

# The Web of Worlds (WoW) Whitepaper

Enabling an open, decentralized and efficient Metaverse  
on the Open Web Platform

**Metaverse Standard Forum**  
**3D Web Interoperability Domain Group**

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**Metaverse**  
**STANDARDS FORUM™**

## Abstract

This whitepaper introduces the concept of a “Web of Worlds” – a platform made up of many addressable, linked spatial experiences (i.e., virtual worlds) that are interconnected, much like today’s websites form the open World Wide Web. By giving each spatial asset and each spatial experience a minimal 3D semantic and identifier, users can move seamlessly from one virtual environment to another, creating a unified, immersive virtual universe. The motivation for this work is described in the Metaverse Standards Forum Blogs:

- [Building The World Wide Webiverse - Metaverse Standards Forum](#)
- [Linked Spatial Experiences: The Web of Worlds - Metaverse Standards Forum](#)

1.	Introduction — the outer world .....	2
1.1	The Metaverse .....	2
1.2	The "Open Web Platform (OWP)" .....	2
1.3	legal requirements and framework .....	5
2.	3D Web Interoperability Working Group .....	5
2.1	Process and Deliverables .....	6
2.2	Use Case Summaries .....	7
2.3	Requirements .....	10
2.	Gap Analysis: Building a Web of Worlds .....	12
4.	Web of Worlds .....	14
4.1	Core building blocks & goals .....	16
4.2	Scope & foundation .....	19
4.4	Principles and Parsimony .....	26
5.	Outlook .....	30

# 1. Introduction — the outer world

## 1.1 The Metaverse

The **Metaverse** is a collective term for a network of immersive, interactive, and persistent **virtual worlds** where people can **socialize, work, play, and create**. It blends elements of virtual reality (VR), augmented reality (AR), and the internet into a shared digital environment.

### Core Concept

The Metaverse is envisioned as a 3D version of the internet, where instead of browsing websites, you **move** through virtual worlds as a digital representation of yourself (using your avatar, preferences, wearables, etc., depending on the Metaverse experience you are visiting). These virtual worlds can host games, meetings, concerts, classrooms, and more — all in real time with other users.

### Vision versus Reality

While the common **idea** is to have a unified, interoperable metaverse — where users can move seamlessly between virtual worlds — the **current reality** is fragmented. Different companies and platforms operate their own “mini-metaverses.” [Havele et al 2022]. Open Web technologies provide an alternative [Havele et al 2023],

## 1.2 The "Open Web Platform (OWP)"

Open Web Platform: the entire collection of royalty-free, open-standard technologies that allow the internet to function for everyone. The platform is not controlled by a single entity, allowing anyone to build software for the web without requiring permission or license fees. Defined as a cornerstone of World Wide Web Consortium (W3C),

### *The promise of web standards*

*W3C standards define an open web platform for application development. The web has the unprecedented potential to enable developers to build rich interactive experiences that can be available on any device. [W3C Web Standards](#)*

The 3D Web Working Group at MSF recognizes the principles, architecture, and Standards from the W3C and other standards organizations focused on open standards in support of the "Open Web Platform" (Table 1).

**Table 1 : Standards Table by Organization**

Organization	Standards / Specifications
W3C (World Wide Web Consortium)	<ul style="list-style-type: none"> <li>• <a href="#">Open Web Platform</a></li> <li>• <a href="#">Design Principles</a></li> <li>• URI</li> <li>• <a href="#">WebXR</a></li> <li>• OAuth (W3C liaison; spec hosted by IETF but used in W3C ecosystems)</li> <li>• <a href="#">Decentralized Identifiers (DID)</a> (V1.0, <a href="#">V1.1</a>)</li> <li>• <a href="#">DID Resolution (DID) (V0.3)</a></li> <li>• <a href="#">DID Methods</a></li> <li>• <a href="#">Verifiable Credentials (VCs)</a></li> <li>• <a href="#">JSON-LD</a></li> <li>• <a href="#">Web App Manifest</a></li> <li>• <a href="#">User Agent Accessibility Guidelines</a></li> <li>• <a href="#">html model element</a></li> </ul>
Web3D Consortium / ISO/IEC	<p><a href="#">X3D Recommended Standards</a></p> <ul style="list-style-type: none"> <li>• ISO/IEC 19775 — Scene Graph Content Model</li> <li>• ISO/IEC 19776-* — File Encodings</li> <li>• ISO/IEC 19777-* — Programming Language Bindings</li> <li>• ISO/IEC 19774-* — HAnim (Humanoid Animation)</li> </ul>
Khronos Group	<ul style="list-style-type: none"> <li>• <a href="#">glTF</a></li> <li>• <a href="#">webgl</a></li> <li>• <a href="#">OpenXR</a></li> </ul>
OGC (Open Geospatial Consortium)	<ul style="list-style-type: none"> <li>• OGC API (family of standards)</li> <li>• GeoPose</li> <li>• 3D Tiles</li> </ul>
IANA (Internet Assigned Numbers Authority)	<ul style="list-style-type: none"> <li>• Model-x Content Type Registry (MIME Types)</li> </ul>

## Core Principles

The open web is defined by several important principles:

- **Universality:** The web is independent of any technical constraints, language, character sets, or culture. Anyone can publish anything without needing permission from a central authority.
- **Decentralization:** There is no single point of control or failure, which has been critical to the web's growth and is essential for its future.
- **Open standards:** The underlying specifications for web technology are developed openly, with broad participation, ensuring interoperability between browsers, devices, and platforms.
- **Accessibility:** Content created on the open web should be accessible to all people, regardless of ability or language.

## Open Web vs. Closed Platforms

The concept of the open Web is often contrasted with "walled gardens"—closed, proprietary platforms run by companies.

	Open Web	Closed Platforms (Walled Gardens)
Control	Governed by open, non-proprietary standards developed by consensus (e.g., W3C and Web3D).	Controlled by a single lead company that sets the rules and controls the ecosystem for engaged partners.
Access	Content is openly indexed and accessible via standard web browsers and search engines.	Content is often restricted to that platform and its proprietary tools. Access agreements are time limited.
Innovation	Encourages broad innovation, as anyone can read, share, build, and publish using the platform.	Limits innovation to a select few developers working within the platform's constraints.
Interoperability	Built on technologies designed to work across different browsers and devices for any user.	Often lacks interoperability with other platforms, locking users into a single ecosystem.

## 1.3 legal requirements and framework

### EU initiative on web 4.0 and virtual worlds

The [EU initiative on Web 4.0 and virtual worlds](#) is one of the next technological transitions. The EU Commission has adopted a strategy for **Web 4.0 and virtual worlds** to guide this transition and ensure an **open, secure, trustworthy, fair, and inclusive digital environment** for EU citizens, businesses, and public administrations.

**Virtual worlds: persistent, immersive environments** based on **3D** and extended reality (**XR**) technologies.

**Web 4.0: digital and real objects** and environments integrated and communicating between each other, enabling **immersive experiences**.

The European Partnership for Virtual Worlds, a €400 million initiative spanning from 2025 to 2027, is a collaborative effort between the European Commission and the [Virtual Worlds Association](#) (VWA). Its primary objective is to develop **secure, sustainable, and human-centric XR** and digital twin technologies within the **framework of Horizon Europe**. This initiative aims to enhance **industrial competitiveness and technological sovereignty across Europe**.

### Industrial Digital Twin

The [Industrial Digital Twin Association](#) (IDTA), a non-profit industry consortium, is responsible for developing and maintaining the Asset Administration Shell (AAS) standard—the industry’s standardized digital twin framework. Recently, IDTA has introduced new standards that incorporate CAD and simulation data as 3D geometry assets.

- [IDTA 02005-1-0 Provision of Simulation Models](#), Dec 2022
- [IDTA 02026-1-0 Provision of 3D Models, June 2024](#), Jun 2024

Both are standard links to external packages containing data for CAD and simulation domains.

### Industrial Data Spaces

The [International Data Space](#) and [Catena-X](#) is a data ecosystem that enables companies across the value chain to exchange data securely and in a standardized way.

Catena-X is an operational data space for digital twins that now also [supports 3D Data in the Engineering domain](#).

- Catena-X / Tractus-X, [Geometry KIT](#), Dec 2025

The embedded ontology facilitates a scene node hierarchy, which subsequently references external data elements as geometry objects.

