Analysis of Commercial Implementations of Metaverse Standards



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NOTE: This report is not an ETSI document and is not a deliverable of the STF 686 ViWISSO project.

About the team

Christine Perey is a Spime Wrangler. She leads and joins teams working collaboratively to advance business prospects in new technology markets where space and time intersect. Bruce Sterling first used the neologism "Spime" in August 2004 at SIGGRAPH that year. He predicted then that at the intersection of space and time, Spimes would arise. Sterling said "true Spimes create spime wranglers. Wranglers are the class of people willing to hassle with Spimes. And it is a hassle. An enormous hassle. But it's a fruitful hassle. It is the work of progress. Handled correctly, it can undo the harm of the past and enhance what is to come."

Giuseppe Scavo is the Data Engineer for this project. He is a seasoned developer and technical leader with over a decade of experience specializing in immersive technologies and artificial intelligence. With a strong academic foundation in Computer Engineering and hands-on expertise in AR and VR, he has played pivotal roles in developing cutting-edge applications and shaping the strategic direction of various organizations. To find and compile the data on which this report is based, Scavo developed and managed a bespoke, metaverse-trained deep research agent.

PEREY Research and Consulting provides industry-specific knowledge and services packaged the way businesses in fast-moving markets need them—concise, concrete and actionable. Companies leverage the value they receive from working with us in business plans and formulating a variety of mission-critical decisions. We offer agencies of all types, investors, service providers and technology vendors who want to expand their mobile augmented reality communications and community opportunities the tools and the professional partnerships that they need.

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1 Scope

This report provides the result of research conducted using a custom deep research agent with full access to information published on the Web between June 6 and 12, 2025 for the purpose of documenting the implementation status of over 300 metaverse-related standards by 29 metaverse technology providers.

This research is an extension of prior studies in 2025 that identified, classified and analyzed nearly 1,500 documents (of which 1,200 were standards specifications) for the Virtual Worlds Interoperability and Standards Status and Opportunities (ViWISSO) Project. This independent project demonstrates how the ViWISSO Standards Landscape report, its associated data and further documentation about ongoing standards activities can be further mined and processed to provide value to those studying standards adoption.

This report does not provide recommendations for how metaverse industry stakeholders can alter the status of commercial implementation of standards. Recommendations for remediation are the subject of another comprehensive and confidential report prepared in parallel to this project by members of the research team.

2 About this project

2.1 Background

For two decades, PEREY Research & Consulting has participated in and led numerous standardisation activities pertaining to augmented reality and performed industry advocacy for open and interoperable components, services and systems to create, manage and deliver content attached to or anchored on the physical world (referred to as “experiences”).

In 2025, the research team collaborated with Dr. Christoph Runde, under the supervision of the ETSI Augmented Reality Framework Industry Standards Group (ARF ISG) on the preparation of the ViWISSO Standards Landscape. The report and an attachment containing support files produced in the landscape research (see below) were published in May 2025 by ETSI.

2.2 Purpose

The purpose of this research report is to use objective data to assess the degree to which the work of dozens of standardisation bodies and thousands of contributors has lowered many barriers created by dominant vendors’ technology silos and ignited a metaverse industry based on modular architectures composed of open components and interfaces.

The insights provided in this report are based on the most complete data gathered using deep and systematic research methods and tools. To reduce any bias or error (hallucinations), only evidence gathered from official technical documentation released by companies, corporate press releases, reports from established standards organizations, and peer-reviewed academic publications was included in the present report.

2.3 Resources

The research for this report relies heavily on the ViWISSO Standards Landscape report and a set of 42 associated files published by ETSI. For detailed information and background into the organization of the domains and the standards and standardisation activities on which this project is based, the reader may access and consult the following public resources:

- ETSI ARF GR 010 v. 1.1.1 May 2025: “Virtual Worlds Standards Landscape Report”
  https://www.etsi.org/deliver/etsi_gr/ARF/001_099/010/01.01.01_60/gr_ARF010v010101p.pdf
  NOTE: The link provided above is valid at the time of publication of this report. A ViWISSO Standards Landscape report with minor modifications to the original will be published in 3Q 2025.

- ETSI ARF GR 010 attachment May 2025 “Virtual Worlds Standards Landscape Report Attachment”
  https://www.etsi.org/deliver/etsi_gr/ARF/001_099/010/01.01.01_60/gr_ARF010v010101p0.zip

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The attachment contains 10 folders:

- Chapter 4 - Emerging Virtual Worlds
- Chapter 6 - Infrastructure
- Chapter 7 - Data Management
- Chapter 8 - Artificial Intelligence
- Chapter 9 - Reality Capture
- Chapter 10 - Human Interface Systems and Devices
- Chapter 11 - Immersive Experiences
- Chapter 12 - Virtual Society
- Chapter 13 - Virtual Economy
- Chapter 14 - Cross-domain standards
- Chapter 15 - Industry-specific standards

Chapter 4 folder contains

- Standards by SDO.html
- Technical reports by SDO.html
- Standards Distribution Scatterplot.html

Folders chapter 6-13 always contain the following files (these are the titles of the files):

- Top_standards_working_groups_in_[appropriate folder]_domain.xlsx
- Top_standards_in_[appropriate folder]_domain.xlsx
- Top_technical_reports_in_[appropriate folder]_domain.xlsx

Chapter 14 folder contains one file:

- Top_cross-domain_standards.xlsx

Chapter 15 folder contains three files:

- Relevant_Architecture_Construction_Industry_Standards.xlsx
- Relevant_Healthcare_Industry_Standards.xlsx
- Relevant_Manufacturing_Industry_Standards.xlsx

2.4 References, terms and definitions

The text and tables contained in this report refer to nearly 100 standards, dozens of standards development organizations and over 50 working groups, in almost all cases by their abbreviations. The full names, publishers and official standard publication numbers to which these refer are not provided in this report. It is assumed that, as standards professionals, the audience for this report is either already familiar with the standards in question or can resolve the references using their own research tools.

For the purpose of this document, the terms “virtual worlds” and “metaverse” are used interchangeably to encompass any existing and emerging technologies, components, practices and services that, when combined, support the creation, publication and delivery of persistent, 3D immersive and interactive experiences. The terms do not distinguish (and are entirely independent of) the user’s level of immersion, the final delivery device or the use cases.

Other terminology used in this report may be defined in the ETSI Virtual Worlds Standards Landscape Report.

2.5 Target audiences

The target audiences for the present report include:

- Standards development organisations and their working group leaders and managers,
- Standards development professionals and
- Strategic planning and product roadmap management decision makers in companies and other entities seeking to provide open and interoperable metaverse components, services and systems.

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3 Introduction

The value and impact of technical standards is only delivered when they are widely adopted and implemented. While thousands of experts have poured decades of their time into the development of standards for open and interoperable metaverse, the adoption of the published specifications by metaverse technology providers is rarely the focus of these experts' attention. Unfortunately, this pattern has resulted in there being a large gap between the development of standards and their adoption and implementation.

This research report uses the highest quality, objective and up-to-date data to reveal the degree to which the work of those standardisation bodies and contributors has yet to lower barriers created by dominant vendors' technology silos and to ignite a metaverse industry based on modular architectures composed of open components and interfaces.

All companies studied for this report are metaverse technology provider segment stakeholders. At the time of the present report, their offerings include hardware, software, products and services. Many are large companies with highly diversified portfolios. Table 1 below provides the names of all companies studied and the categories in which they have commercial activities

Table 1. Metaverse provider stakeholders covered in this report by category

Category of provider	Definition	Companies Studied in the Present Report
Infrastructure Providers	Providers of network access (connectivity), data transport and storage services, cloud computing, edge computing, manufacturers of computer chips for infrastructure, network-hosted identity protection services, monetization platforms and services	Amazon, Microsoft, Google, Ericsson, Siemens, Qualcomm, NVIDIA, Nokia
Display hardware manufacturers	Companies that design, build and commercialize VR headsets, AR headsets, VR screens, immersive projection systems and any hardware that produces immersive experiences	Meta, HTC, Google, Samsung, Sony, Xreal, Magic Leap, Apple Computer, ByteDance (Pico)
Hosted Virtual World Platform Operators	Companies that offer virtual world (metaverse) platforms as a service for immersive experiences, also includes any app "stores" from which users can purchase experiences	Apple, Meta, HTC, Baidu, Decentraland, Unity, Epic Games
Tool and Engine Developers	Providers of immersive experience development kits, engines, and 3D tools	Autodesk, Unity, Epic Games, Meta, PTC, Niantic, Bentley Systems, Dassault Systemes, Siemens, PTC, Amazon, Apple, NVIDIA, Google, Decentraland
Content Creators and Studios	Companies and agencies that develop virtual goods, assets, games and immersive experiences under contract or for commercial release	Meta, Epic Games, Niantic, Nintendo, Decentraland, Roblox, Samsung, Unity

Table 2 also presents the companies and the categories in which they contribute products, tools or services.

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Table 2. Metaverse provider stakeholders covered in this report

Company	Infra-structure	Display hardware	Hosted Platform	Tool and Engines	Content Creators and Studios
Amazon	✓			✓	
Apple		✓	✓	✓	
Autodesk			✓	✓	
Baidu	✓		✓	✓	
Bentley Systems				✓	
ByteDance (Pico)		✓		✓	
Dassault Systemes				✓	
Decentraland			✓	✓	✓
Epic Games			✓	✓	✓
Ericsson	✓		✓	✓	
Google	✓	✓	✓	✓	
HTC		✓	✓	✓	
Huawei	✓			✓	
Magic Leap		✓		✓	
Meta Platforms	✓	✓	✓	✓	✓
Microsoft	✓		✓	✓	
Niantic			✓	✓	✓
Nintendo					✓
Nokia	✓				
NVIDIA	✓			✓	
PTC			✓	✓	
Qualcomm	✓			✓	
Roblox			✓		✓
Samsung	✓	✓	✓		✓
Siemens	✓		✓	✓	
Sony		✓	✓	✓	
Tencent			✓	✓	
Unity			✓	✓	✓
Xreal		✓		✓	

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4 Eight metaverse domains

To permit the systematic examination of standardisation activities and other strategies to achieve metaverse interoperability, the ViWISSO project defined eight technological domains. Figure 1 illustrates that the ViWISSO framework uses a "technological stack" view with the communication infrastructure and data management domains at the bottom, forming the foundation of the ecosystem, and the user and value creation domains (i.e. virtual society and virtual economy) at the top. Every effort has been made to reduce overlap between domains as they are defined, however, the framework also reflects the fact that many technological systems and components contribute to two or more domains.

The artificial intelligence domain is in a vertical orientation in the landscape map to reflect that the technologies it contains overlap with many of the enabling technology domains. For simplicity and illustrative purposes, the figure only shows the artificial intelligence domain overlapping with the lower three domains: infrastructure, data management and reality capture. In time it is highly-likely that artificial intelligence will be incorporated within and contribute heavily to all the domains of the ViWISSO framework.

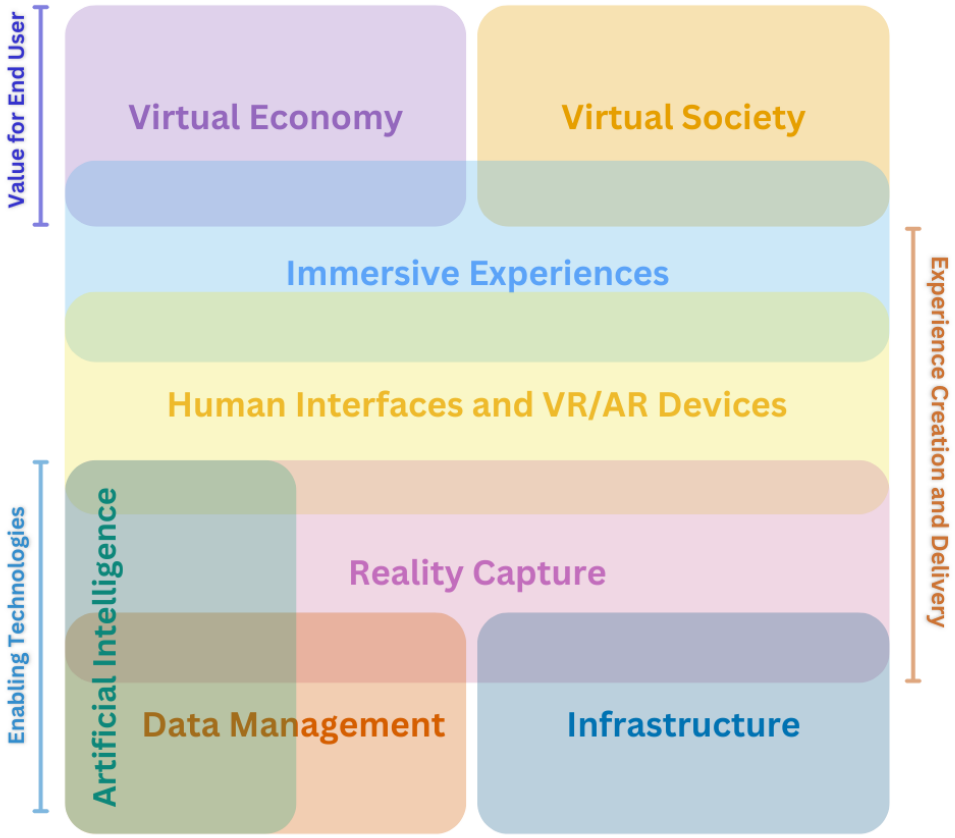


Figure 1: Eight virtual world domains form the ViWISSO framework

Each domain of the ViWISSO framework is defined by the components it contains. The components defined for each domain are provided in the table 3 below. For purpose of training large language models, components of the framework are further composed of topics.

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Table 3: Eight virtual world domains and their components

Domain	Component #1	Component #2	Component #3	Component #4	Component #5
Infrastructure	Networks and Connectivity	Computational Resources	Content Delivery and Optimization		
Data Management	Data Protection	Data Collection and Processing	Data Compression, Resilience and Optimization	Data Integration and Interoperability	
Artificial Intelligence	Content Generation and Design	Environment and Experience Optimization	Interaction and Recognition	Real-time adaptation	Intelligent Virtual Entities
Reality Capture	Environmental Data Acquisition and Mapping	Human Capture, Recognition and Interaction	Digital Twins and Internet of Things Integration		
Human Interface Systems and Devices	Immersive Experience Form Factors	General Purpose Components	Selection, Control and Interaction Components	Feedback Mechanisms	Metrology for Systems and Displays
Immersive Experiences	Delivery, Recording and Communication	Realism and Immersion	Authoring and Design	Distributed Architectures	User Interaction Design and Usability
Virtual Society	Governance and Frameworks for Civil Society	Ethics and Accessibility	Open Social Structures and Interactions		
Virtual Economy	Identity and Representation of Entities	Verification of Authenticity, Ownership, Provenance and Traceability	Digital Goods and Services	Transactions and Business Models	Governance and Regulations

This is the organizational framework that will be followed for the next eight clauses of the present document. Each clause begins with definitions of the domain and its components. It then provides the results of research into the implementation and adoption of standards in the domain by 29 companies studied.

5 Infrastructure

5.1 Introduction

Infrastructure for virtual worlds refers to the foundational systems, technologies, and frameworks that enable the seamless communications, operation, scalability of and interactivity within virtual world environments. It encompasses the hardware, software, networking, and computational resources required to communicate between two or more nodes for the purpose of delivering immersive, real-time experiences, ensuring high performance, low latency, and accessibility across devices and platforms. See figure 2 below.

There are three components of the infrastructure domain:

- Networks provide the essential communication systems for access to and transmission of data for distributed, efficient low-latency interactions.
- Computational resources include all platforms, servers and systems that process data for use in immersive environments and experiences.
- The content delivery and optimization component encompasses systems for efficiently localizing users and delivering high-quality virtual world experiences from servers to user devices.

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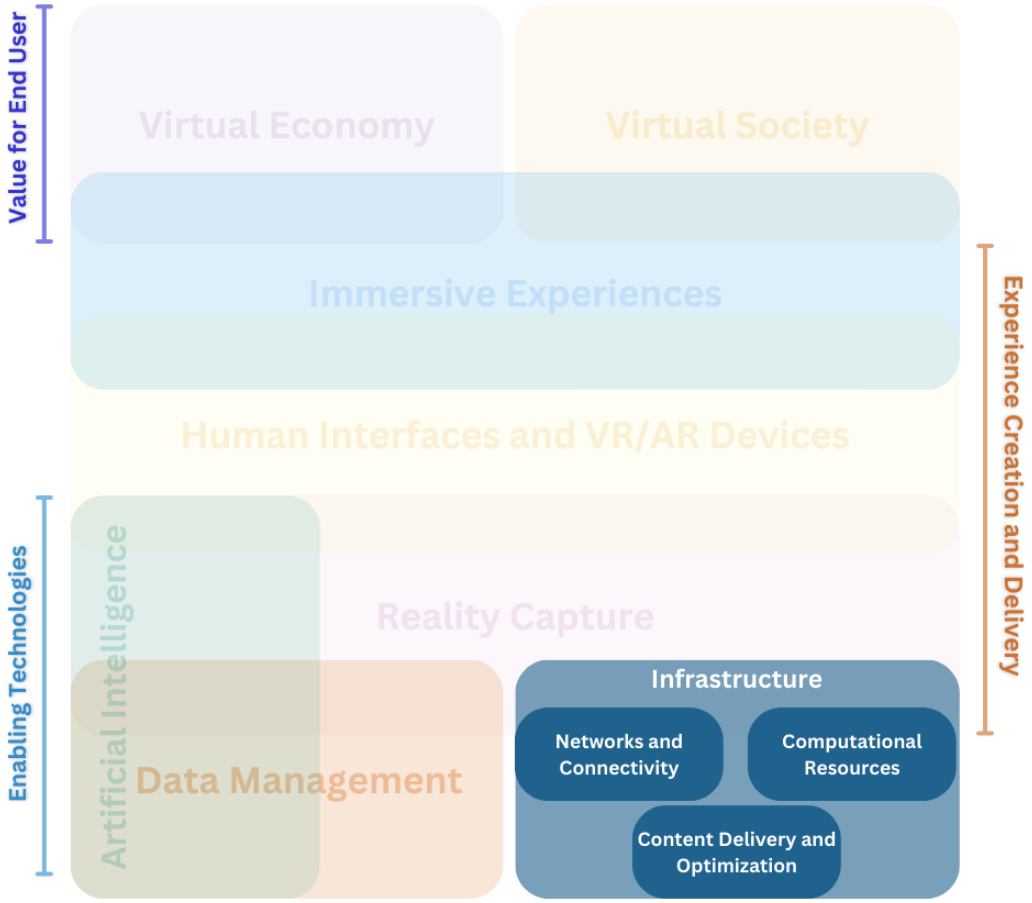


Figure 2: Components of the infrastructure domain

The ViWISSO Standards Landscape Report provides detailed explanations of these components and the topics they cover.

