised into areas and each area is described in a chapter. The implementation of areas does not have to be sequential.

Chapter 2 – Definitions defines terms relevant to Metaverse standardisation. In this document, words beginning with a capital letter are defined in Table 1; words beginning with a small letter have the normal meaning consistent with their relevant context.

Chapter 3 – Assumptions lays down the assumptions underpinning the MMM project. Key among these are the following:

Assumption 1	MPAI is defining Metaverse Functionalities expressed by legitimate industry requirements.
Assumption 2	Appropriate Standards Developing Organisations (SDO) will develop the Common Metaverse Specifications (CMS) providing the Technologies to support the identified Functionalities.
Assumption 3	Appropriate entities will group the CMS Technologies into Profiles responding to *industry* needs. Implementers will select the Profiles that best suit them while retaining a level of Interoperability with other Metaverse Instances.

Chapter 4 – Use Cases analyses actual and potential Metaverse Instances from which to extract Functionalities.

Chapter 5 – Services analyses actual and potential services for Metaverse Instances from which to derive Functionalities.

Chapter 6 – Functionalities provides a list of Functionalities organised in areas that appear useful to design appealing Metaverse Instances.

Chapter 7 – Technologies analyses how well the state of Technology can provide Tools needed to implement the Functionalities.

Chapter 9 – Governance analyses issues needing agreement related to the deployment and operation of Metaverse Instances and legal issues impacting the use of Metaverse Instances that are likely to emerge.

Chapter 8 – Profiles identifies the steps that MPAI intends to carry out in the short term and those required to reach the definition of Metaverse Profiles.

Chapter 10 – References provides relevant references organised by argument.
MPAI publishes the MMM for community comments as part of a larger project where:

1. MPAI:
    a. Develops documents and specifications.
    b. Posts them for comments.
2. Anybody can send comments to the MPAI Secretariat
3. MPAI
    a. Considers comments and contributions.
    b. Publishes documents and specifications in final form.
    c. Reports news and progress of the MMM project.

Legal entities and individuals representing technical departments of universities supporting the MPAI mission and able to contribute to the development of Technical Specifications for the efficient use of data may join MPAI.

Anybody can send comments to the MPAI Secretariat about the MMM that is also available online until 2023/01/23T15 UTC. MPAI plans on approving and publishing MMM Version 1 as a Technical Report on 2023/01/25.

This version of the MPAI Metaverse Model has been developed by the Requirements Standing Committee. MPAI may issue revised versions of the MPAI Metaverse Model.

2 Definitions

Setting terms and definitions in an area is a difficult undertaking, but when the area is as vast as multidisciplinary as the Metaverse and covers so many different fields, the undertaking is not just difficult but unrewarding: too many fields address the same notion with different terms and sometimes the same terms in different fields have different meanings.

The drafting of this document has faced two options in developing terms and definitions: a balkanised terminology leading to a Tower of Babel but not displeasing anyone or a unified terminology serving the purpose of the MMM but displeasing most.

This document has selected the latter, no matter how unrewarding it may be. The intention is to facilitate the creation of a common language across industries and application domains. Table 1 collects the Definitions of the Terms used in this document. If a Term is preceded by a dash "-", it means the following:

1. If the font is normal, the Term in the table without a dash and preceding the one with a dash should come after that Term. The notation is used to concentrate in one place all the Terms that are composed of, e.g., the word Decentralised followed by one of the words Application, Autonomous Organisation, Finance, System, and User Identifier.
2. If the font is *italic*, the Term in the table without a dash and preceding the one with a dash should come before that Term. The notation is used to concentrate in one place all the Terms that are composed of, e.g., the word Interface preceded by one of the words Brain-Computer, Haptic, Speech, and Visual.

Table 1 – Terms and Definitions

Terms	Definitions
Authentication	The process of determining whether a Device, a User or an Object is what it states it is.
Avatar	A rendered Digital Human.
Blockchain	A shared immutable ledger stored on a peer-to-peer network of computers.
Common Metaverse Specifications	(CMS) The collection of standards specifying the technologies enabling Metaverse Interoperability including recognised Profiles.
Connected Autonomous Vehicle	(CAV) A vehicle able to autonomously reach a geographical position by using its own sensing, processing, and actuation capabilities and by exchanging information with other CAVs.
Currency	An accepted medium of exchange enabled by Transactions in a Metaverse Instance.
Data	Information represented in digital form.
- Format	The syntax and semantics of Data.
Decentralised	
- Application	(dApp) A Process that runs on a decentralised computing system.
- Autonomous Organisation	(DAO) An organisation without centralised leadership, where the main governing rules are typically encoded by means of a Smart Contract.
- Finance	(DeFi) A financial technology based on a secure infrastructure of distributed ledgers like those used by crypto currencies.
- System	A set of dApps enabling a group of Users to make decisions without a centralised entity.
- User Identifier	An Identifier that enables the verifiable and persistent association with a User without requiring a centralised registry.
Device	Equipment used to sense and/or actuate a Universe Environment by: - The Universe to interact with a Metaverse Instance or - A Metaverse Instance to interact with a Universe Environment.
Duty	A moral or legal obligation to act or behave.
Entitlement	The state of a User having certain Rights in a Metaverse Instance.
Environment	A portion of a Metaverse Instance or the Universe.
Experience	The state of a human whose senses are continuously affected for a meaningful period.
Export	The porting of an Asset to a different Metaverse Environment or Metaverse Instance or Universe Environment.
Human	
- *Digital*	A Digitised or a Virtual Human.
- *Digitised*	An Object that has the appearance of a specific human when rendered.
- *Virtual*	An Object created by a computer that has a human appearance when rendered but is not a Digitised Human.
- *Personal*	The unique, identifiable information that is connected to a User.
Information and Communication Technologies	(ICT) Technologies that enable the processing and distribution of information via the network.
Interaction	The ability of a User to act on and receive stimuli from a Metaverse Instance or one of its Components.
Interface	A communication pathway enabling systems to interact.

- *Brain-Computer*	(BCI) A communication pathway that allows a human to interact with a Metaverse Instance or a Component by sensing and processing the electrical activity of the brain.
- *Haptic*	A communication pathway that allows a human to interact with a Metaverse Instance or a Component through bodily movements and sensations.
- *Speech*	A communication pathway that allows a human to interact with a Metaverse Instance or a Component using spoken language.
- *Visual*	A communication pathway that allows a human to interact with a Metaverse Instance or a Component through bodily movements and visual messages.
Interoperability	The ability of a Metaverse Instance or one of its Components to exchange and make use of Data from another Metaverse Instance or one of its Components.
Metadata	An attribute of Data, e.g., of a User, an Environment, an Object, or a Service.
- *Audio*	An attribute of an Audio Object.
- *Human*	An attribute of a Human Object.
- *Object*	An attribute of a Metaverse Object.
- *Visual*	An attribute of a Visual Object.
Metaverse	A collection of Digital Environments that are implementations of Common Metaverse Specification Profiles; it is populated by Digital Objects that are representations of either real Objects – called Digitised – or computer-generated Objects – called Virtual – or both.
- Actuator	A Device able to render Data from a Metaverse Instance in a Metaverse Environment.
- Asset	A Data structure in the Metaverse associated with a Fungible or Non-Fungible Token.
- Component	One of the following entities: - Environment. - Process. - Service. - User.
- Device	A device directly connected to a Metaverse Instance.
- Enabling Service Layer	The set of Services such as payment, security, identity, privacy, etc. that enable operation of a Metaverse Instance.
- Event	A modification of an Environment having an impact on a Metaverse Environment, or one or more Users.
- Experience Layer	The set of functions, such as Devices, that generate Experiences.
- Functionality	The ability of a Metaverse Instance to perform an action to achieve the goals set by the Metaverse Manager for the Metaverse Instance.
- Industry	The collection of economic players that support the design, development, deployment, operation, and service and content provisioning to Metaverse Instances.
- Infrastructure Layer	The set of functions such as network, transport, storage, and (cloud, edge) processing that enable a Metaverse Instance to operate.
- Object	A data structure that can be used by a Process, e.g., rendered to cause an Experience.

- Operator	A User engaged in an activity using Services from this or other Metaverse Instances (e.g., a vendor, a service provider)
- Partner	A User participating in the activity of a Metaverse Operator (i.e., the business customer of an Operator)
- Platform Layer	The set of Services, such as content creation, content discovery, and content access functions that enable a Metaverse Instance to operate.
- Process	The instance of a program executed.
- Profile	A recognised subset of the Functionalities (Functionality Profile) or Technologies (Technology Profile) specified by the Common Metaverse Specifications.
- Sensor	A Device able to inject Data into a Metaverse Environment.
- Service	A Functionality that enables a User to perform a particular action in a Metaverse Instance.
- Specifications	(CMS) A collection of standards specifying the technologies enabling Metaverse Interoperability.
- Stakeholder	An entity or a human performing a function aimed at achieving a goal in a Metaverse Instance.
- State	The set of values of the Components or stored data of a Metaverse Instance at a given time.
- Metaverse System	The ensemble of entities and rules ensuring that Metaverse Instances operate in the interest of Metaverse Stakeholders.
- Tool	A Technology or group of Technologies enabling a Metaverse Instance to provide a Functionality.
- Technology	A structured application of scientific and/or technical methods the is functionally usable to support a Functionality.
- User	Either a Digitised Human driven by a human, or else a Virtual Human driven by a Process.
Object	
- *Audio*	The digital representation of an object or a computer-generated Object that can be rendered to and perceived by a human ear.
- *Autonomous*	A Virtual Object with the ability to act (e.g., move, speak, respond, execute) with a degree of autonomy.
- *Digital*	A Digitised or a Virtual Object.
- *Digitised*	The digital representation of an object.
- *Human*	An Object representing a real human.
- Identifier	A name enabling the unique association with any of User.
- *Speech*	The digital representation of a sound emitted by the vocal tract of a human or generated by a computer with similar audio characteristics.
- *Virtual*	A computer-generated Object.
- *Visual*	The digital representation of an object captured by an electromagnetic or high-frequency audio signal or a computer-generated or that can be rendered to and perceived by a human eye.
Oracle	A Service providing information from a Universe Environment to a Blockchain.
Orientation	The yaw, pitch, and roll angles of a representative point of a rendered Object in a coordinate system.
Persona	A manifestation of a User as a rendered Digital Human.
Point of View	The Spatial Attitude of a Digital Human watching the Environment.
Presentation	The rendering of Data in a format suitable for human perception.

Privacy	The Right of a User to keep their personal data secret.
Profile	
- *Functional*	The grouping of Functionalities supported a Metaverse Profile.
- *Technology*	The grouping of Technologies enabled by a Metaverse Profile.
Representation	Data that represent an entity of a Universe Environment in a Metaverse Instance.
Right	The innate or acquired ability of a User to claim ownership or perform an action in a Metaverse Environment.
Scene	A structured collection of Objects.
Scene Description	The representation of the structure of a Scene.
Sense of	
- Agency	The subjective awareness of being able to decide, execute, and control one's own actions in a Metaverse Environment.
- Embodiment	The engagement of senses to form a complete Environment Experience.
- Presence	The feeling of being in a Metaverse Environment with other Digital Humans for real.
Service	Functionality provided by a Metaverse Instance or a Metaverse Environment.
Smart Contract	A Program stored on a Blockchain that runs when activated by an external entity, e.g., a User or another Smart Contract.
Social Graph	A representation of the interconnections between a User and other Users, groups of Users, and Components.
Spatial Attitude	The position and orientation and the corresponding velocities and accelerations of an Object.
Token	
- *Fungible*	A representation of an Asset that is interchangeable with other Assets of the same type.
- *Non-Fungible*	(NFT) A unique digital identifier of an Asset that: - Cannot be copied (i.e., a copy is known to be a copy), substituted, or subdivided. - Is recorded in a digital ledger. - Is used to certify Object authenticity and ownership.
Transaction	The operation that changes the state of the Account of one or more Users and potentially of the Service enabling the Transaction.
Trust-less system	A system allowing a User to make reliable Transactions without trusting or knowing the parties the User makes Transactions with.
Universe	The physical world.
Use Case	A particular example of the use of the Metaverse in an application domain.
User	A device directly connected to a User.
- Account	A dataset that unequivocally identifies a User. A User may have more than one Account.
- Authentication	The process that establishes that a dataset provided by a User corresponds to a specified subset of an Account managed by a Metaverse/Operator.
- Cognitive State	The representation of a User's Personal Status that reflects the way they understand the Environment, such as "Confused", "Dubious", "Convinced".
- Data	The Data generated by a User while in a Metaverse Environment.

- Device	A Device
- Emotion	The representation of a User's Personal Status that results from their interaction with an Environment, such as "Angry", "Sad", "Determined".
- Identifier	A name enabling the unique association with a Metaverse User.
- Keys	The pair of public and private keys where the public key is used to encrypt, and the private key is used to both encrypt and decrypt Data.
- Personal Status	The representation of the information internal to a User characterising their behaviour.
- Profile	A collection of Data including Account and Identifier associated with a Metaverse User.
Wallet	
- *Crypto*	Software or hardware holding the public and private keys of a User to enable them to access their account on a Blockchain.

3 Assumptions

This Chapter introduces the assumptions that are considered important to facilitate the common understanding and execution of the Metaverse standardisation process.

3.1 Process

The process of Metaverse standardisation includes the following steps:

1. Identification of Use Cases, either existing or possible (Chapter 4).
2. Identification of External Services that a Metaverse can use (Chapter 4.19.9).
3. Identification of Functionalities from Use Cases and External Services (Chapter 6). The presence of a Functionality in does not mean that a Metaverse Instance shall support that Functionality, but that the Functionality is a candidate to be included in one of the Metaverse Profiles.
4. Analysis of the state and characteristics of the Technologies required to support the Functionalities (Chapter 7).
5. Analysis of the issues and the process enable the eventual definition of Profiles (Chapter 9).
6. Analysis of the issues regarding the management of the Metaverse System and legal issues (Chapter 8).

3.2 Metaverse Specifications

Eventually, the Metaverse Industry will have access to a collection of Interoperability specifications called Common Metaverse Specifications (CMS). It is expected that the CMS will be developed based on an agreed Functionality master plan using contributions made by different Standard Developing Organisations (SDO). The CMS should adopt the "one Functionality-one Tool" principle followed by successful standards, but it can be unavoidable – although not welcome for the eventual success of Metaverse Interoperability – that more than one tool be specified for the same Functionality.

This document is a first attempt at generating such a Functionality master plan. It contains a first set of Functionalities but makes no claim that all have been identified. Further, it and makes no attempt to identify the standard technologies required to build Interoperable Metaverse Instances.

3.3 Profiling

MPAI assumes that the Metaverse notion will be various implemented as independent Metaverse Instances by selecting specific Metaverse Interoperability levels called *Profiles*. The identification

of entities developing Profiles based on the Common Metaverse Specifications (CMS) is an open issue.

A Metaverse Instance may implement:

1. The *full set* of CMS tools. In this case, the Metaverse Instance will be able to interoperate with any other Metaverse Instance. Obviously, the Metaverse instances not supporting the full CMS tool set will non be able to access all functionalities of the first Instance.
2. *A subset* of the Common Metaverse Specifications. This will be possible in three different modalities:
    1. Without adding technologies. In this case, the Metaverse Instance will be able to interoperate with other Metaverse Instances for the functionalities implemented according to the Common Metaverse Specifications.
    2. Replacing functionalities supported by the Common Metaverse Specifications with proprietary technologies. In this case, the Metaverse Instance will interoperate with other Metaverse Instances for the Functionalities implemented according to the Common Metaverse Specifications but will not interoperate with other Metaverse Instances for the remaining Functionalities.
    3. Adding new Functionalities supported by proprietary technologies. In this case, the Metaverse Instance will not interoperate with other Metaverse Instances for such proprietary functionalities.
3. *No functionality* specified by the Common Metaverse Specifications. In this case, the Metaverse Instance will not be able to interoperate with any other Metaverse Instance.

Note1 A recognised set of Profiles will help Users understand the level of Interoperability existing between any two Metaverse Instances.

Note2 The authority delegated by the jurisdiction under which the Metaverse operates may:

1. Adopt a "laissez-faire" attitude.
2. Prescribe a minimum level of interoperability, hopefully based on a recognised Profile.

Note3 Adoption of the "Common Metaverse Specifications" need not be subject to legal obligations.

Note3 *Developers and deployers of Metaverse Instances should have the freedom to select which Functionalities* of their Metaverse Instances should conform with the Common Metaverse Specifications and which will be autonomously defined. Adoption of an Interoperability level should solely be based on business and other public considerations, such as public service features that laws and regulations of different jurisdictions may impose.

3.4 Metaverse definition

Because MMM assumes that Metaverse Instances will be developed and deployed based on a Profile selected by the Metaverse Manager, MPAI adopts the following minimal definition of Metaverse:

A Metaverse instance is a collection of Digital Environments that are implementations of Common Metaverse Specification Profiles; it is populated by Digital Objects that are representations of either real Objects – called Digitised – or computer-generated Objects – called Virtual – or both.

3.5 Interoperability

Interoperability is defined as the ability of a Metaverse Instance to exchange and make use of Data from another Metaverse Instance. Interoperability is often a fall-back solution when Metaverse Instances do not share the same Data Formats.

This document adapts the MPEG-V Media Context and Control standard [71] to the current Metaverse context. Although the development of MPEG-V was initiated in the first half of the years 2000's, the interoperability points identified by it are still relevant and shown in Figure 1 identifying the 8 interoperability points affecting Sensors, Actuators, Commands, and Metaverses.

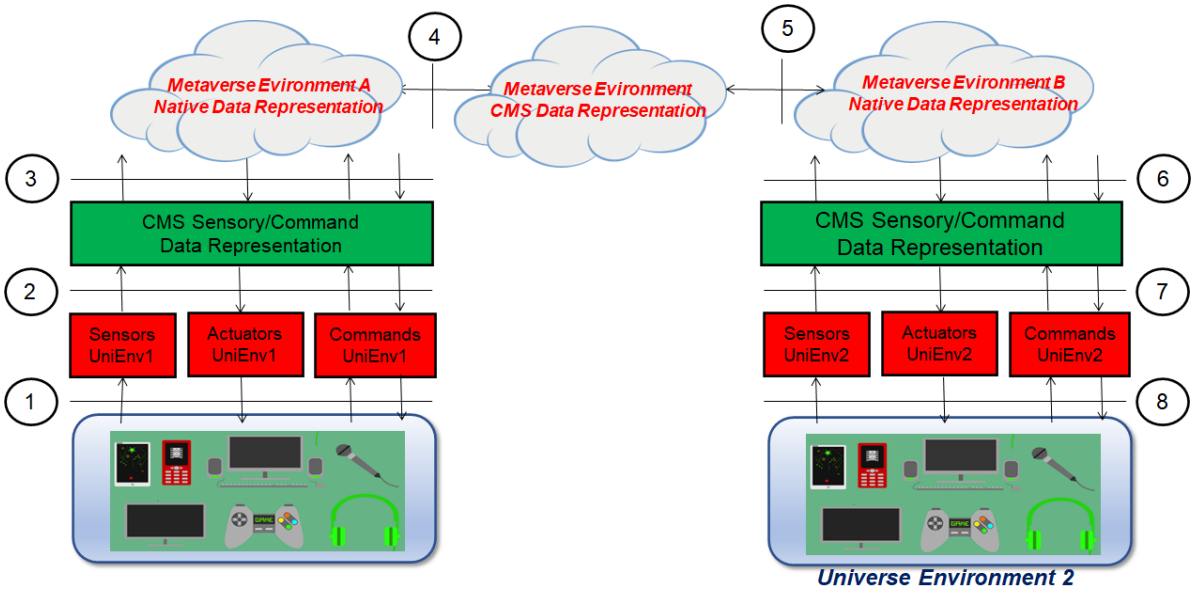

Figure 1 - Sensor-Actuators-Commands-Metaverse interoperability (MPEG-V)

Table 2 describes the interoperability points where Data in a Format moves from an element to another element having a different Data Format.

Table 2 - MPEG-V Interoperability points

#	Information moves from	To
1	Universe Environment 1	Proprietary Sensors and their Commands 1
2	Proprietary format Sensors and their Commands (A)	CMS Sensors and their Commands
3	CMS Sensors and their Commands	Proprietary Format Metaverse Environment (A)
4	Proprietary Format Metaverse Environment (A)	CMS Metaverse Environment
5	CMS Metaverse Environment	Proprietary Format Metaverse Environment (B)
6	Proprietary Format Metaverse Environment (B)	CMS Sensors and their Commands
7	CMS Sensors and their Commands	Proprietary Sensors and their Commands 2
8	Proprietary Sensors and their Commands 2	Universe Environment 2

The workflow of Figure 1 can be described as follows:

1. Metaverse Environment A internally represents Data based on proprietary Formats A using Sensing/Actuation Data and Commands in the CMS Format obtained by converting Sensing/Actuation Data and Commands based on Format 1 from Universe Environment 1. Note that there can be a mismatch between

a. The Sensing Data and Commands received from Universe 1 and Metaverse Instance A because the Profile it implements may not be able to handle all the Sensing and Command Data types received from the Sensors of Universe Environment 1.
b. The Actuators of Universe Environment 1 and the Actuation Data and Commands generated by Metaverse Instance A because of their inability to handle the Data types received.

2. Metaverse Environment B of Metaverse Instance B internally represents Data based on proprietary Formats B. However, by converting its Data from Data Format B to the CMS Data Format, Universe Environment 1 can send Sensing Data to and receive Actuation Data from Metaverse Environment B for use.
3. Metaverse Environment A can serve Universe Environment 2 within the constraints corresponding to sub-points a. and b. of point 1 using the process outlined in point 1. above.

Figure 1 also provides a first general identification of the CMS standardisation areas.

3.6 The Metaverse and AI

Artificial Intelligence (AI) includes a range of technologies that are likely to permeate all the meanders of the Metaverse. MPAI, the Moving Picture, Audio, and Data Coding by Artificial Intelligence international, unaffiliated, non-profit organisation developing standards for AI-based data coding with clear Intellectual Property Rights licensing frameworks has developed a strategy to develop AI-based Data Coding standards that assumes that applications be designed as systems composed of AI Modules (AIM) organised in AI Workflows (AIW) executed in a standard AI Framework (AIF).

The AIF, AIW, and AIM capabilities and features are described by standard JSON metadata and the AIF components expose standard API and the AIWs/AIMs expose interfaces whose input and output Data have a standard Format, while the AIM internals are not specified by MPAI. MPAI has already developed several standards in the AI-based Data Coding space [1,2,3,4,5]. MPAI claims that, in general, improved AIM functionalities can be obtained by improved processing technologies exposing standard input/output Data Format interfaces rather than by using proprietary Data Formats.

The CMS will include more Data Coding Formats than those identified in Figure 1. Hints at these are offered by another model developed by MPAI where the Interaction between Users of Environments A and Environment B – which can be both from the Universe, from different Metaverse Environments, or one from the Universe and the other from a Metaverse Instance – have Interactions that rely on the *analysis* performed on the Data exchanged (Figure 2). Note that, for simplicity, only the processing from Environment A to Environment B chain is shown. The reverse chain where Signals or Data of Environment B are captured to influence Environment A is not shown.

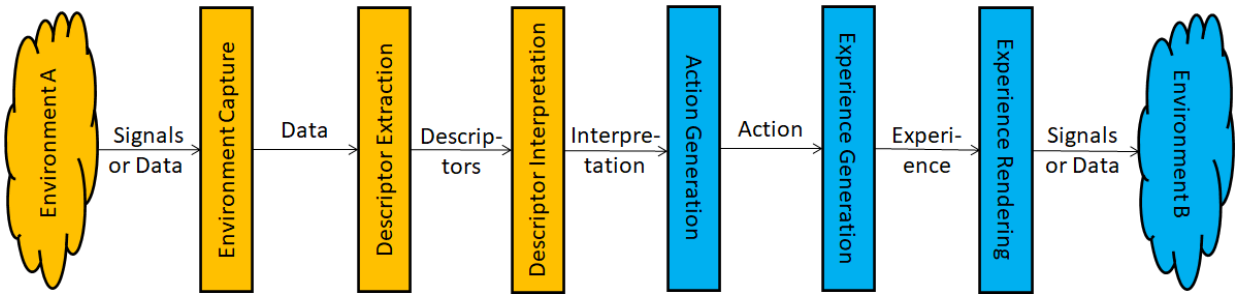

Figure 2 – Environment-to-Environment Interaction Model

Table 3 defines the functions of the processing elements identified in Figure 2.

Table 3 – Functions of components in the Environment-to-Environment Interaction Model

Environment Capture	Captures Environment as collections of signals and/or Data.
Descriptor Extraction	Analyses Data to extract Descriptors.
Descriptor Interpretation	Analyses Descriptors to yield Interpretations.
Action Generation	Analyses Interpretations to generate Actions.
Experience Generation	Analyses Actions to generate Environment.
Environment Delivery	Delivers Environment as collections of signals and/or Data.

Note that Figure 2 assumes that Action causes the Experience Generation Module to generate an Experience. This is an important but not necessarily the only case. For instance, in the case of a Connected Autonomous Vehicle, both Environments are the same (in the Universe) and the Action is likely to be a command to actuate the CAV's motion [6].

3.7 Organisation

To identify Metaverse functionalities, it is useful to assume that a Metaverse Instance will have:

1. **A Metaverse Manager** owning, operating, and maintaining the Metaverse Instance.
2. **Metaverse Operators** running Metaverse Environments under Metaverse Manager licence.
3. **Metaverse Partners** acting in Metaverse Environments under licence of a Metaverse Operator.
4. **End Users**.

The actual organisation of a Metaverse Instance is likely to take many different shapes enabled by different technologies. For instance, a Metaverse Instance could have just one Metaverse Manager and many Users or just one User or have several Metaverse Operators each with a set of Metaverse Partners. The assumption of this Section is sufficiently general and articulated to be used to represent a significant number of use cases from which functionalities can be identified.