## 2. 3D Web Interoperability Working Group

This whitepaper describes how a 3D Web Interoperability vision is layering and compositing of many open standards that together meet the needs of a wide range of Metaverse Standards Forum (MSF) Use Cases.

The Working Group developed and ratified the following Use Cases, which motivate our first project and SDO advocacy agenda, the Web of Worlds:

### 2.1 Process and Deliverables

#### Working Group Scope and Process

The Forum's 3D Web Interoperability Working Group is focused on how to leverage and extend existing web standards to enable the metaverse, and is following a well-defined and rigorous process:

1. After our Working Group Charter was approved by the Metaverse Standards Forum's Oversight Committee, we first developed a set of scenarios focused on the metaverse and the 3D Web. Together, these illustrate many user requirements: consistency of experience, portable personal content, metaverse bookmarks. We also considered use cases such as virtual field trips, and safety simulations.
2. We then conducted a Technology Pattern Inventory – examining current and emerging Web and interactive 3D Standards. We hosted guest speakers and presentations, including updates from the W3C, Web3D, Khronos, and MPEG standards organizations.
3. The last step was a Gap Analysis, which contrasted the requirements from our use cases, which led us to scope our first projects for the group's work agenda and roadmap.
4. This work continues to evolve as Forum stakeholders and Working Group members bring their requirements and use cases to the cross-cutting perspective of web standards—that examines issues, themes, or problems across different domains, disciplines, and categories, rather than viewing them in isolation.

#### Working Group Roadmap

As the Working Group work continues, we will evolve and refine additional use cases from Forum members, feeding a user-centered design process that ensures we are solving industry-relevant problems. Specifically, our use cases illustrate the requirements by which we can evaluate evolving standards. For example:

1. **Mechanisms to link and reference complete or partial virtual worlds**  
Problem Statement: use cases demonstrate various ways to link virtual and physical worlds. How can we distinguish these modes and their requirements?
2. **Functional profiles for metaverse applications – content interoperability**  
Problem Statement: 3D scenes are built from various resources, from geometry and materials to lighting, sensors, and rich content models. How can we define levels of 3D functionality?

### 3. **Role-based access and encryption of assets**

Problem Statement: the metaverse must include capabilities for both network and data security. What standards and options govern these? What are their limitations? How does the metaverse infrastructure enable trust, ownership, previewing, and monetization?

### 4. **3D User Agent ( browser ) investigation**

Problem Statement: a user agent is software that interprets a text string from a Web server on behalf of the user. What capabilities could be added to the user agent to enable an accessible metaverse?

### 5. **Efficient delivery of 3D experiences**

Problem Statement: how to review and evaluate the current solutions for delivering 3D assets and experiences (X3D, glTF, 3DTiles, USDz) and how to identify gaps and requirements.

## 2.2 Use Case Summaries

### i. **Hello Metaverse**

This Use Case illustrates essential requirements for Metaverse interoperability, centered on a basic data metadata packet to establish “dial tone” connectivity with a Metaverse Service. The protocol first declares the basic content summary (for example, age-appropriate thumbnail and content declaration including coordinate-system origin and units of measure). A secondary schema can specify the content of its payload for an interactive graphics scene graph (for example, Functional Profiles corresponding to X3D Components and Profiles, and similarly for glTF Version and Extensions).

### ii. **Metaverse Bookmarks**

Users need persistent, reliable ways to revisit and share meaningful locations and experiences across virtual, augmented, and physical spaces. Current URL systems are limited in representing a user’s exact viewpoint or context within immersive environments. This use case explores enhanced bookmarking methods that extend traditional web addresses to capture spatial coordinates, viewpoints, and even temporal states. By enabling “metaverse bookmarks,” users could:

- Save and return directly to specific virtual places (e.g., an art gallery or concert venue).
- Share immersive experiences with friends, even after environments evolve or events conclude.
- Embed location metadata into media (e.g., screenshots or social posts) so others can discover the original context.
- Connect physical places with their historical or augmented digital overlays.
- Support collaborative, synchronous activities in custom 3D worlds.

The goal is to establish interoperable, extensible standards for persistent addressing in the metaverse, ensuring that digital spaces remain accessible, navigable, and meaningful over time.

### iii. **Portable Personal Content**

Portable personal content allows interactive 3D assets—complete with lighting, behaviors, and familiar controls—to move seamlessly across different metaverse environments. These assets, whether

jewelry, tools, or vehicles, remain functional and recognizable as users carry them from one “microverse” to another.

Consistency is key: interaction metaphors, animations, and affordances should behave predictably across platforms. For example, a vehicle brought into the metaverse should have headlights that illuminate, wheels that roll, and steering that responds within realistic ranges. Similarly, a wearable like a necklace may animate to reveal hidden features or emit light when activated, ensuring intuitive and repeatable experiences.

This use case emphasizes the need for interoperable standards in asset representation—including geometry, appearance, lighting, sensors, and behavior graphs—so that personal digital content is portable, trustworthy, and usable across diverse metaverse worlds.

#### **iv. 3D Web Field Trips**

This use case demonstrates how 3D Web interactive graphics—including spherical panoramas, 3D models, maps, and immersive audio—can power virtual field trips for remote learning. By combining photo and video spheres with interactive 3D environments, educators can visually transport students to real-world locations for exploration, teaching, and collaboration.

The solution is cross-platform, supporting web browsers, mobile devices, VR headsets, and immersive CAVE systems, ensuring accessibility regardless of hardware. Spatialized audio and environmental effects enhance realism, creating compelling, multisensory experiences. These virtual field trips enable students and professionals to conduct observations, measurements, and collaborative activities remotely, expanding access to otherwise difficult or restricted environments.

#### **v. Consistency of Experience**

This use case addresses the need for consistency of Metaverse experiences. Visitors should be able to access the same virtual world through a web browser on any device — whether PC, smartphone, VR headset, MR headset, or AR/MR glasses — and enjoy a consistent, seamless experience. Core elements such as environment scale, object behavior, avatar appearance, accessibility, and interactivity remain uniform across platforms, while adapting appropriately to each device’s capabilities and the creator’s design intent (e.g., full immersion in VR).

This cross-platform consistency ensures that:

- Environments and objects are correctly scaled and interact realistically with physics and collision detection.
- Navigation and controls adjust to the device (keyboard, touch, controllers, gestures, BCI).
- Avatars maintain accurate height, clothing, animations, and lip-sync across devices.
- Multiplayer synchronization delivers smooth, low-latency interactions, with avatars and objects behaving consistently for all participants.
- Security, network performance, and payment processes remain reliable and uniform.
- The overall result is an enhanced sense of immersion and realism, regardless of device type.

By enabling visitors to join the same virtual experience together — whether in fully virtual or mixed reality scenarios — or even a visitor visiting an individual AR/VR experience - this use case demonstrates how cross-platform interoperability strengthens user experience, accessibility, and trust in the 3D Web. This Use Case also exemplifies the requirements for the specification of a 3D User Agent and personal wallet/payload.

#### **vi. Metaverse Universal Manifest**

This use case focuses on the Digital representation of YOU, which requires more than just your avatar in order for you to enjoy true digital presence consistency.

The Universal Manifest holds the metadata and links that form the parts of Digital YOU, enabling digital presence consistency across Metaverse experiences, and removing the need for a separate user set-up for each digital experience. This moves the visitor's experience in the Metaverse as close as possible to that in the real world but with the benefits of the digital world. Metadata and links would, for example, include: -

- Avatar and apparel
- Accessories
- NFTs, Smart Contracts
- Payment methods - currency, store cards, discount cards
- Preferences - clothing choice per experience category (e.g. work, shopping), preferred language, preferred currency
- Consent - usage of personal information, microphone access, other player interactions/communications
- Security and access - access cards, event tickets, verifiable credentials, zero-knowledge proofs
- Personal information - delivery address, clothing sizes, height

It is intended that the visitor would own their own data with a privacy-by-default approach, and that only the data required for a Metaverse experience would be accessible to that experience, thereby protecting visitors and their data in the Metaverse.

#### **vii. AI Agents**

AI agent and human in the same "world" as collaborative partners

Basic collaborative workflow for industrial DMU use case.