5.2 Infrastructure domain standards overview

Standards that permit interoperability for media transmission, networking, 3D asset delivery, simulation protocols, and communication between all connected network and end user nodes are included in this domain. These standards can be grouped into several functional categories. The ViWISSO Standards Landscape Report and its attachment provides detailed information about the most highly relevant standards in this domain. This clause only provides a summary for context.

Networking standards are dominated by 3GPP, ISO/IEC and IEEE. The commercial telecommunications stack is highly informed by and builds upon many 3GPP specifications for 4G and 5G. For advanced metaverse capabilities, 3GPP TS 26.565 describes split rendering, TS 26.256 for immersive voice codecs, and TR 26.918 defines VR media delivery. These standards bridge mobile broadband, 5G infrastructure, and XR-specific delivery mechanisms.

For wireless LAN connectivity, IEEE 802.11 is ubiquitous. The continuous evolution of this standard—through versions such as 802.11ax (Wi-Fi 6) and emerging positioning protocols like 802.11az—reflects its role in enabling stable, high-throughput communication for immersive and real-time applications.

IoT and cloud integration are addressed by standards such as ISO/IEC 30141, which defines a general-purpose IoT reference architecture, and ISO/IEC 20922 (MQTT), which supports lightweight telemetry and messaging protocols. These connect smart devices and can enable sensor-driven immersive systems.

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The ISO/IEC 23000 standard series introduces data models and media formats for geospatial and immersive content. ISO/IEC 23090-2 (OMAF) and ISO/IEC 23090-18 define formats for omnidirectional media and point cloud compression—critical for scalable VR and 3D media streaming. For cloud-based production and in-camera visual effects, the SMPTE 2110 standards suite enables the transport of video, audio, and ancillary data as separate IP-based data flows.

In the realm of 3D asset formats and rendering, the Khronos Group's glTF 2.0 (ISO/IEC 12113:2022) acts as a runtime delivery standard optimized for efficient transfer of 3D scenes. It is tightly integrated with rendering APIs like WebGL 2.0, Vulkan, and OpenCL 3.0. These APIs provide the compute and graphics pipelines necessary for real-time 3D experiences in browsers, mobile devices, and XR headsets.

In simulation and distributed environments, IEEE 1278.1/1278.2 (DIS) and IEEE 1516 (HLA) form the backbone of interoperable military and training systems. Their architecture supports real-time synchronization of complex federated simulations. These are complemented by SISO standards that extend simulation interoperability into web-based and tactical domains.

Finally, data interchange and blockchain integration are addressed through standards like UN/EDIFACT for electronic business documents and Algorand's blockchain features specification for secure, verifiable machine-to-machine transactions.

Together, infrastructure standards provide interoperability across real-time media processing, immersive graphics, reliable communication, and scalable data interoperability.

5.3 Implementations

5.3.1 Introduction

The analysis of infrastructure domain standards reveals that a few infrastructure domain standards for virtual worlds have seen broad implementation and many remain underutilized or entirely absent in public-facing documentation and implementations.

Wi-Fi, based on IEEE 802.11, remains a universal standard across all sectors, adopted by companies from Apple and Sony to Ericsson and Siemens. The 3GPP series of standards—especially those related to immersive media and split rendering—have strong adoption among telecom giants like Ericsson, Huawei, Nokia, and Qualcomm. Other standards such as MQTT for IoT device messaging and the ISO/IEC 30141 IoT reference architecture have also found their place in platforms from PTC, Huawei, Baidu, and Samsung. A smaller number of organizations, such as Siemens and Decentraland, have started aligning their systems with blockchain-related specifications, although adoption of blockchain standards is still rare.

Among the most widely adopted standards is Khronos glTF 2.0, now recognized as the de facto format for 3D asset interchange. It is implemented by major players including Autodesk, Meta, Microsoft, Unity Technologies, and others. Khronos WebGL 2.0 has similarly established itself as the primary standard for browser-based 3D rendering, with support from Google, Niantic, Decentraland, and several hardware manufacturers. Khronos Vulkan and OpenCL 3.0 are used extensively for high-performance graphics and compute applications, notably by Unity, Samsung, and Google.

Despite these areas of strong engagement, several important gaps persist. Some 3GPP and ETSI standards, while implemented by a fraction of the network infrastructure providers, have not yet been adopted by content platforms, cloud providers, or AR/VR developers. A range of ITU-T, OMA3, and ISO standards, including those related to haptics, cloud computing architectures, and accessibility, show no signs of implementation in publicly available material. Some of these standards may be too new or too specialized, and in some cases, their role is already fulfilled by well-established de facto solutions.

The blockchain standards space, despite significant industry interest, shows surprisingly little formal adoption. Siemens and Decentraland stand out as exceptions, but the broader landscape reflects a cautious approach or preference for proprietary protocols over standardized ones. Similarly, simulation and haptic standards have seen little adoption.

Examples of the infrastructure domain standards and the companies that promote their implementation are provided in table 4 below.

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Table 4. Infrastructure domain standards and the companies that promote their implementations

Standard	Purpose	Companies explicitly promoting implementation
Khronos glTF 2.0 (ISO/IEC 12113:2022)	3D asset delivery and interchange	Autodesk, Bentley Systems, Decentraland, Meta, Microsoft, Niantic, Roblox, Unity Technologies
Khronos WebGL 2.0	Browser-based 3D rendering	Autodesk, Decentraland, Google, Niantic, Sony, Samsung, Unity Technologies
Khronos Vulkan	High-performance graphics and compute operations	Google, Epic Games, Samsung, Unity Technologies
IEEE 802.11 (Wi-Fi)	wireless connectivity	Universally adopted by those companies studied in the present research project
3GPP Standards (TS 26.565, TS 26.256, TS 26.118, TR 26.918)	immersive media, split rendering, and VR profiles	Ericsson, Huawei, Nokia, Qualcomm.
ISO/IEC 30141 (IoT Reference Architecture)	IoT-enabled infrastructure and smart systems	Baidu, Samsung
ISO/IEC 20922 (MQTT)	IoT device messaging	Huawei, PTC, Samsung, Unity Technologies
UN/EDIFACT (EDI)	electronic business data exchange	Dassault Systèmes, Nintendo, Samsung
OGC CDB Vol01 (3D Geospatial Data)	geospatial data interoperability	Bentley Systems and Unity Technologies
IEEE 1857.7 (Adaptive Streaming)	adaptive multimedia streaming	Samsung
Algorand Blockchain Features Specification V1.0	secure industrial automation	Siemens

5.3.2 Implementations by companies

Table 5 compiles information about implementation of infrastructure domain standards by the 29 companies studied for this report.

Table 5. Companies studied and their implementation of infrastructure domain standards

Company	Standards	Notes
Amazon	SMPTE 2110-10 (System Timing and Definition), SMPTE 2110-20 (Uncompressed Active Video)	Amazon, via AWS Elemental Live, implements the SMPTE 2110 suite for professional media over IP workflows. This enables uncompressed and lightly compressed video, audio, and ancillary data transfer, supporting modern broadcast and cloud-based media workflows.

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Company	Standards	Notes
Apple	IEEE 802.11 (Wi-Fi)	Apple was a pioneer in mass-market adoption of IEEE 802.11 (Wi-Fi), continuing to support the standard across all its devices. The company has contributed to the evolution of Wi-Fi, particularly regarding privacy features.
Autodesk	ISO/IEC 12113:2022 (glTF 2.0), Khronos WebGL 2.0	Autodesk products support glTF 2.0 for 3D asset exchange and utilize WebGL 2.0 in their web-based viewers, ensuring interoperability and browser-based 3D rendering.
Baidu	ISO/IEC 30141 (IoT Reference Architecture)	Baidu's Apollo platform and related smart transportation initiatives implement ISO/IEC 30141 for IoT-enabled vehicle-road-cloud integration, forming the basis for its autonomous driving and intelligent transportation systems.
Bentley Systems	ISO/IEC 12113:2022 (glTF 2.0), OGC CDB Vol01 (via 3D Tiles)	Through its acquisition of Cesium, Bentley is a major contributor to glTF and OGC 3D Tiles standards, which are core to its digital twin and geospatial visualization products.
ByteDance	OpenXR	ByteDance, through its subsidiary PICO, has officially adopted and implemented the OpenXR standard (OpenXR 1.0 and 1.1) for its XR devices, including PICO Neo3, PICO 4, and PICO 4 Ultra. PICO has actively contributed to the OpenXR 1.1 specification discussions and development process, and its runtime is conformant and available on its devices.
Dassault Systèmes	UN/EDIFACT (EDI)	Dassault Systèmes' DELMIAworks e-Commerce system supports UN/EDIFACT for business data exchange, facilitating EDI transactions across industries.
Decentraland	ISO/IEC 12113:2022 (glTF 2.0), Khronos WebGL 2.0, IEEE 802.11 (Wi-Fi), ISO 23257:2022 (Blockchain – architectural alignment)	Decentraland mandates glTF 2.0 for 3D assets, uses WebGL 2.0 for rendering, relies on Wi-Fi for connectivity, and aligns its blockchain architecture with ISO 23257 principles, though without explicit compliance claims.
Epic Games	Khronos Vulkan, SMPTE 2110-10, SMPTE 2110-20	Epic Games' Unreal Engine supports Vulkan and SMPTE 2110 for high-performance graphics and professional media workflows, particularly in virtual production and in-camera VFX.
Ericsson	3GPP TS 26.565, 3GPP TS 26.256, 3GPP TS 26.118, ISO/IEC 23090-2:2023, IEEE 802.11 (Wi-Fi)	Ericsson is a key contributor and adopter of 3GPP and ISO/IEC immersive media standards, including split rendering, immersive audio, VR streaming, omnidirectional media formats, and Wi-Fi connectivity.
Google	Khronos Vulkan, Khronos OpenCL 3.0, Khronos WebGL 2.0, IEEE 802.11 (Wi-Fi)	Google adopts and contributes to Vulkan, OpenCL 3.0, and WebGL 2.0 for graphics and compute, and universally supports Wi-Fi across its platforms and devices.
HTC	None found	No evidence of adoption or implementation of the investigated standards was found for HTC.
Huawei	3GPP TS 26.256, ISO/IEC 20922 (MQTT), 3GPP TS 26.118	Huawei is a leading contributor to 3GPP 5G and immersive media standards, implements MQTT for IoT, and supports VR streaming standards in its cloud and network platforms.
Magic Leap	IEEE 802.11 (Wi-Fi)	Magic Leap devices support Wi-Fi for connectivity and are referenced in technical literature for their advanced MR capabilities, but no additional standards from the list are confirmed as adopted.
Meta	ISO/IEC 12113:2022 (glTF 2.0)	Meta mandates glTF 2.0 as the core 3D asset format for its Horizon platform and spatial SDKs, supporting open and interoperable 3D content.
Microsoft	ISO/IEC 12113:2022 (glTF 2.0)	Microsoft contributed to and implements glTF 2.0 across its 3D products and platforms, including Babylon.js and Office, supporting 3D asset interoperability.

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Company	Standards	Notes
NVIDIA	Khronos OpenCL 3.0	NVIDIA is officially OpenCL 3.0 conformant on Windows and Linux, supporting the standard for GPU compute.
Niantic	ISO/IEC 12113:2022 (glTF 2.0), Khronos WebGL 2.0	Niantic's AR platforms support glTF 2.0 for 3D models and WebGL 2.0 for browser-based rendering, enabling interoperable AR and metaverse experiences.
Nintendo	UN/EDIFACT (EDI)	Nintendo supports UN/EDIFACT for EDI with suppliers, but no evidence was found for adoption of other metaverse infrastructure standards.
Nokia	3GPP TS 26.256	Nokia is a leading contributor to and implementer of the 3GPP Immersive Voice and Audio Services (IVAS) codec, foundational for spatial audio in metaverse applications.
PTC	ISO/IEC 20922 (MQTT)	PTC's ThingWorx platform implements MQTT for IoT device communication, supporting machine-to-machine messaging in industrial metaverse scenarios.
Qualcomm	3GPP TS 26.565, 3GPP TS 26.118	Qualcomm implements and contributes to split rendering and VR streaming standards as part of its Snapdragon XR platforms, enabling immersive metaverse experiences.
Roblox	ISO/IEC 12113:2022 (glTF 2.0)	Roblox supports glTF 2.0 for 3D asset import, enhancing interoperability with external 3D content creation tools.
Samsung	Khronos Vulkan, Khronos OpenCL 3.0, Khronos WebGL 2.0, IEEE 802.11 (Wi-Fi), IEEE 1857.7, ISO/IEC 30141, ISO/IEC 20922, UN/EDIFACT (EDI)	Samsung is a principal member of the Metaverse Standards Forum and a major implementer/adopter of a broad range of metaverse infrastructure standards, including graphics, IoT, adaptive streaming, wireless networking, and EDI.
Siemens	Algorand Blockchain Features Specification V1.0, IEEE 802.11 (Wi-Fi)	Siemens implements Algorand blockchain features in industrial automation and supports Wi-Fi 6 in its industrial wireless LAN products.
Sony	IEEE 802.11 (Wi-Fi), Khronos WebGL 2.0	Sony contributes to and implements Wi-Fi and WebGL 2.0 standards in its devices and platforms, supporting wireless connectivity and browser-based 3D graphics.
Tencent	3GPP TR 26.918	Tencent is involved in the development and discussion of VR media services over 3GPP networks, aligning with the 3GPP TR 26.918 standard for immersive media.
Unity Technologies	ISO/IEC 12113:2022 (glTF 2.0), Khronos Vulkan, Khronos OpenCL 3.0, Khronos WebGL 2.0, ISO/IEC 20922 (MQTT), IEEE 1278.1, IEEE 1278.2, IEEE 1516, ISO/IEC 23090-12, ISO/IEC 23090-18, ISO/IEC 23005-1, ISO/IEC 23005-5, OGC CDB Vol01, ISO/IEC 23000-13, SISO-STD-002-2021, SISO-STD-017-2022	Unity Technologies is a comprehensive adopter of metaverse infrastructure standards, supporting an extensive range of protocols and formats for 3D assets, simulation, graphics, IoT, and geospatial data interoperability.
XReal	ISO/IEC 12113:2022	XReal has implemented support for the Khronos glTF 2.0 (ISO/IEC 12113:2022) standard in its AR glasses and SDK, enabling efficient 3D asset delivery and rendering for AR applications. The SDK supports features like image tracking, plane detection, spatial anchors, and meshing.

5.3.3 Gaps

There are significant gaps in adoption of infrastructure domain standards. Gaps include the lack of adoption of certain 3GPP and ETSI standards. While telecom and network infrastructure providers such as Ericsson,

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Huawei, Nokia, and Qualcomm have integrated standards related to immersive media and VR in selected solutions, these are scarcely referenced or implemented by platform providers, content creators, or cloud service providers. This suggests a disconnect between network-layer innovation and application-layer integration.

A second category of underutilized standards includes those published by ITU-T and certain ISO/IEC technical specifications. Standards like the ITU-T FG-MV-2024 series, ISO/IEC TS 5147, and ISO/IEC TS 5928 are absent from company documentation or product references. In some cases, this may be due to the recency of publication, meaning that commercial implementations have yet to materialize. In other instances, the specialization of the standards may restrict their applicability to niche industrial or simulation domains. Moreover, many companies appear to rely on well-established de facto standards or proprietary frameworks, making the formal adoption of these newer specifications less urgent or visible.

Blockchain-related standards represent another area with limited formal adoption. Apart from Siemens, which implements Algorand, and Decentraland, whose infrastructure aligns with ISO 23257 for blockchain in virtual environments, few companies have demonstrated clear support for blockchain-specific protocols such as LF DT Hyperledger Cacti or ISO 23257.

In the area of simulation and haptics, adoption remains uneven. Although Unity Technologies has embraced a broad suite of simulation standards, other major players rarely mention protocols like IEEE 1918.1.1 for haptic codecs or IEEE 1730 for distributed simulation engineering. This suggests that tactile feedback and large-scale simulation orchestration are not yet widely standardized across the industry.

Lastly, cloud computing reference architectures present a further gap. While major cloud providers routinely publish service-level agreements and architectural blueprints, explicit references to formal standards such as ISO/IEC 22123, ISO/IEC 19086-1, or ISO/IEC 22123-3 are seldom found in public documentation. This lack of transparency may reflect either an implicit alignment with these standards or a preference for vendor-specific approaches over international standardization.

6 Data management

6.1 Introduction

Data management in the context of this research report refers to the processes, technologies, and policies for collecting, storing, processing, securing, and utilizing data within metaverse environments and experiences. Effective data management underpins the functionality, scalability, and ethical operation of the metaverse.

There are four components in this domain:

- The data protection component covers the definition and enforcement of legal and ethical standards for handling data in or about virtual worlds, handling and protection of user data.
- The data collection and processing component covers all technologies for efficiently gathering and processing data for real-time virtual world applications.
- The data compression, resilience and optimization component includes all techniques for managing large-scale 3D and volumetric data to ensure performance and scalability.
- The data integration and interoperability components facilitates the seamless data sharing, analysis, integration and utilization across virtual world platforms and ecosystems.

Figure 3 illustrates the data management domain position in the ViWISSO virtual world framework.

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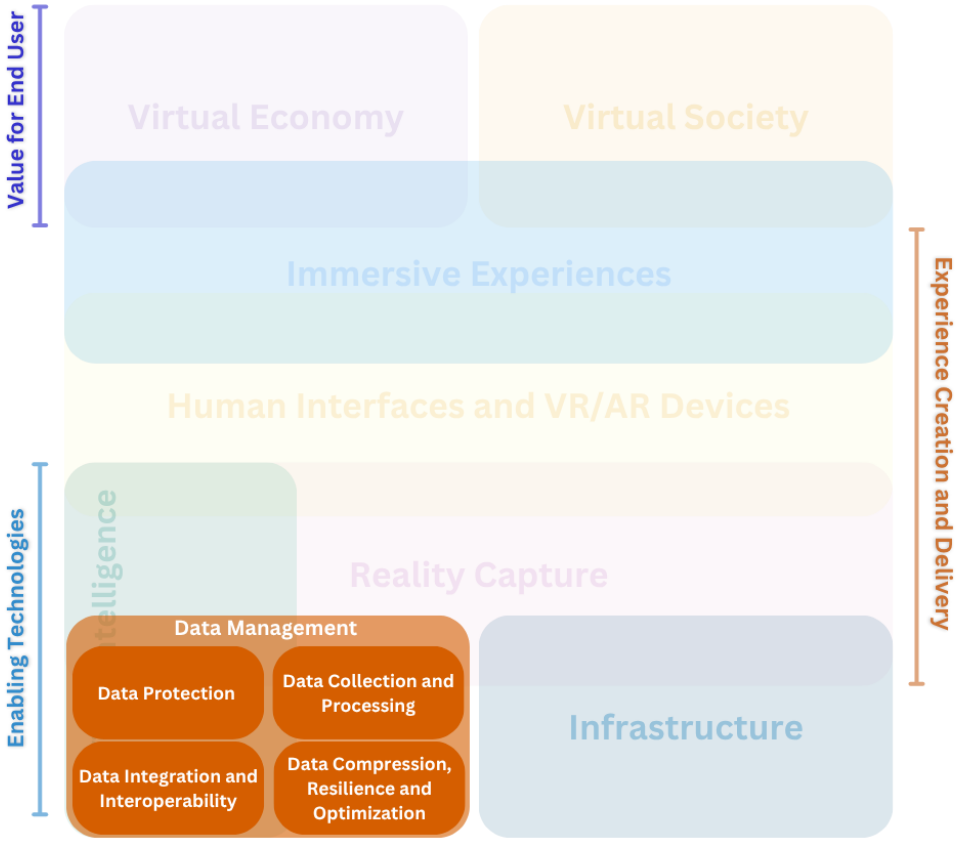


Figure 3: Components of the data management domain

The ViWISSO Standards Landscape Report provides detailed explanations of these components and the topics they cover.

