



 **Fraunhofer**  
FOKUS

Fraunhofer FOKUS Institute for Open Communication Systems

---

# Advanced Web Technologies Metaverse

Alexander Zoubarev | Fraunhofer FOKUS

29.01.2024



# Schedule

No	Week	Date	Topic
1	42	16.10.2023	Introduction and Framework
2	43	23.10.2023	Web Technologies Basics & Media Entertainment for the Web
3	44	30.10.2023	Foundations of Media Streaming
4	45	06.11.2023	Advanced Media Streaming
5	46	13.11.2023	Multiscreen Technologies and Standards
6	47	20.11.2023	Context-Aware Media Streaming & Encoding
7	48	27.11.2023	Dynamic Advertisement
8	49	04.12.2023	Media Players - dash.js, Exoplayer
9	50	11.12.2023	HbbTV and Smart TV
	51	18.12.2023	Holiday break
	52	25.12.2023	Holiday break
	1	01.01.2024	Holiday break
10	2	08.01.2024	Media Delivery in 5G Networks (1)
11	3	15.01.2024	Media Delivery in 5G Networks (2)
12	4	22.01.2024	Interoperable Web-supported Learning Technologies
13	5	29.01.2024	Metaverse Platforms and Technologies
14	6	05.02.2024	Securing Content-Provenance and Authenticity
15	7	12.02.2024	Exercise and Test Preparation
16	8	19.02.2024	Written Test (60min) first slot (details will be announced during the semester)