- **AI creates "World" and enriches it with "Spatial Asset" on the left**
- **AI also uses "spatial computing" function via MCP to compute features**
  - i. **AI computes minimum distance between 2 objects**
- **AI shares the results as a "link to world" with user**

## 2.3 Requirements

These new Use Cases allow us to derive requirements for the Metaverse standards ecosystem on the Web Platform.

These requirements fall into 2 main areas (1) is in relation to the interoperability of 3D worlds, and (2) is the need for digital presence consistency when visiting or accessing 3D worlds.

In terms of interoperability of 3D worlds, important foundations can be found in the URL support of [Anchors](#) and [Inlines](#), which have been in Web3D scene graphs since VRML2.

Requirements are:

### i. **Linked Spatial Assets**

1. A single URI can provide a reference to a single asset instance, which itself might be a *composition of models and scenes (e.g. X3D Inline scene which in turn connects other scenes and models)*.
  - i. Store & bookmark the URI for later use
  - ii. Share the URI with a second user
  - iii. Access to deliver Web Audio and spatialized sound
2. Asset instances can be linked to other instances with any number of URIs
3. The asset can use any number of 3D formats to encode the data payload

### ii. **Linked Spatial Experiences**

1. A single URI can be used to share a single 3d experience (*jump from experience to experience e.g. X3D Anchor*)
2. Existing Web stacks provide authentication and encryption

### iii. **Efficient delivery of Spatial Experiences**

1. Big data can live on the server, in the distributed clouds as an authenticated service. Some models can include data-driven customizations. Digital signatures for authenticity, and data encryption for privacy, can each be applied when appropriate as part of a content package. Multiple interoperable formats can be compressed, streamed, or simply transferred using the Web infrastructure.

In terms of consistency for digital presence, we need a mechanism for a human user to travel “to and between” virtual worlds / experiences, taking with them their data (including avatar, preferences, assets, etc.). We also need a mechanism for a non-human (AI Agent) to access these worlds, with similarly structured identification metadata, to perform other activities such as maintenance.

Therefore, requirements are:

### i. **User (Digital YOU) Transportation and Data Manifest**

1. Security core principles
  - Ownership: You own your own data – self sovereign identity

- Permissions: You decide who has access to your data (on a per data item basis) and when – privacy-by-default
  - Data location: No reliance on a single authority – decentralized storage
2. User Data Manifest
    - Storage of users' data such as avatar links, wearables links, preferences, consent flags, fiat/crypto payment handles, NFT pointers, VC's (or pointers to them), public profile fragments, and privacy metadata.
    - Should use a simple standards-based format for greater interoperability and adoption
  3. Mechanism to transport User Data Manifest and interact with virtual worlds
    - Web-based decentralized transportation
    - Presentation of user manifest data to the virtual world
    - Allow for minimum data sharing
    - E.g. a user's DID-enabled digital wallet to provide user information, verifiable credentials, and zero-knowledge proofs, when the user is visiting virtual worlds.
- ii. **Non-human (AI Agent) functionality**
1. Follows the same standards, API methods, and norms that are required of human users
  2. ....

### 3. Gap Analysis: Building a Web of Worlds

For a Metaverse connected by the Web, many Standards exist today that are not necessarily complete but are collectively the functionality needed to support a full stack of capabilities.

These Standards are in place and proven to support rich applications and innovation in current ecosystems. Some emerging standards are focused on improving performance on client-side hardware (i.e. WebGL, WebGPU, WASM); similarly, WebXR and user devices. Others are working with a scene graph and 3D payloads (i.e. X3D, glTF), deeply provisioned services, and User Interfaces up to the level of the Document Object Model (DOM) API for the HTML page.

Therefore, to best reduce friction today, our assessment is to provide a light API that can use the plumbing of existing Standards across the Web, the power of the cloud, and the power of modern interactive rendering. This glue layer will work across native and Polyfill Apps in full alignment with the WWW. It will support new service-based models that make an abstraction from formats whilst keeping the user's safety and PII (Personally Identifiable Information) a priority: Assets and Experiences via the WebOfWorlds (WoW) API.

Although several metaverse applications based on the Open Web Platform (OWP) already exist, closed solutions primarily built on game engine technology dominate the market. Existing OWP solutions are often **complex** and **require experts** to adapt them to new use cases. Closed **gaming solutions**, on the other hand, often offer improved portability and feasibility because they directly implement concepts such as spatial composition, collaboration, and avatars.

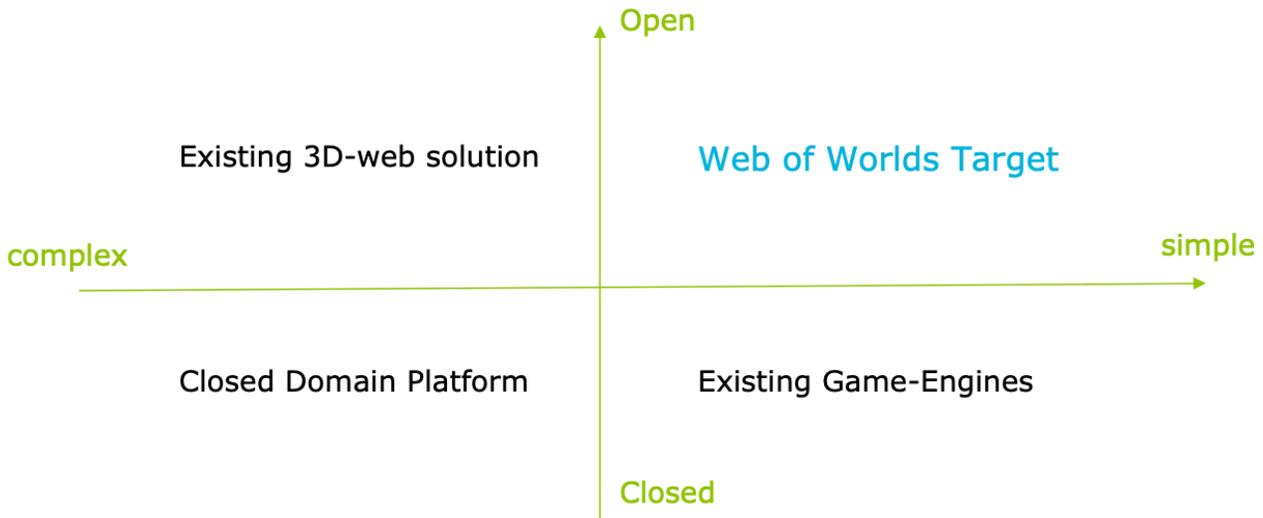


Figure 1 We envision a novel layered and open architecture that builds upon OWP principles and standards, yet provides new, simplified, and direct solutions for virtual worlds on the web

The ability to **directly map the core concepts of use cases as OWP data aspects**, thus **enabling openness, feasibility, and practicality, is lacking**.

In addition, we need to be able to support the user moving between virtual worlds. For this, we already have security, storage, and transportation mechanisms through digital wallets and de-centralized technology. But we are lacking the core element which is the standardized User (Digital YOU) Manifest.

## 4. Web of Worlds

We envision a **novel and open architecture** that builds upon OWP **principles and standards**, yet provides new, **simplified, and direct solutions** for **virtual world consumers and producers**.