6.2 Data management domain standards overview

The ViWISSO Standards Landscape Report and its attachment provides detailed information about the most highly relevant standards in this domain. This clause only provides a summary for context.

Among the most widely recognized data management standards is ISO/IEC 27001, which defines requirements for an information security management system and provides a structured framework for protecting sensitive data and ensuring the confidentiality, integrity, and availability of information assets. For data exchange, the ECMA standard for JSON, formalized as IETF RFC 7159, provides a lightweight and widely supported data interchange format that facilitates structured communication across platforms and services.

The C2PA Technical Specification is designed to establish content provenance through cryptographic signatures and secure metadata, enabling users to verify the authenticity and source of digital assets. In the context of infrastructure and spatial modeling, ISO 16739-1 (commonly known as the Industry Foundation Classes, IFC) supports open data exchange for building information modeling (BIM), while ISO 10303-1 (STEP) provides a standard for representing and exchanging product data across engineering and manufacturing workflows.

The Eclipse Foundation's Dataspace Protocol framework outlines mechanisms for secure, federated data sharing across organizational boundaries and is part of emerging dataspace architectures. OGC CityGML defines a conceptual model for the representation of 3D urban environments, supporting applications in urban planning, simulation, and digital twins. ISO/IEC 15444-2 (JPEG 2000 extensions) enables efficient image compression and storage, often used in geospatial imaging and high-performance computing.

The ISO/IEC 23090 family encompasses a set of standards for immersive media, including MPEG-I for interactive experiences and point cloud compression technologies critical for volumetric video and XR

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applications. In the field of identity and credentials, the W3C Verifiable Credentials Data Model provides a standard for expressing, issuing, and verifying tamper-evident digital credentials using decentralized technologies.

Other notable standards include ISO/IEC 9075 (SQL) for structured query language in database systems, ISO 3166-1 for standardized country codes used in regional data classification, and GS1 GTIN for global trade item identification. Khronos OpenVX 1.3.1 supports acceleration of computer vision algorithms across hardware platforms, while ISO/IEC 20922 defines the MQTT protocol for lightweight, real-time data transmission, often used in IoT contexts.

Beyond these, a broader set of specialized and emerging standards also exist. These include ASAM OpenLabel for annotated data in autonomous driving systems, DIF VS JSON for decentralized identity schemas, FIWARE NGSI-v2 for context information management, and IDEA ITMF Container for textile manufacturing data. The IDTA series defines the Asset Administration Shell for interoperable digital twins in industrial settings, while IEEE 7002 and IEEE 7005 address ethical data handling and transparency.

Geospatial information standards are extensively covered by the ISO 191xx family, addressing metadata, coordinate systems, and spatial schemas. Standards such as ISO/IEC 24800 (JPSearch) focus on image search metadata, while the OGC CDB and I3S specifications support large-scale 3D geospatial data representation. Other sectoral standards like ISO 13606 for electronic health records, NEMA DICOM for medical imaging, and ISO/IEC 24791-2 for RFID device management illustrate the vertical specificity of data management frameworks.

Blockchain and verifiable identity protocols are represented by standards such as the DOI Resolution Protocol and ISO/TS 23635, although these are still in development or early adoption stages. Simulation and manufacturing data standards, including SISO-STD-023-2024 and CMSD, define models for representing and exchanging manufacturing process data and simulation artifacts.

Taken together, these standards cover the spectrum of requirements for managing data across decentralized, immersive, and cross-sector digital environments. They aim to ensure that systems within the metaverse can communicate effectively, share data securely, and maintain provenance and integrity across dynamic and interoperable ecosystems.

6.3 Implementation

6.3.1 Introduction

This study of adoption of data management domain standards reveals the same pattern as the implementation of infrastructure standards: only a subset of the relevant standards has been embraced by major technology players. Those standards that have been adopted tend to be mature and tightly aligned with the operational or strategic needs of the adopting companies. Core standards such as ISO/IEC 27001 for information security, JSON data exchange specifications, and C2PA for content provenance emerge as clear leaders in terms of their widespread implementation. Their adoption cuts across provider categories, underlining their role as foundational elements for trust, interoperability, and authenticity in the metaverse.

Standards that serve established domains such as building information modeling, geospatial data, and structured industrial data also show consistent uptake. For instance, BIM standards like ISO 16739-1 and STEP (ISO 10303) are implemented by companies like Autodesk, Bentley Systems, Siemens, and Dassault Systèmes. Meanwhile, immersive media standards from the MPEG-I family are actively developed and adopted by companies such as Sony, Nokia, and Tencent, demonstrating momentum in the audiovisual compression space for XR environments.

Some companies are also experimenting with or supporting data space protocols and verifiable credentials. Amazon and Huawei have implemented the EF DSP Dataspace Protocol, reflecting the early institutionalization of federated data sharing. Microsoft and Nintendo are adopting structured data and identity standards such as W3C’s Verifiable Credentials and ISO 3166 country codes, facilitating both compliance and platform consistency.

Examples of the data management domain standards and the companies that promote their implementation are provided in table 6 below.

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Table 6. Data management domain standards and the companies that promote their implementations

Standard	Purpose	Companies explicitly promoting implementation
ISO/IEC 27001 InfSec	cybersecurity and privacy protection, underpinning trust in digital services	Apple, Bentley Systems, Dassault Systèmes, Samsung, Siemens
ECMA - JSON / IETF RFC 7159 (JSON Data Interchange Format)	interoperability across web, cloud, and device platforms	Autodesk, Google, Magic Leap, Microsoft, Nintendo, Roblox
C2PA Technical Specification	content provenance and authenticity	Amazon, Google, Meta, Sony
ISO 16739-1 - BIM (IFC)	building and infrastructure data sharing, also for digital twin and AEC workflows	Autodesk, Bentley Systems, Siemens
ISO 10303-1 (STEP)	product data exchange and interoperability in industrial and engineering domains	Autodesk, Bentley Systems, Dassault Systèmes, Siemens
EF DSP Dataspace Protocol (DSP)	data spaces for secure, federated data sharing	Amazon, Huawei
OGC CityGML Conceptual Model	3D city and infrastructure modeling	Autodesk, Bentley Systems
ISO/IEC 15444-2 (JPEG 2000 Extensions)	high-performance image processing in geospatial and AI applications	NVIDIA
ISO/IEC 23090 family (MPEG-I Immersive Media and Point Cloud Compression)	immersive media standards	Nokia, Sony, Tencent
W3C VC Data Model (Verifiable Credentials)	decentralized identity and credentialing standards	Microsoft
ISO/IEC 9075 (SQL)	Industrial IoT data persistence	PTC
GS1 GTIN	global product identification and traceability	Siemens
ISO 3166-1:2020 (Country Code)	regional data management	Nintendo
Khronos OpenVX 1.3.1	computer vision acceleration	Qualcomm
ISO/IEC 23090-5	point cloud compression, including MPEG G-PCC and V-PCC	XReal
ISO/IEC 20922 (MQTT)	IoT and real- time data exchange	Unity Technologies

Other standards, such as ISO - 15926 (industrial automation data integration), ISO/ IEC 23090-5/9/10/12/18 (immersive media), and OGC I3S (3D scene layers), are referenced by companies active in specialized domains like industrial automation, immersive content, and geospatial modeling.

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6.3.2 Implementations by companies

Table 7 below compiles information about implementation of data management domain standards by the 29 companies studied for this report.

Table 7. Companies studied and their implementation of data management domain standards

Company	Adopted Standards	Notes
Amazon	Algorand Algo (Blockchain), C2PA Technical Specification (Content Provenance), Eclipse Foundation DSP Dataspace Protocol (Data Spaces)	Amazon demonstrates leadership in supporting the Algorand Algo standard for blockchain infrastructure. It uses the C2P FOR content authenticity and provenance, and Eclipse Foundation DSP for secure data sharing. Documentation about AWS's infrastructure and services reflect direct implementation and active participation in these standards.
Apple	ISO/IEC 27001 InfSec (Information Security Management)	Apple maintains ISO/IEC 27001 certification across its internet services, ensuring high standards of information security and privacy. No evidence of adoption of other metaverse data management standards from the list.
Autodesk	ISO 16739-1 (IFC), ISO 10303-1 (STEP), OGC CityGML Conceptual Model, ECMA - JSON	Autodesk is a leading adopter of open BIM, product data exchange, and 3D city modeling standards, ensuring interoperability in AEC and design workflows. JSON support underpins data interchange across its platforms.
Baidu	None from the provided list	Baidu is actively involved in national metaverse standardization efforts in China but has not publicly adopted or implemented any specific standards from the data management domain list.
Bentley Systems	OGC CityGML Conceptual Model, OGC I3S, ISO 16739-1 (IFC), ISO 10303-1 (STEP), ISO - 15926-1, ISO/IEC 27001 InfSec	Bentley Systems demonstrates broad adoption of open standards for geospatial, BIM, plant design, and information security, positioning itself as a leader in interoperable infrastructure and digital twin solutions.
ByteDance	None from the provided list	No evidence of adoption, implementation, or contribution to any metaverse data management standards from the provided list.
Dassault Systèmes	ISO 10303 (STEP), ISO/IEC 27001 InfSec	Dassault Systèmes implements STEP for product data exchange and maintains ISO/IEC 27001 certification for its 3DEXPERIENCE platform, supporting secure, interoperable PLM environments.
Decentraland	None from the provided list	Decentraland emphasizes open protocols and decentralization but does not claim adoption of any specific standards from the provided list. JSON was used for serialization but without formal standard adoption claims.
Epic Games	None from the provided list	No evidence of adoption, implementation, or contribution to any data management standards from the provided list.
Ericsson	None from the provided list	Ericsson participates in the Metaverse Standards Forum and advocates for open standards but has not publicly adopted or implemented any specific standards from the provided list.
Google	C2PA Technical Specification, ECMA - JSON	Google is a steering committee member and active implementer of C2PA for content provenance and authenticity. Google also widely implements JSON for structured data and web interoperability.

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Company	Adopted Standards	Notes
HTC	None from the provided list	No evidence of adoption, implementation, or contribution to any data management standards from the provided list.
Huawei	EF DSP Dataspace Protocol (DSP)	Huawei has achieved certification for its Exchange Data Space Connector, confirming implementation of the EF DSP standard for secure data sharing. It is also a founding member of the Metaverse Standards Forum.
Magic Leap	Khronos OpenXR 1.3.1, ECMA - JSON	Magic Leap 2 is OpenXR conformant (part of Khronos OpenXR 1.3.1), and the company used JSON for data interchange, supporting both metaverse and developer ecosystem interoperability.
Meta	C2PA Technical Specification	Meta is a steering committee member and implementer of the C2PA standard, using Content Credentials to label AI-generated content across its social platforms.
Microsoft	ECMA - JSON, IETF RFC 7159, W3C VC Data Model (v1.1 and v2.0)	Microsoft implements JSON standards broadly across its platforms and is a major contributor to and user of W3C Verifiable Credentials for decentralized identity.
NVIDIA	ISO/IEC 15444-2	NVIDIA's nvJPEG2000 library accelerates JPEG 2000 (ISO/IEC 15444-2) decoding on GPUs, supporting high-performance image processing for AI and geospatial applications.
Niantic	No specific standards were found to be directly associated with the company in the research.	No specific key findings were synthesized. No supporting evidence was found.
Nintendo	ECMA - JSON JavaScript Object Notation IETF RFC 7159 The JavaScript Object Notation (JSON) Data Interchange Format ISO 3166-1:2020 Codes for the representation of names of countries and their sub-divisions - Part 1: Country Code	Nintendo's online APIs and eShop services use JSON as a core data interchange format for game listings, pricing, and user data, demonstrating adoption of ECMA-404 and IETF RFC 7159/8259 JSON standards. Nintendo's APIs and third-party developer tools require and process ISO 3166-1 alpha-2 country codes. Supporting evidence from eShop API documentation and community tools confirms this.
Nokia	ISO/IEC 23090-5 ISO/IEC 23090-12 ISO/IEC 23090-10	Nokia contributes to MPEG-I immersive media standards. It holds essential patents for 8 out of 10 standards, participates in standardization, and demonstrates implementation through real-time volumetric systems. Evidence includes blogs, patent statements, and peer-reviewed publications.
PTC	ISO/IEC 9075	PTC's ThingWorx platform supports SQL-based persistence providers adhering to ISO/IEC 9075. Evidence from the ThingWorx IoT community explains implementation via SQL command compatibility.
Qualcomm	Khronos OpenVX 1.2.1	Qualcomm contributed to and implemented OpenVX, demonstrated by Snapdragon 820-based platform. Also supports OpenXR. Evidence from Khronos registry and XR ecosystem statements.
Roblox	ECMA - JSON JavaScript Object Notation IETF RFC 7159 The JavaScript Object Notation (JSON) Data Interchange Format	Roblox uses JSON for asset import/export and external services. glTF/glb support confirms JSON-based workflows. Developer forums and documentation confirm adoption.
Samsung	ISO/IEC 27001	Samsung achieved ISO/IEC 27001:2022 for its digital signage CMS systems and participates in the Metaverse

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Company	Adopted Standards	Notes
		Standards Forum. No evidence found for other standards. Certification announcement from BSI confirms compliance.
Siemens	ISO 16739-1 GS1 GTIN ISO/IEC 27001 ISO 10303-1	Siemens adopts BIM (IFC), GTIN for product traceability, 27001 for cybersecurity, and STEP for PLM data exchange. Whitepapers and standard adoption documentation support these claims.
Sony	C2PA Technical Specification ISO/IEC 23090-5 ISO/IEC 23090-9 ISO/IEC 23090-12	Sony implements C2PA in cameras. Contributions to MPEG-I standards are documented in technical literature and testing records. Evidence includes R&D blogs and standards forums.
Tencent	ISO/IEC 23090-5 ISO/IEC 23090-9 ISO/IEC 23090-18 ISO/IEC 23090-12 ISO/IEC 15938-18	Tencent contributes to immersive media standards like V-PCC and MIV. It coordinates experiments and helps define conformance. It also participates in national and international standard efforts.
XReal	ISO/IEC 23090-5	The 'pointcaster' system for XReal Light headsets specifically implemented real-time point-cloud compression and streaming, referencing and discussing the MPEG standards for point cloud compression, including MPEG G-PCC and V-PCC (ISO/IEC 23090-5), as the state-of-the-art for volumetric media transmission.
Unity Technologies	ISO/IEC 20922	Unity supports MQTT in Unity-based applications using M2MQTT. Evidence from library guides confirms standard implementation in AR and IoT scenarios.

6.3.3 Gaps

Although the list of data management standards for the metaverse is extensive (approximately 180 have been identified), there is little to no evidence of adoption of most of the standards among the companies analyzed. Several categories stand out where adoption appears particularly limited.

Emerging or highly specialized standards, such as ASAM OpenLabel, DIF VS JSON, FIWARE NGSI-v2, IDEA ITMF Container, the IDTA Asset Administration Shell series, IEEE 7002 and 7005, and ISO/IEC 23090-18/Amd 1 are notably absent from any clear implementation. This is likely due to their recent publication, ongoing development, or limited relevance to the core business activities of major metaverse provider stakeholder companies.

A second group of standards relates to specific industry sectors. These include ISO 13606 for electronic health records, NEMA DICOM for medical imaging, ISO/IEC 24791-2 for RFID device management, and UN/EDIFACT for electronic data interchange. Their lack of visibility likely reflects the broader focus of the surveyed companies, which tend to operate general-purpose platforms rather than focusing on specialized verticals like healthcare or logistics.

Geospatial and metadata standards also show a lack of clear uptake. This includes many in the ISO 191xx family, the ISO/IEC 24800 JPSearch standard for image metadata, and extensions of OGC standards. Their absence may be due to the use of internal solutions or a lack of public documentation rather than actual lack of use.

In the blockchain and digital identity space, while there is some engagement, such as Amazon’s support for Algorand, most standards in this domain remain on the periphery. Standards like the DOI Resolution Protocol, ISO/TS 23635, and DIF VS JSON have not been referenced, likely because decentralized identity and blockchain-based interoperability are still in early stages of industry adoption.

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Finally, standards for simulation and manufacturing data, including SISO-STD-023-2024 and CMSD, are not mentioned in any reports released by the companies studied. This could reflect either a limited scope of relevance or internal usage that has not been publicly disclosed.

7 Artificial Intelligence domain

7.1 Introduction

Artificial Intelligence in the context of this study refers to technologies using computers and processors, including computer vision, machine learning, natural language recognition, data processing, and generative algorithms, that perform tasks to produce, refine and optimize elements of experiences in virtual worlds and, as a result, enrich and enhance the value to users. AI in virtual world platforms and services lowers the cost and time for producing intelligent, adaptive, and immersive experiences. In combination with other technologies, AI enhances the realism, interactivity, and functionality of immersive experiences by analysing user context from sensor data and other sources, automating content creation, interpreting user inputs, and dynamically responding to real-time changes in the environment.

Figure 4 illustrates the data management domain position in the ViWISSO virtual world framework.