3.8 Layering

A Metaverse Instance will typically be implemented as a layered structure. Necessary layers are the infrastructure layer and a service layer. In most cases there is also an experience layer. This document assumes that a Metaverse Instance is composed of 4 layers:

1. The **Infrastructure Layer** including the network, transport, storage, and processing (cloud, edge) services.
2. The **Platform Layer** including Metaverse-specific services to create, discover, and access content.
3. The **Enabling Service Layer** including a variety of subsidiary services such as payment, security, identity, and privacy.
4. The **Experience Layer** enabling Experiences enjoyed through Devices.

A Metaverse Instance may also interact with a variety of application-specific services, e.g., traffic information services, weather service, etc. These should not be considered as part of the Enabling Service Layer but simply connected as External Services.

The assumed layered architecture is depicted in (*Figure 3*).

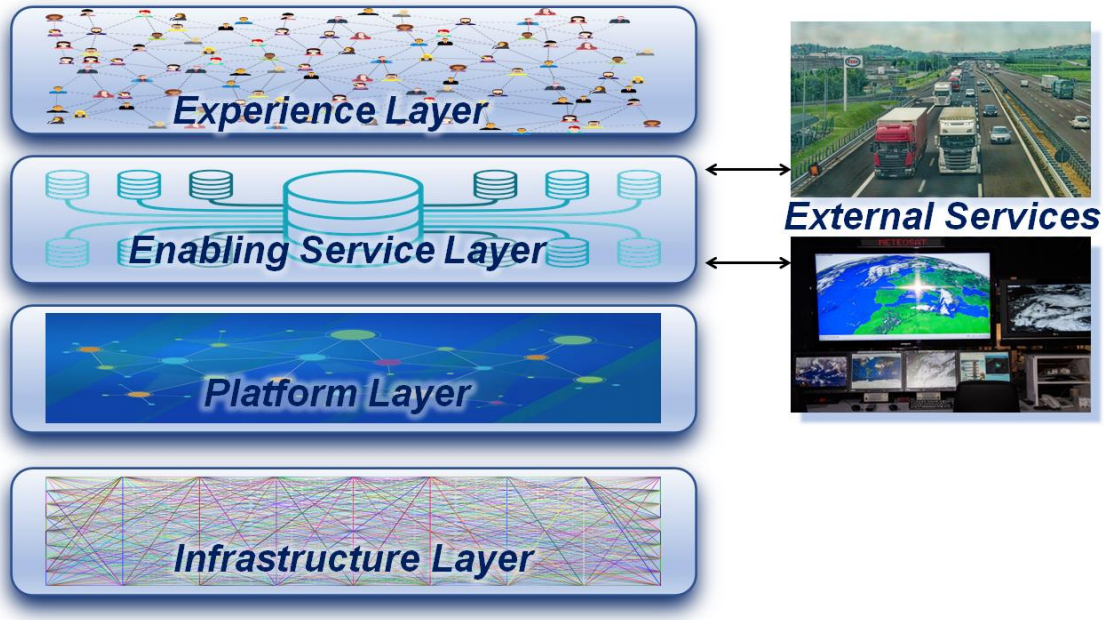

Figure 3 – Metaverse Layer and External Services

In this context, it is worth mentioning that:

1. The word Metaverse Instance will be used to include the full stack of 4 layers. If only one layer, e.g., the Experience Layer is intended, the "Metaverse Experience Layer" expression will be used.
2. The layered architecture is introduced for the sole purpose of identifying requirements. The architecture selected for the design and implementation of a Metaverse Instance should be based on the Metaverse Manager's decision.
3. While it is conceivable that parts of the Infrastructure Layer, as defined above, will be a part of a future extended internet, it can be assumed that the other layers will be variously implemented and independently operated, and their technologies will not be part of a future internet. Therefore, we do not expect that there will be a "single Metaverse" that only fully interoperable Metaverse Instances all able to support the same features simply because the functionalities indispensable in one Metaverse Instance may well not be needed in another. A *governed* Profile approach, however, can guarantee levels of Interoperability between independently developed and operated Metaverses leaving it to entrepreneurs to decide which level of Interoperability is in their interest to offer.
4. Instead of a probably unrealistic idea of fully interoperable Metaverses, this document assumes that there will only be Common Metaverse Specifications (CMS) and CMS Profiles.

3.9 The extent of the Metaverse

A Universe Environment accesses a Metaverse Instance via Sensors and Actuators and so does a Metaverse Environment. Figure 4 contemplates two non-exclusive cases:

1. The Universe Environment uses its own Sensors and Actuators to access or interact with the Metaverse Environment (blue line).
2. The Metaverse Instance is connected to a Universe Environment via Sensors and Actuators that are integral with the Metaverse Instance (red line).

In both cases, Interoperability requires that the Sensor and Actuator have standard Interfaces.

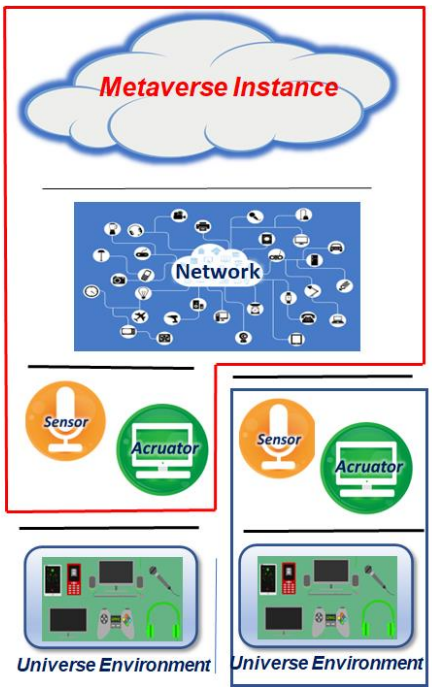

Figure 4 – Connections between a Metaverse Instance and the Universe

3.10 The Metaverse is not just for humans

In its investigations, MPAI is encountering several use cases where the notion of Metaverse is applicable even though the Metaverse Environment does not necessarily include human Users. This is the case, e.g., of a Connected Autonomous Vehicle (CAV) producing, or contributing data to a Metaverse Instance that is intended to be an accurate Representation of the Universe Environment where a CAV happens to be [6]. In this case, the layered architecture of Section 3.8 may very well not include an Experience Layer.

3.11 The Metaverse is not an asymptotic point

While there is consensus that some of the most emblematic functionalities of the Metaverse will become available only after several years of research and development, this does not mean that we should wait for and celebrate the magic moment in which the first Metaverse Instance will be "turned on". Metaverse Instances exist today that offer significant subsets of the Functionalities identified in this document. While they are not implemented using the Common Metaverse Specifications, they should and will be considered by this document as Metaverse Instances.

3.12 The Metaverse is Digital

The MMM consistently uses the following adjectives with the meaning below:

1. "*Digitised*" to refer to the data structure corresponding to the digital representation of an object.
2. "*Virtual*" to refer to the data structure created by a computer, as opposed to a data structure entirely originated from an object.
3. "*Digital*" to refer to both "Digitised" and "Virtual".

3.13 Who is User

MPAI calls a Metaverse User either a Digitised Human driven by a human, or else a Virtual Human driven by a Process. A Metaverse User can be rendered and perceived as an avatar.

3.14 Representation and Presentation

The MMM is based on a clear distinction between the way information is digitally represented and the way information is rendered. For instance:

1. A Digital Human is a Digital Object suitably represented as bits in a Metaverse Instance.
2. An Avatar is a rendered Digital Human and is perceived as physical stimuli.

3.15 Scene and Object hierarchy

A Universe Environment is perceived as one or more scenes containing objects. When mapping it to a Metaverse Environment, a scene and its objects are digital represented. It is desirable that the format of the Digital Scene Representation be shared by all Digital Scenes, whether they are Digitised or Virtual.

Objects have a digital representation composed of at least four types of data:

1. Security Data: Data that guarantees the Identity of an Object.
2. Private Data: Object-related Data accessible by specific Users.
3. Public Data: Object-related Data accessible by all Users.
4. Perceivable Presentation Data: Data used to render the object (e.g., a collection of avatar models that a User selects from as the current Persona).

3.16 Regulation and Governance

The operation of a Metaverse Instance is typically regulated and governed depending on applicable law. This document assumes that the Functionalities identified are provided for use in conformity with applicable law. Section 8.2 identifies some of the regulatory and governance issues that will likely have to be addressed if Metaverse Instances offering seamless and rewarding Experiences to Users are to become possible.

4 Use Cases

This Chapter analyses potential Metaverse Use Cases, sometimes supplemented by specific examples. The fact that one such example is considered in this chapter does not imply that MPAI in any way endorses the specific business model adopted, neither does it suggest any kind of investment, nor that the example should be preferred compared to others not considered. It simply denotes that the business model is worth to be analysed. MPAI welcomes the submission of names of current Metaverse Instances whose business models have characteristics worth being considered for the purpose of defining Metaverse Functionalities. Such submissions should contain a level of detail comparable to the ones used in existing examples.

A section at the end of this chapter will collect relevant workflows derived from the Use Cases.

4.1 Automotive

4.1.1 Description

The Metaverse has the potential to revolutionise the way vehicles are designed and tested, as it allows for the creation of a collaborative design environment within a virtual space. The design of a vehicle can then be performed entirely within a Metaverse Environment, and the same design can also be virtually tested at different stages of its lifecycle. In addition, a Blockchain-supported Metaverse offers new opportunities for the creation of communities or "cults" centered around vehicles. These virtual communities could bring together enthusiasts and experts to share knowledge, discuss the latest developments in the automotive industry, and potentially even collaborate on vehicle design and testing projects within the Metaverse Instance. The Metaverse also

has the potential to enable the interconnection of vehicles, allowing them to communicate with each other and potentially even make decisions as a collective. This could lead to the development of new transportation systems that are more efficient and responsive to the needs of users. For example, a fleet of interconnected vehicles could coordinate their routes and movements in real-time to optimize for factors such as traffic, weather, and passenger demand. The use of the Metaverse for vehicle interconnection could also facilitate the development of autonomous vehicles, as it allows for the creation of a virtual environment in which these vehicles can be tested and refined.

4.1.2 Functionalities

1. Vehicles design and engineering
    a. Collaborative virtual platforms
    b. Virtual meetings
    c. Immersive reality rendering
    d. Data management and traceability leveraging blockchain technology
    e. Testing
2. Virtual showrooms
    a. Choice of vehicle accessories and customisation
    b. Sales meetings
3. Interconnected vehicles
    a. Augmented reality (e.g., driver dashboard)
    b. Intelligent autopilot

4.2 Defence

4.2.1 Description

The defence industry has been using virtual reality for decades, typically in small virtual environments designed to train personnel in the use of equipment such as planes, tanks, and ships and developed on a case-by-case basis by different departments, in a non integrated fashion. A properly designed Metaverse Instance could support realistic, task specific Metaverse Environments in an integrated fashion. As it happens in industrial applications, defence oriented Metaverses can be used to enhance Universe activities, simulate physical events designed to collect more information about the Universe, and offer immersive experiences that would be too expensive or even impossible to have in the Universe.

4.2.2 Functionalities

1. Accurate mapping of terrain
2. Creation of Metaverse Environments for projection to Universe Environments.
3. Immersive Environments
4. Extremely low delay
5. Realistic battlefields
6. Special sensors and actuators
    a. For personnel training
    b. For monitoring (e.g., IoT)

4.3 Education

4.3.1 Description

The Metaverse has the potential to enhance the delivery of educational content in a wide range of fields, including astronomy, physics, chemistry, geography, history, literature, and more. By

providing a sensory experience with interactive possibilities, students in a Metaverse Environment can engage in educational content in a more immersive and dynamic way. This can be particularly useful for fields that rely heavily on experiential learning, as they allow students to interact with and explore concepts in a virtual environment. These interactive possibilities are currently only achievable through traditional means such as text, images, and physical experiments, and the Metaverse offers a new and potentially more effective way to engage with educational content.

4.3.2 Functionalities

1. Virtual classrooms
2. Virtual labs
3. Navigation in virtual objects
4. Student Persona
5. Avatar animation

4.4 Enterprise

4.4.1 Description

An enterprise can make different uses of a Metaverse Instance:

- Connected environments that replicate and connect every aspect of the enterprise to optimise experiences and decision making.
- An integrated virtual space where employees can recreate the company's culture.
- Gamification for learning, loyalty programs, campaigns, skill development, and employee training.
- Enterprise events featuring 3D immersive platforms, NFT-powered registration and ticketing, customisable avatars, global networking, and audience engagement.
- Interacting with audiences, increasing visibility, and improving engagement marketing.
- Product launches, merchandise sales, rewards for customers, or donation collections.

4.4.2 Functionalities

This is an initial list of Functionalities:

1. External relations
    a. Metaverse Environments designed for User relation management
    b. Business meetings.
    c. Support for product maintenance.
    d. Events (e.g., conferences)
2. Internal relations
    a. Digital Twins of workshops, labs, assembly lines.
    b. Work from Home.
    c. Metaverse Environments designed for employees to meet (e.g., virtual coffee machines)

4.5 eSports

4.5.1 Description

Esports refers to competitive gaming played by professional gamers using video games. This activity has gained widespread popularity, with hundreds of millions of people watching esports streams on platforms such as YouTube, Fortnite, and Twitch. The popularity of esports has led to it being re-defined as a social and commercial activity, with gamers competing in intense and lengthy competitions on popular video game titles. By using Blockchains, gamers can own and monetise in-platform Assets within the Metaverse Instance.

4.5.2 Functionalities

This is an initial list of functionalities:

1. Select Persona.
2. Style Persona.
3. Buy, win, or collect Assets (skins, weapons, add-ons).
4. Store Assets in a Crypto Wallet.
5. Post to and Sell Assets in a Marketplace.
6. Move Assets from a game (Metaverse Environment) to another game in the same or different Metaverse Instance.
7. Bet on a gamer or a match.
8. Track a game.
9. Place ads in a game.

4.6 Events

4.6.1 Description

Events are probably the most iconic examples of Metaverse use. One part of the story is different events that have been held in the last couple of years, some with the claimed participation of millions of Users. Another is the different events held to launch products such as several fashion weeks. Still another is the appearance of "general contractor" companies offering the complete realisation of events.

4.6.2 Functionalities

1. Before
    a. Event promotion
    b. Ticketing
    c. Large scale events
2. During
    a. Virtual performers
    b. Everybody can talk to everybody else
    c. Participant Persona
    d. Avatar animation
    e. Participants Status
3. Post-event
    a. Statistics
    b. Re-visiting

4.7 Finance

4.7.1 Description

The Metaverse has the potential to revolutionise the financial sector by providing a virtual platform for a wide range of financial services, e.g., hosting virtual financial events and conferences, enabling virtual meetings and appointments between clients and financial institutions, and facilitating the creation and management of new digital financial assets such as cryptocurrencies, DeFi and NFTs. By leveraging the power of the Metaverse, financial institutions and individuals can access a range of (new and already existing) financial tools and resources in a virtual environment, making it easier and more convenient to conduct financial transactions and manage financial portfolios.

4.7.2 Functionalities

1. Decentralised Finance and NFTs

2. Identity management
3. Virtual bank accounts and marketplaces
4. Meetings with customers
5. Financial events and conferences
6. Financial education and training.

4.8 Food

4.8.1 Description

The notion of the Metaverse can be applied to the food industry. A Metaverse Instance for food could be used by

- Food enthusiasts to order, deliver, and experience new culinary experiences enhanced with the aid of virtual tools.
- Food enthusiasts, business owners, chefs, and companies to explore cuisines, dishes, and food products.
- Business players to advertise or conduct surveys for their brands.

4.8.2 Functionalities

1. Metaverse Environments for people to have dinner together.
2. Multi-sensory menu containing audio, video, smell (High-quality reproduction of food odour).
3. Participants order food from the multi-sensory menu.
4. Metaverse Environment captures people's assessment of their food.
5. Metaverse Environment provides common entertainment while people have dinner.

4.9 Gaming

4.9.1 Description

A more immersive and interactive gaming Experience can be create by allowing Users to interact with other Users within a decentralised virtual social environment. This enhanced level of interaction can make the gaming experience more engaging and dynamic. In addition, Users may see the Metaverse as an opportunity to monetise their gaming skills, just as they might do in the Universe.

4.9.2 Functionalities

1. Multi-player immersive and interactive gaming
2. Immersive gaming environments
3. Play-to-earn
4. Content creation for games
5. Interoperable game assets (clothes, etc.)
6. Asset trading (e.g., NFTs)
7. Marketplace for assets
8. Persistent ownership
9. Autonomous Persona

4.9.3 Examples

4.9.3.1 Pokémon Go

Pokémon Go[1] is an AR mobile game, part of the Pokémon franchise, developed and published by Niantic in collaboration with Nintendo and The Pokémon Company, and running on iOS and Android devices. It uses mobile devices with GPS to locate, capture, train, and battle virtual creatures, called Pokémons, which appear as if they were in the User's Universe Environment.

Users can create and customise their own avatars which are displayed on a map based on the Users' Universe position. Features on the map include "PokéStops" that can be equipped with items used to attract additional Pokémons and "Pokémon Gyms" that serve as battle locations for matches. PokéStops and Gyms are typically located at interesting locations.

Pokémon Go uses a freemium business model, i.e., it is free-to-play: it is combined with local advertising and supports a marketplace for in-app purchases of additional in-game items.

The game can be combined with a "Pokémon Go Plus" device: a Low Energy wearable Bluetooth device that allows Users to perform certain actions in the game without looking at their smart device, e.g., by vibrating when a User is near a Pokémon.

4.9.3.2 Roblox

Roblox[2] is a Metaverse where users download a basic game free to play from a collection of millions of different games all developed within the same graphical environment provided by Roblox. Famous games are, e.g., "Adopt Me!", where users care for virtual pets potentially traded with other players, and "Jailbreak" where users play in a virtual 'cops and robbers' style game. Roblox provides the tools to its community to create their own games.

Users can download every game without any additional software (unless it is to create a game). Users can also create games in the platform and charge real money for people to play it and can charge for bonus features such as digital skins. Creators can also earn money through advertising and micro-transactions by using the platform virtual currency Robux which can be bought and converted back into real money.

4.9.3.3 The Sandbox Game

The Sandbox Game[3] is an on-line game in which players can trade digital lands and create Experiences on top of them to share with other users. The Sandbox platform consist of three key parts:

1. Voxel Editor allows users to model and create in-game assets.
2. Marketplace is where assets are sold.
3. Game Maker enables users to build games without the need for coding skills and contribute to improving the Metaverse Experience with new creations and game scenes.

Three different types of Ethereum and Polygon tokens govern the economic operations in The Sandbox:

- LAND: an NFT representing a digital parcel.
- SAND: a cryptocurrency facilitating purchase of parcels, virtual goods, and services.

[1] https://pokemongolive.com/
[2] https://www.roblox.com/
[3] https://www.sandbox.game/

- ASSET: an NFT representing in-game asset such as equipment and wearables for avatars and creations that are used to populate the digital parcels.

Users can generate revenue by creating ASSETS and renting or selling them or building games experiences.

4.9.3.4 Minecraft

Started as a simple computer game, Minecraft[4] has built on mining and crafting virtual worlds with Lego-like blocks. Initially there were two main modes: survival and creative. In the survival mode, players found supplies and foods to craft tools and avoid creatures. In the creative mode, players get supplies to build whatever they want, they can fly, and do not need to virtually eat.

Minecraft is available as:
1. As Java Edition runs on the PC.
2. As Minecraft Bedrock Edition runs on Android, iOS, and games consoles.
3. On VR headsets like Quest and Windows Mixed Reality.

After an upfront cost of the initial purchase, updates and additional features are provided for free. Minecraft provides a Marketplace where users can buy virtual currency (Minecoins) and spend it on user-created content. Licensed content is also available featuring popular franchises such as Sonic the Hedgehog, Jurassic World, and Major League Baseball. Users can explore and play games in pre-existing worlds created by other players and content creators. Content creators are compensated when players download their work on the Minecraft marketplace. Many users also stream their playing on Minecraft on platforms such as Twitch or YouTube.

4.10 Healthcare

4.10.1 Description

As a word, telemedicine has a long history. However, a Metaverse Environment offering healthcare that simulates a clinic allows patients and doctors to have deeper interactions, e.g.:
1. Users can enjoy a relaxed digital environment to relieve panic and anxiety.
2. Administration of cognitive behavioural therapy and other behavioral methods to help with pain reduction[5].
3. Administration of exposure therapy for PTSD[6].
4. Group meditation practices for well-being[7].
5. Digital twinning of a patient whereby their digital representation can be used to test treatments and medicines.

4.10.2 Functionalities

1. Remote monitoring of patients
2. Remote diagnoses (telemedicine consultations by more than one physician)
3. Haptic Universe perception by the Metaverse (touching patient)
4. Surgery in the metaverse?
5. Training for operations using digital twins

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[4] https://www.minecraft.net/
[5] https://www.fda.gov/news-events/press-announcements/fda-authorizes-marketing-virtual-reality-system-chronic-pain-reduction
[6] https://www.verywellmind.com/virtual-reality-exposure-therapy-vret-2797340
[7] https://techcrunch.com/2022/02/03/tripp-acquires-evolvr/

6. Patients interact with Metaverse Environment that cause anxiety (cognitive therapy, mental health)
7. Virtual fitness
8. Patients stay in a Metaverse Environment that assuages them (virtual wellness)
9. Digital Twins of humans to test impact of medicines, fast-forward the patient to the future etc.
10. Precision medicine.
11. Internet of medical devices.
12. Staff training
13. Personal Medical Records (stored on a Blockchain).

4.11 Hospitality

4.11.1 Description

The hospitality business is about providing leisure, experiences, and entertainment to their customers. In the Metaverse context, an industry primarily based on service and the physical reception of guests – hotels, restaurants, entertainment, nightclubs, casinos, and events – should morph into an experience-based industry. Humans should get from a Metaverse Environment an experience that is as memorable as the one they get from comparable Universe Environments: both physical and virtual locations should provide equally memorable experiences.

4.11.2 Functionalities

1. Before
    a. Preview experience of locations.
    b. Participation in virtual events.
    c. Chatbots answering FAQs or routing the questions to the appropriate departments.
    d. Virtual tours.
2. During
    a. Multi-sensory guide to hospitality services.
    b. Metaverse Environments for “virtual spa”.
    c. Physical massage.
    d. Multi-sensory recommendations services (e.g., tourism).
    e. The Hospitality Metaverse Instance captures the guest’s Personal Status)
3. After
    a. Membership model (e.g., access to exclusive Metaverse Environments, private information retention and protection).

4.12 Professional training

4.12.1 Description

By adopting AR and VR for onboarding and training, learners gain “hands-on” job experience in a remote, risk-free environment and learn how to solve problems in “break-fix” scenarios, even developing new skills improving their performance. Metaverse training can reduce training time and cognitive load, induces positive behavioural change, and gives a pathway for an outlier to come up the learning curve.

4.12.2 Functionalities

1. Training using a twin of the workshop.
2. Tracking of trainee’s performance
    a. Personal feedback from the tracking.

    b. Personal feedback from a human coach.
    c. Suitability for different jobs.
3. Gamification
    a. High-score leaderboard.
    b. Rewards.

4.13 Real estate

4.13.1 Description

A property tour in a twinned Metaverse Environment allows prospective buyers to experience more options without being at the site by having a full walkthrough of a virtual apartment. Depending on the level of twinning, Users can have fewer or more interactions with the twinned Metaverse Environment.

4.13.2 Functionalities

1. 3D reconstruction.
2. Design a building in a Metaverse Environment.
3. Experience the virtual building by walking around in it.
4. Experience a virtual building at different times and in different situations, i.e., how the building "feels" at sunset or when it's packed with people.

4.14 Remote work

4.14.1 Description

More than a conjecture, remote work is already offered by several collaboration platforms, allowing employees to gather in virtual spaces, interact using VR or the web, and engage in productive activities through whiteboards, VR workstations, calendar apps, file sharing, chat, and other virtual replicas of office tools.

4.14.2 Functionalities

1. Achieve the sense of "co-presence" in Metaverse Environments through total immersion in a shared virtual environment:
    a. Work next to colleagues.
    b. Chat at a virtual water cooler/coffee machine.
    c. Schedule and hold virtual meetings.
    d. Hold brainstorming sessions.
    e. Attend virtual employee wellness spaces.
    f. Have lunch together with colleagues.
    g. Delegate tasks to a virtual assistant.
2. "Gamification" of learning and training:
    a. Visual demonstration of concepts and work practices.
    b. Learning by doing.
    c. Higher engagement and improved problem-solving through "quest-based" methods.

4.15 Retail

4.15.1 Description

Important sections of the retail industry have already made advances in experimental uses of the Metaverse. However, we are not yet at the level of Metaverse Instances but of Environments carved out in current Metaverse Instances. The experiments deal with physical goods and virtual

goods having value in a Metaverse Instance, but we are at the level of early steps made by specific segments of the retail industry. To leverage the potential of the Metaverse in retail, adequate satisfaction must be provided to human senses, beyond vision and hearing, because of their essential role in the retail experience. Retail means the ability to appeal to customers' senses to create the psychological conditions that evoke the emotion leading to the willingness to buy.

4.15.2 Functionalities

1. Place furniture and gadgets in a virtual apartment (IKEA)
2. Try-on makeup using an avatar (e.g., L'Oréal and Avon)
3. Try-on clothing, sunglasses or fashion accessories using an avatar.
4. Offer a virtual interactive experience with the object you are considering purchasing such as an automobile.
5. Touch, taste or smell virtual objects using haptic, gustation and olfactory interfaces.

4.16 Social media

4.16.1 Description

The metaverse has the potential to transform the way people connect and share content with each other online. By providing a virtual platform for social networking, the metaverse allows Users to create and maintain relationships with each other in a virtual environment. In addition to facilitating social connections, the metaverse could also provide a space for Users to attend virtual events and gatherings, such as concerts, parties, and meetings. These events could range from small, intimate gatherings to large-scale events with thousands of attendees. The metaverse could also present new opportunities for brands and businesses to reach and engage with Users through virtual influencers, potentially leading to innovative approaches to marketing and advertising.