## Agenda

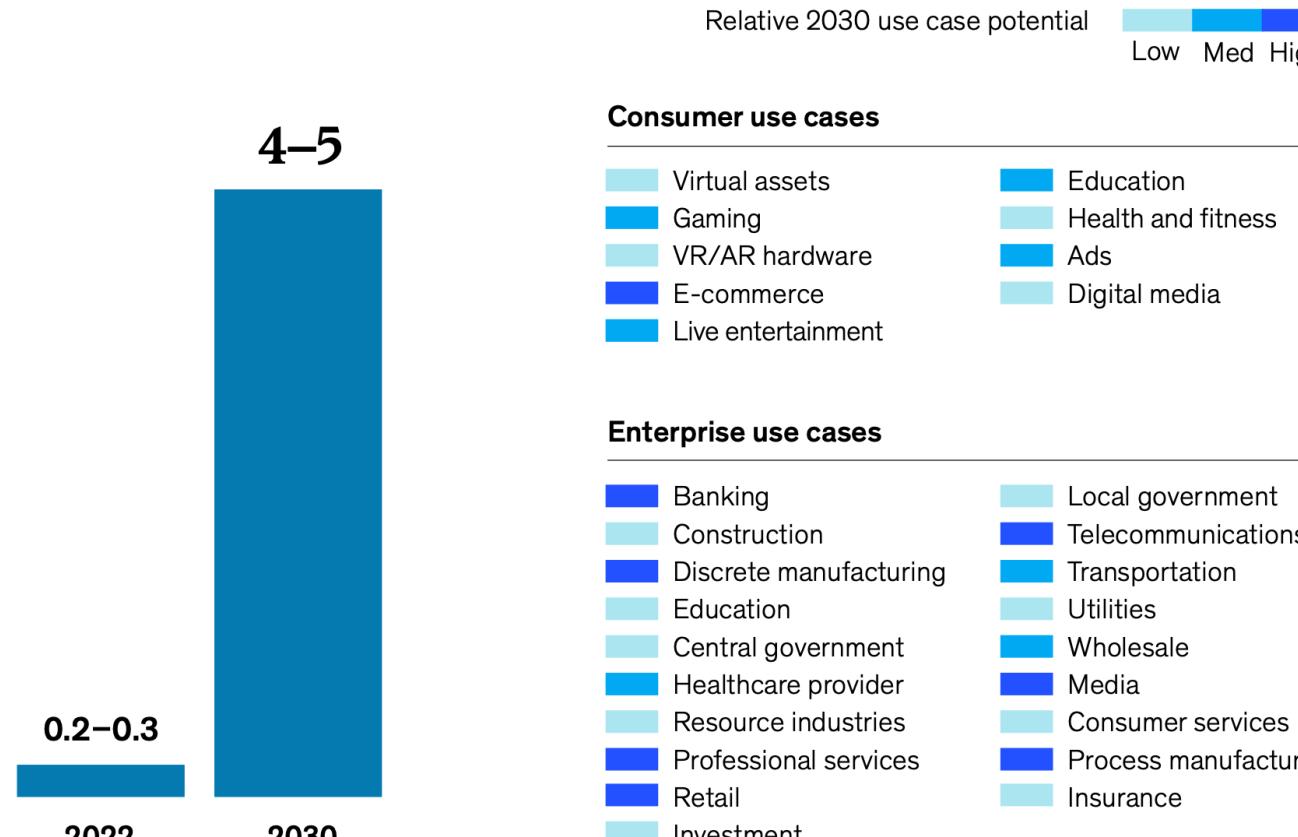
---

- Metaverse Introduction
  - Metaverse Categories and Use Cases
- Metaverse Enablers
  - Devices
  - Graphics Engines
  - Computation
  - Communication
  - QoS/QoE
  - Generative AI
  - 3D Assets
- Standardization

# Advanced Web Technologies – Metaverse

## Motivation

Metaverse impact potential by 2030, \$ trillion



<https://www.mckinsey.com/~media/mckinsey/business%20functions/marketing%20and%20sales/our%20insights/value%20creation%20in%20the%20metaverse/Value-creation-in-the-metaverse.pdf>

# Metaverse Introduction

Metaverse Categories and Use Cases

# Metaverse Introduction

## What is the Metaverse?

---

- The term "**Metaverse**" was coined by Neal Stephenson in his 1992 science fiction novel "Snow Crash."
- The Metaverse is a virtual shared space that combines aspects of social media, online gaming, augmented, and virtual reality where users interact with a computer-generated environment and other users.
- Some definitions count the Metaverse as the three-dimensional evolution of the Internet.
- Metaverse gained attention during the pandemic due to the acceleration of remote work followed by Facebook's rebranding to Meta.



## Metaverse Categories

---

### Consumer Metaverse

Encompasses virtual spaces & experiences designed for personal entertainment, social interaction, gaming and other consumer-focused activities.

- High-fidelity Communication
- Social Media
- Entertainment
- Gaming
- Education
- Health and Wellness

### Enterprise Metaverse

Integrates virtual spaces and collaborative tools within business settings, facilitating remote work, professional networking, and team collaboration.

- Remote Work and Collaboration
- Virtual Events and Trade Fairs
- Virtual Commerce
- Professional Trainings
- Virtual Real estate
- New Employee onboarding

### Industrial Metaverse

Applies virtual reality technologies to enhance processes in industrial settings, including digital twinning, remote operation, and data analytics.

- Digital Twins
- Factory Planning
- Photorealistic Synthetic Data
- Data analytics
- Remote Operation
- Predictive Maintenance

### Use Case: High-fidelity Communication – Meta Codec Avatars

---

High-fidelity communication replicates real-world interactions in terms of sensory richness and detail.

Features:

- Photorealistic Avatars
- Spatial Audio
- Real-time Interaction
- Immersive Virtual Spaces
- Real-world Integration
- Haptic Feedback



source: <https://www.youtube.com/watch?v=MVYrJJNdrEg>

# Enterprise Metaverse

## Use Case: Remote Work and Collaboration via Microsoft Mesh

---

Remote Work and Collaboration leverages virtual and augmented reality technologies to facilitate work, communication, and collaboration in a digital environment

Features:

- Integration in Teams
- Accessible on Desktop and VR
- Virtual Workspaces
- Avatars and Virtual Presence
- Real-time Collaboration
- Immersive Meetings
- Collaborative Tools
- Training and Onboarding



source: <https://www.microsoft.com/en-us/mesh>

# Industrial Metaverse

## Use Case: Digital Twins at Siemens using NVIDIA Omniverse

For Siemens “*The Industrial Metaverse is a world, which is always on. Where real machines and factories, buildings and cities, grids and transportation systems are mirrored in the virtual world.*” [source]

### Features:

- Photo-realistic, physics-related a real-time digital twin
- Persistent simulation
- Predictive Maintenance
- Live interaction
- Combines AI with IoT and 3D Virtual Spaces