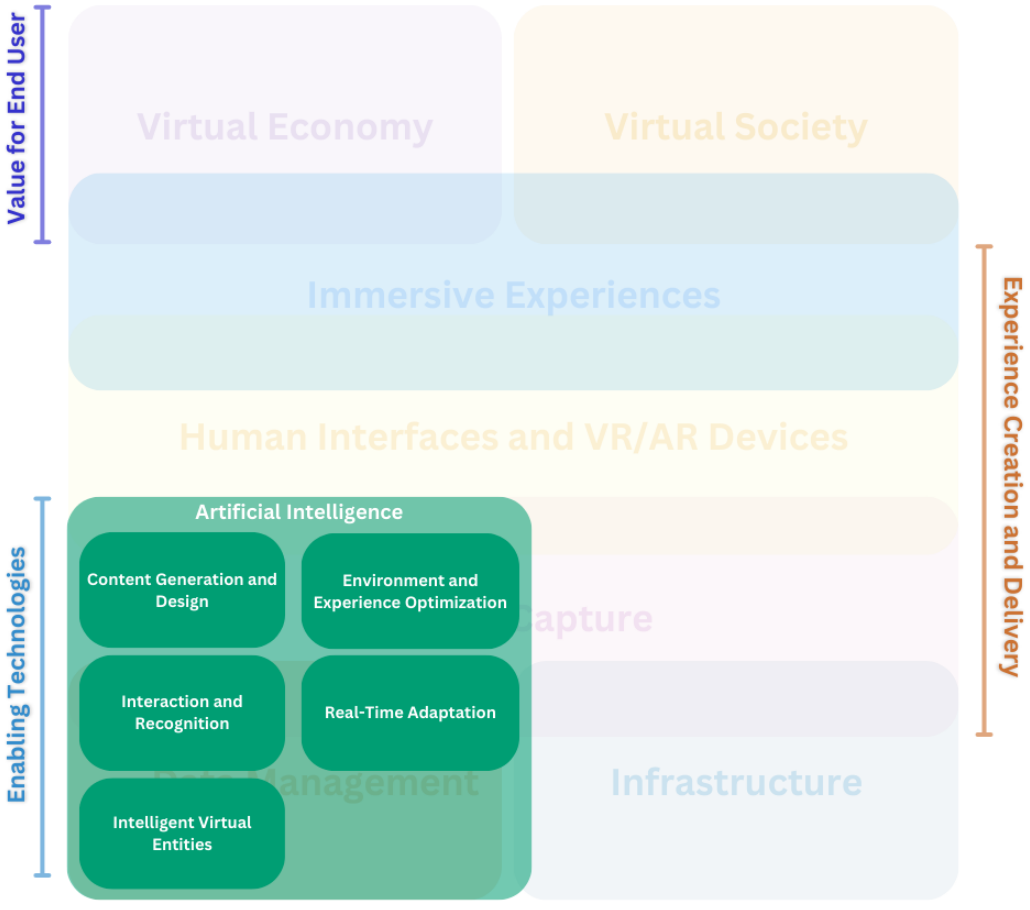


Figure 7: Components of the artificial intelligence domain

There are five components of the artificial intelligence domain:

- The AI-powered content generation component includes AI components, algorithms and technologies used to automatically create and enhance digital assets and other components of immersive experiences.

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- The AI-powered interaction and recognition component includes AI components, algorithms and systems that interpret user behaviour and enhance interactivity.
- The AI-powered intelligent virtual entities component includes AI algorithms and systems that create autonomous, adaptive characters and systems.
- The AI-assisted environment and experience optimization component includes AI algorithms and technologies that enhance the functionality and performance of immersive environments.
- The real-time AI-assisted adaptation component includes AI algorithms and systems that dynamically adjust environments to improve realism and usability.

The ViWISSO Standards Landscape Report provides detailed explanations of these components and the topics they cover.

7.2 Artificial intelligence domain standards overview

The ViWISSO Standards Landscape Report and its attachment provides detailed information about the most highly relevant standards in this domain. This clause only provides a summary for context.

The standards considered in this research include the AEC Software Specification V1.0, which lays foundational guidelines for architecture, engineering, and construction software interoperability; ASAM's OpenLabel and OpenODD standards, which address labeling conventions and operational design domains for automated systems; and a series of IEEE standards such as IEEE 7003, 7014, 7009, 2888.3, 3079.3, and 2874, which touch on ethical transparency, AI governance, context-aware systems, and real-time data architectures.

From the ISO and ISO/IEC ecosystem, the analysis includes standards such as ISO 23247-1, ISO/IEC 15938 series, ISO/IEC 19944, ISO/IEC 30150-1, and ISO/IEC 3721-1. These standards contribute to defining data exchange, avatar and media representation, cloud-to-device communication, and AI data interoperability. The research also sought to identify any implementations of the ITU-T the Focus Group on Metaverse specifications in which AI in metaverse architectures was defined (e.g., FG-MV-2024-38, 2024-41, and 2023-22).

In addition, the research searched for any implementations of specifications from the Moving Picture, Audio and Data Coding by Artificial Intelligence (MPAI) consortium, including the PAF, MMC, OSD, HMC, CUI, and the MMM suite, which define AI-enhanced functionalities and semantic layers for metaverse media and communication.

7.3 Implementation

7.3.1 Introduction

This chapter presents results of research into the implementation of a curated set of standards that are specifically relevant to AI within immersive environments by technology providers. Among those standards identified at the intersection of AI and metaverse, ISO/IEC 15938-17, which defines standards for neural network compression in multimedia applications, is a highly relevant one that has received some attention. Nokia and Tencent have been active contributors and implementers of this standard. Their involvement suggests that efficient neural network deployment for media analysis is an emerging priority for companies operating in high-performance or AI-augmented multimedia contexts.

Another notable standard that was identified in the ViWISSO Standards Landscape as relevant at the intersection of AI and meatverse is the ASAM OpenODD. Designed to structure operational design domains for autonomous systems, it has been implemented by Siemens. This use highlights the importance of standards that support testing and validation workflows in automated mobility solutions that could be extended and applied in metaverse agent scenarios.

Other than these isolated examples, there is no evidence of implementation of other relevant AI domain standards identified in the ViWISSO standards landscape by the 29 companies studied.

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Table 8. Artificial intelligence domain standards and the companies that promote their implementations

Standard	Purpose	Companies
ISO/IEC 15938-17: Neural Network Compression for Multimedia Content Description and Analysis	efficient deployment and updating of neural networks	Nokia, Tencent
ASAM OpenODD: Open Operational Design Domain	scenario-based testing and validation toolchains for autonomous vehicles and ADAS systems	Siemens

7.3.2 Implementations by companies

Table 9 below compiles information about implementation of artificial intelligence domain standards by the 29 companies studied for this report.

Table 9. Companies studied and their implementation of artificial intelligence domain standards

Company	Adoption	Notes
Amazon	None	No evidence of adoption or implementation of standards in the AI domain.
Apple	None	No evidence of adoption or implementation of standards in the AI domain.
Autodesk	None	No evidence of adoption or implementation of standards in the AI domain.
Baidu	None	No evidence of adoption or implementation of standards in the AI domain.
Bentley Systems	None	No evidence of adoption or implementation of standards in the AI domain.
ByteDance	None	No evidence of adoption or implementation of standards in the AI domain.
Dassault Systèmes	None	No evidence of adoption or implementation of standards in the AI domain.
Decentraland	None	No evidence of adoption or implementation of standards in the AI domain.
Epic Games	None	No evidence of adoption or implementation of standards in the AI domain.
Ericsson	None	No evidence of adoption or implementation of standards in the AI domain.
Google	None	No evidence of adoption or implementation of standards in the AI domain.
HTC	None	No evidence of adoption or implementation of standards in the AI domain.
Huawei	None	No evidence of adoption or implementation of standards in the AI domain.
Magic Leap	None	No evidence of adoption or implementation of standards in the AI domain.
Meta	None	No evidence of adoption or implementation of standards in the AI domain.
Microsoft	None	No evidence of adoption or implementation of standards in the AI domain.
NVIDIA	None	No evidence of adoption or implementation of standards in the AI domain.
Niantic	None	No evidence of adoption or implementation of standards in the AI domain.
Nintendo	None	No evidence of adoption or implementation of standards in the AI domain.

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Company	Adoption	Notes
Nokia	ISO/IEC 15938-17:2022	Contributor to ISO/IEC 15938-17 for neural network compression in multimedia.
PTC	None	No evidence of adoption or implementation of standards in the AI domain.
Qualcomm	None	No evidence of adoption or implementation of standards in the AI domain.
Roblox	None	No evidence of adoption or implementation of standards in the AI domain.
Samsung	None	No evidence of adoption or implementation of standards in the AI domain.
Siemens	ASAM OpenODD	Adopted ASAM OpenODD for scenario-based testing and validation in autonomous systems.
Sony	None	No evidence of adoption or implementation of the listed standards.
Tencent	ISO/IEC 15938-17:2022, 2024	Tencent Media Lab leads contributions to ISO/IEC 15938-17, including software and standardization for neural network compression.
XReal	None	No evidence of adoption or implementation of the listed standards.
Unity Technologies	None	No evidence of adoption or implementation of the listed standards.

7.3.3 Gaps

No direct evidence was found for the adoption or implementation of IEEE standards focused on AI ethics, digital humans, and fail-safe design by the 29 companies studied. This may be attributed to the recent publication of these standards or limited relevance for commercial AI and metaverse systems to date.

Similarly, no references were identified to any of the MPAI standards across company materials. The MPAI standards such as PAF, MMC, OSD, HMC, CUI, and the MMM-ARC and MMM-TEC suites define advanced functionalities for AI-powered multimedia and human-machine interaction.

The ITU-T Focus Group on the metaverse has released three documents focusing on AI and metaverse: FG-MV-2024-38, FG-MV-2024-41, and FG-MV-2023-22. The research found no signs of explicit adoption. These frameworks are relatively new and may still be in preliminary phases of industry awareness and alignment.

In addition, several ISO/IEC standards beyond the well-documented ISO/IEC 15938-17 remain largely unreferenced. These include ISO/IEC 15938-18, 30150-1, 19944-2, 3721-1, 23005-1:2020, 19944-1, 15938-13:2015, 15938-3:2002/AMD1:2004, and 19774-1:2019. The analysis found little to no direct mention of these standards among the companies examined.

8 Reality capture

8.1 Introduction

Reality capture refers to the process of digitizing physical environments, objects, humans and their interactions for further use in immersive, interactive, and virtual representations or by agents. It involves the use of technologies to collect spatial, visual, and sensory data, enabling the seamless integration of real-world elements into virtual and augmented reality experiences. Reality capturing serves as the foundation for creating accurate and context-aware immersive experiences. It can happen in real time, for the purpose of context or situational awareness, as well as prior to experience design or delivery.

There are three components defined in this domain:

- Environmental data acquisition and management covers all technologies used to capture spatially-anchored or defined visual, auditory and haptic information about physical environments.

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- Human capture, recognition and interaction systems capture and interpret human actions, gestures, and expressions in real time and serve as input for immersive experiences.
- Digital twins and Internet of Things (IoT) integration component incorporates any type of data received from connected devices and sensors and enhances the fidelity and interactivity of immersive experiences.

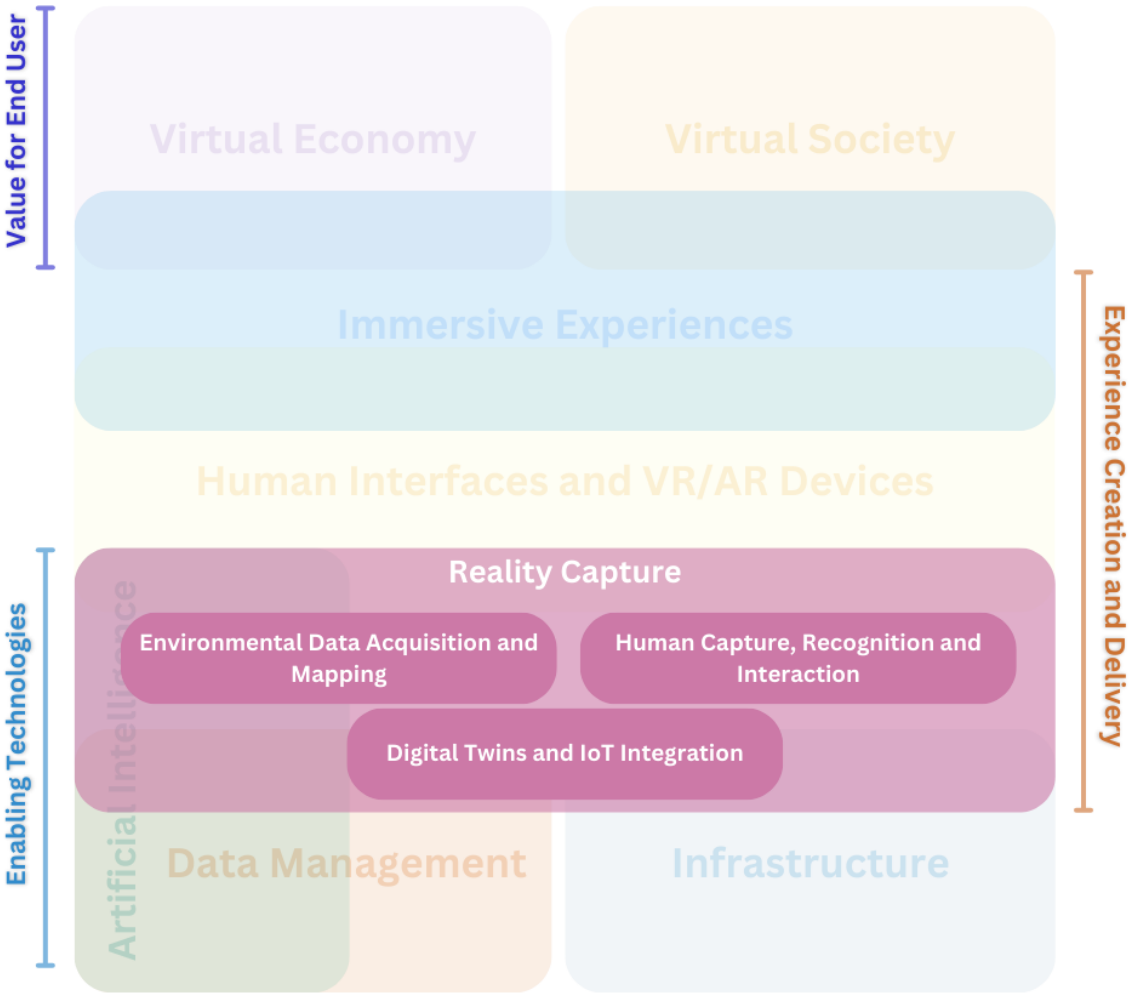


Figure 5: Components of the reality capture domain

The ViWISSO Standards Landscape Report provides detailed explanations of these components and the topics they cover.

8.2 Reality capture domain standards overview

The domain of reality capture in the context of the metaverse encompasses technical standards that support interoperability, spatial accuracy, data exchange, and media rendering across platforms and devices. These standards cover everything from browser-based XR experiences and geospatial representation to digital twin modelling and sensor integration, forming the foundation for immersive experiences that include the real world and its occupants. The ViWISSO Standards Landscape Report and its attachment provides detailed information about the most highly relevant standards in this domain. This clause only provides a summary for context.

One of the most influential standards in this area is the WebXR Device API, along with its related modules. This suite of browser-based specifications enables web applications to deliver virtual and augmented reality content directly to head-mounted displays and other XR devices. The WebXR Depth Sensing Module provides applications with access to spatial depth information, allowing for realistic environment mapping and

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interaction. The WebXR Hit Test Module supports spatial recognition, making it possible for virtual objects to interact with surfaces in the real world. In parallel, the WebXR Lighting Estimation API allows software to respond to real-world lighting conditions, enabling dynamic adaptation of shadows, reflections, and ambient effects in immersive experiences.

Alongside browser-native solutions, there are standards tailored to large-scale geospatial and 3D content delivery. The OGC 3D Tiles Specification was created to optimize the streaming of massive 3D datasets, including point clouds, city models, and terrain data. It facilitates efficient rendering and progressive loading, which is essential for real-time applications like digital twins of cities and industrial environments. Closely related is the OGC CityGML Encoding Standard, a powerful schema used to describe the semantics, geometry, and appearance of urban features. It supports various levels of detail and thematic modules for different aspects of the built environment, such as transportation networks or vegetation. Complementing this is the OGC GeoPose 1.0 standard, which formalizes the representation of position and orientation in Earth-referenced coordinates. GeoPose is essential for any application requiring precise spatial anchoring, such as location-based augmented reality or drone-based inspections.

An important family of standards for reality capture is the ISO/IEC 23090 series, developed under the MPEG-I initiative. These standards define key components for representing and compressing volumetric video and point clouds, allowing for immersive streaming of three-dimensional content. For instance, parts of this series focus on geometry-based point cloud compression, while others introduce dynamic mesh and scene representations.

In the industrial and automation sector, the IDTA 01001-3-0 specification defines the metamodel for the Asset Administration Shell, a cornerstone of digital twin technology. It provides a formal structure for describing assets, their subcomponents, and associated metadata in a way that ensures semantic and syntactic consistency across systems.

For rendering 3D assets across platforms, the Khronos glTF format (GL Transmission Format) is a lightweight yet comprehensive solution. It is designed for efficient delivery of 3D models and scenes, supporting features like physically-based rendering, animations, and textures. It is widely adopted across game engines, browsers, and XR platforms for its versatility and speed.

Additional standards explore broader infrastructure and system modeling. ISO/IEC 30141 introduces a reference architecture for the Internet of Things, outlining how distributed sensor systems can be integrated securely and reliably. Although its scope is general, it intersects with XR and Reality Capture through shared needs for data synchronization, privacy, and device interoperability.

In industrial vision systems, the EMVA GenICam GenApi standard provides a generic API for controlling cameras, ensuring compatibility and discoverability of features across different hardware manufacturers. While rooted in machine vision, the standard offers principles applicable to XR sensors and spatial scanning.

The ETSI ARF and CIM series define system architectures and data exchange models for augmented reality and context-aware applications. These standards include components focused on spatial computing, semantic interoperability, and immersive media composition. Their goal is to enable open and scalable AR frameworks across devices and platforms.

Several IEEE standards also contribute foundational technologies to the Reality Capture stack. IEEE P3333.2.1, for example, focuses on 3D visual data compression, while IEEE 2888.3 outlines communication protocols for environmental sensors in smart cities. Others address immersive system modeling or signal processing for volumetric content.

An important group of standards focuses on biometric and anthropometric data. The ISO 20685 series defines protocols for collecting, validating, and exchanging 3D human body scans. These are key to enabling realistic avatars, ergonomic product design, and medical XR applications.

More recent specifications like ISO/IEC TS 5147 and ISO/IEC 23488 delve into immersive media metadata, data encoding for sensor systems, and synchronization protocols, aiming to support integrated and interactive virtual environments. Similarly, the ITU-T Focus Group on the Metaverse has published a series of technical documents exploring conceptual frameworks, trust models, and governance for immersive platforms.

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Finally, in the realm of media production and overlay visualization, the SMPTE 2076-1 standard addresses the management of transparent media layers within immersive video streams. This is particularly relevant in broadcast XR applications and live augmented content.

8.3 Implementation

8.3.1 Introduction

The focus of the reality capture domain is on frameworks for geospatial data, 3D content, and digital twins. The research presented in this chapter draws only on public evidence of implementation, technical contributions, and participation in standardization forums. Like in the prior domains, there are only a few widely-adopted standards that anchor current development. These include WebXR and its associated modules; the OGC 3D Tiles and CityGML standards for rendering and managing large-scale geospatial content; ISO/IEC 23090 series for immersive media formats such as point clouds and volumetric video; and IDTA's Asset Administration Shell for digital twin interoperability in industrial and automation contexts.