4.16.2 Functionalities

1. Events
2. Social networking
3. Content creation
4. Influencer marketing

4.16.3 Example

4.16.3.1 Somnium Space

Somnium Space[8] is an open-source, social, and persistent VR world. The platform allows users to buy land, homes, and other in-game assets. These assets are all represented as NFTs, and they are tradable on the Ethereum blockchains. Somnium Space is entirely inter-connected, i.e., all users exist within the same Metaverse Instance, rather than within multiple Metaverse Environments.

Two different types of Ethereum tokens govern the economic operations in Somnium Space:

- PARCEL: an NFT representing a digital parcel.
- CUBE: a cryptocurrency facilitating purchase of parcels, virtual goods and services used in Somnium Space.

Users can build and monetise Experiences with in-game assets, advertising space, stream their gameplay, create a store in their Metaverse Environment, develop online courses and other Experiences and Events (e.g., concerts), and charge fees for these ventures. Somnium Space gives users

[8] https://somniumspace.com/

the ability to earn CUBEs based on their “Karma levels”, i.e., a representation of social standing and the perceptions of other Users.

4.17 Travel

4.17.1 Description

A User in a travel oriented Metaverse Environmentcan visit locations without constraints from the distance between locations and see things in VR or AR as a replacement or as a preview of physical travel (as in Thomas Cook’s “Try before you Fly”).

4.17.2 Functionalities

1. Make a visit in a Metaverse Environment that is the digital twin of a location.
2. Make a visit to a Universe Environment assisted by AR (highlights of additional information for particular spots)

4.18 Virtual spaces

4.18.1 Description

Users can buy, sell, and rent virtual real estate within a Metaverse Environment, potentially allowing for the development of virtual communities and businesses. Companies can or ask to develop a virtual land within the Metaverse Instanceand create Experiences such as theme parks, musea, and interactive exhibits. The Metaverse Environment can provide a platform for virtual event spaces, allowing companies to host events such as conferences, trade shows, and product launches within a virtual environment.

4.18.2 Functionalities

1. Virtual real estates
    a. Trading and renting
    b. Development (e.g., buildings)
    c. Marketplace for parcels and Persona wereables, all implemented as NFTs
2. Geo-located marketing
3. Events

4.18.3 Examples

4.18.3.1 Voxels

Voxels[9], one of the oldest Ethereum-based metaverse platforms, operates a Metaverse Instance offering 3D Experiences with a global network of Users on a platform running on centralised servers. By means of a web browser, Users explore, interact, and build virtual buildings on virtual parcels. Users can also develop Metaverse Environments such as art galleries, stores, and social spaces.

Each digital parcel is represented as an Ethereum NFT. In a similar way, the Objects composing a Scene (such as decoration elements and avatar costumes) can be associated with an NFT and listed in the Voxels Marketplace and in OpenSea. Trading of the NFT is enabled by OpenSea acting as an External Service Provider.

The current (as of 2022/11/21) workflow of on Voxels Objects unfolds as follows:

[9] https://www.voxels.com/

1. A User creates an Objects using Voxel's software.
2. The Object is minted as an NFT on the Polygon blockchain.
3. The Object is listed on the Voxels Marketplace and OpenSea.
4. The creating User can set the price of the Object and the royalty for future resales in OpenSea.
5. OpenSea charges another 2.5% on the sale.
6. When the buying User resells the Object, they will pay the royalty to the creating User and 2.5% to OpenSea.

4.18.3.2 Decentraland

Decentraland[10] operates a Metaverse Instance offering 3D Experiences with a global network of Users on a platform running on decentralised servers. Users can explore, interact, and play games using interactive apps, make payments, and communicate peer-to-peer through a web browser without specific software requirements.

Decentraland is composed by a set of 126 smart contracts: 101 deployed on Ethereum and 25 deployed on Polygon. The main types of tokens that govern the economic operations are:

- LAND: an NFT representing a digital parcel.
- MANA: a cryptocurrency facilitating purchase of parcels, virtual goods and services in Decentraland.

An association of two or more directly adjacent parcels of LAND is called Estate. These parcels must be directly adjacent and cannot be separated by a road, a plaza, or any other parcel. Estates are especially useful when building larger scenes that span more than one parcel. Estates are also regulated by a smart contract. Each avatar can be assigned a unique name, managed with a smart contract called NAMES: each name is linked with an NFT.

The platform is governed by the Decentraland DAO that allows MANA, LAND and NAMES owners to vote on how the world behaves: for example, what kinds of wearable items are allowed (or disallowed), moderation of content, LAND policy and auctions, pay for expenses such as software developments, which content servers can join the network, organising events. Community voting power is computed in function of the MANA and LAND allocation of each user.

Aside from the DAO, there is a selected group of users tasked with preventing and handling security issues on LAND and Estate smart contracts. This group of people, called the Security Advisory Board (SAB), comprise several expert entities or individuals initially chosen by the Decentraland team. This team acts as guarantors of contract security, and it oversees providing rapid response to any bug report.

The DAO owns several of the most important smart contracts of the entire Decentraland platform[11], e.g.:

- Points of Interest: containing the list of notable locations in Decentraland that are advertised to users as good places to begin exploring the virtual world.
- Wearables collections: wearables can be grouped into collections before minting. The relevant contracts are owned and controlled by the DAO.
- Marketplace contracts: The Decentraland Marketplace dApp makes use of several smart contracts to manage the process of selling and bidding on LAND, Estates, and other NFTs. These contracts are also where the marketplace fees are defined and can only be changed with the DAOs approval.

[10] https://decentraland.org/
[11] https://docs.decentraland.org/player/general/dao/overview/what-smart-contracts-does-the-dao-control/

Note that the Smart Contracts containing lists of features, such as enabled names etc., can only be modified after a community vote is passed.

4.18.3.3 Over the Reality

Over the Reality (OVER)[12] is an AR platform that merges Metaverse and Universe Environments where Users can augment and enhance their Experiences, through the lens of their smartphones or smart glasses.

Two different types of Ethereum and Polygon tokens govern the economic operations in Over:

- OVRLand: an NFT token that allows decentralized possession of digital assets such as OVRLands (representing a digital parcel that make up the digital layer of subdivision of the Earth into hexagons) and Over Experiences.
- OVR: a cryptocurrency utility token used in Over.

OVRLand owners can decide what kind of experience a User can experience once they enter into the Universe Environment associated with their parcel. Av OVRLand owner acquires third party content posted on their parcel and projected into the associated Universe Environment. AR Experiences can range from static 3D content and interactive highly complex and hyper real scenes that make virtual content merge with the real world. The current Devices are based on iOS and Android and Smart glasses such as Hololens[13], Magic Leap[14] and stereoscopic AR headset such as HoloKit[15].

4.19 Workflows

4.19.1 Attend a Metaverse Event

1. Human:
    a. Wants to attend event (concert).
    b. Wears a VR headset.
2. User:
    a. Pays for a virtual front seat.
    b. Listens to concert.
    c. Talks to other Users sitting next to them on private channels.
    d. Express their “preferences”.
3. Metaverse Environment publishes preferences
4. User selects matches from the posted group of Users with overlapping preferences.
5. Metaverse Environment
    a. Captures the Participants Status.
    b. Creates SFX accordingly.
    c. Informs performer.
6. Metaverse Operator initiates a promotional activity that engages the participants.
7. Participants join the activity.
8. Metaverse Environment informs participants of the result.
9. Metaverse Operator gives award to winner(s).
10. Human takes off their VR headset.

[12] https://www.overthereality.ai/
[13] https://www.microsoft.com/en-us/hololens
[14] https://www.magicleap.com/en-us/
[15] https://holokit.io/

4.19.2 Buy a personal wearable

1. Human:
    a. Wants to buy sunglasses
    b. Wears a VR headset.
2. User:
    a. Enters a Metaverse Environment selling fashionable personal items.
    b. Searches for available wearables on the Metaverse Environment marketplace.
    c. Selects the preferred wearable.
    d. Shares their Persona selected for the purpose of purchasing a wearable with the Environment.
3. Metaverse Environment displays the Persona.
4. User
    a. Dresses their Persona with the selected Asset (e.g., sunglasses).
    b. Migrates to the Persona displayed by the Environment.
    c. Sees the Environment from their current Persona's Point of View.
    d. Changes external conditions in the Metaverse Environment (e.g., lighting etc.).
    e. Selects terms of use of the selected wearable, e.g., the wearable for exclusive use by the selected Persona.
    f. Starts a Transaction on the Blockchain.
5. Blockchain enables the Transaction.
6. User adds the wearable to the collection of the selected Persona.

4.19.3 Buy the real twin of an Object

1. Human
    a. Wishes to buy a tennis racket.
    b. Wears a VR headset and haptic gloves
2. User
    a. Enters their preferred Metaverse Environment (e.g., a virtual sports club).
    b. Goes to a Metaverse Environment (a shop selling sports equipment).
    c. Tries a few rackets that they sense with their haptic glove.
    d. Selects one racket.
    e. Enters a Metaverse Environment (a virtual tennis court).
    f. Plays a game with an autonomous Virtual Human using the racket.
    g. Converses with a salesclerk.
    h. Buys the real racket.
    i. Signals that they are leaving the Metaverse Environment.
3. Human plays tennis in a Universe Environment (a tennis court).

4.19.4 Establish a Metaverse Environment

A human wishing to establish a Metaverse Environment executes the following steps:

1. *Design*: creating the layout, graphics, and interactive elements of the Metaverse Environment, etc.
2. *Program*: coding the Metaverse Environment to enable User Interaction and the execution of actions or events.
3. *Test*: ensuring that the Metaverse Environment functions properly and that the user experience is smooth and enjoyable.
4. *Launch*: making the Metaverse Environment to users and promoting it to the appropriate audience.
5. *Management*: maintaining and updating the Metaverse Environment to fix any bugs or issues and to keep the content fresh and engaging.

6. *Analysis of user data*: collecting data on how users interact with the Metaverse Environment and using this information to improve the User Experience.

4.19.5 Interact with a Metaverse Call Centre

1. Human
    a. Is angry about an orvercharged bill.
    b. Wears a VR headset to discuss the matter with a utility.
2. User talks to a clerk (an autonomous Virtual Human).
3. Virtual clerk has a neutral face and voice.
4. User utters their complaint with an angry voice.
5. Virtual clerk
    a. Understands the User's Personal Status from their voice, face, and gesture.
    b. Activates appropriate strategy with its voice, face, and gesture.
6. User is unconvinced
7. Virtual clerk calls their "boss" (Digitised Human).
8. User is convinced.
9. Human takes off their VR headset.

4.19.6 Navigate a 3D Object

1. Humans (students) attend a lecture about the brain.
2. Wears 3D headset and haptic glove.
3. Lecturer
    a. Displays 3D Object (virtual brain).
    b. Gives students task to report on specific areas of the virtual brain.
4. User
    a. Navigates the brain.
    b. Feels density of brain tissue.
    c. Defines a portion of the brain – manual or automatic.
    d. Counts objects per assigned volume size.
    e. Detects structures in a (portion of) the 3D AV object.
    f. Deforms/sculpts the 3D AV object.
    g. Combines 3D AV objects.
    h. Calls an anomaly detector on a portion with an anomaly criterion.
    i. Follows a link to another portion of the object.
    j. 3D prints (portions of) the 3D AV object.

4.19.7 Relax in a Metaverse Environment

1. Human
    a. Wants to relax at relaxation service
    b. Wears a VR headset.
2. User
    a. Leaves their preferred Metaverse Environment (their virtual desk).
    b. Goes to a Metaverse Environment (virtual spa).
    c. Reviews menu of Experiences watching and/or feeling examples of them, e.g.,:
        i. Sound of running water.
        ii. Repetitive light shows for meditation.
        iii. Hot stones.
        iv. Physically felt massage.
    d. Selects Experience.
    e. Pays with NFTs gained at an online game.

    f. Enjoys Experience.
3. Human
    a. Relaxes.
    b. Takes off their VR headset.

4.19.8 Social gathering across Metaverse Instances

1. A group of humans wear the headsets they have used during the day at work.
2. The Users:
    a. Create a calendar invitation with initial Metaverse Environments that can be shared with the group.
    b. Agree on the means of communicating with the group i.e., group chat or voice channel.
    c. Select the means of teleporting as a group to other Experience-providing Metaverse Environments, e.g., from a virtual group portal.
    d. Select the venue, a virtual science museum displaying digital exhibits that allow group interaction (e.g., like the Exploratorium).
    e. After the visit they decide to go to a Metaverse Environment (e.g., a bar).
    f. Signal they are leaving the Metaverse.
3. The humans take off their VR headsets.

4.19.9 Train a Metaverse Hospital staff

1. Metaverse Operator introduces training session.
2. Doctor (Virtual Human):
    a. Wears haptic gloves.
    b. Demonstrates treatment to participants using patients (Virtual Humans).
3. Participants (Digitised Humans)
    a. Wear haptic gloves.
    b. Repeat the demonstration on similar Virtual Human patients.
4. Metaverse Environment:
    a. Tracks participants' performance.
    b. Analyses performance.
    c. Interprets the performance.
    d. Provides high-level summary to doctor (Digitised Human).
5. Doctor
    a. Reviews summary.
    b. Singles out participants' erroneous operations.
    c. Asks trainee to redo the operations correctly.
6. Doctors and participants take off their VR headsets and haptic gloves.

4.19.10Visit a Metaverse Environment

1. Human wears a VR headset and haptic gloves.
2. User
    a. Enters their preferred Metaverse Environment (e.g., their virtual office).
    b. Signals that they want to search the Metaverses.
    c. Makes a global search across Metaverses.
    d. Signals that they want to go to the selected Metaverse Environment (a shop).
    e. Receives the appropriate AV Experience based on their movement.
    f. Feels the Objects of the shop with their haptic gloves.
    g. Converses with a salesclerk.
    h. Buys the real twin of the selected Object.
3. Virtual shop records the purchase on the User's record.

4. User signals they are leaving the Metaverse Environment.
5. Human takes off their VR headset.

4.19.11 Work in a Metaverse Environment

1. Human wears a VR headset.
2. User
    a. Leaves their preferred Metaverse Environment (their room with their bookshelf).
    b. Enters the company's Metaverse Instance.
    c. Greets the guard (a Digital Human).
    d. Strolls in the virtual main hall and greets colleagues (Digital Humans).
    e. Goes straight to their virtual office set up in an open office workspace.
    f. Meets colleagues just arriving (Digital Humans).
    g. Sits at their virtual desk.
    h. Exchanges jokes with virtual colleague sitting next to them.
    i. Consults schedule.
    j. Holds brainstorming session from their virtual desk with colleagues from other departments.
    k. Delegates note-taking to a virtual secretary.
    l. Has a coffee break.
    m. Attends a planned meeting at a Metaverse Environment (specially created meeting venue).
    n. Has lunch together with colleagues.
    o. Attends virtual employee wellness spaces.
3. Human takes off their VR headset.

5 External Services

This Chapter analyses the services that a Metaverse may provide but are not Metaverse specific. They may be provided by independent entities offering Services to a Metaverse Instance while potentially offering the same to other Metaverse Instances.

5.1 Content Creation

Content Creation is considered here as an External service because the creator economy combines different actors such as content creators, curators, and community builders (such as social media influencers, bloggers, and videographers), and the software and finance tools underpinning them. The Content Creation process materialises into three main steps: regular publication of content on a particular niche, building of a following within that niche, and monetisation of the audience using a variety of channels and methods.

Brands have already added this new media environment to advertising and sales as a new expense item in the lifecycle of their products and services. Depending on the industry, expenses may reach important levels and even be more important than the very capital invested into the development of a product or service. The estimated global content creation turnover is ~100 B$.

To be viable, the thousands of Metaverse Instances that are expected to be deployed in the next few years will have to offer a wide variety of Experiences and there is no doubt that the current creator economy can easily morph to suit the needs of the expected millions of Metaverse Environments and offer new opportunities to the current players to use and/or adapt their skills to the new context [68].

On the other hand, the path to the future is not clearly marked. While it is commonly held that creativity will be the last stronghold of humankind in the face of the Artificial Intelligence onslaught, we can see that today's social networks are already flooded with content produced by generative models, i.e., deep-learning algorithms that allow computers to generate "original" content, such as text, images, video, audio, and code. Pleasant and consistent images can already be obtained by entering a text after a prompt and selecting images from the suggested list. The Metaverse will need content, but that will not necessarily all come from the current creators.

5.2 Content Creation Tools

Content Creation tools are available two sources: either a creation tool directly provided by the Metaverse Instance (e.g., Roblox), or a tool provided by an External Service Provider (e.g., MagicaVoxel[16]).

5.2.1 Roblox

Roblox Users can upload realistic block textures created by them and control the in-game physics of their Environments, build with materials and textures that represent elements of a Universe Environment, e.g., realistic brick, glass, and metal.

5.2.2 MagicaVoxel

The tool can be used to produce content in the MagicaVoxel file format[17]. It can be used in the native format in some Metaverse Instances, such as Voxels. It is also possible to convert MagicaVoxel content for use on other Metaverse Instances, such as Minecraft and Sandbox[18].
The licence of the MagicaVoxel content creation tool states:
Granted: use for any project.
Desired: credits to the content creation tool.
Disallowed: selling the software (original or modified) or shipping the software in other packages.

5.2.3 NVIDIA OmniVerse

NVIDIA Omniverse is a 3D content creation and simulation platform enabling users to create and collaborate on VR environments in real-time. The platform is intended for creation and sharing virtual environments where 3D Objects and Environments are created and manipulated. It also integrates with other applications, such as AutoCAD, Blender, and Unity.

The NVIDIA Omniverse Universal Design Collaboration (UDC), a feature of the Omniverse platform, allows users to collaborate in real-time to share and edit 3D models, text, and other design assets, as well as view and interact with them in a Metaverse Environment. It also includes communication and collaboration tools, e.g., chat and voice communication, and enables track change and task assignment.

A Marketplace is attached to NVIDIA Omniverse where objects can be sold and shared through the use of the Omniverse Marketplace. Omniverse is announced to become be available as an open-source tool to individual creators

5.3 Marketplace

A Service provider owns or operates a marketplace and processes sales or payments for marketplace sellers.

[16] https://ephtracy.github.io/
[17] https://github.com/ephtracy/voxel-model/blob/master/MagicaVoxel-file-format-vox.txt
[18] https://enteropositivo.medium.com/how-i-build-a-sandbox-game-with-magicavoxel-eb797afa8d76

5.3.1 OpenSea

OpenSea[19] is a marketplace supporting the trading of NFTs for different Blockchains, such as Ethereum, Polygon, Solana. It also supports the creation of NFT collections. Trading can be performed using the native Blockchain currencies (e.g., ETH or MATIC) or crypto fungible tokens (e.g., USDC, MANA). The platform charges a 2.5% fee for each successful trading and allows the collection owner to charge royalties on each subsequent trading.

5.4 Crypto Wallets

Crypto wallets are hardware devices or software that store the Private Keys that enable the execution of Transactions on Blockchains. Custom crypto wallets offer traders dedicated solutions compared to those from crypto exchanges. MetaMask, Coinbase, and Trust Wallet are examples of software wallets. Trezor and Ledger are examples of hardware wallet manufacturers.

5.5 Cryptocurrency Exchanges

Cryptocurrency exchanges are centralised and decentralised platforms that facilitate the trading of cryptocurrencies for other crypto assets, including digital and fiat currencies and NFTs. A cryptocurrency User can buy and sell Assets at the current (spot) price or leave orders that will be executed when the Asset reaches the User's desired price target (limit order). Current examples are Binance, Coinbase, and Kraken.

5.6 Development Services

Development Service Providers are intermediaries that help develop the business of an Operator on a Metaverse Environment, e.g., by discovering, buying, or renting locations suitable to attract and place programmatic ads, or building a Metaverse Environments, etc.

5.6.1 LandVault

A Development Service Provider claiming to:

1. Helps brands build a Metaverse Experience and drive engagement.
2. Covering from land rentals to project management, business measurements and insights.
3. Discovering locations suitable to customers and buying or renting real estate.
4. Enabling game developers to monetise their content through interactive, programmatic brand placements.
5. Developing, promoting, and monetising the Metaverse.

5.6.2 Infinite Reality

Infinite Reality [20] provides tools and services enabling creators and companies to develop Metaverse experiences.

5.6.3 DigiSomni

DigiSomni[21] is Development Service Provider specialising in the development of solutions on the open-source platform Vircadia.

5.7 Platforms

This Section deals with services that provide infrastructures on which a Metaverse Instance can be nuilt

[19] https://opensea.io/
[20] https://theinfinitereality.com/
[21] https://digisomni.com/

5.7.1 Metaverse.network

Metaverse.Network[22] is a blockchain for Metaverse Instances & dApps supporting Ethereum-compatible Smart Contracts. Developers can build dApps and games running on the M.N network.

5.7.2 Vircadia

Vircadia[23] is an ecosystem of metaverse applications enabling individuals and organisations to deploy their own virtual world solutions. The ecosystem includes Apache 2.0 components.

6 Functionalities

This Chapter collects and organises the Functionalities extracted from Use Cases, External Services, and other sources according to the following principles:

1. Functionalities are grouped in nine areas.
2. Each area contains a variable number of subareas.
3. Each subarea conrtains a variable number of Functionalities.
4. Each Functionality includes: Title, Description, Comments and Dependencies.

6.1 Introduction

This Chapter collects an initial set of Functionalities that some Metaverse Instances are likely to support. The following disclaimer is reiterated:

The Functionalities identified in this Chapter are NOT expected to be provided by ALL Metaverse Instances. The actual grouping of Functionalities and their enabling technologies (Tools) into Profiles will be part of a subsequent step of the process outlined in Chapter 1 – Introduction.

Figure 5 depicts the operation of a Metaverse Instance interacting with the Universe.

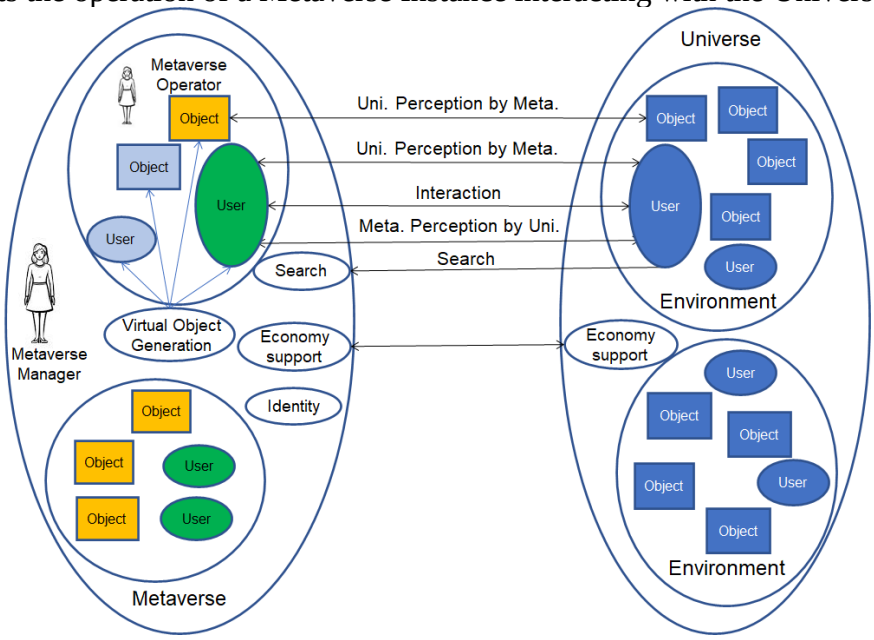

Figure 5 – Universe and Metaverse Users, Objects, and Functionalities

The following nine points describe the Functionality areas described in the following Sections:

[22] https://metaverse.network/
[23] https://vircadia.com/

1. Instance.
    1. The big oval on the left-hand side represents a Metaverse Instance managed by a Metaverse Manager.
    2. The big oval on the right-hand side represents the Universe.
    3. The Metaverse Instance provides Functionalities, some of which are depicted in the big oval on the left-hand side, e.g., Economy Support interacts with its equivalent in the Universe.
2. Environment.
    1. The two smaller ovals on the left-hand side represent two Metaverse Environments.
    2. The one on the top corresponds with the Universe Environment on the top of the right-hand side. It contains a Scene populated by:
        1. Two Digital Humans, one being a Digitised Human twinning a human in the Universe Environment on the top and the other being a Virtual Human generated by the Metaverse Environment.
        2. Two Objects, one twinning an object in the Universe Environment on the top and the other a Virtual Object generated by the Metaverse Environment.
3. Content Representation. A Metaverse Instance needs technologies to represent both Digitised and Virtual Content. The focus is on human-generated and perceptible content.
4. Perception of the Universe by the Metaverse. A Metaverse Instance uses Content Representation technologies to perceive and represent objects in the Universe.
5. Perception of the Metaverse by the Universe. A Universe Environment, including humans and machines, uses Content Representation technologies to perceive Scenes and Objects located in a Metaverse Environment.
6. User. A User – whether a Digitised Human or a Virtual Human – needs several Functionalities to be admitted and operate in a Metaverse Instance.
7. Interaction. A human interacting with a Metaverse Instance or any of its components requires the support of Interaction Functionalities, some of which are identified in Section 6.8.
8. Search. As in the web today, Functionalities are needed to enable a human to search a Metaverse Environment, a Metaverse Instance, all Metaverse Instances, and potentially to search the Universe as well.
9. Economy support. The Metaverse provides Functionalities to Users wishing to conduct economic activities, such as Agreements, Transactions, etc.

Each of the nine areas is further subdivided into subareas. Each subarea contains Functionalities which are described and then followed by examples, comments, and clarifications (labelled as Comments).

6.2 Instance

6.2.1 Introduction

This section collects the functionalities that refer to a Metaverse Instance. It is organised in the following sub-areas:

Go one layer up to the functionality index

6.2.2 Management

This subsection identifies and defines Functionalities that enable a Metaverse Manager to manage a Metaverse Instance.