Siemens to invest €1 billion in Germany and create blueprint for industrial metaverse in Nuremberg metropolitan region

source: <https://www.youtube.com/watch?v=LQyKc6SI5u8>

# Metaverse Enablers

- Devices
- Graphics Engines
- Computation
- Communication
- QoS/QoE
- Generative AI
- 3D Assets

# Metaverse Enablers

## Devices

### Head-mounted Displays



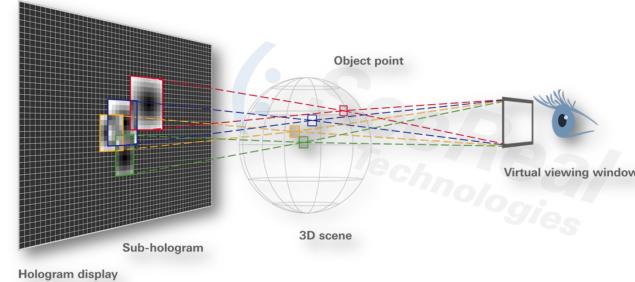
- Worn by the user
- Offer complete immersion
- Used for VR/AR/MR
- **VR**: Completely virtual
- **AR**: Real world with virtual overlay
- **MR**: Real world interacts with virtual objects

### 3D Displays



- Displayed images are perceived as three-dimensional
- Mostly stereoscopic, presenting slightly different images to each eye
- Requires either glasses or parallax barrier on the screen

### Holographic Displays



- Image is not displayed directly on the screen, but in real space
- No need for glasses or parallax barriers
- Do not require 2 eyes to perceive 3D object

## Metaverse Enablers

### Graphics Engines

- Purpose

- Game Development
- 3D Scene Management
- Scripting
- Game Execution
- Physics Simulation
- Light Simulation
- Input Handling
- Rendering

- Additional Offerings

- Stores for 3rd party tools and libraries
- 3D Asset Stores



Source: <https://www.gamesindustry.biz/what-is-the-best-game-engine-for-your-game>

## Metaverse Enablers

### Graphics Engines – Unity and Unreal Engine

- The two most popular Graphics Engines
- Market share of >50% among the two engines
- Asset Stores offer
  - Community-made 3D assets
  - 3D assets provided by professional developers
  - Paid and free libraries



Source: <https://blog.unity.com/technology/creating-immersive-photorealistic-vr-experiences-with-the-high-definition-render>



Source: <https://forums.unrealengine.com/t/unreal-engine-5-1-photorealistic-scene-the-river-lumen-nanite/1297150>

## Metaverse Enablers

### Graphics Engines – Unity 3D Model File Formats

- Supported
  - Standard
    - .fbx, .dae, .dxf, .obj
  - Proprietary
    - Autodesk Maya, Blender, Modo, Cheetah3D
- Unsupported
  - .ma, .mb, .max, .c4d