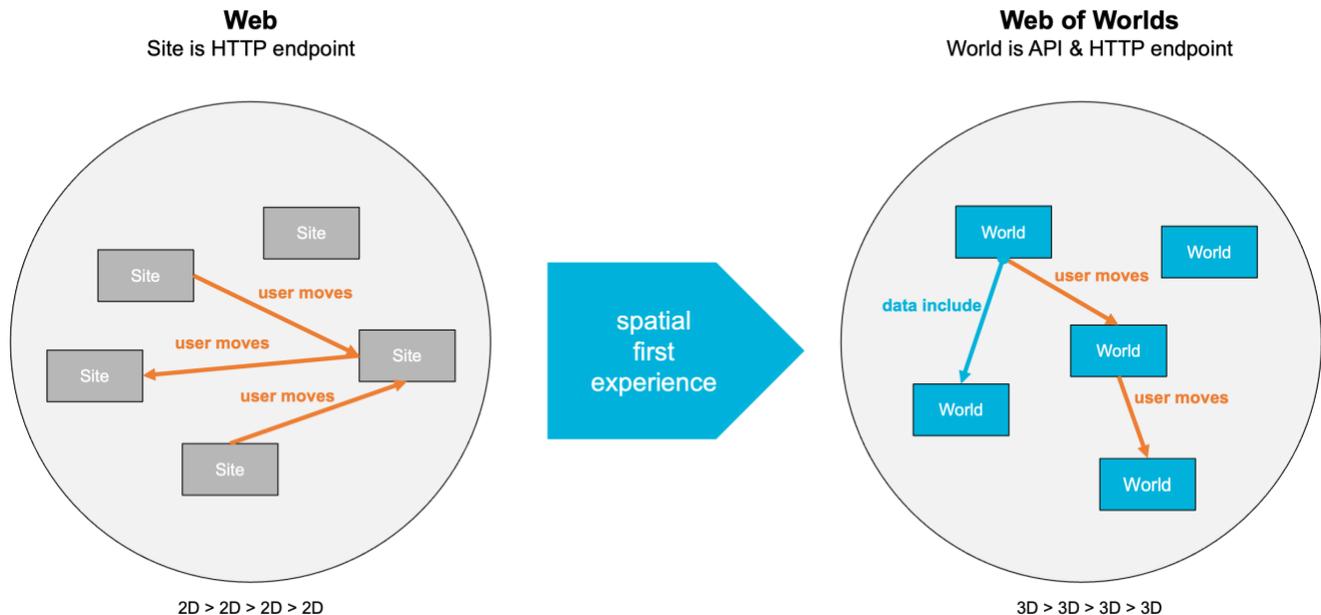


Figure 2 Linked Spatial Experiences: The Web of Worlds

This **open architecture** leverages a limited set of concepts that enhance developer speed while simultaneously accommodating smart distribution of spatial computer operations in dynamic client and server setups.

These new concepts should be accessible and distributable through the **modern web, incorporating decentralized mechanisms**.

Central to this vision is the concept of a persistent and collaborative **spatial world**. All other elements are **subordinate, independent, and shared components** within this **open architecture**.

### The Spatial Worlds

The world is not a single data state or file, but several local aspects that are linked with each other and can be accessed via the same API endpoint.

- **Web-applications** to deliver a **spatial experience** on a **new or known physical device**
- **Users** to handle **active and passive aspects**
- **Views** to expose a viewing pose or camera to the consumer
- **Portals** stores links to external and independent world instance
- **Spatial Composition Graph** hierarchical structure to manage any number of spatial assets links

○

## The User Manifest

Users must be able to move between virtual worlds, carrying with them their digital identity, with full control over how their data is used, when it is used, and how much of it is shared.

It is envisioned to use existing technology and standards that will provide the security (including anonymity), interoperability and transportability required for a User to carry and use their data safely with Virtual Worlds.

- User Digital Wallet
  - A DID-enabled wallet (mobile/extension/hardware app) that stores DIDs, private keys and private Verifiable Credentials.
  - Holds the User Manifest (or pointers to it), manages consent prompts, builds Verifiable Presentations and selective/derived proofs – when visiting a virtual world.
- User Manifest (user data)
  - A JSON-LD file containing metadata and links to the human users' data such as avatar links, wearables links, preferences, consent flags, fiat/crypto payment handles, NFT pointers, Verifiable Credentials (or pointers to them), public profile fragments, and privacy metadata.
  - Data will be public or private – with the User having control over which data a Virtual World can access without permission, and which data will require access notification to the User and access consent from the User.
  - The User will also be able to define which data has a limited life when passed to a Virtual World.
- Data Storage
  - Decentralized

Standardization of the User Manifest will be required to ensure Wallet creators, Issuers, Verifiers, and Virtual Worlds have a common understanding and usage of User Manifest formats and naming conventions.

## The Spatial Assets

Our objective is not to introduce or create a new data format, but rather to leverage existing standards as **spatial assets within the virtual world**. The [RFC2077](#) standard and its associated [model content registrations](#) have formed a robust foundation on the existing web for many years. We anticipate that the **USD-, GLTF-, and X3D-families** of formats, which are already registered, will play a crucial role in various use cases. What is significant here is that we not only transfer and provide data using **HTTP/S**, but we also aim to utilize generic and **harmonized DID resolvers** to facilitate **Asset links within wallets and related structures**

## 4.1 Core building blocks & goals

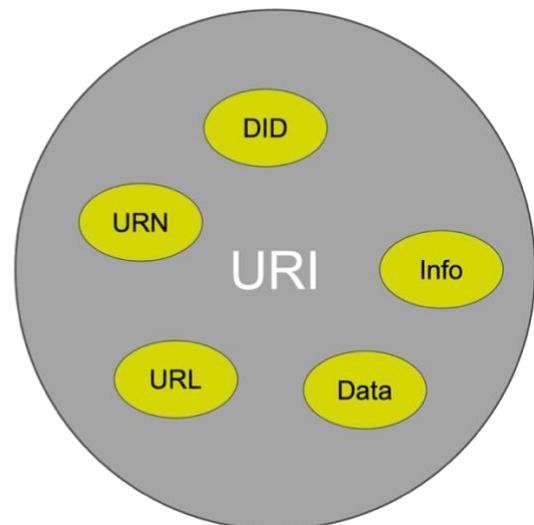
### Connectivity of the Web

Defining Transformation in last 30 years: from **web of hypertext** to the **web of data** [Tim Tim Berners-Lee, 2006-07-27, Linked Data](#),

1. Use **URIs** as **names** for **things**
2. Use **HTTP URIs** so that people can **look up** those **names**.
3. When someone looks up a **URI**, provide useful information using **standards**
4. Include links to other **URIs**. so that they can discover more things.

The modern web is more relaxed in how data semantics and data structure are related to individual data instances. For example, there are external standards (e.g., ISO for X3D and JT), JSON-LD context, and RDF as existing patterns that all participate in this same network.

- **URN**: "name" through namespaces
  - urn:uuid:..., urn:urn:x3d:..., urn:x-i3d:...
- **INFO**: "information assets" through namespaces
  - info:oclnum:...; info:dewey:...
- **DID**: "identify" through methods
  - did:sov:..., did:bctr:..., did:key:
- **URL**: "locate" through schemes
  - http://asfddata:model/JT;base64,AuV54...
- **DATA**: "data" through payload
  - data:model/JT;base64,AuV54...



*Figure 3 URIs are abstract concepts which have a growing number of derived standards as implemented*

([DIDs](#)) are a new type identifier that enables verifiable, decentralized digital identity. A DID refers to any subject (e.g., a person, organization, thing, data model, abstract entity, etc.) as determined by the controller of the DID. In contrast to typical, federated identifiers, DIDs have been designed so that they may be decoupled from centralized registries, identity providers, and centralized registries, identity providers, and certificate authorities.

We envision an open, flexible, and harmonized addressing of linked data and want to enable the mixing of different URI addressing methods (e.g. DID, URN, and URL) in the same context.

## Multi-stage and decentralized web data

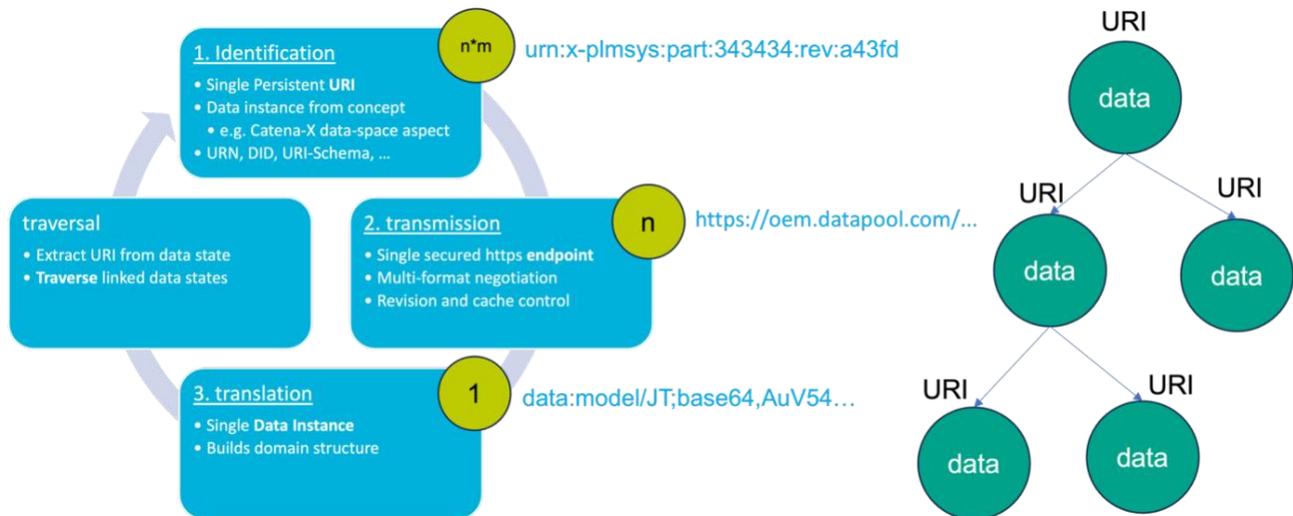


Figure 4 For every URI we usually have multiple stages for the data state provisioning

In the modern web, we can enable open and harmonized data instances provisioning with multi-stage resolver.