Area	1. Metaverse Instance

Subarea	1.1 Management
Title	1.1.1 Complete Layer Management
Description	A Metaverse Manager owns/operates/maintains all Layers of a Metaverse Instance.
Comment	All Layers of a Metaverse Instance are managed and operated by a single entity. The Metaverse Instance may have any architecture, e.g., a non-layered one.
Dependency	TBD

Area	1. Metaverse Instance
Subarea	1.1 Management
Title	1.1.2 Partial Layer Management
Description	A Metaverse Manager owns/operates/maintains some of the Layers of a Metaverse Instance.
Comment	1. The different Layers of a Metaverse Instance or its component services are managed and operated by different entities E.g., the Infrastructure Layer may be managed and operated by a telecom operator. 2. Some Enabling Services, e.g., Blockchain and Marketplace, may be provided by entities possibly providing their services to different Metaverse Instances. 3. Some Services, e.g., traffic monitoring, weather forecast, etc., maybe provided by External Service Providers, and typically used by Metaverse Environments.
Dependency	TBD

6.2.3 Organisation

This subsection identifies and defines Functionalities that enable a Metaverse Manager to operate a Metaverse Instance.

Area	1. Instance
Subarea	1.2 Organisation
Title	1.2.1 Centralised Functionalities
Description	A Metaverse Instance supports centralised Functionalities.
Comment	The Metaverse Manager collects, stores, and manages the Data generated in their Metaverse Instance.
Dependency	TBD

Area	1. Instance
Subarea	1.2 Organisation
Title	Terms of Services - General
Description	A Metaverse Manager sets the Terms of Service of a centralised Metaverse Instance.
Comment	The Terms of Service determine Rights and of Duties that Metaverse Instance Users, e.g., Metaverse Operators, Metaverse Partners, and End Users should have.
Dependency	1.2.1, 1.2.2,

Area	1. Instance
Subarea	1.2 Organisation
Title	1.2.2 Terms of Services - Ethical

Description	The Terms of Service of a Metaverse Instance include the ethical requirements that Users shall conform to.
Comment	The Terms of Service may extend beyond the requirements set by the laws of the jurisdiction under which the Metaverse Instance operates.
Dependency	1.2.1

Area	1. Instance
Subarea	1.2 Organisation
Title	1.2.3 Decentralised Functionalities
Description	A Metaverse Instance supports decentralised Functionalities.
Comment	A decentralised function may be the Smart Contract on which a virtual society is established and the Blockchain for enabling the required Transactions.
Dependency	TBD

Area	1. Instance
Subarea	1.2 Organisation
Title	1.2.4 Rights and Duties – Smart Contracts
Description	Rights and Duties of Users joining a Decentralised Metaverse Instance are set and controlled by Smart Contracts.
Comment	A Smart Contract defines the ownership of a parcel in the Metaverse Instance without centralised control.
Dependency	TBD

Area	1. Instance
Subarea	1.2 Organisation
Title	1.2.5 Permissioned Functionalities
Description	A Metaverse Instance supports permissioned Functionalities.
Comment	Access to a Metaverse Instance requires permission, e.g., because the Metaverse Instance serves the needs of a company.
Dependency	TBD

Area	1. Instance
Subarea	1.2 Organisation
Title	1.2.6 Permissionless Functionalities
Description	A Metaverse Instance supports permissionless Functionalities.
Comment	Access to a Metaverse Instance does not require permission. The Instance is typically decentralised.
Dependency	TBD

Area	1. Instance
Subarea	1.2 Organisation
Title	1.2.7 Trust-less Functionalities
Description	A Metaverse supports Trust-less Functionalities.
Comment	Two Users making a Transaction need to trust each other.
Dependency	TBD

Area	1. Instance
Subarea	1.2 Organisation
Title	1.2.8 Decentralised Apps
Description	A Metaverse Instance uses a Blockchain to enable dApps.

Comment	The Blockchain provides the peer-to-peer infrastructure enabling the Decentralised Application to run.
Dependency	TBD

6.2.4 Features

This subsection identifies and defines the Functionalities that enables a Metaverse Instance to offer a set of features.

Area	1. Instance
Subarea	1.3 Features
Title	1.3.1 Concurrent Users
Description	A Metaverse Instance supports an arbitrary number of concurrent Users and Digital Objects, especially Digitised Humans.
Comment	A User of a Metaverse Instance may add an arbitrary number of Digital Humans to an Environment within the constraints of their subscription plan.
Dependency	TBD

Area	1. Instance
Subarea	1.3 Features
Title	1.3.2 Limit concurrent Users
Description	The Metaverse Manager sets a limit to the number of concurrent Users.
Comment	While the Metaverse specifications should be written in such a way that a limitless increase of a Metaverse Instance complexity is possible, a specific Metaverse Manager may have limited ICT resources and only support a bounded complexity.
Dependency	TBD

Area	1. Instance
Subarea	1.3 Features
Title	1.3.3 Synchronous Experiences
Description	A Metaverse Instance offers Users synchronous Experiences to an arbitrary large number of Users.
Comment	Users can interact with one another and with a Metaverse Environment in real time as if they were in a Universe Environment.
Note	Currently, large events made available by Metaverse Instances cannot offer the same Experience to all participants. Groups of Users are created sharing a full synchronous Experience and have full Interactivity with other Users. Users belonging to other groups may have slightly different Experiences and not have full Interaction with Users in other Groups.
Dependency	TBD

Area	1. Instance
Subarea	1.3 Features
Title	1.3.4 Persistent Environment
Description	A Metaverse Environment is persistent, i.e., it runs continuously and continues to exist and evolve independently of whether there are active Users in it or not.
Comment	A User who left an Environment may find upon returning that it has changed since they left it, i.e., the lights now on because it is “night”.
Dependency	TBD

Area	1. Instance
Subarea	1.3 Features
Title	1.3.5 Persistent Object
Description	An Object remains available for those who have the Right to access it and for as long as the Metaverse Environment Operator decides or until a Process removes it.
Comment	An Object may disappear because a User has achieved a certain number of points in a game or because it is "sunset" in a Metaverse Environment.
Dependency	TBD

6.2.5 Storage

This subsection identifies and defines Functionalities offered by a Metaverse Instance.

Area	1. Instance
Subarea	1.4 Storage
Title	1.4.1 Persistent Storage
Description	A Metaverse stores Data permanently and securely.
Comment	Critical data may be stored on the Metaverse Blockchain.
Dependency	TBD

Area	1. Instance
Subarea	1.4 Storage
Title	1.4.2 Store and Retrieval Interface
Description	A User stores, searches, and retrieves Data through a standard interface.
Comment	A User can search for and access an Event in a Metaverse Instance.
Dependency	TBD

Area	1. Instance
Subarea	1.4 Storage
Title	1.4.3 Time and Space Management
Description	A Metaverse Instance manages the Data it collects based on time and space.
Comment	A User can: 1. Play an Event that happened at a certain time and Metaverse Environment. 2. Schedule an Event to happen in the future.
Dependency	TBD

Area	1. Instance
Subarea	1.4 Storage
Title	1.4.4 Storage Interoperability
Description	A Metaverse Instance supports Interoperability between its own Data and the Data stored in another Metaverse Instance.
Comment	A User may access Data stored on the Ethereum Blockchain used by a Metaverse Instance on while being in another Metaverse Instance that uses the Cardano Blockchain.
Dependency	TBD

Area	1. Instance
Subarea	1.4 Storage
Title	1.4.5 Blockchain Interface

Description	A Metaverse Instance uses a standard interface to store, search and retrieve Data on the Blockchain used by the Instance.
Comment	The Format may be used to store events on the Blockchain.
Dependency	TBD

6.2.6 Process Management

This subsection identifies and defines the Functionalities that enable a Metaverse Instance to manage its Processes.

Area	1. Instance
Subarea	1.5 Process Management
Title	1.5.1 Smart Contract
Description	A Metaverse uses Smart Contracts stored on a Blockchain.
Comment	The Metaverse's Blockchain is used to enable Smart Contracts.
Dependency	TBD

Area	1. Instance
Subarea	1.5 Process Management
Title	1.5.2 Smart Contract Monitoring
Description	The Metaverse Instance monitors Smart Contracts for consistency, e.g., adherence to rules, and security.
Comment	The distributed executability of Smart Contracts may affect the security of a Metaverse Instance. A Metaverse Operator may decide to stop and kill a Smart Contract upon detecting critical situations.
Dependency	TBD

Area	1. Instance
Subarea	1.5 Process Management
Title	1.5.3 Smart Contract Interoperability
Description	The function of a Smart Contracts of a Metaverse Instance can be executed in another Metaverse Instance.
Comment	This is true even if the Blockchains of the two Metaverse Instances are different.
Dependency	TBD

6.2.7 Security

This subsection identifies and defines the Functionalities that enable a Metaverse Instance to offer security functions.

Area	1. Instance
Subarea	1.6 Security
Title	1.6.1 User Profile Security
Description	A Metaverse Instance ensures that a malicious User does not take over the Profile of another User.
Comment	A User is guaranteed that a malicious User does not impersonate them.
Dependency	TBD

Area	1. Instance
Subarea	1.6 Security
Title	1.6.2 Data Security

Description	A Metaverse Instance ensures that a malicious User does not take over the Data of another User.
Comment	A User is guaranteed that a malicious User does not appropriate any of their Assets.
Dependency	TBD

Area	1. Instance
Subarea	1.6 Security
Title	1.6.3 Device Security
Description	A Metaverse Instance ensures that a malicious User does not take over or compromise a Device that has passed security verification.
Comment	A Device Testing regime makes sure that a malicious User cannot take over or compromise a Device used by a Metaverse Instance to capture data from the Universe or by a User to interact with a Metaverse Instance.
Dependency	TBD

Area	1. Instance
Subarea	1.6 Security
Title	1.6.4 Anti-attack security
Description	A Metaverse ensures that a malicious User does not cyber-attack Components or Assets.
Comment	Assets are protected beyond Asset stealing.
Dependency	TBD

Area	1. Instance
Subarea	1.6 Security
Title	1.6.5 Anti-DDOS security
Description	A Metaverse Instance withstands denial of service attacks.
Comment	DDoS stretches a Metaverse Instance's ability to support a large number of concurrent Users.
Dependency	TBD

6.3 Environment

6.3.1 Introduction

This section collects the functionalities that refer to Metaverse Environments. It is organised according to the following sub-areas:

Go one layer up to the functionality index

6.3.2 Management

This subsection identifies and defines Functionalities supporting the management of an Environment.

Area	2. Environment
Subarea	2.1 Management
Title	2.1.1 Environment Operation
Description	A Metaverse Operator operates a Metaverse Environment.
Comment	Operation is carried out within the Metaverse Instance's Terms of Service or DAO's governance rules as typically enabled by Smart Contracts.

Dependency	TBD

Area	2. Environment
Subarea	2.1 Management
Title	2.1.2 Technology import
Description	A Metaverse Operator imports Operator-specific technologies to provide Operator-specific Services.
Comment	A Metaverse Operator uses a custom-made plug-in to provide a Service.
Dependency	TBD

6.3.3 Organisation

This subsection identifies and defines Functionalities supporting the operation of an Environment.

Area	2. Metaverse Environment
Subarea	2.2 Organisation
Title	2.2.1 Environment rules
Description	A Metaverse Operator sets the rules of their Metaverse Environment, and/or the Services offered.
Comment	An Environment may be run by a community with strong behavioural or ethical principles that they want to see enforced in their Environment. The Metaverse Environment publishes the rules.
Dependency	TBD

6.3.4 Services

This subsection identifies and defines Functionalities supporting the Services provided by an Environment.

Area	2. Metaverse Environment
Subarea	2.3 Services
Title	2.3.1 Metadata access
Description	A Metaverse Environment makes the Metadata of an Object accessible to a User.
Comment	A User retrieves information about certain Objects and Events of a Metaverse Environment.
Dependency	TBD

Area	2. Metaverse Environment
Subarea	2.3 Services
Title	2.3.2 Rights acquisition
Description	A Metaverse Environment offers Users the means to acquire Rights.
Comment	Rights may be acquired as a reward for doing something in the Metaverse Environment or by paying a fee.
Dependency	

Area	2. Metaverse Environment
Subarea	2.3 Services
Title	2.3.3 Data access Rights
Description	A Metaverse Environment makes Data accessible to a User based on their Rights.

Comment	A User experiences a current or past Event of a Metaverse Instance subject to acquiring of specific Rights.
Dependency	TBD

Area	2. Metaverse Environment
Subarea	2.3 Services
Title	2.3.4 Dispute resolution
Description	A Metaverse Environment offers a basic dispute resolution service.
Comment	A User may wish to choose a practical shortcut to resolve a dispute about matters related to a Metaverse Environment.
Dependency	TBD

Area	2. Metaverse Environment
Subarea	2.3 Services
Title	2.3.5 Policing/surveillance/monitoring
Description	A Metaverse Environment exercises policing/surveillance/monitoring.
Comment	A Metaverse Manager may sanction a User who has concocted false Data.
Dependency	TBD

6.3.5 Types

This subsection identifies and defines Functionalities supporting different types of a Metaverse Environment.

Area	2. Metaverse Environment
Subarea	2.4 Types
Title	2.4.1 Private Environment
Description	Certain Users are allowed to access, and other Users are precluded from accessing a Private Metaverse Environment.
Comment	If the Metaverse Environment is Public, any User is allowed to access the Environment, but may not necessarily access every Object.
Dependency	TBD

Area	2. Metaverse Environment
Subarea	2.4 Types
Title	2.4.2 Persistent Environment
Description	A Persistent Metaverse Environment is Persistent continues to evolve irrespective of whether there are Users in it or not.
Comment	A company meeting room in a Metaverse Environment, or a public square may be Persistent. A space created by two humans who need to chat and that is closed after the space is no longer in use may be Ephemeral.
Dependency	TBD

Area	2. Metaverse Environment
Subarea	2.4 Types
Title	2.4.3 Twin Environment
Description	A Twin Metaverse Environment replicates aspects of a Universe Environment.
Comment	A room and a human in a Universe Environment may be replicated *as is* in a Metaverse Environment. Alternatively, an Environment can be Original in the sense that it does not refer to any Universe Environment.
Dependency	TBD

6.3.6 Metaverse-Universe Association

This subsection identifies and defines Functionalities supporting construction, operation, and use of a Twin Environment.

Area	2. Metaverse Environment
Subarea	2.5 Metaverse-Universe Association
Title	2.5..1 Twin Environment features
Description	A Twin Environment is constructed, operated, and used as a replica of a Universe Environment for some specific function.
Comment	Examples of Universe Environment are: 1. A space affected by fire (Smart Firefighting). 2. An inhabited area (Smart City). 3. A transportation system (Intelligent Transport System). 4. A manufacturing shop floor (Smart Manufacturing). 5. A space where a company operates. 6. A real estate item. 7. A space intended for agriculture. 8. An educational institution. 9. A healthcare institution. 10. A potential battlefield.
Dependency	TBD

Area	2. Metaverse Environment
Subarea	2.5 Metaverse-Universe Association
Title	2.5.2 Object Perception
Description	A Metaverse Environment digitally represents the perceptible objects in a Universe Environment.
Comment	Object types include audio, visual, touch, smell, and taste.
Dependency	TBD

Area	2. Metaverse Environment
Subarea	2.5 Metaverse-Universe Association
Title	2.5.3 Twin Environment Delay
Description	A User of a Twin Environment does not perceive a delay as they perceive in a Universe Environment.
Comment	The arm of a human represented and rendered as the arm of a Digitised Human in a Metaverse Environment is perceived as moving synchronously with the original arm in the Universe Environment.
Dependency	TBD

Area	2. Metaverse Environment
Subarea	2.5 Metaverse-Universe Association
Title	2.5.4 Consistency with Universe
Description	A Metaverse Environment is consistent with a Universe Environment.
Comment	A Metaverse Environment mirroring a Universe Environment provides an Experience that is consistent with the Experience a User might have in that Universe Environment. The Experience may not be consistent if the Metaverse Environment seeks to provide an a partially alternative Experience, e.g., a Universe Environment on the Moon.

Dependency TBD

Area 2. Metaverse Environment
Subarea 2.5 Metaverse-Universe Association
Title 2.5.5 Metaverse-Universe Misalignment
Description A Metaverse compensates temporary misalignments of its State with a Universe Environment.
Comment A neural network may be trained using past data patterns to compensate for or recover from a temporary loss of data from the User's Universe Environment, e.g., because of a temporary network discontinuity.
Dependency TBD

Area 2. Metaverse Environment
Subarea 2.5 Metaverse-Universe Association
Title 2.5.6 Universe-to-Metaverse linkage
Description A Metaverse Environment is linked with a Universe Environment through a digital representation of that Universe Environment that is suitable for the Metaverse Environment's purpose.
Comment A Metaverse Environment may use a map of a Universe Environment with the degree of accuracy appropriate for the intended application, so that an event happening in the latter, such as the presence of a Device within range of a key point, triggers the rendering of an Object/Scene on the Device. The mapping may be provided by a third party.
Dependency TBD

Area 2. Metaverse Environment
Subarea 2.5 Metaverse-Universe Association
Title 2.5.7 Metaverse-to-Universe feedback
Description The evolution of a Metaverse Environment associated with a Universe Environment is fed back into the Universe Environment.
Comment
1. A specific event in the Metaverse Environment may cause a display in the Universe Environment or generate a perceivable signal to show an alarm.
2. The Digital Twin of a Universe Environment detects an anomaly in the Data received from a Universe Environment and generates an alert in another Universe Environment.

Dependency TBD

Area 2. Metaverse Environment
Subarea 2.5 Metaverse-Universe Association
Title 2.5.8 Metaverse access about the Universe
Description A User accesses a Twin Environment to obtain information about the Universe Environment.
Comment A human in a queue can know their position in the queue by visiting the Twin Environment of the Universe Environment where there is the queue.
Dependency TBD

6.4 Content Representation

6.4.1 Introduction

This section identifies the functionalities that the digital representation of content in the Metaverse may support. It is organised according to the following sub-areas:

Go one layer up to the functionality index

6.4.2 Scene Description

This subsection identifies and defines Functionalities of a Scene Description.

Area	3. Content Representation
Subarea	3.1 Scene Description
Title	3.1.1 Scene Description Format
Description	The Scene Description Format represents both Virtual and Digitised Scenes.
Comment	A Scene with two Digitised Humans uses the same Scene Description as a Scene with two Digital Humans.
Dependency	TBD

Area	3. Content Representation
Subarea	3.1 Scene Description
Title	3.1.2 Addition of Objects
Description	The Scene Description that includes Virtual Objects integrates Digitised Objects into the Scene and vice-versa.
Comment	If there is object occlusion, the Digitised Scene Description may not allow access to the full Digitised Objects.
Dependency	TBD

Area	3. Content Representation
Subarea	3.1 Scene Description
Title	3.1.3 Object types in Scene
Description	The Scene Description Format integrates both static and dynamic Objects.
Comment	The Scene Description Format has the capability to represent Objects with their Spatial Attitude.
Dependency	TBD

Area	3. Content Representation
Subarea	3.1 Scene Description
Title	3.1.4 Audio and Visual Objects in Scene
Description	The Scene Description format handles Audio and Visual Objects.
Comment	The Scene Description format handles a Virtual Human with an attached Speech from a human.
Dependency	TBD

Area	3. Content Representation
Subarea	3.1 Scene Description
Title	3.1.5 Five-sense Objects in Scene
Description	The Scene Description Format represent a Scene that includes Objects able to stimulate the five human senses (Touch. Smell, and Taste in addition to Sight and Sound) and other data sources in a Universe Environment.

Comment	The Scene Description represents the expanding smell of perfume in a room.
Dependency	TBD

Area	3. Content Representation
Subarea	3.1 Scene Description
Title	3.1.6 Network constraints
Description	The Scene Description Format copes with the constraints of a network connection.
Comment	A human sees images gradually improving definition when the network connection with a Universe Environment has a bitrate insufficient to cope with the bitrate required to transmit the scene.
Dependency	TBD

6.4.3 Object Representation

This subsection identifies and defines Functionalities of an Object Representation.

Area	3. Content Representation
Subarea	3.2 Object Description
Title	3.2.1 Object Identifier
Description	An Object has an associated Identifier.
Comment	A Digital Object representing a landmark object in a Universe Environment has an Identifier. The Digitised Objects in the Full Environment Representation generated by a CAV are assumed to have CAV-generated Identifiers.
Dependency	TBD

Area	3. Content Representation
Subarea	3.2 Object Description
Title	3.2.2 Decentralised Identifier
Description	An Object has a unique Identifier independently of the existence of a central authority.
Comment	Digital ledgers can offer this functionality (Decentralised Identifier).
Dependency	TBD

Area	3. Content Representation
Subarea	3.2 Object Description
Title	3.2.3 Object details
Description	An Object is represented with an arbitrarily large level of fine details.
Comment	Support of an arbitrary level of detail for any Objects representing objects may be long to come. However, some Metaverse Environments that are Digital Twins of, e.g., biological laboratory Environments, could come much sooner.
Dependency	TBD

6.4.4 Content Metadata

This subsection identifies and defines the Functionalities of Content Metadata.

Area	3. Content Representation
Subarea	3.3 Content Metadata
Title	3.3.1 Scene and Object Metadata
Description	The Metadata of a Scene or an Object carries ownership information.

Comment	Ownership information can cover: 1. Legal ownership. 2. Creator information. 3. Authoring tool provider information. 4. Provenance. 5. Transferability of ownership. 6. …
Dependency	TBD

Area	3. Content Representation
Subarea	3.3 Scene and Object Metadata
Title	3.3.2 Metadata editing
Description	A User is not allowed to edit or delete ownership information.
Comment	An Object's provenance information is permanent.
Dependency	TBD

6.5 Perception of the Universe by the Metaverse

6.5.1 Introduction

This Section identifies the Functionalities of a Metaverse to perceive a Universe Environment. It is organised according to the following sub-areas:

Go one layer up to the functionality index

6.5.2 Audio

This subsection identifies and defines the Functionalities of Audio Data sensed from the Universe by the Metaverse.

Area	4. Perception of the Universe by the Metaverse
Subarea	4.1 Audio
Title	4.1.1 Audio Scene Description
Description	The audio from a Universe Environment is sensed to create a digital representation of the audio component of that Environment (Audio Scene Description).
Comment	The Metaverse Environment perceives the human playing a piano and the singer walking in an Environment as two Audio Objects, one static and the other with a moving position and orientation.
Dependency	TBD

Area	4. Perception of the Universe by the Metaverse
Subarea	4.1 Audio
Title	4.1.2 Audio Scene Objects
Description	The Audio Scene Description provides the individual Audio Objects, their Spatial Attitude, and other Metadata.
Comment	The Metaverse should be able to access the individual Audio Objects to achieve a more complete understanding of the Audio Scene.
Dependency	TBD

Area	4. Perception of the Universe by the Metaverse
Subarea	4.1 Audio
Title	4.1.3 Personal Status in Digital Humans

Description	The Audio Scene Description of a Universe Environment populated by humans is used to extract the Personal Status of a particular Digital Human who may be present in the Metaverse Environment or attending from another Environment in the same or different Metaverse or from the Universe.
Comment	At a meeting in a Metaverse Environment, a Virtual Secretary is tasked to draft a report using the Speech uttered by the attending Digital Humans and their Personal Statuses.
Dependency	TBD

Area	4. Perception of the Universe by the Metaverse
Subarea	4.1 Audio
Title	4.1.4 Group Status in Digital Humans
Description	The Audio Scene Description of a Universe Environment populated by a group of humans is used to extract the Group Status from the Digital Humans.
Comment	The Personal Status can express the degree of happiness or excitement of a group of thousands of Digital Humans attending an event.
Dependency	TBD

6.5.3 Visual

This subsection identifies and defines the Functionalities of Visual Data sensed from the Universe by the Metaverse.

Area	4. Perception of the Universe by the Metaverse
Subarea	4.2 Visual
Title	4.2.1 Visual Scene Description
Description	The visual component of a scene of a Universe Environment is sensed to create its digital representation (Visual Scene Description).
Comment	A CAV creates a digital representation of a Physical Environment using a variety of technologies such as Radar, Lidar, Video camera, and Ultrasound.
Dependency	TBD

Area	4. Perception of the Universe by the Metaverse
Subarea	4.2 Visual
Title	4.2.2 Visual Scene Objects
Description	The Visual Scene Description includes the individual Visual Objects, their Spatial Attitude, and other Metadata.
Comment	The individual Digital Objects perceived by a CAV may have attributes such as Timestamp, Object Type (e.g., Audio or Visual), ID and ID of corresponding object of different Type, Motion State, Spatial Attitude, and Predicted Trajectory.
Dependency	TBD

Area	4. Perception of the Universe by the Metaverse
Subarea	4.2 Visual
Title	4.2.3 Personal Status in Digital Humans
Description	The Visual Scene Description is of an Metaverse Environment populated by Digital Humans is used to extract the Personal Status of a particular Digital Human who may be present in the Metaverse Environment or attending from another Environment in the same or different Metaverse or from the Universe.

Comment	At a meeting in a Metaverse Environment, a Virtual Secretary is tasked to draft a report using the face and gesture expression displayed by the attending Digital Humans and their Personal Statuses.
Dependency	TBD

Area	4. Perception of the Universe by the Metaverse
Subarea	4.2 Visual
Title	4.2.4 Group Status in Digital Humans
Description	A Metaverse uses the Visual Scene Description of a Metaverse Environment populated by Digital Humans to extract the Group Status from that group of Digital Humans.
Comment	The Personal Status can express the degree of happiness or excitement of a group of thousands of Digital Humans attending an event.
Dependency	TBD

6.5.4 Tactile

This subsection identifies and defines the Functionalities of Tactile Data sensed from the Universe by the Metaverse.

Area	4. Perception of the Universe by the Metaverse
Subarea	4.3 Tactile
Title	4.3.1 Haptic Objects
Description	A Metaverse Environment perceives the tactile characteristics of the surfaces of the objects in a Universe Environment.
Comment	A haptic sensor captures the details of a surface.
Dependency	TBD

6.5.5 Smell

This subsection identifies and defines the Functionalities of Smell Data.

Area	4. Perception of the Universe by the Metaverse
Subarea	4.4 Smell
Title	4.4.1 Smell Objects
Description	A Metaverse Instance has machine olfaction capabilities (electronic nose).
Comment	Smell comes from different chemical substances such as those affecting the humans' normal life or substances used in chemical processes (and possibly obnoxious).
Dependency	TBD

6.5.6 Taste

This subsection identifies and defines the Functionalities of Taste Data.