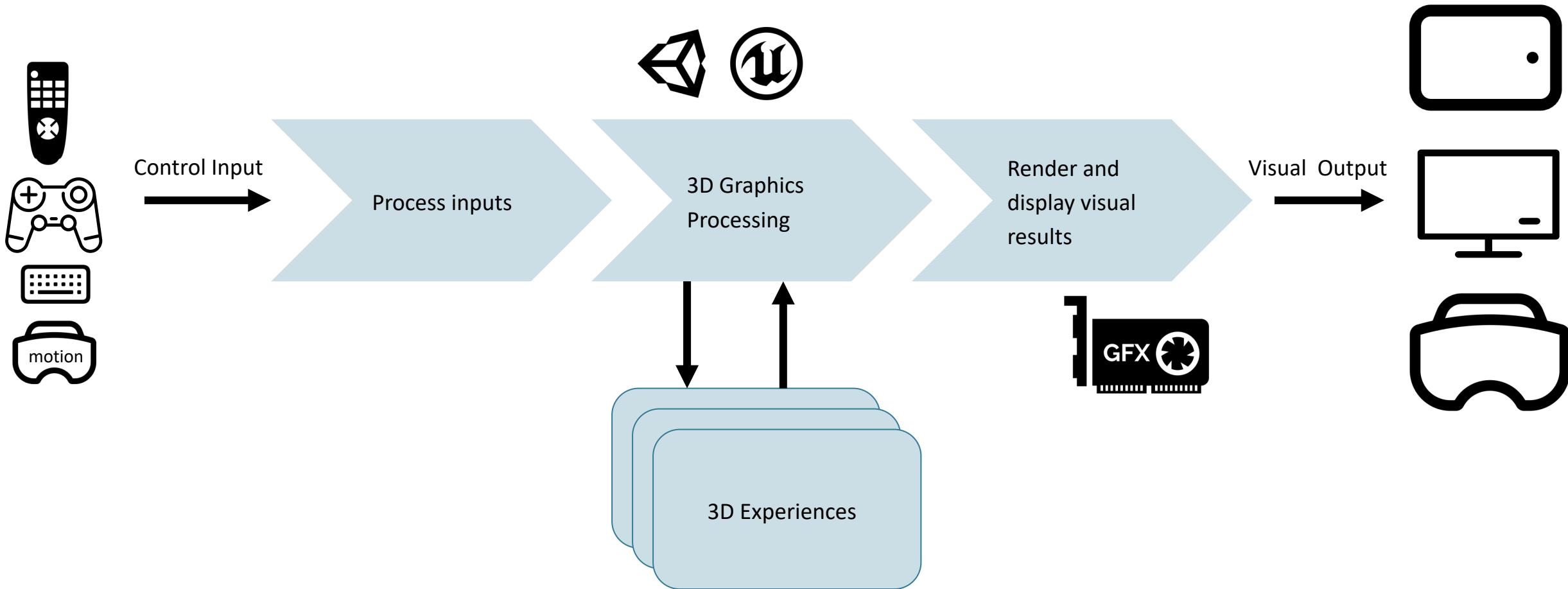
Source: <https://blog.unity.com/technology/creating-immersive-photorealistic-vr-experiences-with-the-high-definition-render>



Source: <https://forums.unrealengine.com/t/unreal-engine-5-1-photorealistic-scene-the-river-lumen-nanite/1297150>