Examples of the reality capture domain standards and the companies that promote their implementation are provided in table 10 below.

Table 10. Reality capture domain standards and the companies that promote their implementations

Standard	Purpose	Companies explicitly promoting implementation
WebXR Device API and Related Modules (WebXR Depth Sensing Module, Hit Test Module, Lighting Estimation API Level 1)	Direct implementation in hardware/software platforms, developer documentation, and browser support	Apple (Vision Pro), HTC (Viverse), Magic Leap, Meta (Quest), Microsoft (HoloLens 2, Edge), Unity Technologies (via unity-webxr-export)
OGC 3D Tiles Specification v1.1	Platform integration, technical contributions	Bentley Systems (via Cesium acquisition), NVIDIA (Omniverse), Niantic (Scaniverse)
OGC CityGML Encoding Standard	Direct support in GIS/BIM workflows, urban mapping services	Autodesk (AutoCAD Map 3D), Baidu (3D city models)
ISO/IEC 23090 Series (Immersive Media Standards)	Technical contributions, patent declarations, and product implementation (point cloud compression, volumetric media)	Nokia (leading contributor, multiple parts), Tencent (ISO/IEC 23090-9:2023)
IDTA 01001-3-0 (Asset Administration Shell)	Implementation in automation and digital twin solutions	Siemens
OGC GeoPose 1.0	Geospatially-anchored and defined location and orientation in 6DOF	Siemens (referenced in asset location submodels)
Khronos glTF 2.0	Integration in immersive platforms	Niantic (Scaniverse, GS extension proposal), NVIDIA (Omniverse)

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8.2.2 Implementation by companies

Table 11 below compiles information about implementation of reality capture domain standards by the 29 companies studied for this report.

Table 11. Companies studied and their implementation of reality capture domain standards.

Company	Standards	Notes
Amazon	None	No information was found regarding Amazon's adoption or implementation of any of the listed metaverse-related standards in the Reality Capture domain.
Apple	WebXR Device API, WebXR Depth Sensing Module, WebXR Hit Test Module, WebXR Lighting Estimation API Level 1	Apple has implemented the WebXR Device API and its modules in Safari on visionOS (Vision Pro), enabling immersive web experiences and cross-platform XR content. This is a direct, public adoption of W3C WebXR standards.
Autodesk	OGC CityGML Encoding Standard	Autodesk supports the OGC CityGML Encoding Standard in its AutoCAD Map 3D product, enabling import/export of 3D city models in CityGML format.
Baidu	OGC CityGML Encoding Standard	Baidu utilizes the OGC CityGML Encoding Standard in its mapping and 3D city model services, as evidenced by academic references to Baidu's CityGML-based 3D building models.
Bentley Systems	OGC 3D Tiles Specification v1.1	Bentley Systems' Cesium division is the contributor of the OGC 3D Tiles Specification v1.1 standard to the OGC. Bentley has since integrated 3D Tiles into its iTwin Platform and digital twin solutions. Bentley is also a principal member of the OGC.
ByteDance	None	No specific standards were found to be directly associated with ByteDance in the Reality Capture domain.
Dassault Systemes	None	No information was found regarding Dassault Systemes' adoption or implementation of any reality capture domain standards.
Decentraland	None	No information was found regarding Decentraland's adoption or implementation of any reality capture domain standards.
Epic Games	None	While Epic Games' Unreal Engine is used in digital twin solutions, there is no evidence of direct adoption or conformance to any of the reality capture domain standards.
Ericsson	None	No information was found regarding Ericsson's adoption or implementation of any of the reality capture domain standards.
HTC	WebXR Device API, WebXR Depth Sensing Module, WebXR Hit Test Module, WebXR Lighting Estimation API Level 1	HTC has adopted these standards in its Viverse Worlds metaverse platform, enabling browser-based VR access on various headsets.
Huawei	None	No information was found regarding Huawei's adoption or implementation of any of the reality capture domain standards.

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Company	Standards	Notes
Magic Leap	WebXR Device API, WebXR Depth Sensing Module, WebXR Hit Test Module, WebXR Lighting Estimation API Level 1	Magic Leap supports these standards as documented in developer resources, enabling immersive AR/VR experiences.
Meta	WebXR Device API, WebXR Depth Sensing Module, WebXR Hit Test Module	Meta has implemented these standards in its Meta Quest devices, supporting immersive web and PWA applications.
Microsoft	WebXR Device API, WebXR Hit Test Module	Microsoft has adopted these standards in its Windows Mixed Reality platform and HoloLens 2, with support in Microsoft Edge.
NVIDIA	OGC 3D Tiles v1.1, USD, glTF	NVIDIA Omniverse supports OGC 3D Tiles and integrates USD.
Niantic	OGC 3D Tiles, glTF	Niantic has contributed to standardization efforts around Gaussian Splats and glTF, and uses OGC 3D Tiles for streaming geospatial content.
Nintendo	None	No information was found regarding Nintendo's adoption or implementation of any reality capture domain standards.
Nokia	ISO/IEC 23090 Series	Nokia is a leading contributor to the ISO/IEC 23090 family of immersive media standards, with extensive technical contributions.
PTC	None	No information was found regarding PTC's adoption or implementation of any reality capture domain standards.
Qualcomm	None	No information was found regarding Qualcomm's adoption or implementation of any reality capture domain standards.
Roblox	None	No information was found regarding Roblox's adoption or implementation of any reality capture domain standards.
Samsung	None	No information was found regarding Samsung's adoption or implementation of any reality capture domain standards.
Siemens	IDTA 01001-3-0, OGC GeoPose 1.0	Siemens has implemented these standards to support standardized information exchange in automation and digital twin solutions.
Sony	None	No information was found regarding Sony's adoption or implementation of any reality capture domain standards.
Tencent	ISO/IEC 23090-9:2023	Tencent has adopted this standard for point cloud compression and participates actively in related standardization.
Unity Technologies	WebXR Hit Test Module	Unity supports this standard through its 'unity-webxr-export' project, enabling browser-based AR/VR with Unity.
XReal	WebXR Depth Sensing Module, WebXR Hit Test Module	XReal devices are supported by community projects like 'xreal-webxr' that enable WebXR bindings. These include implementations for depth sensing and hit test modules, although there is no official standard adoption beyond WebXR.

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8.2.3 Gaps

Outside of a very few cases, there are many gaps in the uptake of reality capture domain standards by the 29 companies studied for the present project. The EMVA GenICam GenApi 2.1.1 standard, commonly associated with machine vision systems, does not appear to be adopted in the context of XR or immersive media applications. Similarly, the ETSI ARF and CIM series—including ARF 008, ARF 003, ARF 004-4, ARF 005, ARF 004-3, ARF 004-2, ISG CIM 050, and ISG CIM 009—do not show adoption by the companies examined.

The IDTA 01005-3-0 specification also lacks signs of implementation, as do a number of IEEE standards such as IEEE 2888.3, IEEE 2048.101, IEEE P2888.1, IEEE P3333.2.1, and IEEE 1857a. These standards, while potentially significant in their technical contributions, do not appear in company strategies or product descriptions.

The ISO 20685 series, which includes parts 1 and 2 along with the base 20685 specification, also remains unadopted based on available data. Other standards that show no observed adoption include ISO/IEC 30141, which provides a reference architecture for the Internet of Things, and ISO/IEC TS 5147:2023.

A wide range of immersive content and data standards, including ISO/IEC 23488, 3721-1, 21794-2, 23005-1:2020, 23001-10, 18038:2020, 21794-1, and 15938-3:2002/AMD3:2009, also show no trace of implementation at the present time. The ITU-T Focus Group on the Metaverse series, though ambitious in scope, does not yet appear in commercial implementations.

Further gaps are visible in geospatial and XR-related infrastructure standards such as OGC CDB Vol01, Vol00, and IndoorGML, as well as in the oneM2M WI-0110 specification and SMPTE 2076-1. These findings suggest that while the ecosystem of standards has a lot to offer, industry uptake is uneven and concentrated around a a few mature or strategically-aligned specifications.

9 Human interface systems and devices

9.1 Introduction

Virtual world human interfaces are integrated systems of hardware and software components. Together, components create systems and devices that when used with design principles or guidelines, facilitate interaction with and immersion in virtual reality and augmented reality experiences. These systems enable users to perceive, navigate, and interact with digital content and other entities in intuitive and engaging ways, bridging the physical and virtual worlds to create seamless experiences.

There are five components defined in this domain:

- Form factors for immersive experiences range from purpose-built spaces into which users enter for 3 dimensional experiences (including in some cases, audio, vibration, temperature and other signals detectable by user senses, in addition to vision), to devices that include a frame for resting on the user’s head, nose and/or ears to provide visuals, including monocular systems for delivery of text in nearfield view and stereoscopic displays for 3D depth, usually with audio.
- A delivery platform or device always includes some general purpose components without which the user is unable to consume virtual world and immersive experiences. These include sensors, memory, computational resources, optics and displays.
- Selection, control and interaction components of a delivery platform support user’s ability to select, control, navigate and interact with assets or spaces in virtual world experiences.
- Feedback mechanisms include a wide range of optional components which, when integrated in a full immersive experience delivery system, automatically communicate with users about changes in status.
- Technologies used for the measurement, calibration and validation of virtual world human interaction system characteristics are also necessary to study and improve how users perceive and interact with digital content, ensuring accurate rendering, perceptual realism, and user comfort.

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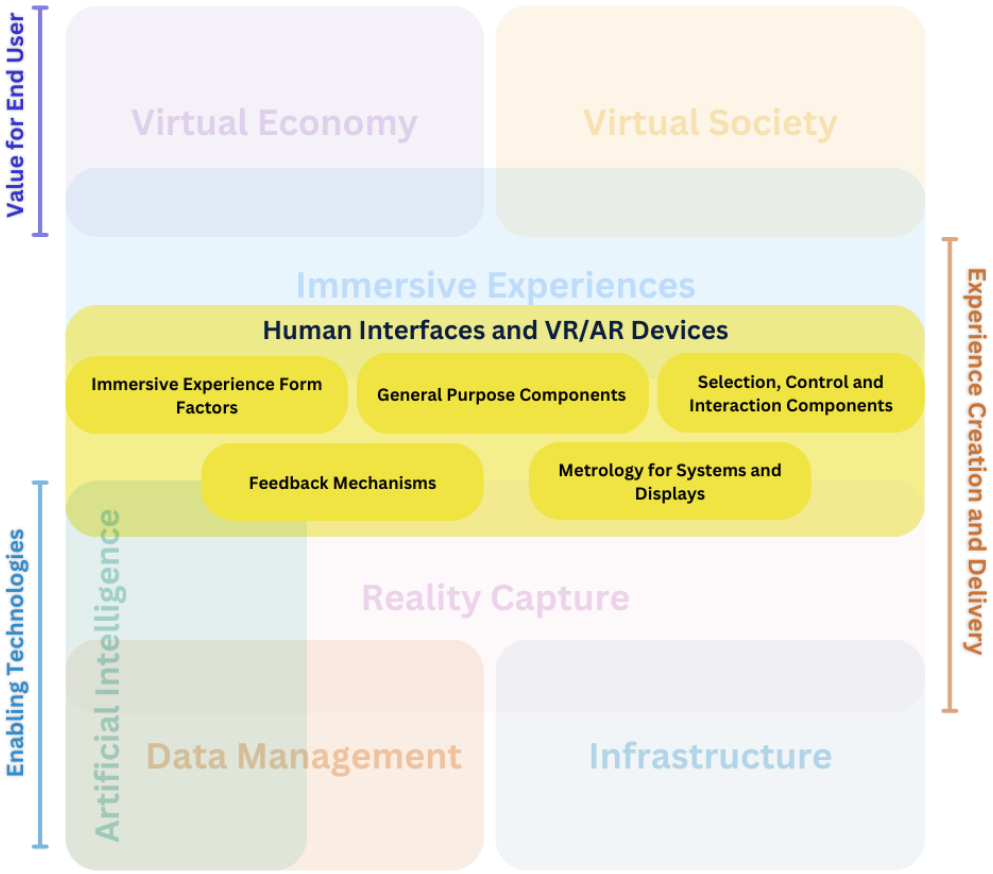


Figure 6: Components of the human interface systems and devices domain

The ViWISSO Standards Landscape Report provides detailed explanations of these components and the topics they cover.

9.2 Standards overview

Human interface standards form the backbone of interoperability, safety, usability, and accessibility in the metaverse. Key standards such as OpenXR and the WebXR Device API ensure that XR applications can operate seamlessly across platforms and browsers. Extensions like the WebXR Hand Input and Gamepads Modules further standardize interaction using hands and controllers.

Safety is addressed through standards like UL 8400, which outlines compliance requirements for XR devices, while IEC 63145-22-20 sets benchmarks for display quality in near-eye systems. Ergonomic guidelines are drawn from the ISO 9241 series to enhance user comfort and prevent physical strain.

Haptics and sensory feedback are enabled through standards such as ISO/IEC 23090-31, which synchronize tactile input with audio-visual content. Gesture control is supported by the ISO/IEC 30113 series, providing consistent interaction methods across systems.

On the accessibility front, the W3C's XR Accessibility User Requirements and standards like ISO/IEC 24751-1 promote inclusive design, ensuring XR is usable by people with varying abilities. Additional contributions from CTA 2095 and ITU-T documents extend this focus to usability and personal adaptability.

Finally, regional standards such as China's SAC GB/T 38259 and Germany's DIN SPEC 91333 reflect national approaches to XR development and may influence broader international efforts.

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Collectively, these standards, alongside the complete list of standards analyzed, establish a structured foundation for building safe, interoperable, and inclusive XR experiences across the evolving metaverse.

9.3 Implementation

9.3.1 Introduction

This section reviews how leading technology companies are adopting metaverse-related standards within the domain of Human Interface Systems and Devices. A clear trend emerges: only a few standards have achieved widespread implementation across both hardware and software ecosystems. These dominant standards have matured through open collaboration and are directly aligned with industry needs for XR runtime interoperability, browser-based immersion, and safety compliance.

The Khronos OpenXR standard stands out as the most widely adopted. It has become the foundation for cross-platform XR runtime interoperability, enabling developers to build once and deploy across multiple devices and systems. Companies such as Epic Games, Microsoft, Meta, Unity, and Qualcomm have adopted OpenXR, integrating it deeply into their engines, headsets, SDKs, and runtime environments. Both hardware manufacturers and platform providers have aligned with this standard, confirming its role as a central pillar for XR application development.

Alongside OpenXR, the WebXR Device API and its related modules — specifically the Hand Input Module and Gamepads Module — have gained substantial traction. These standards underpin browser-based immersive experiences, allowing developers to deliver VR and AR content over the web. Major adopters include Apple, Google, Microsoft, Meta, Samsung, Niantic, and Decentraland. The WebXR ecosystem provides developers with standardized input support for hand tracking and controllers, which is increasingly essential as XR usage expands beyond dedicated apps and into web-native environments.

Device safety and performance also play a role in shaping adoption trends. UL 8400, a safety standard specifically created for AR/VR/MR equipment, has been implemented by Magic Leap, which is currently the only company with a certified device. This marks a precedent for safety regulation in immersive hardware. In parallel, IEC 63145-22-20 has been referenced by Sony in relation to its OLED microdisplay technology, which meets the image quality benchmarks defined in this standard. These two examples reflect an emerging focus on standardized hardware evaluation in terms of visual performance and user protection.

Examples of human interface systems and devices domain standards and the companies that promote their implementation are provided in table 12 below.

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Table 12. Human interface systems and devices domain standards and the companies that promote their implementations

Standard	Purpose	Companies
Khronos OpenXR	cross-platform XR runtime interoperability	Bentley Systems (via Cesium), Dassault Systems, Epic Games, Google (Android XR), HTC (VIVE), Magic Leap, Microsoft (HoloLens 2, Windows Mixed Reality), NVIDIA (CloudXR), Qualcomm (Snapdragon Spaces), Roblox, Samsung, Tencent (as contributor), and Unity Technologies
W3C WebXR Device API	Immersive experiences in web browsers	Amazon (AWS), Apple (Vision Pro), Decentraland, Google (Chrome, Android), Magic Leap, Meta (Quest), Microsoft (Edge, HoloLens 2), Niantic (8th Wall, Niantic Studio), Samsung (browser)
W3C WebXR Hand Input Module - Level 1 and WebXR Gamepads Module - Level 1	standardized hand and controller input for immersive web experiences	Apple, Google, Meta, Microsoft, Niantic
UL 8400	safety standard for VR/AR/MR technology equipment	Magic Leap 2
IEC 63145-22-20	Quality of OLED microdisplays for AR headsets	Sony

Other standards from this domain (such as ISO/IEC 23090-31 for haptics coding, W3C XR Accessibility User Requirements, and the ISO 9241 series on ergonomics and haptics) are promoted by some metaverse companies and referenced in accessibility initiatives, but there is no direct evidence of formal adoption or implementation as company policy among the 29 companies studied in this project.

9.3.2 Implementations by companies

Table 13 below compiles information about implementation of human interface systems and devices domain standards by the 29 companies studied for this report.

Table 13. Companies studied and their implementation of human interface systems and devices domain standards

Company	Adopted Standards	Notes
Amazon	WebXR Device API	Amazon, primarily through AWS, has implemented and promoted the WebXR Device API for immersive XR experiences in web browsers. AWS provides technical documentation, open-source projects, and best practices for XR development using this standard. There is no evidence of adoption of other standards in this domain.
Apple	WebXR Device API, WebXR Hand Input Module - Level 1, WebXR Gamepads Module - Level 1	Apple has adopted and implemented WebXR standards in its Vision Pro headset and Safari on visionOS, supporting natural input, hand tracking, and gamepad/controller input. Adoption is focused on dedicated XR hardware, with explicit developer guidance and active participation in W3C standardization.
Autodesk	None	No evidence was found of Autodesk adopting or implementing any of the standards in this domain, despite supporting XR workflows and devices. References to now-deprecated WebVR exist, but not to WebXR or other current standards.