Area	4. Perception of the Universe by the Metaverse
Subarea	4.5. Taste
Title	4.5.1 Taste Objects
Description	A Metaverse Instance senses and classifies tastes.
Comment	Taste is often strictly connected to olfaction.
Dependency	TBD

6.5.7 Other Data

This subsection identifies and defines the Functionalities of Other Data sensed from the Universe by the Metaverse.

Area	4. Perception of the Universe by the Metaverse
Subarea	4.6 Other Data
Title	4.6.1 Data from devices
Description	A Metaverse Environment uses Devices to acquire information other than the 5 human senses from a Universe Environment.
Comment	A Metaverse Environment, e.g., a Twin Environment, acquires data from IoT devices deployed in the Universe Environment that it mirrors, e.g., a vineyard.
Dependency	TBD

Area	4. Perception of the Universe by the Metaverse
Subarea	4.6 Other Data
Title	4.6.2 BCI Data
Description	A Metaverse Environment captures the signals generated by a Brain-Computer Interface (BCI) Device applied to a human.
Comment	Currently, BCI Devices are commercially available. However, there are no standards for the Interface of a BCI Device.
Dependency	TBD

Area	4. Perception of the Universe by the Metaverse
Subarea	4.6 Other Data
Title	4.6.3 Atmospheric Data
Description	A Metaverse Environment captures air temperature, air pressure, and humidity.
Comment	The Metaverse Environment acquires the temperature of the room and provides an interface to change the temperature in the Universe.
Dependency	TBD

Area	4. Perception of the Universe by the Metaverse
Subarea	4.6 Other Data
Title	4.6.4 Visual Object Data not in the visible range
Description	A Metaverse Environment captures electromagnetic signals at frequencies that are outside the visual range or multi-frequency signals.
Comment	An Autonomous Vehicle uses Radar and Lidar, and even Ultrasound to create a Digital Twin of Universe Environment where it is.
Dependency	TBD

6.6 Perception of the Metaverse by the Universe

6.6.1 Introduction

This section identifies the functionalities that a Universe, including humans, may have available to perceive a Metaverse. It is organised according to the following sub-areas:

Go one layer up to the functionality index

6.6.2 Audio

This subsection identifies and defines the Functionalities of Audio Data actuated by the Metaverse on the Universe.

Area	5. Perception of the Metaverse by the Universe
Subarea	5.1. Audio
Title	5.1.1 Audio Environment Models
Description	An Environment offers Audio Environment Models.
Comment	The model can refer to any Environment, e.g., a meeting room or a public square. A realistic experience may require that the room walls have a reverberation like that of a real room, while a public square has no reverberation.
Dependency	TBD

Area	5. Perception of the Metaverse by the Universe
Subarea	5.1 Audio
Title	5.1.2 Speech Model
Description	A Service or a Virtual Human in a Metaverse Environment uses a particular Speech Model to utter a synthetic speech.
Comment	The Speech Model can be provided as a data structure of a known format or as a model utterance.
Dependency	TBD

Area	5. Perception of the Metaverse by the Universe
Subarea	5.1 Audio
Title	5.1.3 Synthetic Audio Objects
Description	A Metaverse Environment produces Synthetic Audio Objects rendered as sounds that produce an Experience indistinguishable from sounds perceived in the Universe.
Comment	A Virtual Human speaks in a way that is indistinguishable from the utterances of a particular human.
Dependency	TBD

6.6.3 Visual

This subsection identifies and defines the Functionalities of Visual Data actuated by the Metaverse on the Universe.

Area	5. Perception of the Metaverse by the Universe
Subarea	5.2 Visual
Title	5.2.1 Visual Environment Models
Description	A Metaverse Environment offers or allows import of Visual Environment Models.
Comment	The Model can refer to any type of Environment, e.g., a meeting room or a set of interconnected rooms.
Dependency	TBD

Area	5. Perception of the Metaverse by the Universe
Subarea	5.2 Visual
Title	5.2.2 Standard Visual Models
Description	Imported Visual Models have a standard format.
Comment	The ISO 19650 standard uses building information modelling (BIM) to manage information over the whole life cycle of a built asset.
Dependency	TBD

Area	5. Perception of the Metaverse by the Universe
Subarea	5.2 Visual
Title	5.2.3 Virtual Human Models
Description	An Metaverse Environment offers or allows import of Virtual Human Models.
Comment	ISO/IEC 19775 integrates 3D graphics and multimedia objects that can be dynamically modified by external mechanisms.
Dependency	TBD

Area	5. Perception of the Metaverse by the Universe
Subarea	5.2 Visual
Title	5.2.4 Virtual Human Model Animation
Description	A User animates a Model via a standard interface.
Comment	Animation of a Digitised Human can be based on the actual motion of the human. Animation of a Virtual Human can be autonomous.
Dependency	TBD

6.6.4 Tactile

This subsection identifies and defines the Functionalities of Tactile Data actuated by the Metaverse on the Universe.

Area	5. Perception of the Metaverse by the Universe
Subarea	5.3 Tactile
Title	5.3.1 Tactile information
Description	A Metaverse Instance generates tactile information.
Comment	Human-machine interfaces exist based on suits and gloves.
Dependency	TBD

6.6.5 Smell

This subsection identifies and defines the Functionalities of Smell Data actuated by the Metaverse on the Universe.

Area	5. Perception of the Metaverse by the Universe
Subarea	5.4 Smell
Title	5.4.1 Smell 3D Models
Description	A Metaverse Environment offers or lets import Smell 3D Models.
Comment	Commercial Smell Models already exist.
Dependency	TBD

Area	5. Perception of the Metaverse by the Universe
Subarea	5.4 Smell
Title	5.4.2 Standard Smell 3D Models
Description	Imported Models have a standard format.
Comment	Possible file formats are FBX, OBJ, MAX, 3DS, C4D.
Dependency	TBD

6.6.6 Taste

This subsection identifies and defines the Functionalities of Taste Data actuated by the Metaverse on the Universe.

Area	5. Perception of the Metaverse by the Universe

Subarea	5.5 Taste
Title	5.5.1 Taste generation
Description	A Metaverse Instance has the capability to generate tastes that can be perceived by humans.
Comment	Taste is often strictly connected to olfaction.
Dependency	TBD

6.6.7 Other Data

This subsection identifies and defines the Functionalities of Other Data actuated by the Metaverse on the Universe.

Area	5. Perception of the Metaverse by the Universe
Subarea	5.6 Other Data
Title	5.6.1 Other Data generation
Description	A Universe Environment uses Devices to acquire information from a Metaverse Environment.
Comment	A Universe Environment, e.g., a human or a machine, may download data (i.e., export data from) from a Metaverse Environment. E.g., the Data produced by 1. Data generated by a Digital Twin of a vineyard. 2. Data generated as a results of the Data provided by an External Service Provider.
Dependency	TBD

6.7 User

6.7.1 Introduction

This section identifies User-related functionalities. The functionalities of this Chapter are organised according to the following subareas:

Go one layer up to the functionality index

6.7.2 Identity

This subsection identifies and defines the Functionalities related to User Identity.

Area	6. User
Subarea	6.1. Identity
Title	6.1.1 Metaverse Environment Authenticates User
Description	A Metaverse Environment authenticates a User.
Comment	A User may be authenticated through a device or method based on one out of several technologies, e.g.: 1. Multi-factor 2. Device Biometrics (iris, fingertips, voice, face, gestures, hand motions, body motions, etc.) 3. Behavioural Biometrics. 4. Cryptographic Security Keys. 5. Certificate-based authentication. 6. Hardware Security Keys. 7. Device Identity Technologies. 8. Decentralised Identifiers (DIDs)
Dependency	TBD

Area	6. User
Subarea	1. Identity
Title	6.1.2 User verifies the identity of a User
Description	A User verifies the identity a User they are dealing with.
Comment	A User should be able to know the Identity of another User.
Dependency	TBD

Area	6. User
Subarea	1. Identity
Title	6.1.3 Personae
Description	A User appears as a different Persona that refers to the same User Identity.
Comment	A User may have a Persona for gaming and a Persona for business.
Dependency	TBD

Area	6. User
Subarea	1. Identity
Title	6.1.4 Identity portability
Description	A User uses the same identity they have used in another Metaverse Environment or Metaverse Instance.
Comment	A User has a portable identity, e.g., a crypto wallet used across multiple Metaverse Environments.
Dependency	TBD

6.7.3 Profile

This subsection identifies and defines the Functionalities related to User Profile.

Area	6. User
Subarea	6.2 Profile
Title	6.1.5 Profile portability
Description	A User Profile is used in different Metaverse Environments or Metaverse Instances.
Comment	A User can use a Persona created in another Metaverse Environment.
Dependency	TBD

Area	6. User
Subarea	6.2 Profile
Title	6.1.6 Profile Subset
Description	A User uses a subset of their Profile in another Metaverse Environment or Metaverse Instance.
Comment	A User Profile cannot use all the Data in their Profile because a particular Metaverse Environment or Metaverse Instance does not support certain technologies.
Dependency	TBD

6.7.4 Data

This subsection identifies and defines the Functionalities related to User Data.

Area	6. User
Subarea	6.3 Data

Title	6.3.1 User Data Privacy
Description	A Metaverse Manager guarantees the privacy of the Data Users generated in their Metaverse Instance.
Comment	1. The operation of a Metaverse, including protection of User Privacy, is conducted based on the applicable laws. 2. It would be useful to define a minimum set of Privacy principles applicable to any Metaverse Instance.
Dependency	TBD

Area	6. User
Subarea	6.3 Data
Title	6.3.2 Social Graph
Description	A Metaverse Instance or Environment enables a User to port their Social Graph to another Metaverse Instance or Environment.
Comment	A User should be able to retain the digital representation of their relationships no matter where they act.
Dependency	TBD

6.7.5 Perception of the Metaverse

This subsection identifies and defines the Functionalities related to the perception of a Metaverse Instance by a User.

Area	6. User
Subarea	6.4 Perception of the Metaverse
Title	6.4.1 Presence
Description	A Metaverse offers a User an individual sense of Presence.
Comment	A Metaverse makes Users in a Metaverse Environment feel truly present with other Digital Humans and have Experiences like that they would have in the Universe.
Dependency	TBD

Area	6. User
Subarea	6.4 Perception of the Metaverse
Title	6.4.2 Embodiment
Description	A Metaverse offers a User an individual sense of Embodiment.
Comment	A Metaverse provides sensorial feedback to enable them to experience the Environment more completely.
Dependency	TBD

Area	6. User
Subarea	6.4 Perception of the Metaverse
Title	6.4.3 Awareness
Description	A Metaverse offers a User a subjectively felt awareness that they are conceiving, executing, and controlling their own actions in the Environment.
Comment	A User may hit an object in the Metaverse, and the object moves as a result of the User action.
Dependency	TBD

Area	6. User
Subarea	6. User

Title	6.4 Perception of the Metaverse
Description	A User Experiences a rendered Object in a Metaverse Environment.
Comment	The User enjoys a VR Experience while immersed in the Metaverse.
Dependency	
Area	6. User
Subarea	6.4 Perception of the Metaverse
Title	6.4.5 AR Perception
Description	A User Experiences a rendered Object in a Universe Environment.
Comment	The User enjoys an AR Experience.
Dependency	TBD

6.7.6 Virtual Human-oriented functionalities

This subsection identifies and defines the Functionalities related to Virtual Humans.

Area	6. User
Subarea	6.5 Virtual Human
Title	6.5.1 Virtual Human Proprioception
Description	An autonomous Virtual Human has proprioception.
Comment	Proprioception helps the autonomous Virtual Human have a more natural walk.
Dependency	TBD

Area	6. User
Subarea	6.5 Virtual Human
Title	6.5.2 Virtual meetings
Description	Users have virtual meetings.
Comment	Users from different Environments belonging to different Metaverses, including the Universe, can join a meeting.
Dependency	TBD

6.8 Interaction

6.8.1 Introduction

This Section identifies the functionalities that a human may have available to interact to with a Metaverse Instance. It is organised according to the following sub-areas:

Go one layer up to the functionality index

6.8.2 Interfaces

This subsection identifies and defines the Functionalities related to Interfaces in a Metaverse Instance.

Area	7. Interaction
Subarea	7.1 Interfaces
Title	7.1.1 Metaverse Device Interface
Description	The Common Metaverse Specifications include specifications of the Interfaces of Devices that are part of a Metaverse (Metaverse Devices)
Comment	Comments include Sensing and Actuation data formats.
Dependency	TBD

Area	7. Interaction

Subarea	7.1 Interfaces
Title	7.1.2 User Device Interface
Description	The Common Metaverse Specifications include specifications of the Interfaces of Devices that are attached to a User (User Devices).
Comment	Comments include Sensing and Actuation data formats.
Dependency	TBD

6.8.3 Speech

This subsection identifies and defines the Functionalities related to Speech Interfaces with a Metaverse Instance.

Area	7. Interaction
Subarea	7.2 Speech
Title	7.2.1 Speech Interface
Description	Users interact with a User using their voice.
Comment	Users may use: 1. Their voice as if they were interacting with humans. 2. Their voice transformed to improve or distort the features of their voice or emulate the features of another voice. 3. A synthetic version of their voice unrelated with the speech features.
Dependency	TBD

Area	7. Interaction
Subarea	7.2 Speech
Title	7.2.2 Speech analysis
Description	A Metaverse Environment extracts text and Personal Status of a human from their speech.
Comment	The Metaverse Environment should have an improved conversation by understanding all aspects of the human it is interacting with.
Dependency	TBD

Area	7. Interaction
Subarea	7.2 Speech
Title	7.2.3 Speech enhancement
Description	A Metaverse Environment adds other types of information to its speech to simulate the Personal Status of a human.
Comment	The Metaverse Environment or one of its Objects may improve the quality of the conversation by adapting its speech to the emotion shown by the human, the Metaverse Environment or one of its Objects.
Dependency	TBD

Area	7. Interaction
Subarea	7.2 Speech
Title	7.2.4 Speech translation
Description	A User speaking a language has their utterances translated into the languages of their choice and hear the Users they are interacting with in their language with a delay caused by translation not affecting the naturalness of the dialogue.
Comment	Speech Translation is a key Process that may negatively affect the User Experience if it is not efficiently implemented.
Dependency	TBD

Area	7. Interaction
Subarea	7.2 Speech
Title	7.2.5 Spoken Dialogue System
Description	A Metaverse Environment understands the speech utterances of the User and generates an appropriate response based on this interpretation and previous interactions.
Comment	The Metaverse Environment is capable of producing emotional speech synthesis in any language with any chosen identity.
Dependency	TBD

6.8.4 Visual

This subsection identifies and defines the Functionalities related to Visual Interfaces with a Metaverse Instance.

Area	7. Interaction
Subarea	7.3 Visual
Title	7.3.1 Interaction though an avatar
Description	A User interacts with a Metaverse Environment or its Components using an avatar representing them.
Comment	The avatar may: 1. Faithfully reproduce the visual appearance of the human. 2. Alter their visual appearance compared to that of the human. 3. Have an unrelated visual appearance.
Dependency	

Area	7. Interaction
Subarea	7.3 Visual
Title	7.3.2 Personal Status from Visual
Description	A Metaverse Environment extracts information about the Personal Status of the User conveyed by their visual appearance.
Comment	The Metaverse Environment could try and understand all aspects of the User it is interacting with for improved conversation.
Dependency	TBD

Area	7. Interaction
Subarea	7.3 Visual
Title	7.3.3 Simulated Personal Status
Description	A Virtual Human impersonating a Component displays a simulated Personal Status.
Comment	An influencer may animate the face, head, and body of their Digital Human to improve their impact.
Dependency	TBD

Area	7. Interaction
Subarea	7.3 Visual
Title	7.3.4Sign communication
Description	A User interacts with a Metaverse Environment or its Components using signs.
Comment	A vision-impaired User may use finger-alphabet to interact with a Metaverse Instance or its Components.

Dependency	TBD

6.8.5 Haptic

This subsection identifies and defines the Functionalities related to Haptic Interfaces with a Metaverse Instance.

Area	7. Interaction
Subarea	7.4 Haptic
Title	7.4.1 Haptic Interaction
Description	A User interacts with a Metaverse Environment, or its Components using the sense of touch.
Comment	A possibly impaired User: 1. Receives a response from a Metaverse Environment, or its Components expressed in the Braille alphabet. 2. Interacts with Components through bodily sensations and movements (and allow to also enjoy the Experience). 3. Activates action commands and receive appropriate tactile images possibly accompanied by the stimulation of other visual and audio sensory modalities.
Dependency	TBD

6.8.6 BCI

This subsection identifies and defines the Functionalities related to BCI Interfaces with a Metaverse Instance.

Area	7. Interaction
Subarea	7.5 BCI
Title	7.5.1 Brain-Computer Interaction
Description	A User interacts with a Metaverse Environment, or one of its Components using a Brain-Computer Interface.
Comment	BCI may offer an impaired User the possibility to interact with a Metaverse Environment, or its Components.
Dependency	TBD

6.9 Information search

6.9.1 Introduction

This Section identifies the functionalities of the services that enable humans to discover the information the need in a Metaverse Instance or in a specified group of Metaverse Instances. It is organised according to the following sub-areas:

Go one layer up to the functionality index

6.9.2 Discovery

This subsection identifies and defines the Functionalities related to Information Discovery.

Area	8. Search
Subarea	8.1 Discovery
Title	8.1.1 Information collection

Description	A Metaverse Manager or Operator collects, organises, and makes available to Users information about their Environments and other Metaverse Instances or Environments.
Comment	This is a function similar to the one provided by today's search engines.
Dependency	TBD

Area	8. Search
Subarea	8.1 Discovery
Title	8.1.2 Search API
Description	A Metaverse Environment exposes API enabling a search engine to access the Environment's Metadata.
Comment	This requires the specification of Environment Metadata such as content, events, services etc. offered, the type of Interoperability, the hardware functionalities required to access the content, free or pay, etc.
Dependency	TBD

Area	8. Search
Subarea	8.1 Discovery
Title	8.1.3 Component Search
Description	Users can search for any type of Components in one or more Metaverse Instances.
Comment	A User can search for a particular NFT with attached conditions.
Dependency	TBD

6.9.3 Recommendation

This subsection identifies and defines the Functionalities related to Recommendations.

Area	8. Search
Subarea	8.2 Recommendation
Title	8.2.1 Notification
Description	A Metaverse Environment notifies Users about potentially interesting Metaverse Experiences.
Comment	A User has subscribed to a notification Service that notifies them of specific Events.
Dependency	TBD

6.10 Economy support

6.10.1 Introduction

This section Identifies the functionalities that a Metaverse Instance may make available to support economic activities in its Instance. It is organised according to the following sub-areas:

Go one layer up to the functionality index

6.10.2 Activities

This subsection identifies and defines the Functionalities related to Economic Activities in a Metaverse Instance.

Area	9. Economy
Subarea	9.1 Activities

Title	9.1.1 Activity Right
Functionality	A User obtains the Right to develop an activity in a Metaverse Instance or Environment.
Comment	The activity may be not for profit or for profit. The User becomes an Operator of a Metaverse Manager or a Partner of a Metaverse Operator.
Dependency	TBD

Area	9. Economy
Subarea	9.1 Activities
Title	9.1.2 Right to offer Services
Description	A User obtains the Right to offer Services in their Environment.
Comment	Services may be provided inside the Environment or outside (other Environments in the same or different Metaverse or the Universe).
Dependency	TBD

6.10.3 Assets

This subsection identifies and defines the Functionalities related to Assets in a Metaverse Instance.

Area	9. Economy
Subarea	9.2 Assets
Title	9.2.1 Asset Creation
Description	A User creates Assets in a Metaverse Environment.
Comment	Asset creation does not necessarily imply ownership.
Dependency	TBD

Area	9. Economy
Subarea	9.2 Assets
Title	9.2.2 Asset Monetisation
Description	A User who has created an Asset has the Right to monetise that Asset.
Comment	The User having created the Asset has the Right to request immediate payment and/or subsequent royalties for their NFTs.
Dependency	TBD

Area	9. Economy
Subarea	9.2 Assets
Title	9.2.3 Asset Monetisation Right
Description	A User obtains the Right to monetise an Asset.
Comment	A User purchases an Asset with the Right to resell it.
Dependency	TBD

Area	9. Economy
Subarea	9.2 Assets
Title	9.2.4 Asset trading
Description	A User acquires, leases, alienates, or exports Assets.
Comment	A Metaverse Instance may set rules governing the life cycle of Assets.
Dependency	TBD

Area	9. Economy
Subarea	9.2 Assets

Title	9.2.5 Blockchain-enabled Asset trading
Description	A Metaverse Instance relies on a Blockchain to enable Asset trading.
Comment	A Metaverse Instance may use an existing Blockchains or deploy a proprietary one.
Dependency	TBD

Area	9. Economy
Subarea	9.2 Assets
Title	9.2.6 Marketplace-oriented Asset trading
Description	A Metaverse Instance offers or relies on a Marketplace to enable Asset trading.
Comment	The marketplace may use a Smart Contract to enable Asset trading.
Dependency	TBD

6.10.4 Agreements

This subsection identifies and defines the Functionalities related to Agreements in a Metaverse Instance.

Area	9. Economy
Subarea	9.3 Agreements
Title	9.3.1 User Agreement
Description	Users make agreements between and among themselves.
Comment	Users may use Smart Contracts to govern the terms and condition of the participation in the agreement.
Dependency	TBD

Area	9. Economy
Subarea	9.3 Agreements
Title	9.3.2 Environment Agreement
Description	Users make Agreements while being in an Environment.
Comment	Users may be in the same or different Environment or Metaverse. The case of a User being in the Universe should also be considered.
Dependency	TBD

6.10.5 Transactions

This subsection identifies and defines the Functionalities related to Transactions in a Metaverse Instance.

Area	9. Economy
Subarea	9.4 Transactions
Title	9.4.1 Transaction Right
Description	A User obtains the Right to make Transactions.
Comment	Transactions may involve: 1. Fungible Tokens (fiat or virtual currency). 2. Non-Fungible Tokens (NFT).
Dependency	TBD

Area	9. Economy
Subarea	9.4 Transactions
Title	9.4.2 Intra-Metaverse Transactions
Description	Users make Transactions while being in an Environment.

Comment	Users may be in the same or different Metaverse Environment of the same Metaverse.
Dependency	TBD

Area	9. Economy
Subarea	9.4 Transactions
Title	9.4.3 Inter-Metaverse Transaction
Description	The object of the Transactions concerns different Assets in one or more Metaverse Instances or in the Universe.
Comment	Objects subject to transactions may be Environments, Objects, and Assets.
Dependency	TBD

7 Technologies

This Chapter has the task to verify how well available technologies match the requirements of the Functionalities. The technology areas considered are: Sensory information, Data processing, User Devices, Network, and Energy.

7.1 Sensory information

7.1.1 Introduction

This section provides an overview of the technologies handling the information sensed by and/or actuated for A metaverse Instance that is related to humans, viz. audio, visual, touch. smell, taste, and brainwaves. For each information type, when meaningful, four aspects are considered: how the human body perceives information (physiology), how the information that the human senses can be digitally represented, and technologies for sensing and actuating the information.

A postulated condition to obtain realistic Metaverse Experiences is that the 3D audio and visual fields be represented and rendered in such a way that Users do not perceive the Metaverse Experience different from the one they would experience in the Universe. Three decades of digital audio and video standards have given rise to several often-competing information representation technologies and standards for sensing, storing/transmitting, and actuating audio and visual information. Products and services based on them are now ubiquitous and used by billions of people every day. The same cannot be said for audio and visual information with a "3rd dimension" which is at a stage where new technologies come to the fore every other day and whatever standard appears finds it hard to achieve global recognition. Proposal and adoption of standards is even more difficult to succeed for other information types such as touch, smell, taste, and brainwaves.

The scope of this Section in its current form is only to identify and characterise a field whose development is of a vital importance to the success of the Metaverse vision.

7.1.2 Audio

In this subsection, Audio is used to indicate a signal perceived by the human hearing system. By processing the information that the two sensors (ears) have pre-processed, the brain can create a good internal representation of a 3D audio field in the frequency range of 16 Hz to 16 kHz (approximately).

The focus of this subsection is on:

1. Sensors suitable for sensing audio scenes populated by humans and other sound-generating objects for transmission to a Metaverse Instance and/or for local or remote processing to create Audio Scene Descriptions.
2. Actuators suitable for actuating Audio Scene Descriptions intended for human consumption.

Some Digital Twin applications may use sound information not intended for human consumption. For instance, ultrasound used by a Connected Autonomous Vehicle typically in the 40-250 kHz range. The current version of this document does not consider these non-human perceptible sensing/actuation technologies.

7.1.2.1 Physiology

Sound waves reach the outer ear, are guided through a canal, and they hit a thin membrane called Drum whose oscillations are propagated to three tiny bones, Called the Hammer, the Anvil, and the Stirrup, they amplify the oscillations. The Stirrup hits another membrane called the Oval Window which contains the organ of equilibrium and the Cochlea. The latter contains three canals filled with a liquid: the first conducing the liquid to the tip of the Cochlea, the second taking it back, and the third containing the organ of hearing whose bottom is covered by hair cells. The Cochlea performs a function like a frequency analysis: the base of the cochlea detects high frequencies and lower frequencies are detected by parts that are farther away from the base. The wave of the liquid causes the hair cells to move and their bending activates a neural response in the auditory nerve fibbers of the eighth cranial nerve to the brain.

7.1.2.2 Representation

Sensing devices sense the sound field at the points where they are located. There are different audio information representation formats depending on the sensing device used, e.g., mono, stereo, multichannel and the purpose for which they are used, e.g., compression for storage and transmission.

The format of an Audio Data stream is typically divided in two parts:
1. The data generated by conversion of the audio signal(s).
2. The metadata that includes:
    a. Timestamp.
    b. Spatial Attitude of the sensing device.
    c. Sensing characteristics of the microphone(s) used (e.g., cardioid),
    d. Microphone array geometry (in the multichannel case).
    e. Sampling frequency.
    f. Number of bits/sample.