- Identification
  - Single Data instance form multi-value concepts.
- Transmission
  - Security transmits single data state
- Translation
  - Build domain data in data consumer and extracts all URI
- Traversal
  - Travers linked data states

## 3D application development & foundation

### Any User

The specific users and their primary roles are unfamiliar to us. Unlike a closed system, there is no user login or roles that can be directly compared. Digital products and applications come with their own built-in user management systems. We simply assume that users intend to use the virtual worlds to address task and goals, making runtime a crucial factor: shorter runtime is better.

### Any Device

Users rely on devices to operate interactive applications. Our system extends across three main categories of devices: **desktop**, **mobile**, and **immersive** devices. All these classes necessitate some form of network connection for app and data transfer. Additionally, all devices feature **IO interfaces** for

user interaction, with the screen being the most vital output component as it generates images for the users' visual system.

### Interactive Application

Users utilize various devices to run different types of applications; **Web apps**, which run within a user agent (i.e., browser), and **Native apps**, which operate directly on the host OS. Web apps and web api data are installed and removed on the fly (e.g. Zero Install, Zero footprint) and are by far the most common pattern. Native apps need to be installed and removed by the user or an independent device management system.

### Simplicity and feasibility

Through our process of Usability Engineering, we have derived requirements from Use Cases and also examined the Standards landscape with an eye for compatibility and harmonization. That is, we are following the principal of Occam's Razor to identify and simplify a common abstract, functional support layer that can unlock the gates to rich safe Metaverse experiences.

## 4.2 Scope & foundation

### Linked spatial assets

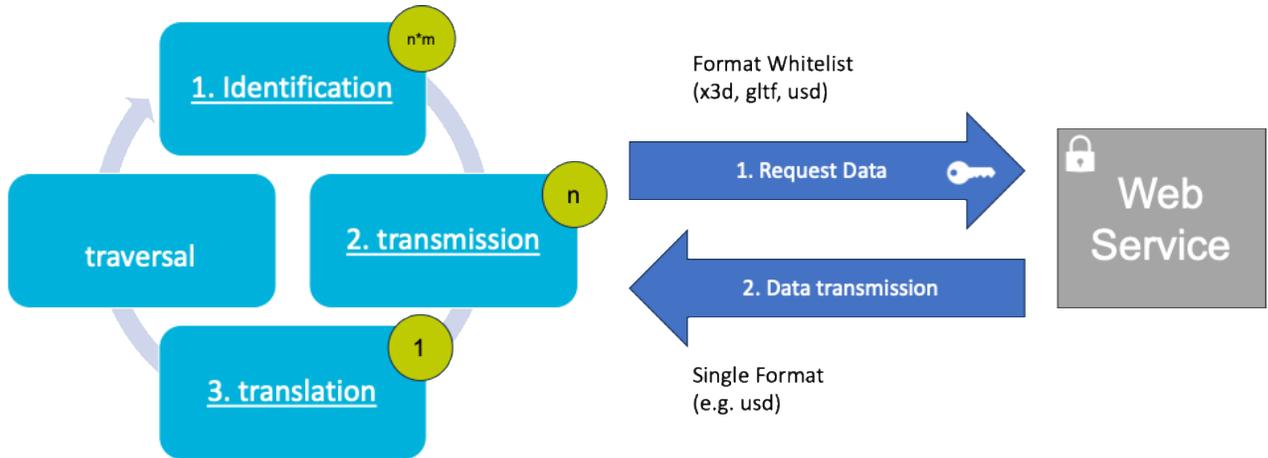


Figure 5 Example shows a asset data provisioning.

Spatial data on the modern web today is not just a single file or representation, but a domain state in a distributed data network. It makes sense to store the individual data states in open standards.

A common and important pattern is the use of the [RFC20277](#) family of formats for spatial asset encoding.

We expect the data to comply with the RFC2077 definition

- Orthogonal space
  - Orthogonal system
  - Spatial (3 or more) and temporal dimensions
- Model structure
  - Models are composed of Objects
  - Objects are instantiated/transformed elements
  - Elements are local or extern linked data with aggregation semantic (e.g. referencing a VRML and IGES )
- Structured Data
  - Multidimensional structures
  - Conversion should be structure preserving

Not all standards provide the ability to link to external asset stats.

Asset link	Any-Format	In-Format	No links
Standard	X3D, Step	JT, USD, Collada, ...	glTF, .obj, .stl

Currently, 42 formats are registered directly with [IANA](#),

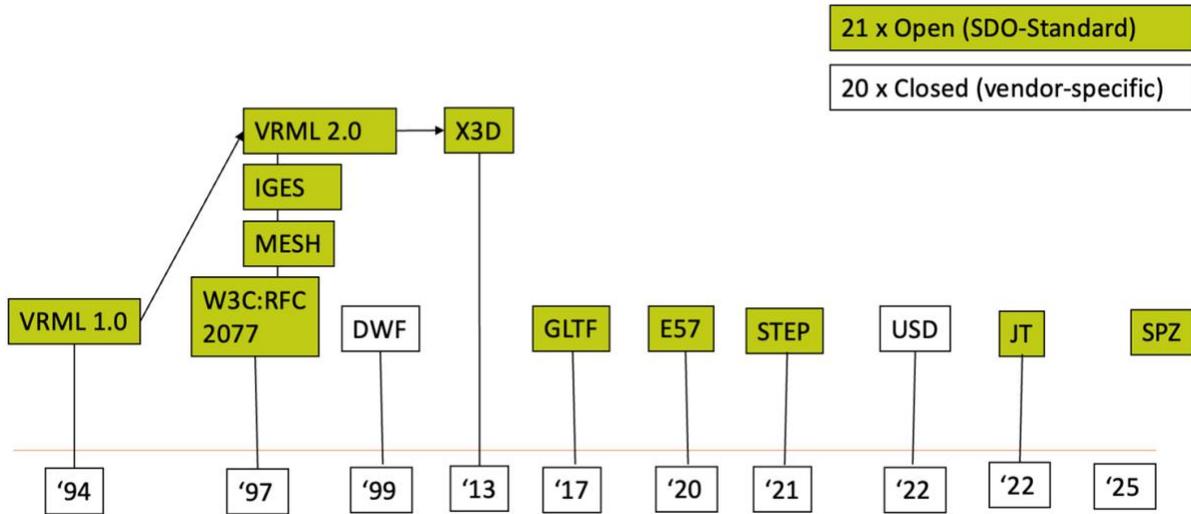


Figure 6 RFC2077 + IANA assignments for model content type (extract)

Date	Content Type	Organization	SDO Reference
01.07.16	model/gltf+json	Khronos	ISO/IEC 12113:2022
12.05.17	model/3mf	Apple	ISO/IEC 25422:2025
06.11.17	model/gltf-binary	Khronos	ISO/IEC 12113:2022
06.03.18	model/stl	DICOM	[DICOM_WG_17]
01.06.18	model/vnd.usdz+zip	Pixar	
13.02.20	model/mtl	DICOM	[DICOM_WG_17]
13.02.20	model/obj	DICOM	[DICOM_WG_17]
20.07.20	model/e57	ASMP	ASTM E2807
23.03.21	model/vnd.sap.vds	SAP	
07.04.21	model/vnd.pytha.pyox	pytha.com	
07.07.21	model/step+zip	Prostep	[ISO-TC_184-SC_4]
20.07.21	model/step-xml+zip	Prostep	[ISO-TC_184-SC_4]
05.08.21	model/step	Prostep	[ISO-TC_184-SC_4]
10.08.21	model/step+xml	Prostep	[ISO-TC_184-SC_4]
08.03.22	model/prc	PDF Association	[ISO-TC_171-SC_2]
08.03.22	model/u3d	PDF Association	[PDF_Association]
19.09.22	model/vnd.usda	Pixar	
22.12.22	model/vnd.cld	Illusico	
24.01.23	model/JT	Siemens	ISO 14306:2017
23.03.23	model/vnd.bary	Nvidia	ISO/IEC 12113:2022