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Company	Adopted Standards	Notes
Baidu	None (participation in national working groups)	Baidu is active in China's national metaverse standards working group and is integrating XR technologies, but there is no explicit evidence of adoption of any listed international standards. Involvement is at the level of industry coordination rather than direct implementation.
Bentley Systems	Khronos OpenXR	Through its acquisition of Cesium, Bentley Systems is an active participant in the Khronos Group and supports OpenXR for interoperability in digital twins and infrastructure engineering. Bentley advocates for open standards and has contributed to related specifications.
ByteDance	Khronos OpenXR	ByteDance, through its subsidiary PICO, has officially adopted and implemented the OpenXR standard (specifically OpenXR 1.0 and 1.1) for its XR devices, including the PICO Neo3, PICO 4, and PICO 4 Ultra.
Dassault Systemes	Khronos OpenXR	Dassault Systemes is a Khronos Group member and participant in the OpenXR standard. Its SolidWorks product supports VR for OpenXR-compatible headsets via third-party bridges.
Decentraland	WebXR Device API	Decentraland has adopted the WebXR Device API to enable VR access via browsers, with ongoing development for XR compatibility. There is no evidence of adoption of other listed standards.
Epic Games	Khronos OpenXR	Epic Games is a founding member and major contributor to OpenXR. Unreal Engine integrates OpenXR as the default API for XR development, supporting a wide range of devices and features.
Ericsson	None	Ericsson is focused on 5G and network requirements for XR but has not adopted or referenced any of the human interface system standards. It is a significant contributor in the area of 3GPP standards and network enablement for XR.
Google	Khronos OpenXR, WebXR Device API, WebXR Hand Input Module - Level 1, WebXR Gamepads Module - Level 1	Google has adopted OpenXR (Android XR) and the WebXR Device API (including Hand Input and Gamepads Modules) in Chrome and Android platforms. Google is an active contributor to the W3C Immersive Web group.
HTC	Khronos OpenXR	HTC’s VIVE devices are OpenXR conformant, demonstrating strong adoption of the standard for cross-platform XR interoperability.
Huawei	None (beyond general support for open standards)	Huawei is a founding member of the Metaverse Standards Forum and supports open interoperability standards but has not explicitly adopted or implemented any individual standards from the provided list.
Magic Leap	Khronos OpenXR, WebXR Device API, UL 8400	Magic Leap is a leader in standards adoption, with Magic Leap 2 conformant to OpenXR, supporting the WebXR Device API, and being the first device certified to UL 8400 for XR equipment safety.
Meta	WebXR Device API, WebXR Hand Input Module - Level 1, WebXR Gamepads Module - Level 1	Meta has implemented these WebXR standards in the Meta Quest browser and developer ecosystem, supporting hand tracking and controller input in immersive web experiences.

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Company	Adopted Standards	Notes
Microsoft	Khronos OpenXR, WebXR Device API, WebXR Hand Input Module - Level 1, WebXR Gamepads Module - Level 1	Microsoft is a leading adopter and contributor to OpenXR. HoloLens 2 and Windows Mixed Reality both supported OpenXR and the WebXR Device API (including Hand and Gamepads Modules), however, these devices are discontinued.
NVIDIA	Khronos OpenXR	NVIDIA implements and supports OpenXR in its CloudXR platform and is an active participant in the Khronos Group, migrating from proprietary APIs to OpenXR for XR streaming solutions.
Niantic	WebXR Device API, WebXR Hand Input Module - Level 1, WebXR Gamepads Module - Level 1	Niantic's platforms (8th Wall, Niantic Studio) are built on the WebXR Device API, supporting hand tracking and controller input for web-based XR experiences.
Nintendo	None	No evidence of adoption or implementation of any listed standards.
Nokia	None (leadership in standards forums)	Nokia is a principal member and board member of the Metaverse Standards Forum, contributing to the development of interoperability standards but with no direct adoption of the standards in this domain.
PTC	None	No evidence of adoption or implementation of any listed standards.
Qualcomm	Khronos OpenXR	Qualcomm is a promoter member of the Khronos Group and has adopted OpenXR in its Snapdragon Spaces XR Developer Platform, providing conformant runtimes and SDKs for AR headworn devices.
Roblox	Khronos OpenXR	Roblox has adopted OpenXR as the backend for all VR devices, enabling platform-agnostic support and future-proofing VR experiences.
Samsung	Khronos OpenXR, WebXR Device API	Samsung has adopted OpenXR in its XR products and SDKs, and has implemented the WebXR Device API in the Samsung Internet browser.
Siemens	None	No evidence of adoption or implementation of any standards in this domain.
Sony	IEC 63145-22-20	Sony's OLED microdisplays for AR headsets are specified and marketed according to IEC 63145-22-20, addressing AR image quality measurement.
Tencent	Khronos OpenXR (contributor)	Tencent is a contributor member of the Khronos Group but with no explicit adoption or implementation of listed standards beyond OpenXR.
Unity Technologies	Khronos OpenXR	Unity provides a first-party OpenXR plugin for AR/VR development and is a contributor to the Khronos OpenXR working group. Unity does not natively support WebXR or other standards from the list.
XReal	Khronos OpenXR	XREAL has officially adopted the Khronos OpenXR 1.1 standard for its AR glasses as of 2024, enabling cross-platform XR application development and compatibility with major XR engines and applications.

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9.3.3 Gaps

While a few human interface system standards have seen meaningful uptake within the XR industry, a large portion of the available standards show no evidence of implementations by the companies studied. These gaps reveal important areas where standardization has yet to translate into industry-wide implementation, despite the technical relevance or potential value of the standards themselves.

One notable gap concerns ergonomics and haptics-related standards, such as those within the ISO 9241 series, ISO/IEC 30113, and ISO/IEC 23005. These frameworks offer comprehensive guidance on user comfort, physical interaction, and tactile feedback—areas that are undeniably critical in immersive environments. However, while these standards are often cited in academic literature or included in regulatory discussions, there is no clear evidence that leading XR companies publicly claim compliance with them in product documentation, marketing, or technical specifications.

A similar pattern emerges with gesture-based interface standards, particularly the ISO/IEC 30113 series and DIN SPEC 91333. Although gesture recognition technologies are increasingly built into XR hardware and software platforms, these functionalities appear to be developed through proprietary systems or open-source libraries rather than in direct alignment with formal standards. As a result, standard-based interoperability in gesture input remains largely unrealized across the ecosystem.

The situation is also true for standards concerning haptics coding and media context, such as ISO/IEC 23090-31 and related specifications. These standards are designed to support synchronized tactile feedback in immersive experiences, offering new dimensions of user interaction. However, their adoption appears to be confined to experimental settings or research prototypes, rather than reflected in commercial deployments or official documentation.

Accessibility standards represent another major area of under-adoption. Despite growing awareness around the need for inclusive design, there is little to no formal recognition of accessibility standards like the XR Accessibility User Requirements (XAUR), CTA 2095, or ISO/IEC 24751-1 among the companies studied. Many organizations express general commitments to accessibility, but they do not reference or implement these specific standards in ways that are visible or verifiable.

In the domain of device safety, adoption is similarly limited. Aside from UL 8400, which has been formally adopted by Magic Leap, no other safety or device-specific standards from the reviewed list appear in company disclosures. This suggests that safety assurance may often be handled through internal testing or local regulatory compliance, rather than through alignment with international, XR-specific standards.

Finally, there is a noticeable absence of implementation of regionally defined standards, especially those originating in China or Germany. For example, SAC GB/T 38259 and DIN 92419—while important within their respective jurisdictions—do not appear to have been formally adopted even by companies headquartered in those regions, such as Baidu, Huawei, or Tencent. This may reflect a disconnect between national standardization efforts and international industry practice, or a preference for internal protocols over external certification.

These gaps highlight a broader trend: while companies may embrace the functional goals behind standards—such as better accessibility, improved ergonomics, or richer sensory feedback—they often pursue them through proprietary solutions rather than formal standard compliance. As the metaverse continues to evolve, these under-adopted standards represent areas where industry alignment could improve consistency, quality, and user experience across platforms.

10 Immersive experiences

10.1 Introduction

In the present document the term “immersive experiences” refers to enabling technologies and actors involved in generating and packaging assets and behaviours for interactive, and digitally mediated activities or simulations within virtual worlds or mixed real-and-digital environments. These experiences engage users through sensory inputs (e.g. visual, auditory, haptic, olfactory) and dynamic interactions, offering opportunities for many use cases including economic activities, exploration, learning, entertainment, or collaboration in digitally constructed and mixed digital-physical world settings.

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There are five components of immersive experience domain:

- The delivery, recording and communication component includes software for the purpose of producing and recording immersive experiences in virtual worlds and mixed digital-real environments is the core of this component. It includes real time transmission of bi-directional 2- or 3-dimensional representations of and to users.
- The realism and immersion component is composed of protocols, formats, software tools and systems used to create, describe, manipulate, and render signals of three-dimensional objects, scenes and environments, enabling sensory-rich and immersive experiences that permit suspension of disbelief by mimicking and/or interacting with real world properties.
- Authoring and design encompasses software tools and technologies for creating, prototyping and compiling software for immersive experience delivery.
- The distributed architectures component includes all technologies and interfaces supporting the delivery of immersive experiences residing on two or more network-connected resources, ensuring distribution of computational resources, storage capacity and power consumption for scalability and reliability.
- User interaction design and usability component contains guidelines, frameworks and tests used by experience developers to ensure consistent, intuitive, responsive, safe and accessible interactions in immersive environments, including interaction paradigms, interaction patterns and interaction metaphors.

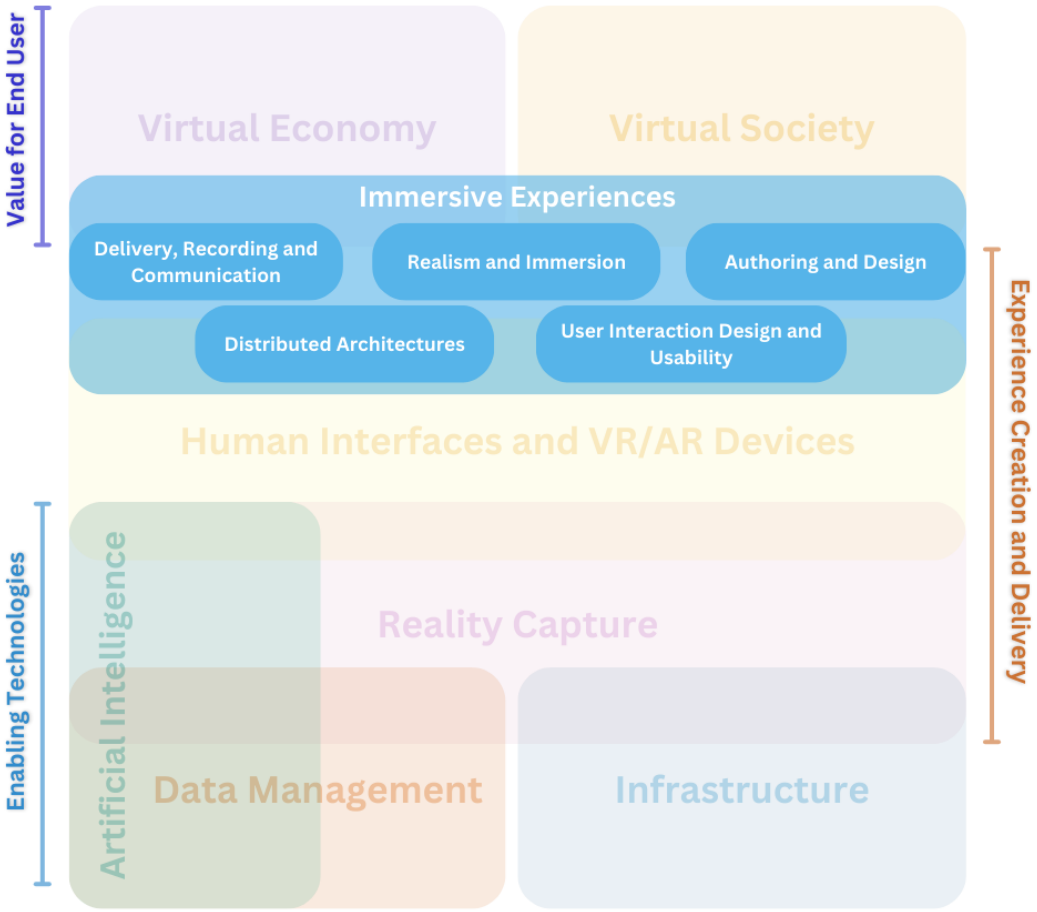


Figure 7: Components of the immersive experiences domain

The ViWISSO Standards Landscape Report provides detailed explanations of these components and the topics they cover.

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10.2 Immersive experiences domain standards overview

The standards examined in this chapter cover specifications aimed at supporting the infrastructure and content of extended reality systems, including augmented reality (AR), virtual reality (VR), and mixed reality (MR). These standards are not confined to a single layer of the technology stack but extend across multiple layers, from hardware abstraction and device communication to asset representation, media encoding, and content delivery.

At the interface level, standards such as Khronos OpenXR, which provides a unified API for XR runtimes and hardware. It is widely adopted for enabling applications to run across multiple devices without modification. Similarly, W3C's WebXR Device API and Augmented Reality Module define web-based access to XR capabilities, supporting immersive experiences directly within browsers. These interface standards are critical for ensuring cross-platform functionality and consistent user interaction patterns.

Specifications such as Khronos glTF (GL Transmission Format) is widely adopted for compact and efficient models optimized for real-time rendering. This facilitate interoperability in digital asset pipelines, from content creation tools to runtime engines.

This research also examines adoption of standards concerned with immersive media encoding and spatial fidelity. The 3GPP IVAS (Immersive Voice and Audio Services) codec suite and ISO/IEC 23090-2 (OMAF – Omnidirectional Media Application Format) are notable in this regard. IVAS defines audio codecs capable of delivering spatialized, high-quality voice experiences, essential for telepresence and virtual communication. OMAF addresses the packaging and delivery of 360° and VR video, supporting efficient streaming and rendering across devices.

A smaller but significant portion of the standards investigated relates to advanced rendering and simulation. Khronos ANARI, for example, abstracts access to rendering engines in scientific visualization and simulation contexts, enabling high-performance graphics in environments where traditional game engines are not used. VRM 1.0, originally developed for avatar data in Japanese virtual platforms, has been included in this research for its relevance to identity representation and interoperability of user-controlled avatars across platforms.

In terms of organizational sources, the immersive experiences domain standards examined for adoption cover work from a range of SDOs including 3GPP, ETSI, ISO/IEC, IEEE, Khronos Group and W3C. Each contributes a specific technical focus.

10.3 Implementation

10.3.1 Introduction

The research conducted into commercial implementations of immersive experience domain standards by metaverse provider stakeholders reveals that, although a broad set of standards are available, only a few have achieved significant traction. The most widely adopted is the Khronos OpenXR specification. OpenXR is implemented across a broad ecosystem that includes Autodesk, Epic Games, HTC, Magic Leap, Meta, Microsoft, Samsung, and Unity Technologies, among others. This standard enables hardware-agnostic development environments and is increasingly embedded in core XR product stacks.

Similarly, the W3C WebXR Device API and related modules have been adopted by companies such as Google, Microsoft, Niantic and Magic Leap, reflecting their strategic interest in browser-based immersive content and AR capabilities. These standards are enabling scalable, device-independent experiences via the web. Alongside OpenXR and WebXR, a defacto standard (MaterialX) is used by Autodesk and Dassault Systèmes to ensure material interoperability across content creation pipelines; and the VRM 1.0 format, implemented by Decentraland for avatar export and portability.

Outside of the above-mentioned standards, NVIDIA has implemented Khronos ANARI for advanced rendering pipelines, and Samsung has adopted parts of the ISO/IEC 23090 series for volumetric video encoding.

Examples of immersive experience domain standards and the companies that promote their implementation are provided in table 14 below.

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Table 14. Immersive experience domain standards and the companies that promote their implementations

Standard	Purpose	Companies explicitly promoting implementation
Khronos OpenXR	XR device and platform interoperability	Autodesk, Bentley Systems, Epic Games, HTC, Magic Leap, Meta, Microsoft, Qualcomm, Samsung, Sony (supporter/contributor, not confirmed as implementer), and Unity Technologies
W3C WebXR Device API and Related Modules (W3C)	enabling immersive web experiences across browsers and devices	Amazon, Google, HTC, Magic Leap, Microsoft, Niantic
ASF - MaterialX (MaterialX v1.39.1)	open format for material and look-development content	Autodesk, Dassault Systèmes, Epic Games
3GPP Immersive Voice and Audio Services (IVAS) Codecs	immersive, spatial audio	Nokia
ISO/IEC 23090-2 (Omnidirectional Media Format, OMAF)	360° media storage and delivery for immersive experiences	Ericsson is a contributor to this standard
Khronos ANARI	advanced 3D rendering	NVIDIA has implemented in its VisRTX project
VRM 1.0	avatar export and interoperability	Decentraland

10.3.2 Implementation by companies

Table 15 below compiles information about implementation of immersive experience domain standards by the 29 companies studied for this report.

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Table 15. Companies studied and their implementation of immersive experience domain standards

Company	Adopted Standard(s)	Notes
Amazon	WebXR Device API	Amazon has implemented the WebXR Device API standard in its AWS Amplify and Babylon.js cloud platform, enabling developers to build and deploy VR applications. No evidence of adoption of other immersive experience standards from the list.
Apple	None	Apple does not support the WebXR Augmented Reality Module - Level 1 or immersive-ar sessions on visionOS or iOS as of June 2025. No evidence of adoption or implementation of any listed immersive experience domain standards.
Autodesk	ASF - MaterialX v1.39.1, Khronos OpenXR 1.1.43 Specification	Autodesk has adopted and implemented MaterialX across multiple products and is an active contributor to its development. The company also supports OpenXR in its VRED product line, enabling broad XR device interoperability.
Baidu	None	No evidence of adoption or implementation of any immersive experience domain standards from the list.
ByteDance	None	No evidence of adoption or implementation of any immersive experience domain standards from the list.
Bentley Systems	Khronos OpenXR 1.1.43 Specification	Bentley Systems has adopted the OpenXR framework to enable multi-device XR support in their CAD and BIM software, facilitating interoperability in the AEC sector.
Dassault Systèmes	ASF - MaterialX v1.39.1	Dassault Systèmes has contributed to MaterialX and advanced PBR material standards in glTF. No evidence of adoption of OpenXR or other immersive experience domain standards was found.
Decentraland	VRM 1.0	Decentraland has implemented VRM 1.0 for avatar export, supporting cross-platform identity in the metaverse. No evidence of adoption of other immersive experience domain standards was found.
Epic Games	Khronos OpenXR 1.1.43 Specification, ASF - MaterialX v1.39.1	Epic Games is an adopter of OpenXR in Unreal Engine, and supports MaterialX for material import. No evidence of adoption of other immersive experience domain standards was found.
Ericsson	ISO/IEC 23090-2	Ericsson is a contributor to the ISO/IEC 23090-2 Omnidirectional Media Format (OMAF), for immersive media. No evidence of adoption of other immersive experience domain standards was found.
Google	WebXR Device API, WebXR Augmented Reality Module - Level 1	Google is a key contributor and implementer of the WebXR Device API and AR Module, with integration in ARCore and Chrome on Android. No evidence of adoption of other immersive experience domain standards was found.
HTC	Khronos OpenXR, WebXR Device API	HTC is an official OpenXR adopter, with its VIVE hardware conformant to the standard. Its Viverse Worlds platform supports WebXR for browser-based VR.
Huawei	(Planned/Roadmap) 3GPP TS 26.250	Huawei references and plans for 3GPP IVAS codec adoption but has not confirmed implementation.