7.1.2.3 Sensing

Acquisition of all the data coming from a microphone array may produce a very high-rate bit stream. Different forms of compression are typically used to enable the transmission of the sensed sound field to a Metaverse Instance. A Universe or Metaverse Environment can perform other types of processing, e.g., to extract relevant information for further processing (e.g., the Audio Scene Description, or extraction of the text from speech).

MPEG-H 3D Audio [51] is a standard for spatial audio coding developed by the Moving Picture Experts Group (MPEG). The standard supports low latency, high quality, and localisable audio requirements, and the quality of the sound after decoding scales up with the bitstream transferring rate and provides a universal representation of encoded 3D sound in channel-based, scene-based, and object-based formats. While channel-based and scene-based are part of the standard mainly

for backward compatibility reasons, the main novelty is the object-based format that enables unprecedented flexibility in rendering spatial sound. This format consists of audio objects in channels to be mixed for creating the sensation of the scene-based audio using the speakers.

Spherical microphone arrays are useful tools to capture scene-based audio due to their ability to provide a multi-channel full azimuth and elevation coverage in capturing real-life conditions. Besides, higher order ambisonics (HOA) is an encoding method using the microphone arrays to represent the scene in spherical harmonic coefficients taking the bandwidth limitations for transmission into consideration. Representation of the captured acoustic field in HOA also simplifies the Audio Scene Representations. MPAI-CAE is a standard specifying AI-based technologies for audio related technologies [2]. In this standard, the Sound Field Description Composite AIM is the technology for transforming the Data from the microphone array into SHD. It also transcodes the scene-based format in object-based representations with their metadata thus enabling the recreation of the Audio Scene by using the relevant objects' spatial attributes.

7.1.2.4 Actuation

Transmission of Audio data from a Metaverse to a Universe Environment for rendering as 3D Audio is typically subject to the same bitrate constrains of the opposite transmission direction. The signal rendered to the ears of a human should change based on the actual physical movement of the human.

To mimic the auditory scenes we hear in real life, immersive audio techniques are used to provide a "life-like" sound experience much beyond what traditional methods can provide. Immersive audio offers an audio experience surrounding the listener, creates a sensation over the audience for source arrival directions, distance, and orientations with a credible auditory imitation.

Audio Scene Description is a format to represent the Audio Objects with their Spatial Attitude that is rendered by analysing the spatial attributes of the Audio Objects and managing the resulting experience. The renderer is aware of the number of speakers and their positions in the room or binaural audio.

7.1.3 Visual

In this subsection, Visual is used to indicate the signal perceived by the human visual system.

The focus is on:

1. Sensors suitable for sensing visual scenes populated by humans for transmission to a Metaverse Instance and/or for local or remote processing to create a Visual Scene Description.
2. Actuators suitable for actuating Visual Scene Descriptions intended for human consumption.

Some Digital Twin applications may use visual information not for human consumption, e.g., a Connected Autonomous Vehicle can use RADAR devices in the frequency range of a few tens of GHz or LiDAR devices in the frequency range close to the visible range. The relevant sensing/actuation technologies are not considered here.

7.1.3.1 Physiology

The human retina includes ~5 million photoreceptor cells for colour vision sensitive to the electromagnetic field in the 400 to 700 kHz frequency range (approximately) and ~100 million rods for vision at low light levels. The eye performs several low-level processing to reduce the amount of information transmitted to the brain: edges, temporal changes, moving objects, brightening/dimming of the scene, etc. This data reduction is necessary because the number of receptor cells is two

orders of magnitude more than the axons of the optic nerve and in any case the brain would not be able and have the structure to process such a amount of raw information.

7.1.3.2 Representation

Sensing of visual information with a human-made device has close to 2 centuries of history. From static 2D images captured using chemical principles (photography) to dynamic 3D images captured using chemicomechanical principles (cinematography), to dynamic 3D images captured using electronic principles (television), to dynamic 3D images captured with pixel-based depth information to camera arrays.

The format of an Visual Data stream is typically divided in two parts:

1. The data stream generated by digitising the visual signals captured by the sensors.
2. The metadata that includes:
    a. The time.
    b. The Spatial Attitude.
    c. The camera geometry (in the camera array case).
    d. The colour space (colours can be reproduced by properly combining RGB colours).
    e. The number of pixels in the horizontal and vertical direction for each stream (RBG or other).
    f. The depth information for each pixel.
    g. The frame frequency.
    h. The number of bits/sample.

7.1.3.3 Sensing

Wholesale acquisition of the data coming from a camera (array) with modern resolutions produces a bitrate of hundreds of Mbit/s or tens of Gbit/s. Different forms of compression are typically used to enable the transmission of the sensed electromagnetic field to a Metaverse Instance. A Universe or Metaverse Environment can perform other types of processing may to extract the relevant information for further processing (e.g., the Visual Scene Description, Object recognition, etc.).

Some visual sensing technologies are:

1. A 2D sensor provides information that can be processed to extract the Objects of the Visual Scene, but the result is often not satisfactory.
2. A depth sensor is added to substantially improve the creation of a Visual Scene.
3. Two 2D sensors placed at slightly offset positions produce images that are processed to create a Visual Scene.
4. A 3D scanner captures data from a physical object's surface and digitally represents its shape in a 3D format. A laser 3D scanner projects a laser line along the surface of an object while the sensor records the distance and the coordinates of each point. The result is a "point cloud" representing the object.
5. A precise shifting fringe pattern is projected on the surface of the object to be scanned scanner using a structured light, and two sensors capture the geometry of the object surface based on the pattern distortion and calculate the 3D coordinate by triangulation.
6. Motion capture (mocap) captures the movement of a human, e.g., a performer, using sensors and markers attached to them. The captured information is used to animate an avatar model, e.g., in computer animation.

7.1.3.4 Actuation

The design of a Head Mounted Display should consider the following data:

1. The human eye can typically resolve 1 pixel/min or 60 pixels/º.

2. The typical field of view of a human is somewhat larger than 180º.
3. The human eye can typically detect flicker up to ~90 Hz for normal scenes.
4. Humans typically perceive an environment to be "right" if the Motion-to-Photon latency is <20ms.

The first 2 issues can be resolved by increasing the number of pixels generating light to the human wearing an HMD, and the third issue requires an increase of the bitrate. The fourth issue involves most elements involved in a Metaverse Experience.

The operation of a Visual Actuator is generally based on the projection of the electromagnetic energy generated in correspondence to the Visual Scene Representation of by a Metaverse Instance.

7.1.4 Touch

7.1.4.1 Physiology

The somatosensory system provides the sense of touch using a range of receptors located at various points and depth in the skin and other organs:

1. Mechanoreceptors in the upper layers of the skin sense pressure, texture, and vibration, and those in the lower layers and along tendons and joints sense vibrations, skin tension, and limb movement.
2. Thermoreceptors sense hot and cold.
3. Painreceptors play the role to urge moving away from the cause of the pain stimulus.
4. Proprioceptors sense tiny variations in muscle tension and length information from their locations in tendons, joint capsules, and muscles to enable the brain to have a representation of the body in space.

The density of nerve endings at human fingertips is so large that their discrimination capability is almost as good as that of human eyes. Therefore, a Metaverse Instance providing an Experience that is just audio-visual is very far from what that humans can have in the Universe where, by physically interacting with objects, they can perceive more profoundly and meaningfully with tactile experiences and receive more emotional responses.

7.1.4.2 Representation

As described above, the tactile experience is thus highly multidimensional. [56] reduces it to five dimensions: macro and fine roughness, warmness/coldness, hardness/softness, and friction (moistness/dryness, stickiness/slipperiness).

Most products with haptic functionality are vertically integrated with components that cannot interoperate. The haptic landscape is currently highly fragmented. There are efforts under way in ISO to develop a standard coded representation of haptic signals and potentially to develop a standard coded representation of interactive haptic experiences

7.1.4.3 Sensing

Humans use the sense of touch to interact, explore, manipulate, and extract the object properties indicated above and others, such as shape. This information is captured by receptors of various types unevenly distributed all over the body and located at different layers of the skin.

Tactile sensors are data acquisition devices sensing tactile object properties via direct physical contact based on a range of different technologies, such as [55]:

1. Capacitive sensors measure the variations of capacitance from an applied load over a parallel plate capacitor.
2. Piezoresistive sensors measure the changes in the resistance of a contact when force is applied.

3. Optical sensors transduce mechanical contact, pressure, or directional movement into changes in light intensity or refractive index that are detected by visual sensors.
4. Magnetic sensors detect changes in magnetic flux caused by the application of a force using the Hall effect, magnetoresistive or magnetoelastic sensors.
5. Binary sensors detect on/off events caused by mechanical contact.
6. Piezoelectric sensors produce an electric charge proportional to an applied force, pressure or deformation.
7. Hydraulic sensors convert fluid pressure into mechanical motion.

Many haptic sensing devices can be borrowed from the expanding field of robotics.

7.1.4.4 Actuation

The user experience of a Metaverse Instance can be augment by the use of haptic actuators. Some types of haptic actuators are:

1. Eccentric Rotating Mass actuators create a vibration by acting on a small magnetic DC motor that spins an eccentric unbalanced weight.
2. Linear Resonant Actuators create a vibration by acting on a voice coil.
3. Solenoid actuators create a vibration by acting on a solenoid.
4. Piezo Haptic actuators create a vibration using piezoelectric material mounted in a cantilever beam configuration.
5. Thermoelectric Device actuators use a thermoelectric device as their thermal source to transform an electrical current into a heat flux based on the Peltier or Seebeck effect.
6. Ultrasonic actuators use speakers or integrated 3D ultrasound sensors to transfer tactile effects onto a user's hands.
7. Pneumatic actuators provide haptic actuation by acting on small motors that use air pressure.

7.1.5 Olfaction

7.1.5.1 Physiology

According to the more accredited theory, the process giving rise to human perception originates in the neurons terminating in the olfactory epithelium where odour molecules bind to them. The process of human olfaction begins when the hair-like projections of the olfactory sensory neurons located in the nasal cavity are activated by in-air molecules. Activated proteins of the olfactory receptor trigger biochemical reactions. The olfactory bulb picks up the signals coming from receptor cells sensitive to the stimulating molecules. The signals travel to the specific portion of the cortex (piriform) and from there to various other parts of the brain where they are combined with other inputs and eventually interpreted as an odour by another part of the cortex (orbitofrontal).

7.1.5.2 Representation

Olfaction enables humans to sense the chemical composition of their environment which may transmit different sources of information about, e.g., food, other humans, danger signalled by smell, etc.

Currently there is no recognised "Odour Representation" that would offer a digital representation of odours. Such a representation would enable, e.g., odour classification or generation of a specific odour identified by a code. Proprietary solutions designed to satisfy specific needs typically use a trained neural network model to classify odours, making up for the absence of a standard format but inhibiting interoperability.

7.1.5.3 Sensing

A machine able to sense odour is called an electronic nose or e-nose. This is an array of sensors able to detect, identify, and measure air-borne molecules. Each odour may be the result of a combination of possibly complex molecules thus making the number of individual odours potentially very large. The current three main classes of sensor technologies are metal-oxide gas sensors, piezoelectric sensors, and conducting polymer sensors.

7.1.5.4 Actuation

Odour actuation, i.e., the generation molecules able to stimulate the human nose is done by combining basic olfactants to. Traditional Principal Component Analysis applied to mass spectrometry data of a large number of essential oils can be used to define the basic olfactants, i.e., the much smaller number of odour components. A specific odour can thus be obtained by a linear weighted combination of those basic odours. Assuming that this is the best way to generate the basic olfactants and that most odours can be obtained by weighted linear combination, the process to define a standard for odour synthesis could be easily developed.

7.1.6 Gustation

7.1.6.1 Physiology

It is traditionally assumed that the taste receptors in the mouth can sense five taste modalities (sweet, salty, sour, bitter, and savoury/umami) and that different receptors are dedicated to sense a specific modality out of the five basic ones. However, the existence of other basic taste modalities has also been postulated. Other receptors present in the mouth are trigeminal nerve endings sensing tactile sensations (texture), thermoception (temperature), and nociception (pain). Therefore, what humans call taste is in fact a combination of different experiences from different sources, e.g., smell, food texture, and temperature. The gustatory receptors may very well not be the major contributors to the sense of taste.

The information sensed by the taste receptors is relayed to the brain. The insula is the primary cortical substrate involved in the perception of taste in the mammalian brain. According to some reports, the insula in rodents is organised in distinct regions that selectively respond to one of the five basic tastes. Some other reports state that the cortical neurons processing gustatory information of monkeys respond to multiple tastes, and tastes are not represented in discrete spatial locations.

7.1.6.2 Representation

The five taste modalities are a very basic form of standardisation. However, the complex nature of the gustation sense makes it difficult to identify a path to full standardisation of the gustation sense in the short-to-medium term.

7.1.6.3 Sensing

The equivalent of the e-nose is the e-tongue, currently used to replace humans who may not wish to engage in sampling different materials such as water (quality), or beverage (counterfeiting), etc. An e-tongue typically measures the voltage of multichannel electrodes where each electrode responds to certain combinations of molecules. A training process may be used to determine the meaning of a particular set of voltages.

7.1.6.4 Actuation

Examples of actuation devices are:

1. Electrodes used to simulate the taste and feel of real food in the mouth.

2. The National University of Singapore's *digital lollipop* (2012) able to transmit to the tongue four of the basic taste sensations (not umami).
3. The *Norimaki Synthesizer* is a rod-shaped device able to simulate any flavour represented by the five basic taste sensations. The device uses five gel nodules made of dissolved electrolytes. The user feels a taste by licking it.
4. A taste display reproducing tastes by using data obtained from taste sensors [62].

7.1.7 Brain signals

7.1.7.1 Physiology

The ~85 billion neurons of the brain are electrical devices operating on chemical principles. An approximate description is:

1. The channels in the membrane of a cell allow positive and negative ions to flow into and out of the cell.
2. The normal potential inside a cell is more negative than the outside by ~-70 mV, but the membrane potential is not constant because of the different inputs from the dendrites.
3. Excitatory inputs raise the neuron's membrane potential and inhibitory inputs make it more negative thus promoting or inhibiting the generation of communication units between neurons.
4. If the sum of all excitatory and inhibitory inputs brings the neuron's membrane potential to ~-50 mV, the neuron fires a spike.
5. The spike moves from one neuron to another thanks to chemical processes taking place across synapses.

7.1.7.2 Information representation

The activity of the so-called pyramidal neurons in the cortical brain regions (occipital, temporal, parietal, frontal cortices) is best placed to reach the scalp because they are perpendicularly oriented to the cortical surface because the cell bodies point towards the grey matter, and the dendrites towards the surface.

Thousands of simultaneously activated neurons are required to generate a sufficiently strong signal to travel across the meninges, theskull, and the scalp to be detected by electrodes on the scalp, taking the different conduction properties of each layer into account. The values that oscillate between positive and negative values at frequencies ranging from ~0.1 Hz to ~30 Hz. The higher the frequency, the higher the attenuation.

Signals are classified depending on the dominant frequency f:

- delta ($f < 4$ Hz)
- theta ($4\text{ Hz} < f < 7$ Hz)
- alpha ($8\text{ Hz} < f < 12$ Hz)
- beta ($12 < f < 30$ Hz)
- gamma ($f > 30$ Hz).

Most cognitive processes relevant to the BCI occur within tens to hundreds of milliseconds.

7.1.7.3 Sensing

Electroencephalography (EEG) is the most widely used system to capture the electric field of the brain because of its portability, relatively low cost, ease of use, non-invasivity, and high temporal resolution, EEG is employed in a wide spectrum of biomedical applications, e.g., to operate external devices, control the environment, and interact.

An array of electrodes is used to capture the brain signals. Intercranial electrodes can sense electrical signals directly from the brain using up to a few thousand sensors, while extracranial electrodes do the same from outside. The number of electrodes of the latter can vary from 10 to a few 100s. They are mounted in elastic caps, meshes, or rigid grids, to ensure that the captured data are collected from the intended scalp positions.

The captured signals are then amplified and digitised. There are many models of electrode arrays each characterised by the number and quality of electrodes, the quality of the digitisation, the quality of the amplifier, and the sampling rate. Minimisation of the impedance between the electrode surface and the scalp is the primary design criterion for the design of EEG electrodes because the primary loss of signal comes from that impedance.

Electrodes can be invasive and non-invasive: the latter can be wet, semi-dry, and dry depending on the presence of electrolytes at the electrode-skin interface. The electrodes can be passive or active: the latter have a preamplification stage to reduce the noise from the electrical activity of the environment.

The typical brain signal processing workflow is:
1. Brain signals are acquired and pre-processed to enhance signal quality.
2. Space and frequency domain features are extracted.
3. Classification algorithms are applied to the features to decode the user's mental situation.

7.1.7.4 Actuation

Some activities aiming at affecting the brain through physical means are known, e.g., [63].

7.2 Data processing

The need to process Data can only increase. Here two aspects are analysed: Basic Processing and Computing Services.

7.2.1 Basic processing

For decades, the Moore law – the doubling every 24 and later every 18 months of the transistor density achievable with the lowest cost transistors – has been a good, even conservative predictor of the ability to pack processing capability into a silicon chip. The Moore law was later complemented by Ray Kurzweil's proposal that the computational power – the number of calculations/s – should also consider the layout and clock speed, not just the transistor density.

In the 2000's, the increase in performance of a processor has substantially slowed down compared to the preceding decades. In the last 15 years since 1990, processor performance increased by ~50%/year, but in 2018 the increase had slowed to just 3.5%/year. The slowdown was caused by several factors:
1. **Hard to pack small transistors**. To add more transistors to a chip more space *and* more energy are required, but the physical limit is being reached. This is the end of "Dennard scaling" stating that the energy need per transistor area is roughly constant because smaller transistors can be packed more densely.
2. **Difficult to increase clock speed**. To increase clock speed above a certain level, more energy is required/more heat is produced. The CPU speed, especially for fan-less laptops, has not increased beyond 3-4 GHz since the first half of the '2000s.
3. **Inefficient to add more cores**. To exploit the processing capability of dual-core, quad-core, and even octo-core CPUs, the processing must be well distributed among the cores, or the gain

is lost. Exceptions are specialised tasks like graphics where different parts of the screen can be simultaneously updated.

4. **Slow growth of supercomputer processing power**. Unlike the ~80%/year of a decade ago, the processing power only grows by ~40%/year because more chips must be packed in multi-million core supercomputers because the computer chips stop improving. More energy is required to operate and refrigerate supercomputers.

Possible research avenues that may maintain a sustainable future growth in processing performance are:

1. **Packing transistors in more layers to reduce chip size**. This is done in memory chips, stacking transistors in 128 layers or more, etched in one go. Such chips are good for portable/wearable devices and Internet of Things devices. Energy and heating problems affect dynamic random-access memory (DRAM) because almost every part of the chip is constantly powered.
2. **Using AI to design efficient chip architecture**. Especially with AI it is possible to design 3D chips making better use of the 3rd dimension. AI can design solutions in a process where they compete against one other and the best designs compete and evolve, until an optimal design is found that can no longer be improved.
3. **Combining chiplets**. These components take some of the load off CPUs (the CPUs themselves could be designed as chiplets). The recently established UCIe™ intends to develop a specification defining the chiplet interconnection within a package, enabling an open chiplet ecosystem and interconnect at the package level [27] offering the following advantages:
    a. No need to use the same processor node.
    b. Possibility to mix chiplets with different geometry.
    c. Flexibility in adopting 2.5D and 3D technology.
    d. Possibility to connect chiplets with those of other companies.
4. **Using other technologies**:
    a. *Graphene-base CPUs* can achieve x1000 speed of and consume x1/100 less energy than silicon chips and enable devices with smaller size and greater functionality.
    b. *Superconducting computers* offer the possibility to make 3D chips that are very dense still use very little energy at the cost of cooling to extremely low temperatures.
    c. *Quantum computers* can handle certain types of tasks far more quickly than traditional computers, solving problems that current computers would take a very long time to solve.
    d. *Optical computers* process, store, and communicate using light waves from lasers or incoherent sources. The electronic transistor is replaced by an "optical transistor" [26].
    e. *Neuromorphic computers* integrate features inspired by neurobiological systems and could provide energy-efficient solutions to AI problems.

7.2.2 Computing services

7.2.2.1 Cloud computing

Cloud computing is the delivery of hosted services over the internet. Adoption of this computing paradigm allows devices to outsource data processing and storage to external computers. It should balance several elements:

1. Powering and cooling costs. In appropriate conditions, these are reduced because a small number of large and centralised computers and servers is more efficient that if it is done on many devices.
2. Collection of data and distribution or processed data usually implies a lot of traffic back and forth the Devices to the cloud. Unless the bitrate available between devices and data centres is sufficiently high, cloud computing ceases to be competitive.

When more than one geographically separated Devices are involved, cloud computing is not an option, but a necessity. Therefore, cloud computing will be one computing paradigm supporting the Metaverse vision because it will enable the level of data storage, processing and distribution required by Metaverse Instances. Such Instances will likely take different forms: at one end of the spectrum, those of the size of today's big social networks and, at the other end of the spectrum, many smaller Instances serving specific needs, e.g., those of a company.

Cloud computing can play a role in five areas:
1. The **Metaverse service providers** may build private data centres or use managed services. However, most Metaverse Instances will be likely be built on public cloud providers.
2. **Pay-as-you-go models for on-demand compute and storage**. Public cloud providers can provide distributed points of presence around the world, thus lowering latency.
3. **Artificial intelligence and machine learning**. As cloud computing is already offering computing and data storage, it is natural that AI/ML will also be offered.
4. **Metaverse-as-a-Service** (MaaS), i.e., fully hosted, and managed offerings allowing customers to deploy their own custom Metaverse Environments with minimum efforts.
5. **Metaverse services built entirely from scratch** possibly leveraging Metaverse platforms (e.g., Vircadia and Metaverse.Network), as the foundation for Metaverse-as-a-Service offerings.

7.2.2.2 Edge computing

Cloud computing will not be the only computing paradigm relevant to the Metaverse. Performance and availability of Metaverse Environments can be improved by pushing Metaverse hosting and analytics to the edge so that devices can access storage and processing power from a close-by location. In the edge computing paradigm, data centres play the role of the gateway that pre-processes data before sending it to the cloud or handles a share of the processing and data storage.

Irrespective of where the User is located, a Metaverse Environment should be downloaded into a local edge data centre near the User and the other users represented by Digital Humans should also download the same Environment into their local edge data centre. The Metaverse Environments in each Device must then be synchronised with each other so that the scene the Users perceive is as smooth as possible and the interaction with it is natural.

Today's data centres and networks typically lack the speed, capacity, and latency to enable the immersive experiences envisaged by the Metaverse vision. The next Section will examine the state of the art of the telecommunication networks.

7.3 User Devices

The two main categories of Devices are:
1. Augmented Reality Devices, where the Metaverse Experience is superimposed to the Universe Experience.
2. Virtual Reality Devices where the Metaverse information is consumed by a User who is immersed in it.

Future VR headsets are expected to create audio-visual experiences that are like real-life doing better than today's bulky and heavy devices that typically require a significant personal effort if worn for a long time. They will likely morph into devices of different form factors and functionalities and will be the melting pot of the technologies that will drive adoption of the Metaverse vision.

An AR headset needs most of the technologies required by a VR headset. The differences are caused by the following considerations:

1. In VR, the human's view of a Universe Environment is blocked and replaced by the presentation of a Metaverse Environment. The human's experience is completely mediated by the Metaverse Environment.
2. In AR, the human's experience is based on the Universe Environment where they reside and augmented with elements drawn from a Metaverse Environment.
3. In VR, the light of the screen where the Metaverse Environment is rendered reach the eye through a lens. The lens is adjusted based on the eye movement using eye-tracking technologies. Visual, sound, and haptic stimuli are used to interact with a Metaverse Environment.
4. In AR, the signal of the camera is analysed using computer vision, mapping, and depth sensing technologies and transmitted to a Metaverse Environment proving appropriate elements drawn from a Metaverse Environment that are relevant to what the human sees.

The operation of a VR headset can be described by the following steps:

1. The User moves their head, e.g., they turn to look at somebody (virtually) sitting next to them.
2. The User's head rotation and movement are tracked by Gyroscope, Accelerometer and Magnetometer to track and create an immersion and presence feeling in the User.
3. The User's translation and position can also be tracked (using both inboard and outboard devices) following the position of the user's head, body, and hands.
4. The coded information of the movement is sent to the Metaverse Environment.
5. The Metaverse Environment generates the scene that the User should see and hear.
6. The coded information of the scene is sent back to the User.
7. The coded information is rendered with a large Field of View (FoV) matching the capabilities of the human vision (>180º) to create an immersion feeling.
8. The rendered scene is displayed showing to the eyes two different images of the scene viewed from slightly different angles to create a depth perception.
9. The VR headset screen generates photons, and the loudspeakers generate soundwaves.
10. The photons traverse the HMD lenses that make it easier for the eyes to accommodate the light from displays despite them being a few cm away. Fresnel lenses are used to have thinner and lighter lenses and sharper images.
11. The User's retina senses the photons, and the ear senses the sound waves.
12. The User's optic and acoustic nerves send millions of spikes per second to the brain.
13. The User becomes aware of the new scene.
14. The User activates a haptic device to convert their hand and finger movements into data understood by the Metaverse Environment.
15. The User charges batteries when the battery is low.

7.4 Network

Communication Service Providers will play an essential role in enabling the Metaverse vision because the ability of a Metaverse Instance to provide a satisfactory Experience will depend on the network being flawless in its ability to support the features listed in Subsection 7.4.2:

1. As analysed in Section 7.1.3.4, to provide a User with the flawless visual experience that most claim to be a necessary condition for the Metaverse experience to be acceptable, the network must be able to provide a very high bitrate to a VR or AR headset.
2. If the experience is altered by network inadequacy, the User's Sense of Agency, Embodiment, and Presence will be lost and the User will be catapulted back to the Universe.
3. As analysed in Subsection 7.3, the operation of a VR headset implies a Motion-to-Photon latency that it is claimed should be less than 20 ms.