Figure 7 Last decade

## Linked spatial experiences



Figure 8 Linked Spatial Experiences example: Showing the portal information to the second world

The various world instances can be linked and built again, a network of data states. The links must support the following requirements:

- **Portal:** Links to move/jump to another world
- **Data Inline:** Include a section of the spatial composition in a second world
- **User Manifest:** (e.g. avatar, preferences, assets) shared between worlds

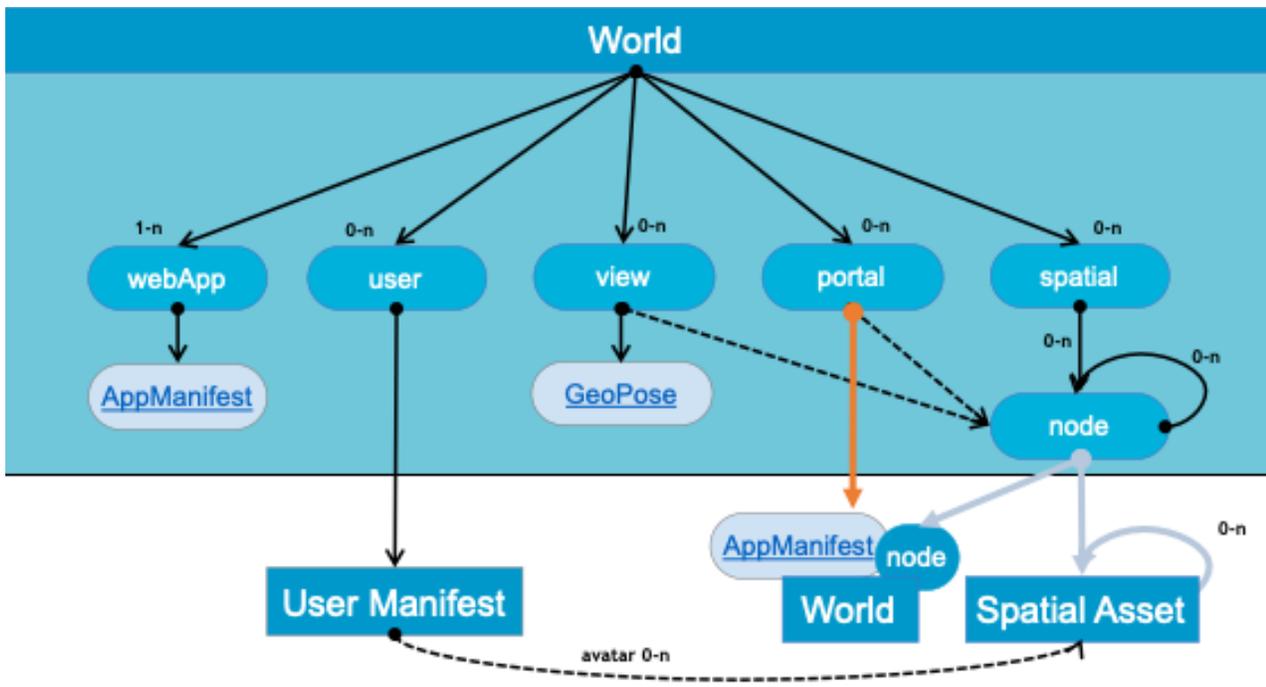


Figure 9 Exposed world structures and aspects

## Dynamic Spatial Composition

The new [HTML-model](#) element can only refer to a single asset. However, we assume that most virtual worlds don't just contain a single spatial asset link; they typically use hundreds or even thousands of asset links in a spatial composition.

We don't consider this spatial composition a static file; instead, we envision it as a dynamic structure that is directly integrated into the persistent world. The spatial composition graph.

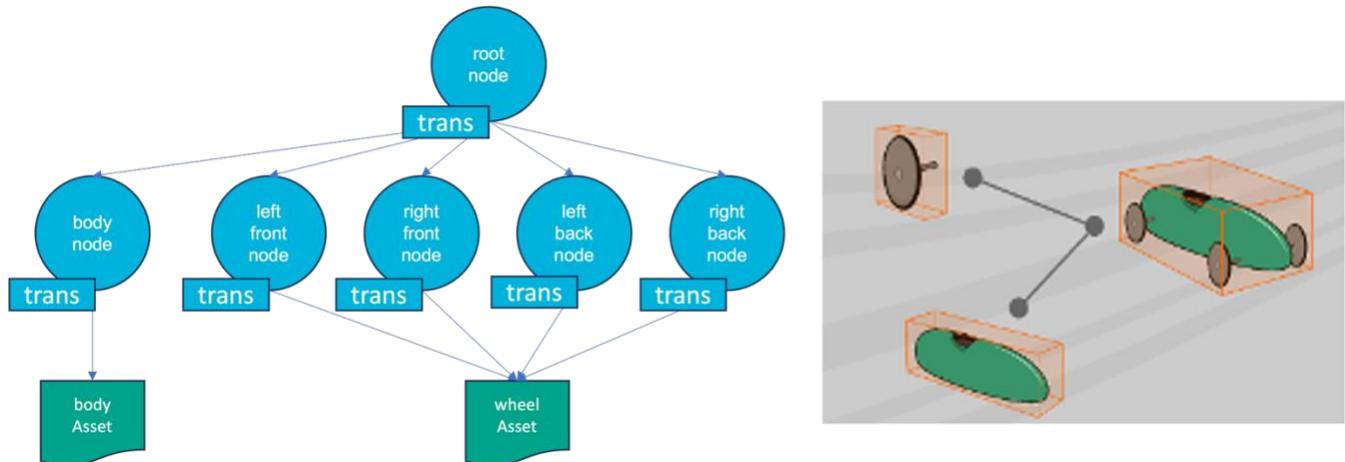


Figure 10 Example for spatial composition graph with 5 nodes and 2 external spatial assets

This minimalistic hierarchical structure allows the addressing of different spatial objects for the following use case pattern.

### Links to Spatial Assets

Generic URI with harmonized resolver (e.g URL, DID, URN ).

### Links to internal Node reference

Live reference to an internal node instance in the same world.

### Links to external Node reference

Live reference to an external node instance in a different world

## Efficient spatial computing

**Spatial computing** involves interacting with digital content in a 3D space, as if it were an integral part of the real or virtual world.

### Interactive Spatial Computing



*Figure 11 Spatial Experience classification*

**In any Spatial Experience we have to follow core concepts: Users use devices to run interactive 3D applications, utilising spatial computing functions in real-time on 3D data composition.**

Interactive 3D application run at least one realtime **session** for a user controlled **time period**.

### Efficient 3D Rendering on the open web

As a component of spatial computing, **3D graphics techniques** are often the **defining feature** of the **interactive 3D experience on the web**.

Efficient 3D rendering is primarily about reducing the overall system workload. This naturally includes the data that is transmitted, but above all the compute that arise at different client and CPU/GPU server components.

The various phases of the 3D web have shifted local calculations from browser plug-ins to browser runtimes and distributed systems. In these environments, intelligent systems can distribute the overall solution between the client and server.

For many solutions, data size sensitivity is a key challenge. This data size dependency is the key factor in many scenarios.