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Table 15. Companies studied and their implementation of immersive experience domain standards

Company	Adopted Standard(s)	Notes
Magic Leap	Khronos OpenXR 1.1.43 Specification, WebXR Device API	Magic Leap fully adopted OpenXR and was a leading contributor. It also supported WebXR on its devices.
Meta	Khronos OpenXR, glTF	Meta is an OpenXR contributor and ensures all Quest and PC runtimes are compliant. It uses glTF for 3D assets.
Microsoft	Khronos OpenXR, WebXR Device API, WebXR Augmented Reality Module - Level 1	Microsoft implemented OpenXR across HoloLens 2 and Windows Mixed Reality platforms. It supports WebXR standards in Microsoft Edge.
NVIDIA	Khronos ANARI	NVIDIA implemented the ANARI standard in its VisRTX project.
Niantic	WebXR Device API, glTF	Niantic implements the WebXR Device API in its Niantic Studio and 8th Wall platforms, and uses glTF as its primary 3D format.
Nokia	3GPP TS 26.250, TS 26.253, TS 26.252	Nokia is a lead contributor and early adopter of the 3GPP IVAS codec family.
PTC	None	No evidence of adoption of immersive experience domain standards was found.
Qualcomm	Khronos OpenXR	Qualcomm has adopted OpenXR as the foundation of its Snapdragon Spaces XR platform, contributing to its development and industry adoption.
Roblox	None	No evidence of adoption of other immersive experience domain standards was found.
Samsung	Khronos OpenXR, ISO/IEC 23090-5	Samsung is an active OpenXR contributor and has implemented ISO/IEC 23090-5 (Visual volumetric video-based coding) through its work on MPEG-5 EVC and related codecs.
Siemens	None	No evidence of adoption of other immersive experience domain standards was found.
Sony	Khronos OpenXR (supporter/contributor)	Sony is a contributor and supporter of OpenXR but has not publicly committed to implementing it in PlayStation VR or other products as of 2025.
Unity Technologies	Khronos OpenXR 1.1.43 Specification	Unity has adopted and implemented OpenXR as a core part of its XR framework and development tools. No adoption of WebXR was found as of June 2025.
XReal	ISO/IEC 23090-5 Information technology	The 'pointcaster' system for XReal Light headsets specifically implemented real-time point-cloud compression and streaming. There is also evidence of the company discussing the MPEG standards for point cloud compression, including MPEG G-PCC and V-PCC (ISO/IEC 23090-5) for volumetric media transmission.

10.3.3 Gaps

While several standards are popular within the immersive experience domain, most remain absent from implementation across the companies examined in this research. These gaps in adoption are not merely isolated anomalies but rather reflect a broader pattern, where a large number of the standards included in the study have no meaningful traction among metaverse technology providers.

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Among these are key specifications developed by 3GPP, such as those focused on split rendering and immersive audio (e.g., TS 26.249 and TS 26.565). Outside of forward-looking references in corporate roadmaps—such as those by Huawei—or contribution activity from players like Nokia, there is little evidence that these technologies have been implemented in actual products or services.

Similarly, the ETSI ARF series, which lays out frameworks and interoperability requirements for augmented reality systems, has not been adopted or referenced by any of the companies surveyed. The same holds true for a broad set of IEEE standards that address immersive communication, media encoding, and networked interaction. Despite their technical relevance, no confirmed implementations were identified.

Several ISO/IEC standards aimed at immersive media, including those from the 23090-x, 23488, 21145, and 3721-x families, also remain unused. Only isolated exceptions exist, such as ISO/IEC 23090-2 and 23090-5, adopted by Ericsson and Samsung respectively. The broader suite of immersive media standards remains unmentioned in corporate documentation, suggesting a limited reach in industry practice.

In addition, work from consortia and bodies such as the Haptics Industry Forum (HIF), Immersive Digital Experiences Alliance (IDEA), Moving Picture, Audio and Data Coding by Artificial Intelligence (MPAI), the Open Mobile Alliance (OMA), and the International Telecommunication Union (ITU-T), appears to be largely unacknowledged. Even within the W3C WebXR family, modules beyond the core Device API and Augmented Reality Module have yet to surface in public implementations by major platforms.

11 Virtual society

11.1 Introduction

A virtual society is composed of communities of individuals and organizations who share common interests and interact, collaborate, and engage in shared social activities within immersive environments or in the real world with assistance of immersive interfaces. A virtual society operates under social norms, governance structures, and ethical frameworks, often mirroring or adapting elements from physical societies.

There are three components in this domain.

- The governance and frameworks for civil society component includes the adaptation or mirroring of physical-world legal principles in virtual environments is important to ensure legitimacy and accountability, such as enforcing property rights, citizenship, privacy laws, and due process.
- The ethics and accessibility component includes all the guidelines for responsible behaviour, ensuring fairness, respect, and equality within the society.
- The tools and processes that foster engagement between users for a healthy and diverse society are in the open social structures and interactions component.

The ViWISSO Standards Landscape Report provides detailed explanations of these components and the topics they cover.

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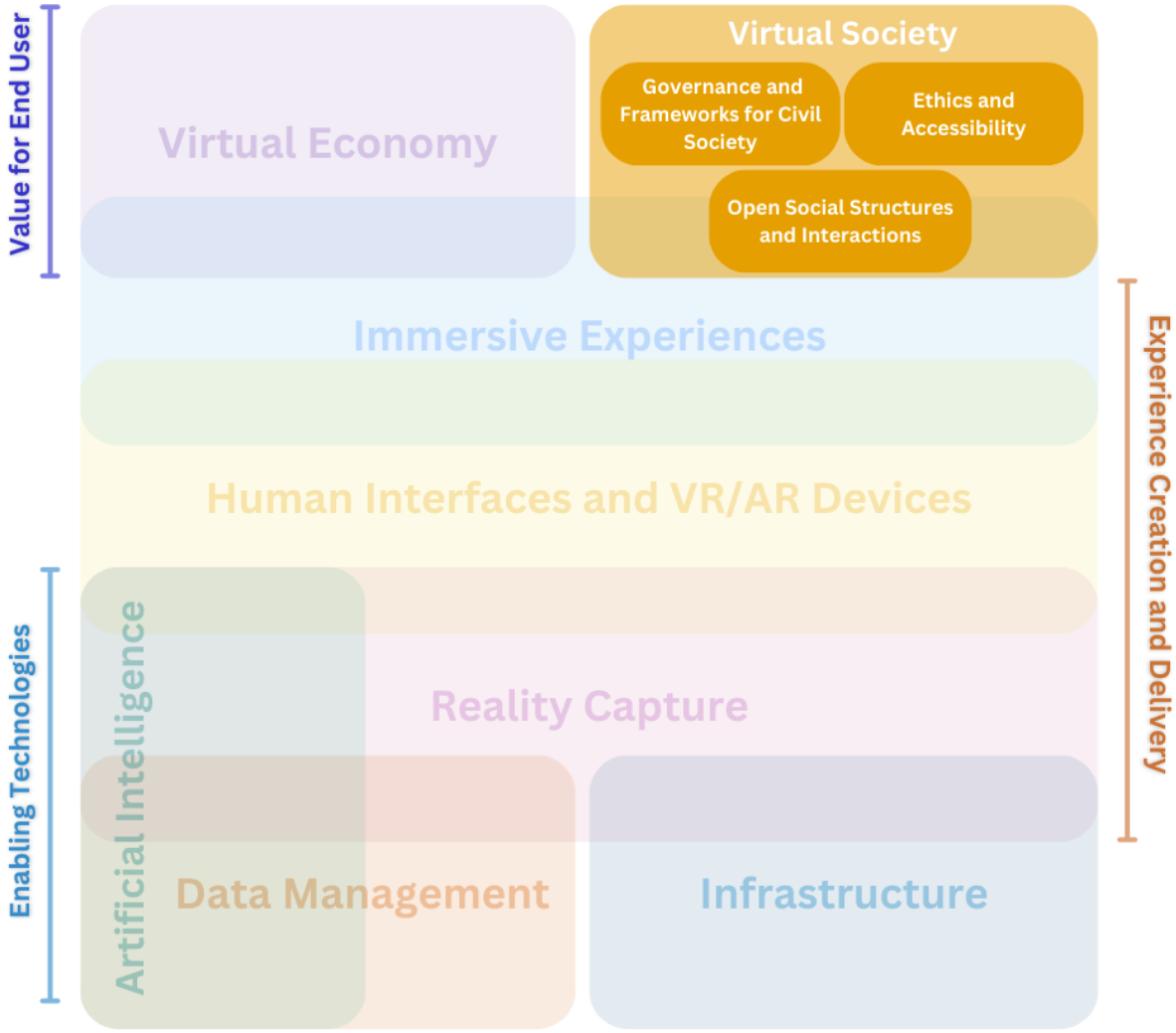


Figure 8: Components of the virtual society domain

11.2 Virtual society domain standards overview

At the core of this domain are identity-related standards, including the W3C Verifiable Credentials Data Model (v1.1 and v2.0) and the Decentralized Identifiers (DIDs v1.0). These provide structures for establishing and verifying identities in decentralized systems. The Verifiable Credentials model defines how claims about a subject—such as a user's qualifications, attributes, or permissions—can be issued, transmitted, and verified cryptographically without relying on centralized authorities. DIDs complement this by offering globally unique, resolvable identifiers that are independent of centralized registries, forming the backbone of user sovereignty in digital identity systems.

Asset representation standards, like ERC-721, address the need to define, exchange, and authenticate ownership of unique digital items. As a widely adopted non-fungible token (NFT) standard on Ethereum, ERC-721 is used to represent digital collectibles, virtual goods, and access credentials that require provable scarcity and uniqueness.

Business transaction standards, such as UN/EDIFACT, are long-established frameworks for electronic data interchange (EDI). These define syntax rules and message structures for automating commercial transactions, enabling companies to integrate virtual commerce with traditional supply chain and financial systems.

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In addition to these, several interoperability-focused and governance-driven standards have been proposed or are under development. These include frameworks such as MPAI-PAF (Portable Avatar Format), OMA3 IWPS (Inter-World Portaling System), and IEEE 3812.1 (Identity Framework for the Metaverse). These aim to enable consistent representation of avatars, cross-platform travel between virtual worlds, and governance of digital identity and access—but many remain in early stages or lack commercial integration.

Broader conceptual and ethical principles are explored through initiatives like IEEE 7000-2021, which outlines design processes for ethically aligned AI systems, and guidelines on accessibility, inclusion, and diversity. These are intended to ensure that metaverse societies do not replicate or exacerbate real-world inequities but instead enable broad participation and fair treatment.

Other notable standards in the virtual society domain include Linux Foundation's DT AnonCreds and TIPF CESR/ACDC/KERI, which bring forward cryptographic techniques and secure data structures to enhance decentralized trust and authorization models.

11.3 Implementation

11.3.1 Introduction

The most consistently adopted standards in this domain are in three categories: identity frameworks, digital asset protocols, and legacy transaction systems. In particular, the W3C Verifiable Credentials Data Model and Decentralized Identifiers (DIDs) have emerged as popular tools for enabling decentralized and verifiable digital identities. These standards have been implemented by a handful of companies, such as Microsoft, Huawei, and Decentraland, often in the context of blockchain-based services or platform governance. Their adoption suggests a growing awareness of the need for interoperable identity layers in virtual environments, especially where user autonomy and trust are critical.

Similarly, the ERC-721 standard has seen uptake as a method for representing unique digital assets. Its role in powering NFTs and access tokens makes it relevant to companies exploring blockchain-based user interaction models and ownership schemes. Microsoft and Decentraland, in particular, have adopted ERC-721 to support decentralized governance and user-generated economies.

One of the more surprising findings is the recurring use of UN/EDIFACT, a standard that predates the metaverse by decades but continues to play a central role in backend supply chain and financial transactions. Companies like Amazon, Samsung, Ericsson, and Microsoft rely on this framework to manage large-scale commercial data exchange. Its presence in the Virtual Society domain underscores the importance of integrating new digital ecosystems with existing enterprise infrastructure.

Examples of virtual society domain standards and the companies that promote their implementation are provided in table 16 below.

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Table 16. Virtual society domain standards and the companies that promote their implementations

Standard	Purpose	Companies explicitly promoting implementation
UN/EDIFACT - EDI Electronic Data Interchange	automated, standardized business data exchange for supply chain integration across large enterprises	Amazon, Ericsson, Microsoft, Samsung
W3C VC Data Model (Verifiable Credentials Data Model v1.1)	decentralized identity verification and credential management	Decentraland, Huawei, Microsoft
DIDs (Decentralized Identifiers v1.0)	decentralized digital identity	Decentraland, Huawei, Microsoft
ERC-721 (Non-Fungible Token Standard)	representing unique digital assets, such as NFT-based access tickets and enterprise blockchain applications	Decentraland, Microsoft

11.3.2 Implementations by companies

Table 17 below compiles information about implementation of virtual society domain standards by the 29 companies studied for this report.

Table 17. Companies studied and their implementation of virtual society domain standards

Company	Standard(s)	Notes
Amazon	UN/EDIFACT - EDI Electronic Data Interchange	Amazon has implemented the UN/EDIFACT EDI standard for automated business document exchange with vendors, integrating it into its core supply chain and vendor management systems. No evidence of adoption for other metaverse-related standards.
Apple	None found	No evidence was found of Apple adopting any of virtual society standards identified.
Autodesk	None found	Autodesk is a founding member of the Metaverse Standards Forum, indicating support for open standards and interoperability. However, there is no direct evidence of adoption or implementation any of the virtual society standards identified.
Baidu	None found	No evidence was found of Baidu adopting any of the virtual society domain standards identified.
Bentley Systems	None found	Bentley Systems is publicly committed to open standards and interoperability, particularly in 3D data formats (e.g., 3D Tiles, glTF, USD), but there is no evidence of it adopting any of the virtual society domain standards identified.
ByteDance	None found	No evidence of virtual society domain standards implementation was found to be associated with ByteDance in the research.

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Company	Standard(s)	Notes
Dassault Systems	None found	No evidence of virtual society domain standards implementation was found to be associated with Dassault Systemes in the research.
Decentraland	W3C VC Data Model v1.1, DIDs v1.0, ERC-721	Decentraland has implemented W3C Verifiable Credentials and Decentralized Identifiers for user identity and credential verification. The ERC-721 standard is used for NFT-based access tickets and digital assets, supporting decentralized governance and interoperability.
Epic Games	None found	No evidence of virtual society domain standards implementation was found to be associated with Epic Games in the research.
Ericsson	UN/EDIFACT - EDI Electronic Data Interchange	Ericsson has adopted the UN/EDIFACT EDI standard for electronic transactions with suppliers. No evidence of adoption of other virtual society domain standards.
Google	None found	Google is a principal member of the Metaverse Standards Forum, indicating commitment to open standards development. However, there is no evidence of adoption for other virtual society domain standards.
HTC	None found	No evidence of virtual society domain standards implementation was found to be associated with HTC in the research.
Huawei	DIDs v1.0, W3C VC Data Model v1.1	Huawei has implemented DIDs and W3C Verifiable Credentials in its blockchain services and is a founding member of the Metaverse Standards Forum. No evidence of adoption for other standards in the list.
Magic Leap	None found	No evidence of virtual society domain standards implementation was found to be associated with Magic Leap in the research.
Meta	None found	No evidence of virtual society domain standards implementation was found to be associated with Meta in the research.
Microsoft	UN/EDIFACT - EDI, W3C VC Data Model v1.1, DIDs v1.0, ERC-721	Microsoft has adopted UN/EDIFACT for business document exchange, W3C Verifiable Credentials and DIDs for decentralized identity, and ERC-721 for NFT solutions within its Azure and Entra product lines.
Niantic	None found	No evidence of virtual society domain standards implementation was found to be associated with Niantic in the research.
Nintendo	None found	No evidence of virtual society domain standards implementation was found to be associated with Nintendo in the research.
Nokia	None found	No evidence of virtual society domain standards implementation was found to be associated with Nokia in the research.
NVIDIA	None found	No evidence of virtual society domain standards implementation was found to be associated with NVIDIA in the research.
PTC	None found	No evidence was found of PTC adopting any of the virtual society domain standards.
Qualcomm	None found	No evidence was found of Qualcomm adopting any of the virtual society domain standards.

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Company	Standard [s]	Notes
Roblox	None found	No evidence was found of Roblox adopting any of the virtual society domain standards.
Samsung	UN/EDIFACT - EDI Electronic Data Interchange	Samsung supports the UN/EDIFACT EDI standard for supplier data exchange, with no evidence of adoption for other virtual society domain standards.
Siemens	None found	No evidence was found of Siemens adopting any of the virtual society domain standards.
Sony	None found	No evidence was found of Sony adopting any of the virtual society domain standards.
Tencent	None found	No evidence was found of Tencent adopting any of the virtual society domain standards.
Unity Technologies	None found	Unity is a founding member of the Metaverse Standards Forum and supports open standards development but has not been shown to adopt any of the virtual society domain standards.
XReal	None found	No specific standards were found to be directly associated with Xreal in the research.

11.3.3 Gaps

The virtual society domain also shows a consistent disparity between the wide range of metaverse-related standards that have been proposed and the limited number that have been adopted by companies operating within the domain. This gap is especially visible in areas concerning accessibility, interoperability, and ethical governance.

Despite the availability of well-defined standards from organizations such as ITU-T, IEEE, ISO/IEC, and MPAI, there is no direct evidence of adoption of frameworks addressing accessibility, diversity, ethical AI design, or metaverse-specific education models. Standards like the ITU-T FG-MV series on interoperability and IoT, the CTA guidelines for inclusive design, IEEE 7000-2021 on ethically aligned AI, ISO/IEC e-learning frameworks, and MPAI's proposed metaverse models are unimplemented across the companies examined.

Similarly, although interoperability remains a key talking point across industry discourse, practical implementation of avatar and identity standards such as MPAI-PAF (Portable Avatar Format), OMA3 IWPS (Inter-World Portaling System), and IEEE 3812.1 (Metaverse Identity Framework) has yet to materialize.

More specialized standards—including cryptographic credentialing models like TIPF CESR, ACDC, KERI, LF DT AnonCreds, ISO/IEC DIS 9234, and the W3C VC Data Model version 2.0—also show no signs of adoption. Their novelty, ongoing development status, and narrow application scope likely contribute to the absence of implementation in current platforms.

Finally, there is a notable distinction between participation in standardization forums and actual implementation. Companies such as Autodesk, Google, NVIDIA, and Unity are active or founding members of standards initiatives, suggesting a strategic interest in shaping standards. Yet this involvement does not appear to translate into the use of those standards in real-world products and services, highlighting the divide between conceptual engagement and operational commitment.

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12 Virtual economy

12.1 Introduction

The Virtual Economy refers to the buying and selling of goods and services within virtual environments, including both digital and physical items. It uses systems of interconnected components that drive economic activities, transactions, and business models facilitated between entities (e.g. organizations, people and agents) within digital and mixed (digital-physical) environments. Participants can register with appropriate authorities and use tools to engage in exchanges of assets, experiences and services permitting the creation and fluctuations of value through a variety of immersive and decentralized platforms.