4. As depicted in Figure 6 in Subsection 7.4.1, the global network infrastructure will require a substantial overhaul to enable a proper combination of long-distance distribution – covered by cloud computing – and "last mile" distribution – covered by edge computing.
5. Data centres shall ensure that Metaverse Instances that require it are always "on" and continue to exist and evolve no matter whether Users are signed in or leaving. The current set up can manage multiplayer online games populated by hundreds of Users, but full-fledged Metaverse Instances will deal with much larger numbers of concurrent Users.

7.4.1 Network architecture

Figure 6 is an indicative representation of a network architecture supporting the interaction between Metaverse Instances and End User Devices.

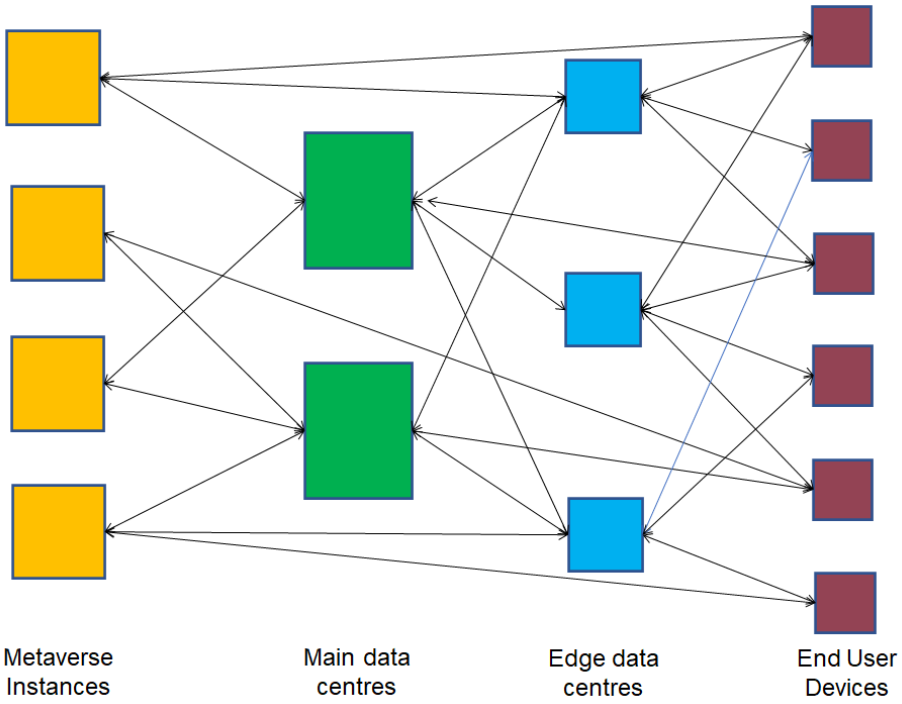

Figure 6 - Network architecture supporting Metaverse Instances

Note that the network architecture is not meant to be hierarchical. Depending on various factors, such as the actual network elements configuration, a Device can be connected directly with a Metaverse Instance or to a Main data centre or to the Edge.

The ideal goal of the network is to make the Experience of a User in a Metaverse Instance indistinguishable from the Experience that humans have in the Universe. One requirement is that the so-called Motion-to-Photon latency, i.e., the time taken by:

1. The Device to capture and process a scene.
2. The Network to carry the Data to the Metaverse Instance.
3. The Metaverse Instance to process the Data.
4. The Network to carry the Data back to the Device.
5. The Device to process and present the Data

be smaller than the time beyond which humans perceive a difference with a comparable situation in the Universe.

7.4.2 Network features

The performance of the Network supporting a Device should be assessed by the following parameters affecting the user or the network operator:

1. Bitrate available to the Device
2. Symmetrical or asymmetrical bandwidth
3. Bit error rate
4. Jitter
5. Latency
6. Security
7. Support to network services
8. Number of connectable Devices per unit area
9. Maximum tolerable velocity of a Device
10. Energy consumed to carry 1 bit
11. Energy consumed by a Device.

In the following, the evolving characteristics of mobile and fixed networks will be analysed.

7.4.3 Mobile networks

The radio access network (RAN) is the part of a network staying between a Device and the core network. In principle, the Metaverse should be agnostic as to the channel through which Data reach the Metaverse. However, the RAN can be exposed to instabilities radio channel instabilities and have a negative impact on the user experience.

Over the last 3 decades, different generations of RAN standards have offered increasingly improved performance to end users.

1. 5G, the latest generation, has or is *expected* to have soon, the following typical features:
    1. Use of higher frequency bands (in the 28 and 39 GHz bands).
    2. 20 Gbit/s available in a cell and 200 Mbit/s to a single user thanks to higher spectral efficiency and reduced cell size.
    3. Lower latency (down to 1 ms).
    4. Up to 1 million connected device/km^2/ (from 100 thousand of 4G).
    5. A single shared network supports virtual networks each having its own latency, throughput, security, and bandwidth characteristics.
    6. Support to devices moving at a speed of up to 500 km/h.
    7. Reduction of 5G networks' energy consumption per transported bit by 10 compared to 4G by 2025 and by 20 in 2030 (claim).
2. 6G, the next generation, is *expected* to have the following typical features:
    1. Higher frequency bands (even above 1 THz).
    2. 1Tbit/s available in a cell and 1 Gbit/s to a single user.
    3. Reduced latency to 100 μs.
    4. Increased number of devices/km^2 to 10 million.
    5. Reduced error rate by 10 times.
    6. Twice the battery life of devices.
    7. Improved energy efficiency of the telecom network x2.
    8. AI-based management of complex networks.
    9. AI-based personalised services.
    10. Reduced energy consumption below 1 nJ/bit.

7.4.4 Fixed networks

Broadband on the move is good for users and 5G is already providing mobile broadband at a level not accessible to many fixed network users. 6G, planned to be deployed at the end of the decade, is promising more.

The ITU-T has published Network 2030, "A Blueprint of Technology, Applications and Market Drivers Towards the Year 2030 and Beyond" [31] targeting:

1. A rich set of mechanisms to allow for interaction between the applications and the infrastructure beyond raw datagram delivery.
2. Extended edge/access with a function-rich thin interconnection between network edges.
3. Very high value broadband combined with time-aware network overcoming the current "best effort" internet delivery.
4. Multi-access and internet at the level of infrastructure integration and communication service support.

The European Telecommunication Standards Institute (ETSI) is working on the Fifth Generation Fixed Network (F5G) to "complement the 5G wireless network and support the growing number of cloud services requiring high bandwidth and/or low latency connections" and to "provide the evolution required to match and further enhance the benefits that 5G has brought to mobile communications" [32]. It addresses three main features:

1. Full-fibre connection (FFC).
2. Enhanced fixed broadband (eFBB).
3. Guaranteed reliable experience (GRE).

The declared goal of F5G is to provide over 10 times higher bandwidth, 10 times denser fibre connections, and 10 times better reliability and latency.

7.5 Energy

Energy is what enables Devices and Networks to perform their irreplaceable role in the development of the Metaverse. The energy aspect is considered from the viewpoint of the ability to:

1. Store energy for use by mobile/portable devices.
2. Enable energy consumption by:
    1. An IT equipment to process Data
    2. A network to carry bits.

7.5.1 Storage

Storage for portable devices is important to enable portable device with a long time between battery recharges. Today's predominant battery technology for electronic devices is Lithium-ion operating as follows:

1. When a Lithium-ion battery is charged, Lithium ions move from the cathode's Lithium Cobalt Oxide ($LiCO_2$) to the anode's carbon.
2. When the battery provides energy, the ions move back to the cathode.

In early Li-ion batteries, a liquid electrolyte was used to separated anode and cathode. In later batteries, a porous separator soaked in an electrolytic gel allowed thinner batteries. The separator of later Lithium polymer cells used a solid polymer but with longer charging times.

While the preferred power storage technology for consumer electronics devices, Lithium-ion batteries have limitations:

1. **Battery recharging can be done a limited number of times** because some ions remain captured in the material. The battery fails to operate when free ions are no more available.
2. **Battery charging enlarges the anode's volume** leading to a decrease of the battery's ability to store ions.

3. **Energy density improvement is slow**, as seen from the case of the iPhone: the iPhone1 had a 5.18Wh battery and the iPhone 6S's has a 6.55Wh battery. It took 8 years to get an improvement of just ~ 26%.

Alternative materials are used for positive and negative electrodes, and electrolytes to obtain denser packing of Lithium ions in electrodes, facilitate their movement through the electrolyte, and improve safety.

For the future, different approaches are studied:

1. **Lithium-Sulphur (Li-S) batteries** improve today's Li-ion batteries thanks to 3D electrodes and nanomaterials with larger energy density. The theoretical energy density limit of Li-ion batteries is ~ 320 Wh/kg against the current ~ 200 Wh/kg, but the theoretical limit for Li-S is ~ 500 Wh/kg because Sulphur can hold two Lithium ions compared to the 0.5 to 0.7 for the material currently used to separate anode and cathode. Li-S batteries can be used for electric vehicles, but the technology could be adapted to portable electronic devices as well.
2. **Supercapacitors** offer higher energy storage than conventional capacitors for applications such as burst or pulse load applications (e.g., LED flash), power amplifiers, specific audio circuits, and devices drawing very little current over a long time as in IoT. To overcome the supercapacitors' 2.5-2.7 V range (opposed to Li-ion batteries' 3.5-3.7 V range), supercapacitors can be connected in series, but complexity increases. Supercapacitors have also a low energy density: 10 Wh/kg against the 200 Wh/kg of Li-ion batteries.
3. **Fuel cell**s have been used to convert the chemical energy of fuel into electricity and are considered a good option for electric vehicles. For the time being, their size does not allow their use for electronic device batteries.
4. **NanoBolt lithium tungsten** batteries can use a web-like nano structure obtained by adding tungsten and carbon multi-layered nanotubes that bond to the copper anode substrate thus enabling more ions to attach during charge/discharge cycles.
5. **Zinc-manganese oxide** batteries can exploit the chemical conversion reaction in a zinc-manganese oxide batter and increase energy density in conventional batteries without increasing cost.
6. **Gold nanowire gel electrolyte** batteries can use electrolyte gels - not as combustible as liquids – covering coating gold nanowires with manganese dioxide. The resulting electrodes can stand 200,000 charge/discharge cycles, instead of the 6,000 cycles of a conventional battery.

7.5.2 Consumption

The Metaverse is likely to cause a change of habits that will results in significant social savings e.g., by reducing the need for physical displacement and the use of real estate for commercial buildings. The importance of these savings can be assessed by the following data in the USA [44]:

- Commercial buildings emit 826 MT/year of CO_2 and consume 35% of the electrical energy.
- To commute for 50 km by gas-powered car to those buildings a human emits 3.2 T of CO_2/year.

The percentage of end use of energy by sector in AU, CA, CH, a selection of EU countries, JP, KR, NZ, UK, US are:

Residential heating	11%
Other residential	9%
Industry	31%
Passenger cars	21%
Other vehicles	14%
Services	14%

The positive side of Metaverses is their potential to save a share of the currently consumed energy (and their future increases). The negative side is the energy cost of running big data centres containing Environments and Objects, transmitted over the Internet, and the Devices rendering complex Environments. An estimate of both factors is a necessary step before engaging in mass deployment of the Metaverse.

Table 4 gives some data related to *global* energy consumption (all values approximate) of some technologies expected to underpin the development of the Metaverse. The measure of Energy consistently used is kWh expressed with data ranging from 10^3 to 10^{18}, according to the following conventional abbreviations:

kilo (k) $=10^3$	Mega (M) $=10^6$	Giga (G) $=10^9$	Tera (T) $=10^{12}$	Peta (P) $=10^{15}$	Exa (E) $=10^{18}$	Zetta (E) $=10^{18}$

Table 4 - Global energy consumption and data transmission (estimates)

Use type	Target	Data	Unit	Year	Ref.
Energy supply	All	165	PWh	2020	[46]
Energy supply	Electricity	27	PWh	2020	[46]
Energy consumption	All	111	PWh	2020	[46]
Energy consumption	Electricity	23	PWh	2020	[46]
Energy consumption	ICT	0.6	PWh	2017	[48]
Energy consumption	Data centres	0.3	PWh	2021	[49]
Energy consumption	Internet	0.2	PWh	2021	[49]
Data transmission	Internet	1.2	ZByte	2016	[47]
Data transmission	Internet	3.3	ZByte	2021	[47]

An initial analysis of some of the technologies to be taken into consideration because of their relevance to energy consumption is done in the following:

1. **Datacentres**.
    1. A 2015 study before the advanced cloud gaming platforms like Google's Stadia and Microsoft's Xbox Cloud Gaming stated that datacentres were responsible for ~2% of global greenhouse gas emissions [43].
    2. A Meta data centre planned to be deployed in the Netherlands (and currently on pause) to host a portion of the metaverse in Europe has an expected energy consumption of 1.4 TWh/year.
2. **AI Model training**.
    1. According to a 2019 study by the University of Massachusetts at Amherst, one AI language processing model's estimated carbon footprint and electricity cost is >284 T of CO_2 [43].
    2. Generative AI systems used to train AI models to generate a set of images given a text prompt, e.g., DALL-E[24], require a large amount of computing power. An idea of the power consumed by DALL-E can be derived from the fact that the system is a scaled-down version of the text-writing AI system GPT-3[25] trained on pairs of text and images drawn from the internet. To train GPT-3, 1.3 GWh were used and the training produced 0.5 MT of CO_2.
    3. Nvidia reports[26] that its StyleGAN3 consumes 225MW to generate portraits of people that don't exist.

[24] https://venturebeat.com/2021/01/05/openai-debuts-dall-e-for-generating-images-from-text/
[25] https://venturebeat.com/2021/06/01/microsoft-gpt-3-and-the-future-of-openai/
[26] https://www.reddit.com/r/MachineLearning/comments/q6ark8/r_stylegan3_aliasfree_generative_adversarial/

3. **Blockchains**.
    1. In a Bitcoin network that processes ~7 transactions/s[27], a single Bitcoin transaction consumes 0.9 MWh[28].
    2. According to the Cambridge Bitcoin Electricity Consumption Index[29], Bitcoin accounts for ~0.40% of the world's total electricity consumption, and ~0.34% of the world's total electricity production.
    3. Digiconomist[30] estimates that Bitcoin's annual energy consumption has risen from 9.6 TWh in February 2017 to 73.2 TWh in January 2020.
    4. A 2021 study found that Bitcoin mining consumes around 91 TWh of electricity annually, i.e., 0.5% of all energy consumption worldwide and more than seven times the electricity used by all of Google's global operations.
    5. A single Bitcoin transaction consumes more energy than 100 000 Visa transactions.
    6. According to ARK Invest[31], traditional banking emits ~1,4 MT of CO_2/y and gold mining emits 144 MT while Bitcoin emits 61 MT, less than 5% and 45% of traditional banking and gold mining, respectively.
4. **Gaming**.
    1. A 2020 Greening The Beast study[32] estimated that high-end gamers with state-of-the-art VR hardware, will spend as much as $2,200 over the course of five years on electricity and pump as much as 1T of CO_2/y.
    2. University of Bristol (UK) found that, if just 30% of gamers using 720p or 1080p devices were to transition to cloud gaming by 2030, it would cause a 29.9% increase in CO_2 emissions. If 90% of gamers moved to the cloud, it would increase gaming's overall CO_2 emissions by 112%.

The IT industry, however, is quite accustomed to facing challenges:

1. In 2017, the IEA expected global data centre energy demand to grow by only ~3% to 200 TWh in 2020 because the growth for data centre services is offset by improved servers, storage devices, network switches and data centre infrastructure, including by the use of hyperscale data centres [39].
2. A 2020 analysis[33] found that energy consumption for all datacentres rose less than 10% from 2010 to 2018 in spite of an increase of 2,600% in server, storage, and network workloads hosted by the cloud datacentres.
3. Others estimate that this offset may not continue indefinitely because the most obvious energy savings are introduced first.
4. Perspectives of cloud service providers
    1. Google has committed to operating on 24/7 carbon-free energy in all its datacentres by 2030.
    2. Microsoft intends to be "carbon negative" by 2030, which includes a plan to stop using diesel fuel in its datacentre generators by 2030.
    3. Amazon Web Services aims to power its operations with 100% renewable energy by 2025.
5. There are less energy-consuming implementations of blockchains compared to Bitcoin. As an example, Ethereum after switching to a proof-of-stake consensus mechanism (i.e., using ETH instead of energy to secure the network) only uses ~0.0026 TWh/y across the entire global

[27] https://www.investopedia.com/terms/b/bitcoin-mining.asp
[28] https://digiconomist.net/bitcoin-energy-consumption
[29] https://cbeci.org/cbeci/comparisons
[30] https://digiconomist.net/bitcoin-energy-consumption
[31] https://ark-invest.com/articles/analyst-research/bitcoin-myths/
[32] https://www.mic.com/impact/gamings-environmental-impact-is-bigger-than-you-think-21753800
[33] https://www.nytimes.com/2021/06/24/technology/computer-energy-use-study.html

network. From these values it is possible to estimate[34] at 2.6 MWh for the network's annual electricity consumption (September 2022), which corresponds to 870 T of CO_2/y emissions.

8 Governance

Governance of this new entity called "Metaverse" may require the establishment of forms of governance. The following are potential areas:

1. Governance of the Metaverse System to be applied to all or to significantly large number of Metaverse Instances in case the industry decides that this level of governance is in the common interest. Section 8.1 identifies potential issues related to that kind of governance at the global level.
2. Governance by public authorities operating at a national or regional level. Section 8.2 identifies potential issues for Metaverse Regulation.
3. Governance of a Metaverse Instance, i.e., the governance exercised by a Metaverse Manager on the ecosystem hosted by their Metaverse Instance.
4. Governance of an Operator's Environment, i.e., the governance exercised by an Operator on the ecosystem hosted by their Metaverse Environment.

It should be noted that the need for new forms of governance may arise based on new technologies. An example is the Decentralised Autonomous Organisation (DAO) where the governing rules are encoded as a Smart Contract deployed on a Blockchain. DAOs appear to be good examples of how new technologies can make the rigid hierarchical structure of traditional governance ineffective.

This chapter does not intend to offer solutions to problems, not even to determine that a given issue is a problem. Its purpose is simply to initiate a process that will hopefully lead to the identification and formulation of problems in the expectation that these will be resolved.

8.1 Metaverse Governance

This is a governance layer that may be applied to all or to significantly large numbers of global Metaverse Instances in case the industry decides that having this level of governance is in the common interest.

Such governance of the Metaverse system could be competent for management of the Common Metaverse Specifications. For instance, rules or guidelines for:

1. Management of the life cycle of a CMS Specification technology, e.g.:
    1. Identification of a Functionality.
    2. Acceptance of a technology supporting a Functionality.
    3. Update of a technology.
    4. Removal of a technology.
2. Management of the life cycle of a CMS Profile, e.g.:
    1. Identification of a Profile.
    2. Acceptance of a Profile.
    3. Update of a Profile.
    4. Removal of a Profile.
3. Identification of a Metaverse Instance.
4. Definition of Metadata for a Metaverse Instance.
5. Interactions between Metaverse Instances.
6. Interactions between Metaverses and External service Providers.
7. Etc.

[34] https://ethereum.org/en/energy-consumption/

8.2 Metaverse regulation

Over millennia, centuries and decades, different communication technologies have had an impact on society and have been regulated to different extents. The Rights and Duties of Metaverse Stakeholders, e.g., Managers, Operators, and Users in a Metaverse Instance may also be the target of regulation and governance.

This chapter highlights some areas for which adapted or new regulation may be required. For each of these entities, Rights that might be claimed and Duties that might be imposed are introduced.

8.2.1 Property

The property law applicable to a Universe Environment governs the various forms of ownership of physical and intangible assets, including land, personal property, and intellectual property deriving from the creations of the mind, such as inventions, artistic and literary works, designs and symbols, and names and images used in commercial creations.

Humans spend millions to buy virtual property in Metaverse Environments – land parcels, buildings, avatar clothes etc. – because they believe that, as it happens in the Universe, those Environments will be "more and more populated", and the property around them could have "more and more value". While the mentioned forms of physical property that are physical or intellectual but map directly to a Universe Environment are protected by the applicable property law, is the ownership of a Metaverse Asset governed by the same law?

When a User purchases an item in the Metaverse, the Transaction may be recorded in a Blockchain, and the User assigned ownership of an NFT stored in a Crypto Wallet. The NFT and the Metaverse property, however, are distinct. The NFT resides in the Blockchain and is based on the rules of the Blockchain, and the Metaverse property resides on private servers and is subject to the Terms of Service of the Metaverse Instance. Depending on their formulation, the Metaverse Manager may be entitled to remove or transfer a property item in the Metaverse Instance by unlinking it from the original NFT ID. They could also ban Users and prevent them from exploiting a property item because of an action contravening the Metaverse Terms of Service or because the Terms of Service have been changed, possibly without notice, making prohibited tomorrow yesterday's permissible actions.

The notion of property in the Metaverse has further twists. In most cases, NFT holders have no rights to a token's underlying creative content. For instance, a User buying an NFT of a media clip does not acquire the ownership of the media it contains, but only the exact expression of the clip. Moreover, NFTs can be programmed to limit the extent the purchased content can be shared or edited, and to attach royalties to the NFT, e.g., triggering monetary benefit to the creator each time the NFT is transferred.

The probability of success of the Metaverse vision will improve if the notion of property in the Metaverse would have a clearer definition much as was done by the Anne's Act three centuries ago.

8.2.2 Trademark

A trademark is a distinctive sign or symbol that is used to identify and distinguish the goods or services of one enterprise from those of other enterprises[35]. Therefore, a trademark identifies the brand owner of a particular product or service. A trademark can be used under license of the

[35] https://www.wipo.int/trademarks/en/

trademark holder. If that trademarked object is used, the distinctive ability to conjure up an image of a good quality object with that trademark may be diluted. However, if a sweater manufacturer's trademark is presented as being used on an object of that manufacturer, there should be no dilution because the trademark will continue to make people remember the manufacturer as a great sweater manufacturer [65]. A film producer asking an actor to wear a sweater bearing the trademark of the manufacturer may not need to pay the trademark holder.

If a trademark is used in a Metaverse Environment some questions arise:
1. To what extent do the laws regulating the use of a trademarked object in a Universe Environment apply to a Metaverse Environment?
2. How can a Digital Object reproducing a trademarked object be used in a Metaverse Environment?
3. When does an avatar driving a famous sports car in a Metaverse Environment violate the sports car manufacturer's copyrighted design and trademark?

8.2.3 Authorship

Content created by a human in a Universe Instance is protected by copyright, a type of intellectual property that protects original works of authorship as soon as an author fixes the work in a tangible form of expression[36]. But what if a User creates content – e.g., avatars, virtual buildings, squares, and objects, and digital artwork, etc. – in a Metaverse? A few questions may be asked:
1. Are these content items considered "original works" of authorship fixed in a tangible form of expression in a Metaverse Environment?
2. Are they protected by copyright and do the authors have the right to recreate, trade, and display the work out to others?
3. Is this an untouchable right or do other rights such as those mentioned in Subsection 8.2.1 Property take precedence?
4. Does the act of propagating an Asset created by a User in a Metaverse Instance as their own creative work infringe on the copyright as it happens for copyrighted work in a Universe Instance?

8.2.4 Contract

A contract is a legally binding agreement between two or more parties each promising to do something or to refrain from doing something based on certain conditions. Contracts are enforceable by the laws of the Universe Environment in which they are made, and courts can be involved to ensure that all parties in a contract fulfil their obligations under the terms of the agreement.

If the contract in a Metaverse Environment is about renting/alienating an Asset, or the provisioning of a service, then contract laws should probably also apply. As indicated in 8.2.1, contract law and not property law should also regulate property in a Metaverse Environment.

8.2.5 Tort

Tort law governs events where a party suffers property damage, or a personal injury directly or indirectly caused by another party. The notions applicable to a Universe Environment may be adapted to a Metaverse Instance and emotional distress and virtual property damage could be identified as damages suffered in a Metaverse Environment. Physical injuries suffered in a Metaverse Environment are not yet contemplated, but the performance of an Actuator (e.g., a smell generator) activated by a command from a Metaverse Instance because of the activities taking place there may be a possible issue in the future.

[36] https://www.copyright.gov/what-is-copyright/

8.2.6 Defamation

Humans may suffer defamation in real life, the press, or on social networks causing harm to an individual's reputation, personal relationships, and professional opportunities. Defamation may also happen in a Metaverse Environment. For instance, a Virtual Human can make false statements about a User or a human thus possibly damaging the reputation of that User or human. Is the human responsible for that Virtual Human responsible for the statements made by their Virtual Human?

8.2.7 Privacy

Privacy law regulates how personal information is collected, stored, and used. Some areas of privacy concern in the Metaverse are:

1. Prevailing law. To what extent is a User in a Metaverse Instance operating under a given jurisdiction bound by the laws of that jurisdiction?
2. Privacy regulations. What privacy regime(s) should be applied to, e.g., an EU citizen User checking out a U.S. Metaverse Operator's property hosted by an Australian Metaverse Manager?
3. Data collection depending on the type of data, e.g., sensor, location, physiological or social, etc.
4. Users' data rights and ownership.
5. Adaptation of current privacy regulations to the Metaverse.
6. User-to-User privacy.
7. Minors' privacy.
8. Data recording. VR headsets can record information about a person's movements, appearance, and surroundings.

8.2.8 Taxation

User may make Transactions in a Metaverse Instance and they may generate value for the affected natural persons or legal entities of a Universe Environment. If a Transaction in a Metaverse Environment is directly connected with goods or services of a Universe Environment, e.g., when the User makes an online purchase of goods and services, the application of taxes may be straightforward. If, however, an Asset is exchanged for another (e.g., an NFT acquired with a cryptocurrency), it may be less obvious that: (a) a taxable transaction (small "t") has occurred and (b) the value of that transaction for tax purposes.