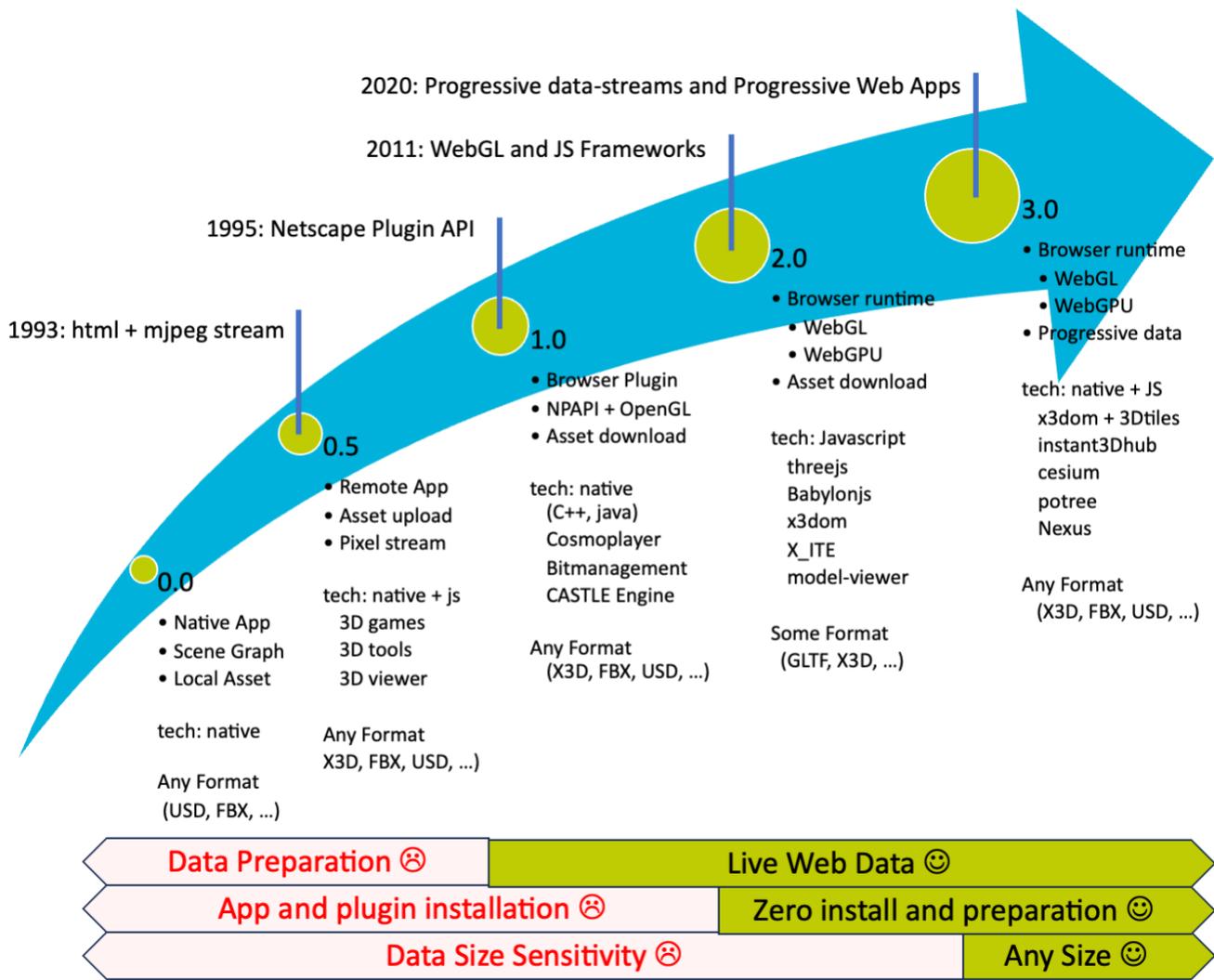


Figure 12 phases and evolution of 3D web

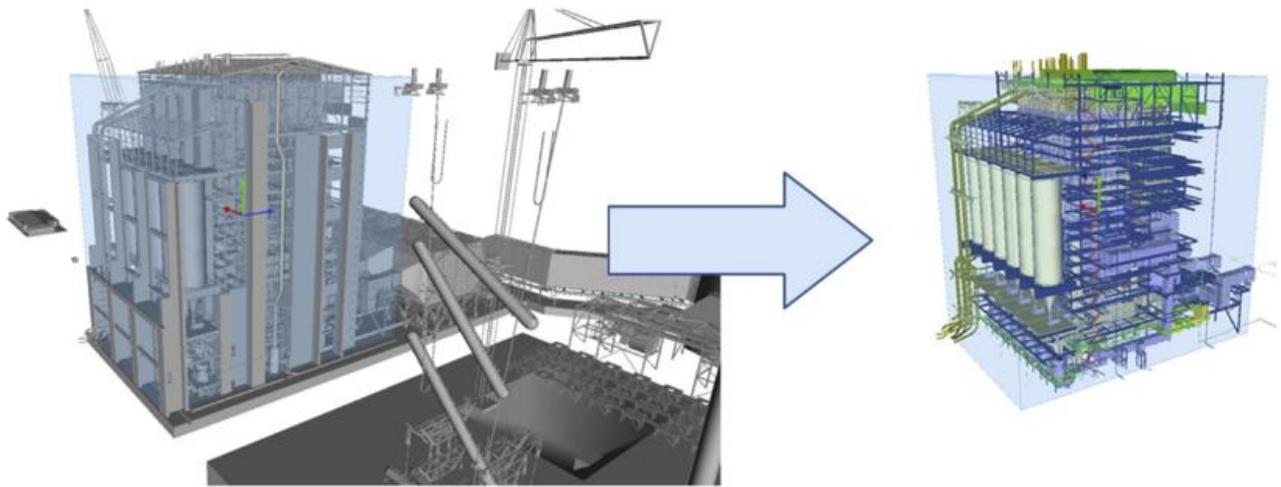
Web 3D Phase	Live Web App	Live Web Data	Any Format	Any Device	Any Size	Zero Preparation	Serverless Computing	Always Secured
0.0 Native App	No	No	Yes	No (PC)	No	No (download)	Yes	No (local copy)
0.5 Remote App	Partial (pixelstre.)	No	Yes	Yes (PC+M+XR)	No	No (install)	No (GPU)	No (vm copy)
1.0 UA+Plugin	Yes	Yes	Yes	No (PC)	No	No (Plugin)	Yes	Yes
2.0 UA+WebAPI	Yes	Yes	No (X3D, GLTF)	Yes (PC+M+XR)	No	Yes	Yes	Yes
3.1 Hybrid SG	Yes	Partial (dyn data)	Partial (static data)	Yes (PC+M+XR)	Partial (static data)	No (SI process)	Yes	Partial (SI process)
3.2 Layerd SIG	Yes	Yes	Yes	Yes (PC+M+XR)	Yes	Yes	No (CPU)	Yes

Figure 13 3D phases details and classification

## Spatial Computing Operator

Beside the interactive experience we envision basic operator which can be use important feature in for API and AI Agent controlled workflows

- Compute Bounding Volume
- Compute Volume Selection
- Compute Ray intersect
- Compute Minimal Distance
- Compute Clashes / Collision



*Figure 14 example shows "volume selection" operation in a given world*

## User and AI Agent Symmetry

User and AI Agent can read, manipulate and operate in a shared virtual world

Together, they create systems that can:

- Understand 3D environments
- Reason about space and objects
- Act autonomously inside physical or virtual worlds
- Collaborate with humans naturally

## 4.3 Principles and Parsimony

**A simple api spec to glue existing standards and capabilities in a consistent architecture and environment (Webby).**

We have published the API as [OpenAPI](#) description in a public github repository with an open-source license.

<https://github.com/WebOfWorlds/WoWAPI>

The goal is to encourage **several closed and open-source implementations**. Not every implementation has to provide all features, and different levels will play a role here in the **future classification**. There will be **various open-source implementations** to enable **different use-case aspects and requirements**. We expect **strong open-source implementations** that build on existing browser frameworks (e.g. **Three.js, babylonjs, X3DOM, X\_ITE** ). These open-source and close-source implementations allow interested parties to **host platforms** on the web that provide individual virtual worlds as **persistent URIs and addressable instances**. When a new or returning **user** opens the **URI** on his device, the platform should deliver the matching **web app**, which in turn delivers the **spatial experience** in an **interactive session**.