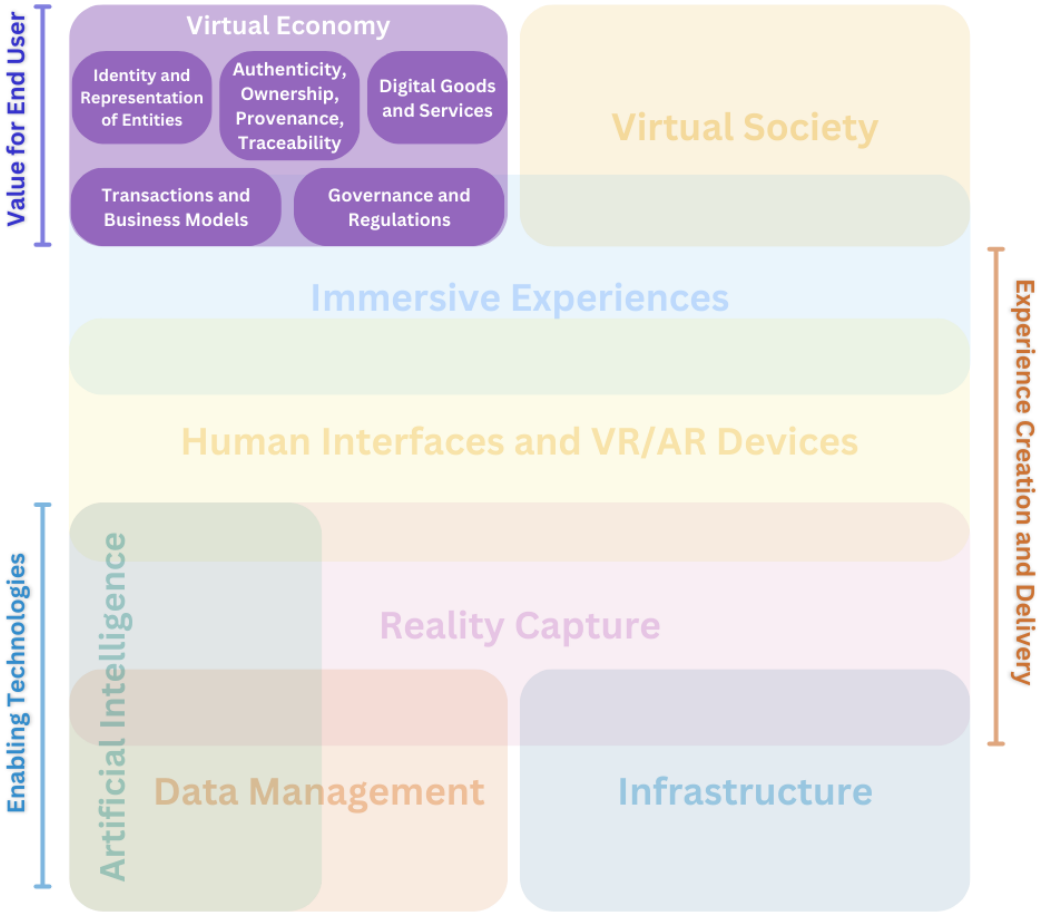


Figure 9: Components of the virtual economy domain

The five components of the virtual economy domain include:

- The identity and representation of entities component covers all technologies for the creation and maintenance of credentials and data that verifiably establish and maintain an entity's identity for the purpose of representation in one or more virtual world platforms, and in experiences where value can be exchanged.
- The verification of authenticity, ownership, provenance and traceability component covers any means of making assertions for the purpose of claiming or confirming authenticity, origins and transfer of digital assets, and preventing fraud or theft.
- The digital goods and services component encompasses all digital assets and services that entities can buy, sell, or trade in virtual environments.

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- Transactions and business models pertaining to all aspects of buying, selling, and trading digital assets or services within immersive environments are the focus of this component.
- Governance and regulations component covers all rules and processes of decision-making that affect the way in which powers are granted, exercised and rescinded in virtual world platforms and experiences to protect financial instruments and support administrative structures established for economic activities.

The ViWISSO Standards Landscape Report provides detailed explanations of these components and the topics they cover.

12.2 Virtual economy domain standards overview

The standards shaping the virtual economy cover a wide range of technical layers, from blockchain and digital identity to content authenticity, smart contracts, and supply chain traceability. Ethereum token protocols—ERC-20 for fungible tokens, ERC-721 for NFTs, and ERC-1155 for hybrid asset management—form the foundation for digital asset representation in virtual environments. Content provenance is addressed by the C2PA specification, which provides cryptographically verifiable metadata for authenticity and trust in AI-generated media.

For identity and credentialing, the W3C Verifiable Credentials models and DIF DID extensions define how users and systems can issue, verify, and manage identities and claims in decentralized ecosystems. Selective disclosure is further enabled through IETF's SD-JWT.

The GS1 GLN and traceability standards offer robust tools for tracking assets across both physical and virtual supply chains, while ISO 4217 ensures consistent currency representation in payment systems. DASH-IF CPIXF adds a layer of secure digital rights management in streaming and content delivery workflows.

Other standards, such as those from ISO, IEEE, and ITU-T, provide frameworks and taxonomies for blockchain governance, multimedia protection, smart contracts, and metaverse architecture. Meanwhile, interoperability across distributed systems is supported by Hyperledger Cacti and TIPF protocols like ACDC and KERI.

OMA3's proposals for inter-world identity and token persistence, as well as IAB's OpenMedia for advertising telemetry, reflect the growing need for standardization in user experience, commerce, and data portability across platforms. Together, these standards build the infrastructure needed for secure, interoperable, and trustworthy economic activity in the metaverse.

12.3 Implementation

12.3.1 Introduction

The analysis of data performed for this report shows that only a few of the investigated virtual economy standards has seen implementation by the companies studied. Among the most frequently adopted are the Ethereum token defacto standards—ERC-20 for fungible assets, ERC-721 for non-fungible tokens, and ERC-1155 for batch asset management—which form the backbone of virtual currencies and NFT ecosystems.

The C2PA Technical Specification also stands out as a key standard, used for verifying the authenticity and provenance of digital content across multiple platforms and devices. In parallel, GS1 standards (GLN and Traceability) are being used by Siemens and Tencent to manage product identity and logistics, bridging physical and digital commerce. DASH-IF CPIXF supports secure media streaming and DRM interoperability, while ISO 4217 provides essential structure for representing currency in digital transactions.

Some identity-focused standards, most notably the W3C Verifiable Credentials Data Model and DIF DID Spec Extensions, which underpin decentralized identity systems, have also begun to see adoption for virtual economy use cases.

Examples of virtual economy domain standards and the companies that promote their implementation are provided in table 18 below.

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Table 18. Virtual economy domain standards and the companies that promote their implementations

Standards	Companies that explicitly promote implementations
ERC-20, ERC-721, ERC-1155 (Ethereum Token Standards)	ERC-20 adopted by Amazon, Decentraland, HTC, Samsung. ERC-721 by Amazon, Decentraland, Microsoft, Samsung. ERC-1155 by Decentraland. These standards support fungible and non-fungible token economies, enabling virtual currencies, NFTs, and efficient asset management in metaverse platforms.
GS1 Standards (GLN, Traceability)	GS1 GLN adopted by Amazon, Microsoft, Siemens. GS1 Traceability by Tencent. Used for supply chain, logistics, product identification, and asset traceability in both physical and virtual contexts.
DASH-IF CPIXF (Content Protection Information Exchange Format)	Adopted by Amazon, Microsoft, Nokia. Provides secure content encryption, DRM interoperability, and protection for streaming media.
ISO 4217 (Currency Codes)	Adopted by Apple and Unity Technologies. Used for representing currencies in digital transactions, in-app purchases, and financial reporting systems.
W3C VC Data Model & DIF DID Spec Extensions	Adopted by Microsoft. These standards enable decentralized identity, verifiable credentials, and trust frameworks across platforms.
Algorand Algo (Algorand Blockchain Features)	Adopted by Siemens. Supports industrial automation and blockchain-triggered transactions with low-latency consensus and stateless smart contracts.
IAB OM (OpenMedia)	Adopted by Samsung. Used for connected TV advertising measurement and telemetry across digital media environments.

12.3.2 Implementations by companies

Table 19 below compiles information about implementation of virtual economy domain standards by the 29 companies studied for this report.

Table 19. Companies studied and their implementation of virtual economy domain standards

Company	Standards	Notes
Amazon	C2PA Technical Specification, DASH-IF CPIXF, ERC-721, ERC-20, GS1 GLN	Amazon is a leader in implementing both content provenance (C2PA) and secure media streaming (DASH-IF CPIXF). It supports Ethereum token standards (ERC-20, ERC-721) for blockchain and NFT infrastructure via AWS, and GS1 GLN for global supply chain management. No evidence of adoption of other virtual economy standards.
Apple	ISO 4217	Apple implements ISO 4217 for currency codes across its platforms (Apple Pay, App Store, APIs). No evidence of adoption of other virtual economy standards.
Autodesk	C2PA Technical Specification	Autodesk is compliant with C2PA for content authenticity and provenance. It is active in metaverse standards advocacy but has not adopted other virtual economy standards.
Baidu	None found	No evidence of adoption, implementation, or contribution to any of the virtual economy standards.
Bentley Systems	None found	Bentley supports open standards generally but not in any of the specific standards from the virtual economy domain.

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Company	Standards	Notes
ByteDance	C2PA Technical Specification	ByteDance, through its subsidiary TikTok, has publicly adopted and implemented the C2PA Technical Specification (Content Credentials) standard for labeling AI-generated content. TikTok is the first video sharing platform to implement C2PA's Content Credentials technology, automatically labeling AI-generated content uploaded from other platforms and attaching Content Credentials to content created on TikTok. This initiative is part of a broader industry effort to increase transparency and authenticity in digital media, and ByteDance is actively driving industry adoption of this standard.
Dassault Systems	None found	No evidence of adoption, implementation, or contribution to any virtual economy standards.
Decentraland	ERC-20, ERC-721, ERC-1155	Decentraland is a model adopter of Ethereum token standards, using ERC-20 for its currency (MANA), ERC-721 for LAND NFTs, and ERC-1155 for batch asset management.
Epic Games	None found	No evidence of adoption, implementation, or contribution to any virtual economy standards.
Ericsson	None found	No evidence of adoption, implementation, or contribution to any virtual economy standards.
Google	C2PA Technical Specification	Google is a steering committee member and adopter of C2PA, implementing it in Search, Ads, and exploring further integrations.
HTC	ERC-20	HTC implements ERC-20 token support in its Exodus blockchain smartphone, enabling in-wallet token swaps.
Huawei	None found	No evidence of adoption, implementation, or contribution to any virtual economy standards.
Magic Leap	None found	No evidence of adoption, implementation, or contribution to any virtual economy standards.
Meta	C2PA Technical Specification	Meta is a C2PA steering committee member and is implementing C2PA Content Credentials across its social platforms for AI-generated content provenance.
Microsoft	C2PA Technical Specification, DASH-IF CPIXF, W3C VC Data Model v1.1/v2.0, DIF DID Spec Extensions, ERC-721, GS1 GLN	Microsoft is a major adopter of content provenance (C2PA), secure streaming (DASH-IF CPIXF), decentralized identity (W3C VC, DIF DID), NFT standards (ERC-721), and GS1 GLN for supply chain management.
NVIDIA	None from the provided list	No evidence of adoption, implementation, or contribution to any virtual economy standards.
Niantic	None found	No evidence of adoption, implementation, or contribution to any virtual economy standards.
Nintendo	None found	No evidence of adoption, implementation, or contribution to any virtual economy standards.

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Company	Standards	Notes
Nokia	DASH-IF CPIXF	Nokia is active in MPEG/DASH standardization and implements DASH-IF CPIXF for streaming and volumetric video.
PTC	None found	No evidence of adoption, implementation, or contribution to any virtual economy standards.
Qualcomm	C2PA Technical Specification	Qualcomm integrates C2PA authentication in its Snapdragon platform, enabling secure, on-device content provenance for AI-generated media.
Roblox	None found	No evidence of adoption, implementation, or contribution to any virtual economy standards.
Samsung	C2PA Technical Specification, ERC-20, ERC-721, IAB OM	Samsung is the first smartphone OEM to natively implement C2PA. It supports ERC-20 and ERC-721 tokens in its blockchain SDK and has adopted IAB OM for CTV ad measurement.
Siemens	Algorand Algo, GS1 GLN	Siemens implements Algorand blockchain features for industrial automation and GS1 GLN for global supply chain and healthcare product identification.
Sony	C2PA Technical Specification	Sony is a C2PA steering committee member and is implementing C2PA in its camera hardware for in-camera content authenticity.
Tencent	GS1 Traceability	Tencent implements GS1 Traceability standards for product and data traceability in logistics and e-commerce.
Unity Technologies	ISO 4217	Unity uses ISO 4217 for currency codes in its in-app purchasing systems.
XReal	None found	No evidence of adoption, implementation, or contribution to any virtual economy standards.

12.3.3 Gaps

Very few of the investigated standards show evidence of reference, or implementation among the companies analysed in the context of the virtual economy. The standards that could be relevant include a range of specifications across digital identity, blockchain infrastructure, industrial metaverse architectures, and data interoperability protocols.

Among the identity-related standards, the DIF VS JSON specification for verifiable credentials and the IETF SD-JWT for selective disclosure tokens are not currently adopted. Similarly, the DOI Resolution Protocol and IEEE 2874, which facilitate persistent linking of digital objects, remain unreferenced.

Several IEEE standards—namely IEEE 3800, 3812.1, 3305, and 2874—propose metaverse and data trading architectures but lack any implementations. The same is true for the financial messaging standards ISO 20022-1 and ISO 15022-1, as well as key blockchain-related ISO documents including ISO 22739:2024, ISO 23257:2022, ISO/TS 23635:2022, and ISO 23258:2021.

Technical frameworks under ISO/IEC, such as those addressing multimedia contracts and intellectual property management (e.g., ISO/IEC 21000-4, 21000-20, 21000-23, 23093-2, 14496-13), also appear absent from current implementations. This includes ISO/IEC TS 5928:2023, which defines taxonomies for digital platforms.

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In the realm of metaverse governance and interoperability, the Linux Foundation's Hyperledger Cacti and the MPAI suite—comprising Functionality Profiles, Functionalities, and the Metaverse Model (MMM-TEC)—show no signs of adoption.

Emerging initiatives like OMA3's Inter-World Portaling System (IWPS) and Soulbound Token Shield (SBT), the OMG standards for digital receipts and currency specification, and TIPF's cryptographic event and data container formats (CESR, KERI, ACDC) are also currently unadopted.

Finally, the long-established UN/EDIFACT Electronic Data Interchange (EDI) standard, while widely used in traditional commerce and appeared in the virtual society domain, does not appear in virtual economy implementations reviewed in this analysis.

13 Conclusion

The current landscape of metaverse standards reveals very low adoption of the standards available in each of the eight domains studied. While a handful of technical specifications—such as Khronos OpenXR for runtime interoperability, Khronos glTF for 3D asset delivery, or IEEE 802.11 for WiFI connectivity— have achieved widespread implementation, most standards are not adopted. These include frameworks for ethical AI, accessibility, content provenance, verifiable identity, and metadata structuring. The reasons for these gaps are complex and multifaceted.

One of the most immediate explanations lies in the fragmented nature of the metaverse itself. Unlike mature industries, the metaverse is still rapidly evolving. Another challenge is that it spans a wide array of technologies—ranging from immersive displays to AI reasoning, blockchain-based economies, and decentralized identity management. Standards that may be essential in one subdomain (for example, ISO/IEC 23247 for digital twins in industrial contexts) are irrelevant or redundant in another, such as virtual social platforms or gaming environments. As a result, companies tend to prioritize those standards that align most directly with their commercial products and priorities, often ignoring or delaying the implementation of others.

In many cases, the limited adoption can also be attributed to the immaturity of the standards ecosystem. A number of the specifications examined are either recent publications or still in flux, undergoing revisions or development within standardization bodies. Companies are hesitant to commit to frameworks that have not yet reached technical or community consensus. This is especially visible in emerging areas such as decentralized identity (e.g. SD-JWT, DID) and ethical governance frameworks (e.g. IEEE 7000 series. The fear of investing in soon-to-be-obsolete or insufficiently supported technologies tends to reinforce a cautious wait-and-see approach.

Beyond technical readiness, competitive dynamics also play a crucial role. Many of the largest technology firms have built proprietary ecosystems—complete with SDKs, runtime environments, developer tools, and monetization pipelines. Apple, for instance, continues to promote its own frameworks for AR (such as ARKit and visionOS) instead of fully embracing open standards like WebXR. In such contexts, adopting open protocols might be perceived as reducing control over user experience or diluting a strategic advantage. Proprietary solutions often offer more vertical integration, better optimization, or more immediate support than generalized standards, reinforcing the incentive to build inward rather than adopt broadly.

Equally important is the lack of strong market incentives or external pressure to adopt many of these standards. In areas like accessibility, ethical AI, or identity interoperability, the absence of regulatory mandates means that implementation is often voluntary—and therefore low on the priority list unless there is public scrutiny or commercial benefit. While these standards are often well-designed and grounded in important principles, their real-world impact depends on broader uptake and the presence of systemic incentives, which are currently missing or underdeveloped.

Another contributing factor is the complexity involved in implementing many of the standards. Even those that address clear problems—such as interoperable avatars or cross-platform portaling—can require substantial engineering effort to integrate into existing systems. In the absence of robust tooling, developer libraries, or active support communities, companies may postpone adoption simply due to the resource burden. This is compounded by legacy systems or infrastructure choices that are not easily aligned with newer protocols, especially in large organizations with established pipelines.

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Additionally, the gap between support and actual implementation should not be overlooked. Several companies express public endorsement of open standards or participate in working groups like the Metaverse Standards Forum, yet offer no clear evidence of real-world usage or deployment. This kind of performative alignment—where support is rhetorical but not technical—suggests a degree of strategic ambiguity. Companies may wish to influence the development of standards without immediately committing to the costs of implementation.

Finally, geopolitical and regulatory fragmentation also affects the adoption landscape. Different regions may prioritize different frameworks depending on their national policies, privacy laws, or economic strategies. Chinese companies, for instance, may align with domestic standards or consortia not covered by global inventories, while European actors may be more inclined toward ISO/IEC compliance due to regional directives. This lack of harmonization introduces yet another layer of friction to global standardization efforts.

In summary, the gaps in adoption are not entirely a matter of oversight or lack of awareness. They reflect a deep structural tension between ambition and implementation, between the promise of interoperability and the realities of product development, strategic positioning, and institutional inertia. Overcoming these gaps will require not only better standards, but also clearer incentives, more robust tooling, and greater alignment between public and private sector priorities.

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