The NFTs of a Metaverse Instance can be variously considered as commodities, banking, and securities or investment contracts depending on the way NFTs are created and exchanged. Depending on the case in question, the applicable law may differ. The banking, money transfer, and other financial regimes are likely to apply to the issuance, lending, and trading of cryptocurrencies in a Metaverse Environment.

The purchase/sale of Assets should involve sales/income tax regimes, but what if it is difficult to identify the tax residency position of an individual consumer in a Metaverse Instance? The problem is further complicated in the case of a Decentralised Autonomous Organisation (DAO) if the tax residency of the DAO is not known.

A retailer who sells physical goods in a Universe Environment (e.g., a shop) may sell digital goods such as NFTs, skins, and avatar accessories in a Metaverse Environment instead. In the EU, this may be considered as a provision of electronic services, which may trigger a different set of VAT rules.

8.2.9 Mental health

The mental health of those disconnected from the real world because they reside for a long time Metaverse Environment could be seriously impact. “Zoom fatigue” was claimed by some in the early Covid-19 days when people started spending too much time on virtual meetings. The same could be seen in a more aggressive form with the Metaverse.

Who is responsible for a potential mental breakdown for a person subjected to severe stress while operating in a Metaverse Environment?

8.3 Metaverse Stakeholders

This Section contains an initial identification of the Rights and Duties of a Metaverse Stakeholder operating under the laws applicable to their Metaverse Instance. They are expressed in a way that implies that a specific Right or Duty can *conceivably* be assigned to a Metaverse Stakeholder. The actual assignment will depend on the *specific* case and the *extent* to which a Right or Duty can be assigned will depend on the context.

In the Subsections below, it is assumed that Rights and Duties may be imposed by a higher-level Stakeholder, in the order Manager-Operator-User, to a lower-level Stakeholder.

8.3.1 Manager

8.3.1.1 Rights

A Metaverse Manager has the Right to:

1. Select the jurisdiction applicable to their Metaverse Instance
2. Adopt a particular business model.
3. Set the Terms of Service.
4. Set other rules, e.g., privacy and ethical.
5. Decide the level of Interoperability of their Metaverse Instance.
6. Perform any of the following: reject, accept, sanction, or expel a Metaverse Operator.
7. Police their Metaverse Instance.
8. Settle disputes arising between Metaverse Operators.
9. Operate one or more Metaverse Environments as a Metaverse Operator.

8.3.1.2 Duties

A Metaverse Manager has the duty to:

1. Make known the technical features of their Metaverse Instance.
2. Offer a declared level of security.
3. Guarantee the Privacy of the Data of their Metaverse Operators and Users.
4. Declare to what extent the Manager is accountable for what happens in their Metaverse Instance.

8.3.2 Operator

8.3.2.1 Rights

A Metaverse Operator has the Right to:

1. Offer Services to the Users of the Metaverse Instance where they operate.
2. Set the Terms of Service.
3. Set other rules, e.g., privacy or ethical, in the framework of the rules set by the Metaverse Manager.
4. Post ads in their Environment.

5. Establish a compulsory licence in their favour for work created in their Metaverse Environment

8.3.2.2 Duties

A Metaverse Operator has the Duty to:
1. Make known the specific rules applying to their Metaverse Environment.
2. Limit the access to their Metaverse Instance to those qualified, i.e., those of legal age.

8.3.3 User

8.3.3.1 Rights

A User has the Right to be made aware of:
1. The legal framework that applies to:
    1. A Metaverse Instance
    2. Multiple connected Metaverse Instances.
2. Which data types are collected:
    1. Biometric
    2. Behavioural
    3. Emotional
    4. Others
3. By whom they are collected:
    1. The Manager.
    2. An Operator.
    3. A Partner.
    4. A Service.
4. For what purposes they are collected:
    1. Advertisements
    2. Statistics
5. For how long the data will be retained.
6. Whether an Object in a Metaverse Environment is Digital or Virtual.
7. The identity of relevant owners of Objects.
8. The nature of the consent that is requested of the User.

Note: It would be desirable that the User can have their rights available in a machine-readable form.

8.3.3.2 Duties

A User has the duty:
1. To accept the requirements of a Metaverse Instance's legal framework.
2. To act in good faith in the Metaverse.
3. To declare whether their self-described identity is faithful or fictitious.

9 Profiles

The final goal of Metaverse standardisation is the creation of Profiles. In the proposed process, Metaverse Functionalities will be continuously and openly enriched. Functionalities are published, proposals of new or modified Functionalities are received by secretariat@mpai.community, the MPAI-MMM group acts on the requests possibly revising and posting revised Functionalities. These are the indispensable material used standardization to specify standard technologies, but they are not the standard. This Chapter sketches a path leading from now to Interoperable Metaverse Instances.

This is the path envisaged by MPAI. Note that activities will likely not be carried out strictly in sequence:

1. The *MPAI Metaverse Model (MMM)* is the key document sketching the path. It is published on the MPAI website from 2023/01/03. Interested parties can make comments to the MPAI Secretariat until 2023/01/23T23:59 UTC. People making comments will be invited to join the Requirements (MMM) meetings in charge the MMM. The MMM V1 is planned to be published as a *Technical Report* on 2023/01/25.
2. The next target for MPAI is to develop a limited number of *Functionality Profiles*. As the name implies, these Profiles will not reference Technologies, because the CMS does not exist yet, but only Metaverse Functionalities. They will be constructed by taking some major existing Metaverse Instances and developing Profiles that reference Functionalities, as opposed to Technologies. The Functionality Profiles will help provide an in-depth view of the required Technologies and fine tune the implementation of the MMM process.
3. The next target will be the development of the *Metaverse Architecture* specification. This document will identify the main functional blocks underpinning a Metaverse Instance and the data types exchanged between them.
4. The next target will be the development of the *Functional Requirements of the Data types* identified in the Metaverse Architecture specification.
5. The next target will be the development of the *Common Metaverse Specifications*, in three steps:
    1. Development of the *CMS Table of Contents* using the Functional Architecture and the Functional Requirements of the Data types.
    2. Mapping of the MPAI standardised technologies that satisfy the Functional Requirements of point 4. above into the CMS.
    3. Inclusion of the Technologies though the usual process of call for Technologies.
6. Drafting of the *Metaverse System Governance* mission.
7. The *Technology Profile Specifications* will be developed.

This is MPAI's initial proposal. Of course, there will be a need for entities with a stake in this process to be involved in moving ahead.

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Annex 1 - MPAI Basics

In recent years, Artificial Intelligence (AI) and related technologies have been introduced in a broad range of applications, have started affecting the life of millions of people and are expected to do so even more in the future. As digital media standards have positively influenced industry and billions of people, so AI-based data coding standards are expected to have a similar positive impact. Indeed, research has shown that data coding with AI-based technologies is generally *more efficient* than with existing technologies for, e.g., compression and feature-based description.

However, some AI technologies may carry inherent risks, e.g., in terms of bias toward some classes of users. Therefore, the need for standardisation is more important and urgent than ever.

The international, unaffiliated, not-for-profit MPAI – Moving Picture, Audio and Data Coding by Artificial Intelligence Standards Developing Organisation has the mission to develop *AI-enabled data coding standards*. MPAI Application Standards enable the development of AI-based products, applications, and services.

As a rule, MPAI standards include four documents: Technical Specification, Reference Software Specifications, Conformance Testing Specifications, and Performance Assessment Specifications. The last type of Specification includes standard operating procedures to enable users of MPAI Implementations to make informed decision about their applicability based on the notion of Performance, defined as a set of attributes characterising a reliable and trustworthy implementation.

In the following, If a Term begins with a small letter, it has the commonly used meaning and if with a capital letter, it has either the meaning defined in *Table 1* if it is specific to this Technical Report and in *Table 5* if it is common to all MPAI Standards.

In general, MPAI Application Standards are defined as aggregations – called AI Workflows (AIW) – of processing elements – called AI Modules (AIM) – executed in an AI Framework (AIF). MPAI defines Interoperability as the ability to replace an AIW or an AIM Implementation with a functionally equivalent Implementation.

MPAI also defines 3 Interoperability Levels of an AIF that executes an AIW. The AIW and its AIMs may have 3 Levels:
Level 1 – Implementer-specific and satisfying the MPAI-AIF Standard.
Level 2 – Specified by an MPAI Application Standard.
Level 3 – Specified by an MPAI Application Standard and certified by a Performance Assessor.

MPAI offers Users access to the promised benefits of AI with a guarantee of increased transparency, trust and reliability as the Interoperability Level of an Implementation moves from 1 to 3. Additional information on Interoperability Levels is provided in reference [1].

Figure 7 depicts the MPAI-AIF Reference Model under which Implementations of MPAI Application Standards and user-defined MPAI-AIF Conforming applications operate [1].
MPAI Application Standards normatively specify the Syntax and Semantics of the input and output data and the Function of the AIW and the AIMs, and the Connections between and among the AIMs of an AIW.

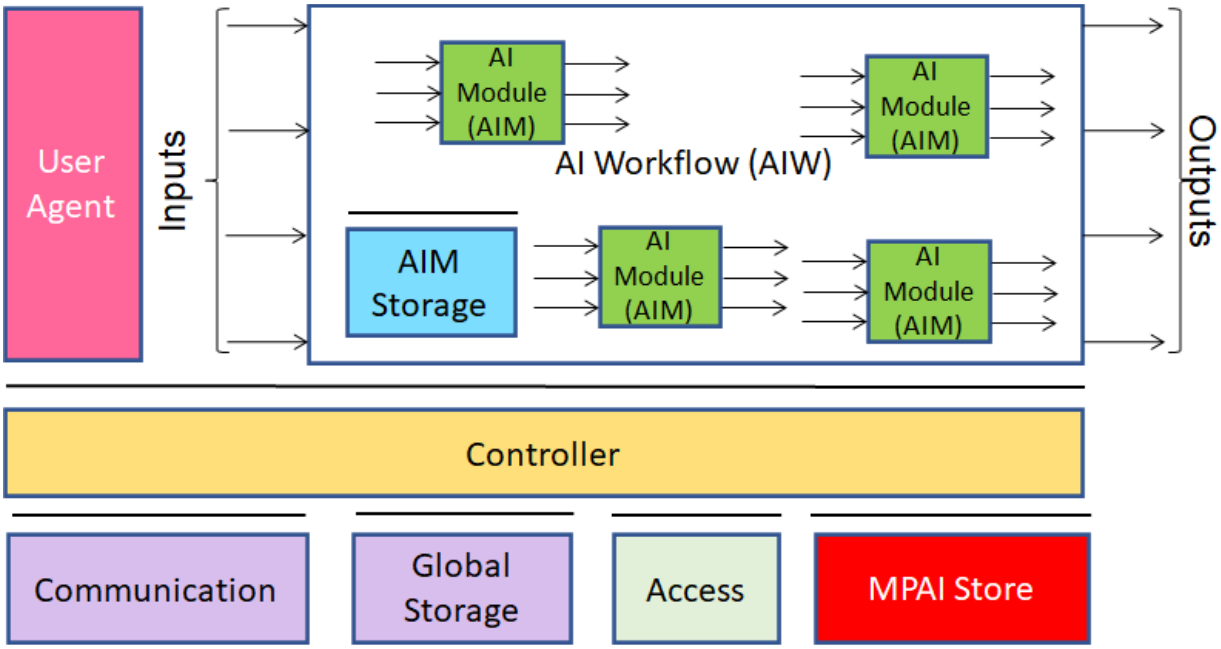

Figure 7 – The AI Framework (AIF) Reference Model

It should be noted that an AIM is defined by its Function and data, but not by its internal architecture, which may be based on AI or data processing, and implemented in software, hardware or hybrid software and hardware technologies.

MPAI Standards are designed to enable a User to obtain, via standard protocols, an Implementation of an AIW and of the set of corresponding AIMs and execute it in an AIF Implementation. The MPAI Store in *Figure 7* is the entity from which Implementations are downloaded. MPAI Standards assume that the AIF, AIW, and AIM Implementations may have been developed by independent implementers. A necessary condition for this to be possible, is that any AIF, AIW, and AIM implementations be uniquely identified. MPAI has appointed an ImplementerID Registration Authority (IIDRA) to assign unique ImplementerIDs (IID) to Implementers.[37]

A necessary condition to make possible the operations described in the paragraph above is the existence of an ecosystem composed of Conformance Testers, Performance Assessors, the IIDRA and an instance of the MPAI Store. Reference [1] provides an informative example of such ecosystem.

[37] At the time of publication of this Technical Report, the MPAI Store was assigned as the IIDRA.

Annex 2 - General MPAI Terminology

The Terms used in this standard whose first letter is capital and are not already included in *Table 1* are defined in *Table 5*.

Table 5 – MPAI-wide Terms

Term	Definition
Access	Static or slowly changing data that are required by an application such as domain knowledge data, data models, etc.
AI Framework (AIF)	The environment where AIWs are executed.
AI Module (AIM)	A processing element receiving AIM-specific Inputs and producing AIM-specific Outputs according to according to its Function. An AIM may be an aggregation of AIMs.
AI Workflow (AIW)	A structured aggregation of AIMs implementing a Use Case receiving AIM-specific inputs and producing AIM-specific inputs according to its Function.
AIF Metadata	The data set describing the capabilities of an AIF set by the AIF Implementer.
AIM Metadata	The data set describing the capabilities of an AIM set by the AIM Implementer.
Application Programming Interface (API)	A software interface that allows two applications to talk to each other
Application Standard	An MPAI Standard specifying AIWs, AIMs, Topologies and Formats suitable for a particular application domain.
Channel	A physical or logical connection between an output Port of an AIM and an input Port of an AIM. The term “connection” is also used as a synonym.
Communication	The infrastructure that implements message passing between AIMs.
Component	One of the 9 AIF elements: Access, AI Module, AI Workflow, Communication, Controller, Internal Storage, Global Storage, MPAI Store, and User Agent.
Conformance	The attribute of an Implementation of being a correct technical Implementation of a Technical Specification.
Conformance Tester	An entity authorised by MPAI to Test the Conformance of an Implementation.
Conformance Testing	The normative document specifying the Means to Test the Conformance of an Implementation.
Conformance Testing Means	Procedures, tools, data sets and/or data set characteristics to Test the Conformance of an Implementation.
Connection	A channel connecting an output port of an AIM and an input port of an AIM.
Controller	A Component that manages and controls the AIMs in the AIF, so that they execute in the correct order and at the time when they are needed.
Data	Information in digital form.
Data Format	The standard digital representation of Data.
Data Semantics	The meaning of Data.

Device	A hardware and/or software entity running at least one instance of an AIF.
Ecosystem	The ensemble of the following actors: MPAI, MPAI Store, Implementers, Conformance Testers, Performance Testers and Users of MPAI-AIF Implementations as needed to enable an Interoperability Level.
Event	An occurrence acted on by an Implementation.
Explainability	The ability to trace the output of an Implementation back to the inputs that have produced it.
Fairness	The attribute of an Implementation whose extent of applicability can be assessed by making the training set and/or network open to testing for bias and unanticipated results.
Function	The operations effected by an AIW or an AIM on input data.
Global Storage	A Component to store data shared by AIMs.
Identifier	A name that uniquely identifies an Implementation.
Implementation	1. An embodiment of the MPAI-AIF Technical Specification, or 2. An AIW or AIM of a particular Level (1-2-3).
Internal Storage	A Component to store data of the individual AIMs.
Interoperability	The ability to functionally replace an AIM/AIW with another AIM/AIW having the same Interoperability Level
Interoperability Level	The attribute of an AIW and its AIMs to be executable in an AIF Implementation and to be: 1. Implementer-specific and satisfying the MPAI-AIF Standard *(Level 1)*. 2. Specified by an MPAI Application Standard (*Level 2)*. 3. Specified by an MPAI Application Standard and certified by a Performance Assessor (*Level 3)*.
Knowledge Base	Structured and/or unstructured information made accessible to AIMs via MPAI-specified interfaces
Message	A sequence of Records.
Normativity	The set of attributes of a technology or a set of technologies specified by the applicable parts of an MPAI standard.
Performance	The attribute of an Implementation of being Reliable, Robust, Fair and Replicable.
Performance Assessment	The normative document specifying the procedures, the tools, the data sets and/or the data set characteristics to Assess the Grade of Performance of an Implementation.
Performance Assessment Means	Procedures, tools, data sets and/or data set characteristics to Assess the Performance of an Implementation.
Performance Assessor	An entity authorised by MPAI to Assess the Performance of an Implementation in a given Application domain
Port	A physical or logical communication interface of an AIM.
Profile	A particular subset of the technologies used in MPAI-AIF or an AIW of an Application Standard and, where applicable, the classes, other subsets, options and parameters relevant to that subset.
Record	Data with a specified structure.
Reference Model	The AIMs and theirs Connections in an AIW.
Reference Software	A technically correct software implementation of a Technical Specification containing source code, or source and compiled code.

Reliability	The attribute of an Implementation that performs as specified by the Application Standard, profile and version the Implementation refers to, e.g., within the application scope, stated limitations, and for the period of time specified by the Implementer.
Replicability	The attribute of an Implementation whose Performance, as Assessed by a Performance Assessor, can be replicated, within an agreed level, by another Performance Assessor.
Robustness	The attribute of an Implementation that copes with data outside of the stated application scope with an estimated degree of confidence.
Scope	The domain of applicability of an MPAI Application Standard
Service Provider	An entrepreneur who offers an Implementation as a service (e.g., a recommendation service) to Users.
Specification	A collection of normative clauses.
Standard	The ensemble of Technical Specification, Reference Software, Conformance Testing and Performance Assessment of an MPAI application Standard.
Technical Specification	(Framework) the normative specification of the AIF. (Application) the normative specification of the set of AIWs belonging to an application domain along with the AIMs required to Implement the AIWs that includes: 1. The formats of the Input/Output data of the AIWs implementing the AIWs. 2. The Connections of the AIMs of the AIW. 3. The formats of the Input/Output data of the AIMs belonging to the AIW.
Testing Laboratory	A laboratory accredited by MPAI to Assess the Grade of Performance of Implementations.
Time Base	The protocol specifying how Components can access timing information
Topology	The set of AIM Connections of an AIW.
Use Case	A particular instance of the Application domain target of an Application Standard.
User	A user of an Implementation.
User Agent	The Component interfacing the user with an AIF through the Controller
Version	A revision or extension of a Standard or of one of its elements.
Zero Trust	A cybersecurity model primarily focused on data and service protection that assumes no implicit trust.

Annex 3 - Notices and Disclaimers Concerning MPAI Standards (Informative)

The notices and legal disclaimers given below shall be borne in mind when downloading and using approved MPAI Standards.

In the following, "Standard" means the collection of four MPAI-approved and published documents: "Technical Specification", "Reference Software" and "Conformance Testing" and, where applicable, "Performance Testing".

Life cycle of MPAI Standards

MPAI Standards are developed in accordance with the MPAI Statutes. An MPAI Standard may only be developed when a Framework Licence has been adopted. MPAI Standards are developed by especially established MPAI Development Committees who operate on the basis of consensus, as specified in Annex 1 of the MPAI Statutes. While the MPAI General Assembly and the Board of Directors administer the process of the said Annex 1, MPAI does not independently evaluate, test, or verify the accuracy of any of the information or the suitability of any of the technology choices made in its Standards.

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Comments on MPAI Standards are welcome from any interested parties, whether MPAI members or not. Comments shall mandatorily include the name and the version of the MPAI Standard and, if applicable, the specific page or line the comment applies to. Comments should be sent to the MPAI Secretariat. Comments will be reviewed by the appropriate committee for their technical relevance. However, MPAI does not provide interpretation, consulting information, or advice on MPAI Standards. Interested parties are invited to join MPAI so that they can attend the relevant Development Committees.

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Users of MPAI Standards should consider all applicable laws and regulations when using an MPAI Standard. The validity of Conformance Testing is strictly technical and refers to the correct implementation of the MPAI Standard. Moreover, positive Performance Assessment of an implementation applies exclusively in the context of the MPAI Governance and does not imply compliance with any regulatory requirements in the context of any jurisdiction. Therefore, it is the responsibility of the MPAI Standard implementer to observe or refer to the applicable regulatory requirements. By publishing an MPAI Standard, MPAI does not intend to promote actions that are not in compliance with applicable laws, and the Standard shall not be construed as doing so. In particular, users should evaluate MPAI Standards from the viewpoint of data privacy and data ownership in the context of their jurisdictions.

Implementers and users of MPAI Standards documents are responsible for determining and complying with all appropriate safety, security, environmental and health and all applicable laws and regulations.

Annex 4 - The Governance of the MPAI Ecosystem (Informative)

Level 1 Interoperability

With reference to *Figure 7*, MPAI issues and maintains a standard – called MPAI-AIF – whose components are:

1. An environment called AI Framework (AIF) running AI Workflows (AIW) composed of interconnected AI Modules (AIM) exposing standard interfaces.
2. A distribution system of AIW and AIM Implementation called MPAI Store from which an AIF Implementation can download AIWs and AIMs.

A Level 1 Implementation shall be an Implementation of the MPAI-AIF Technical Specification executing AIWs composed of AIMs able to call the MPAI-AIF APIs.

Implementers' benefits	Upload to the MPAI Store and have globally distributed Implementations of - AIFs conforming to MPAI-AIF. - AIWs and AIMs performing proprietary functions executable in AIF.
Users' benefits	Rely on Implementations that have been tested for security.
MPAI Store	- Tests the Conformance of Implementations to MPAI-AIF. - Verifies Implementations' security, e.g., absence of malware. - Indicates unambiguously that Implementations are Level 1.

Level 2 Interoperability

In a Level 2 Implementation, the AIW must be an Implementation of an MPAI Use Case and the AIMs must conform with an MPAI Application Standard.

Implementers' benefits	Upload to the MPAI Store and have globally distributed Implementations of - AIFs conforming to MPAI-AIF. - AIWs and AIMs conforming to MPAI Application Standards.
Users' benefits	- Rely on Implementations of AIWs and AIMs whose Functions have been reviewed during standardisation. - Have a degree of Explainability of the AIW operation because the AIM Functions and the data Formats are known.
Market's benefits	- Open AIW and AIM markets foster competition leading to better products. - Competition of AIW and AIM Implementations fosters AI innovation.
MPAI Store's role	- Tests Conformance of Implementations with the relevant MPAI Standard. - Verifies Implementations' security. - Indicates unambiguously that Implementations are Level 2.

Level 3 Interoperability

MPAI does not generally set standards on how and with what data an AIM should be trained. This is an important differentiator that promotes competition leading to better solutions. However, the performance of an AIM is typically higher if the data used for training are in greater quantity and more in tune with the scope. Training data that have large variety and cover the spectrum of all cases of interest in breadth and depth typically lead to Implementations of higher "quality".

For Level 3, MPAI normatively specifies the process, the tools and the data or the characteristics of the data to be used to Assess the Grade of Performance of an AIM or an AIW.

Implementers' benefits	May claim their Implementations have passed Performance Assessment.

Users' benefits	Get assurance that the Implementation being used performs correctly, e.g., it has been properly trained.
Market's benefits	Implementations' Performance Grades stimulate the development of more Performing AIM and AIW Implementations.
MPAI Store's role	- Verifies the Implementations' security - Indicates unambiguously that Implementations are Level 3.

The MPAI ecosystem

The following *Figure 8* is a high-level description of the MPAI ecosystem operation applicable to fully conforming MPAI implementations as specified in the Governance of the MPAI Ecosystem Specification [1]:

1. MPAI establishes and controls the not-for-profit MPAI Store.
2. MPAI appoints Performance Assessors.
3. MPAI publishes Standards.
4. Implementers submit Implementations to Performance Assessors.
5. If the Implementation Performance is acceptable, Performance Assessors inform Implementers and MPAI Store.
6. Implementers submit Implementations to the MPAI Store
7. MPAI Store verifies security and Tests Conformance of Implementation.
8. Users download Implementations and report their experience to MPAI.

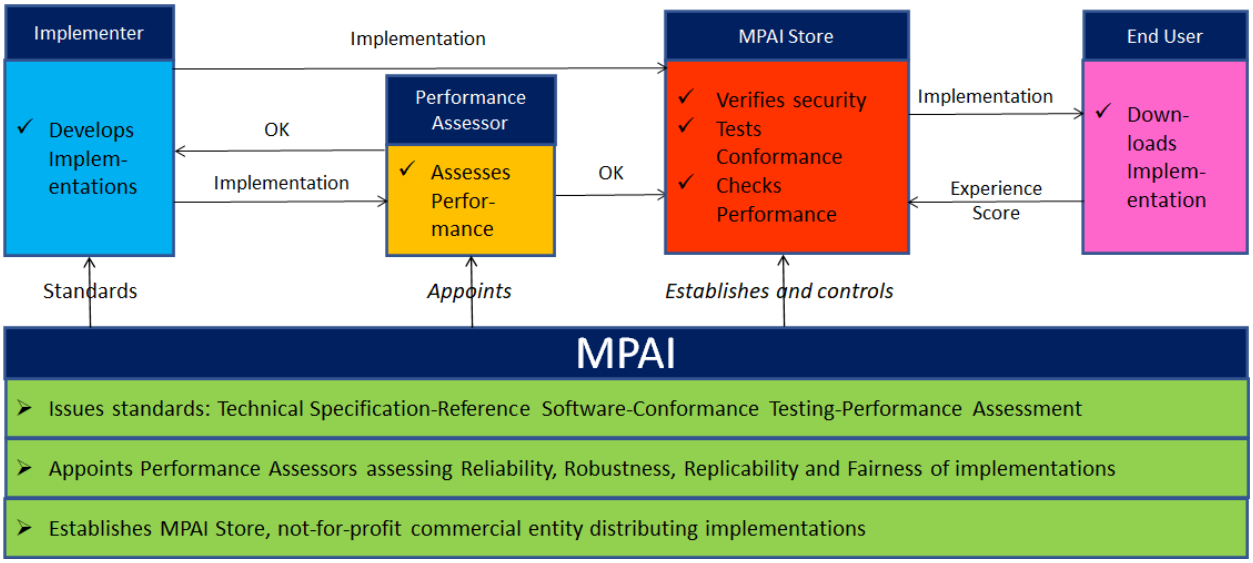

Figure 8 – The MPAI ecosystem operation