	UnityWrapper	x3dWorlds	Threedy.io
License	Free	Free	Commercial
Roadmap	Q3 2025	Q2 2025	Q2 2025
User Manifest	Full, Avatar Link	Full, Avatar Link	Partial, Min. Avatar
WebXR Clients	Patial	Full, immersive-VR	Partial
Technology	Unity WebAssembly	x3dom, X_ITE	Instant3Dhub
Asset Format	gltf-binary, gltf+json, vnd.usda	gltf-binary, gltf+json, x3d+xml	e57, gltf-binary, gltf+json, JT, step, step+xml, step+zip, step+xml+zip, vnd.usda, vnd.usdz+zip, x3d-vrml, x3d+fastinfoset, x3d+xml, las

# Consistent architecture

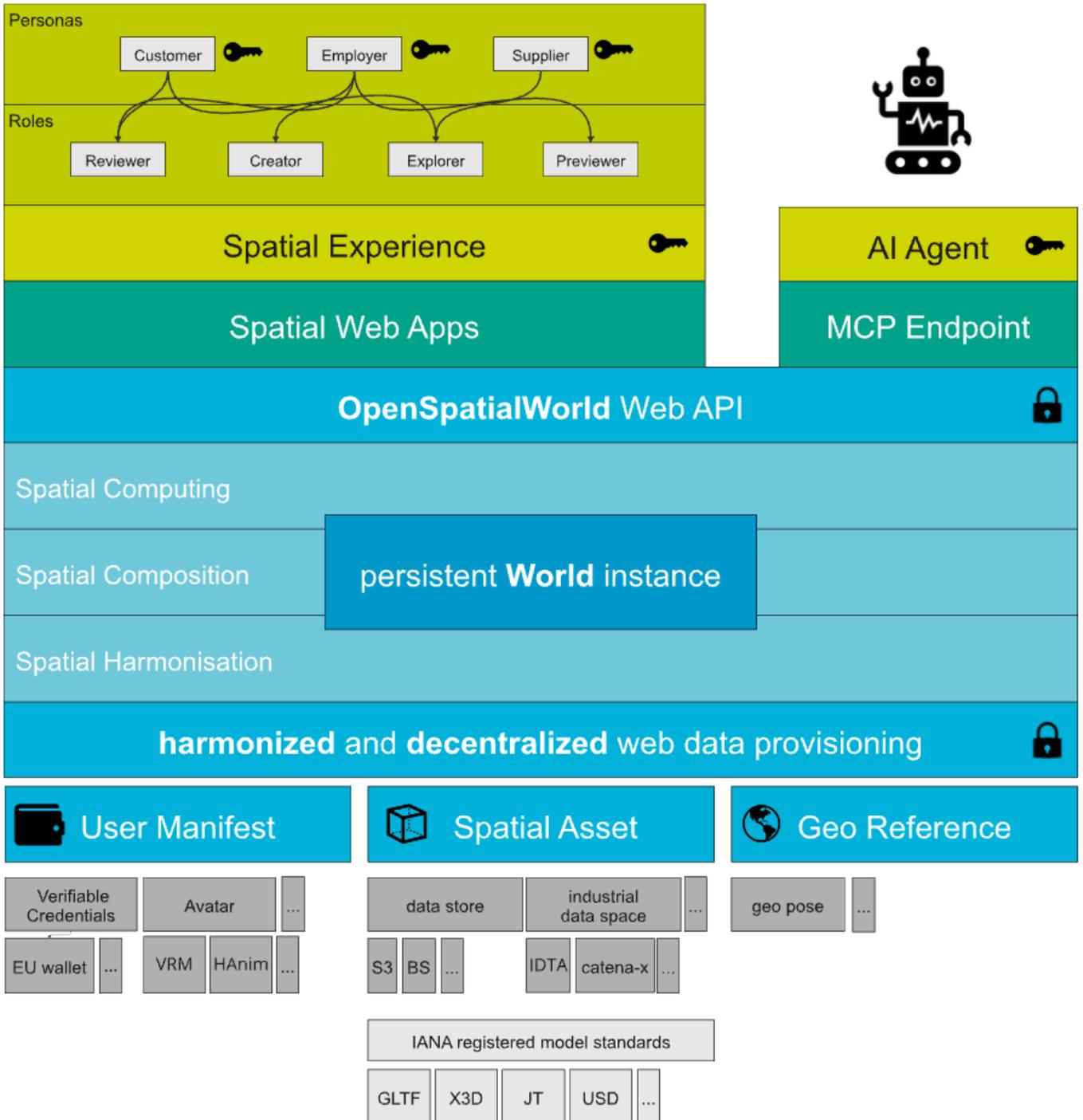


Figure 15 Unified API and service architecture

## Spatial Experience delivery

The goal is for all of this **spatial experience** to be delivered in a standard and installed **browser** or **user agent**. Installation of software on end devices should be avoided.

This standard web URI can be shared, bookmarked to encoded in a QR-Code to be delivered to the client

This list shows the current discussion of supported scenarios but is not complete.

Open Spatial Experience with default web app, view and user manifest

<http://example.com/world/604djg942>

Open Spatial Experience with default web app, view and linked user-manifest

[http://example.com/world/604djg942?userManifestURI="did:example:"](http://example.com/world/604djg942?userManifestURI=)

Open Spatial Experience Open with default web app, given view and linked user-manifest

[http://example.com/world/604djg942?userManifestURI="did:example"#join=view.5845:"](http://example.com/world/604djg942?userManifestURI=)

## Spatial composition manipulator

	<b>Create</b> +Assets Links	<b>Create</b> +Asset Copy	<b>read</b>	<b>update</b> +Assets Links	<b>update</b> +asset copy	<b>delete</b>
REST	/node/ POST => JSON-Tree <= JSON-Tree with new nodeID	/node/ POST => model" asset	/node/ GET =>fields-whitelist + depth <= JSON-Tree	/node/ Update => JSON-Tree + depth	/node/ Update	/node/ Delete => NodeID
MCP	Tools createNodes => JSON-Tree	? binary data in Tools	resource	Tool updateNodes => Jjson-Tree	? binary Data in tools	Tool deleteNodes => NodeID group

### e.g. create spatial nodes with linked assets

<http://example.com/world/604djj942/wow/scene/node/35643>

POST

```
{
  "name": "body",
  "assetURI": "http://example.com/data/carbody056834",
  "children": [
    {
      "name" "leftFront"
      "localTransform": [ ... ]
      "assetURI": "did:example:123?service=wheelAssembly35"
    },
    {
      "name" "rightFront"
      "localTransform": [ ... ]
      "assetURI": "did:example:123?service=wheelAssembly35"
    },
    {
      "name" "leftBack"
      "localTransform": [ ... ]
      "assetURI": "did:example:123?service=wheelAssembly35"
    },
    {
      "name" "rightBack"
      "localTransform": [ ... ]
      "assetURI": "did:example:123?service=wheelAssembly35"
    }
  ]
}
```

# 5. Outlook

- a. SDO adoption plan
  - i. W3C

Assessment: Clearly aligned priorities... including MediaFragments for 3D; 3D User Agent; Immersive Web/WebXR; WebGPU, WASM, Universal Manifest .

Recommendation: use Liaisons and Community Groups to advocate for 3D Media Fragment specification. Advance 3D User Agent discussions across SDOs

- ii. Web3D Consortium

While the [X3Dv4 scene graph](#) supports a rich palette of data and rendering capabilities from gltf to geospatial point clouds to CAD and medical volumes, **the WoW proposal only requires a small subset of well-defined types, rules, and behaviors**. Specifically, the Web3D Consortium is actively aligning a **X3D WoW Profile**: a base set of existing ISO-IEC X3D standard scene graph nodes that can meet the stated requirements. These include the specific Nodes from the following Components (as a recommended practice for X3Dv4 and an eventual standard in X3D 4.1:

Component	X3D Nodes
<a href="#">Grouping</a>	Transform Group StaticGroup
<a href="#">Core</a>	MetadataSet <i>supports multiple schemas for: Ontologies, Schema, Metaverse Manifest</i> Metadata*
<a href="#">Networking</a> *any URI	Anchor Inline
<a href="#">Navigation</a>	Viewpoint OrthoViewpoint NavigationInfo
<a href="#">Geospatial</a>	GeoOrigin GeoLocation GeoViewpoint

The new X3Dv4 Recommended Practice language will also upgrade its Networking Component specification for extended support of URIs and 3D *experience fragments* directly compatible with the WoW API.

**b. Next Steps**

- i. Test beds and demos of WoW**
- ii. Content Profiles**
  - 1. Profiles and Components**
  - 2. Header declarations and MIMEs**
- iii. 3D User Agents**

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