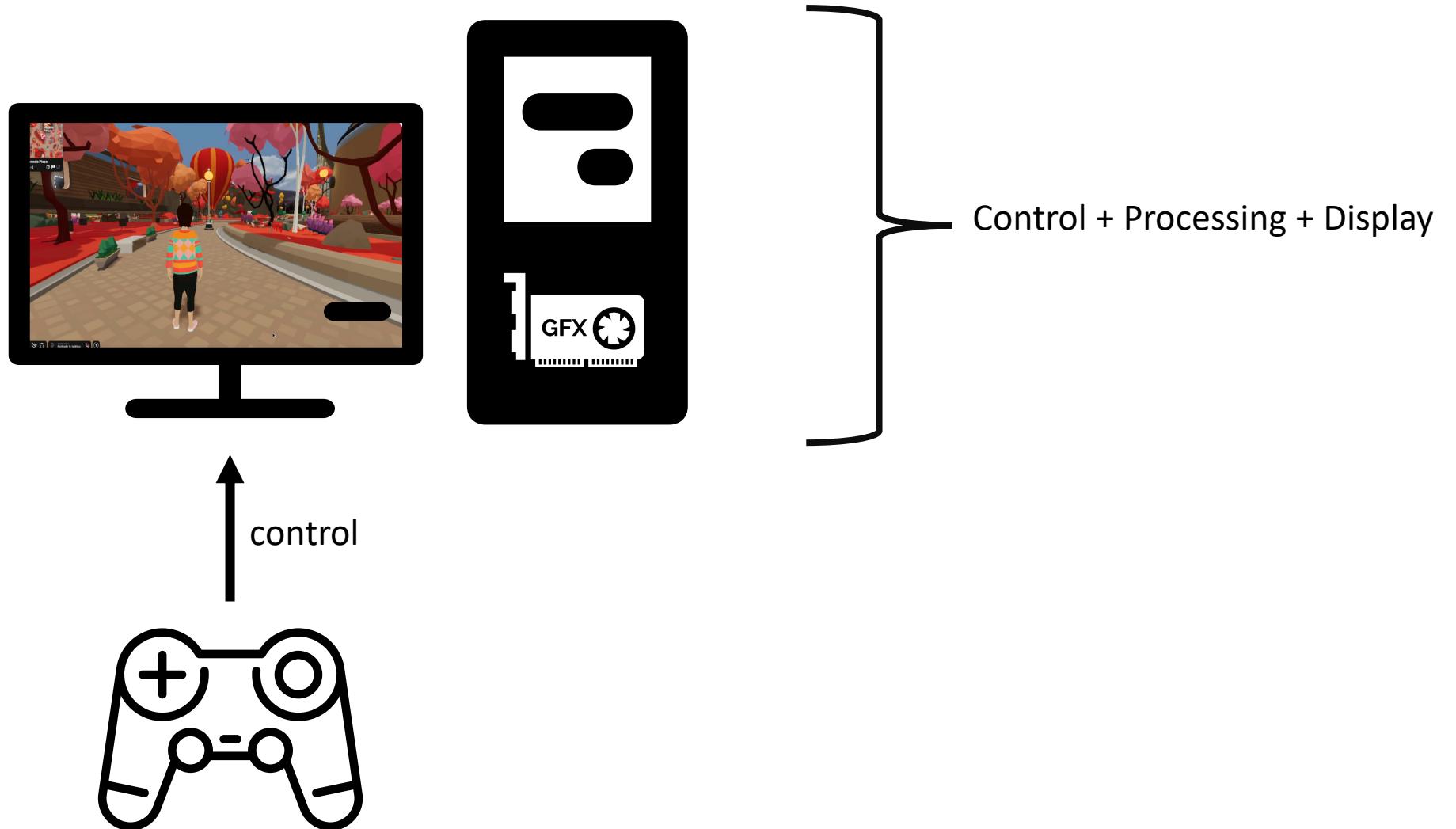
# Metaverse Enablers

## Computation



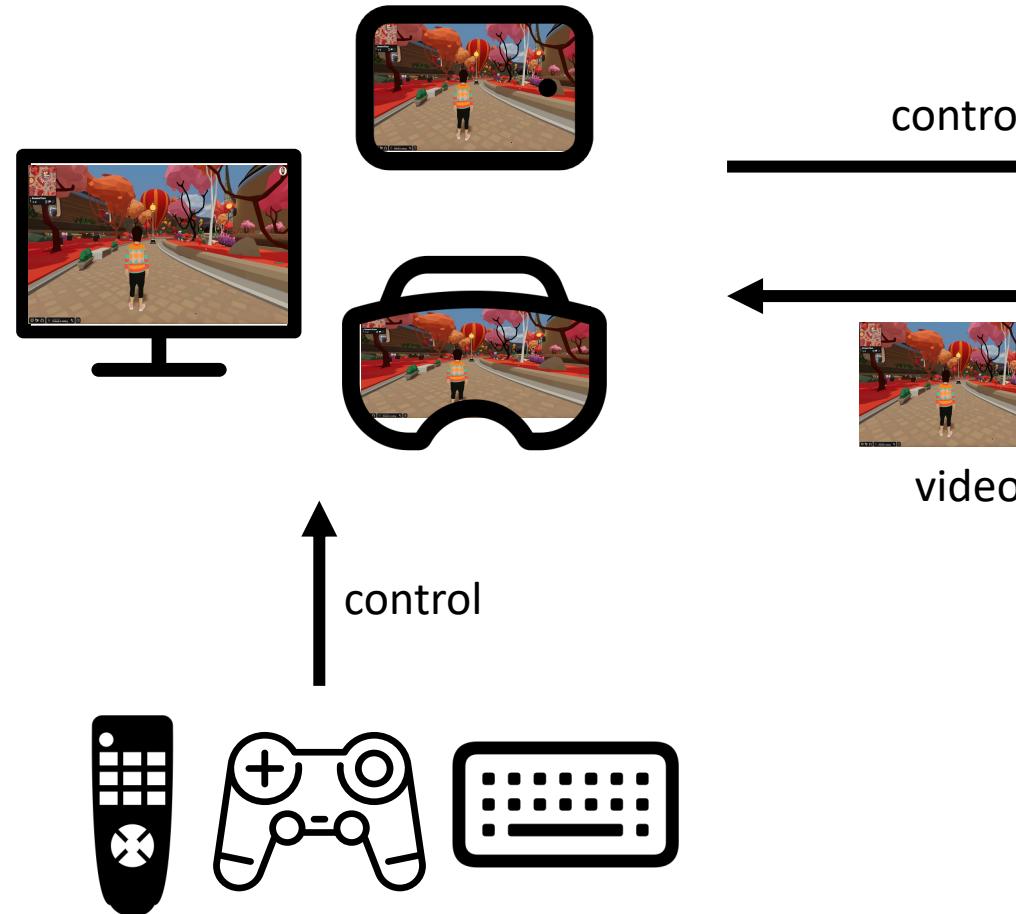
# Metaverse Enablers

## Computation – Local rendering



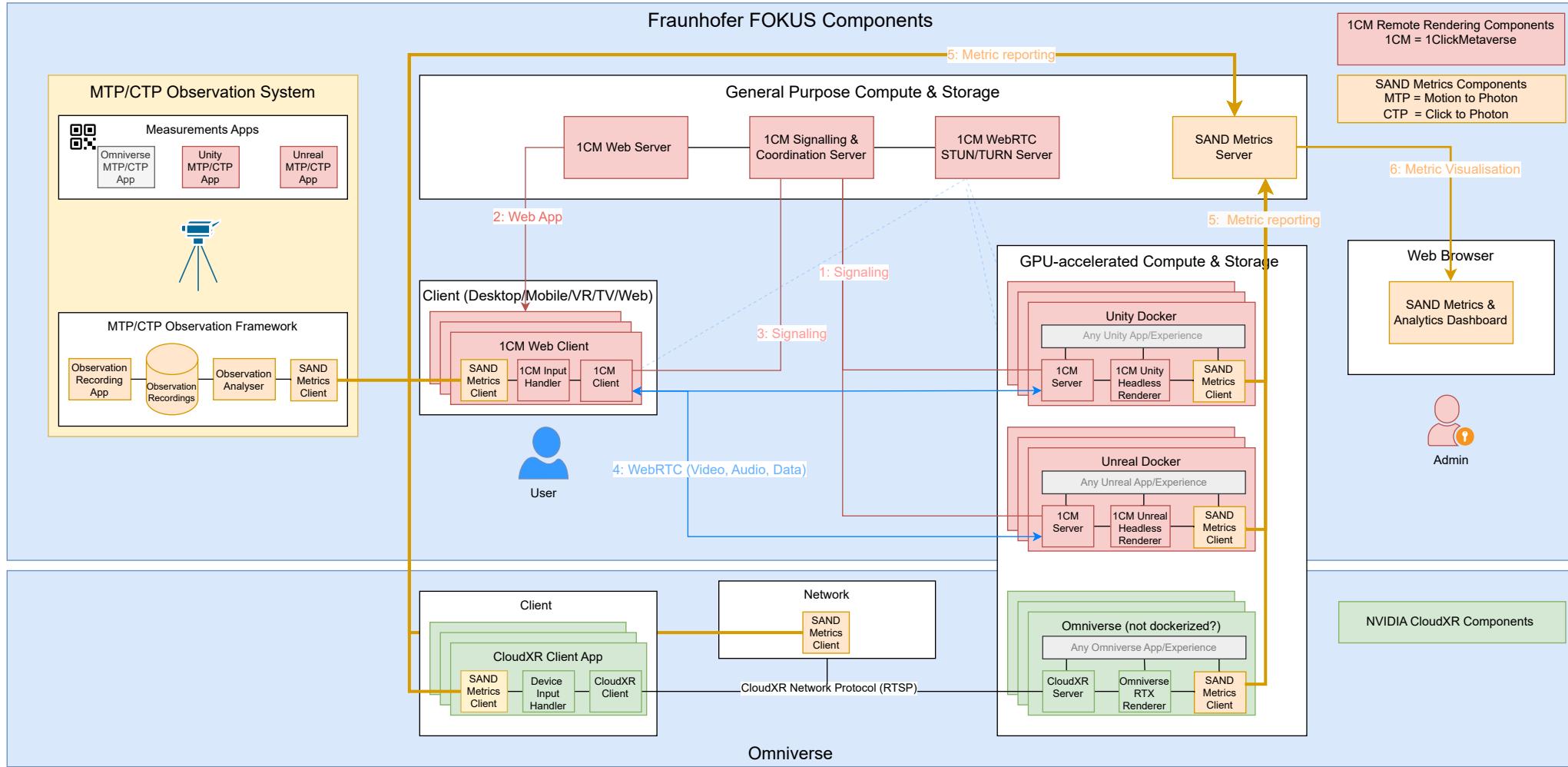
# Metaverse Enablers

## Computation – Remote Rendering



# Metaverse Enablers

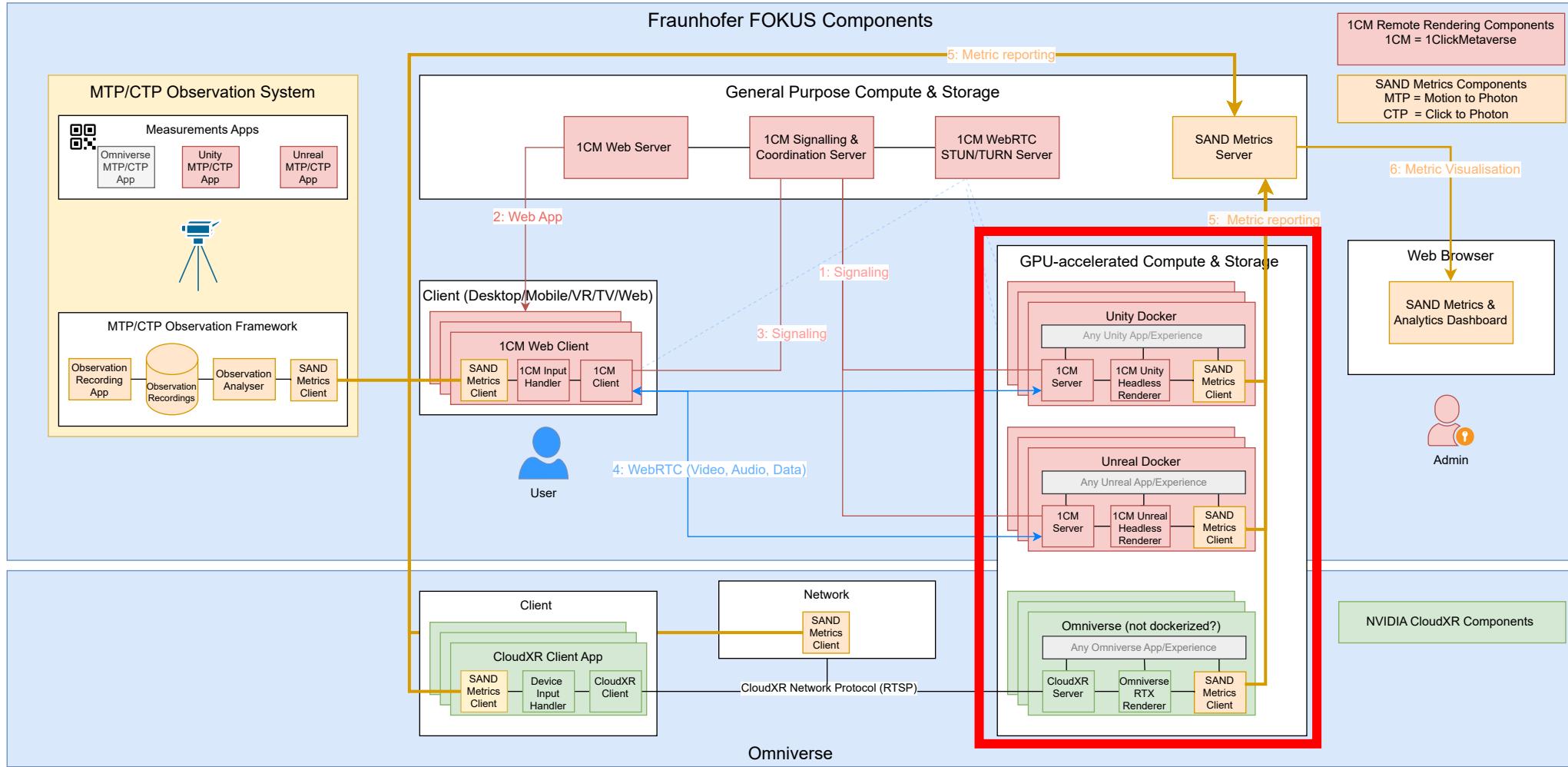
## Computation – 1ClickMetaverse Remote Rendering Architecture



<https://www.fokus.fraunhofer.de/go/metaverse>

# Metaverse Enablers

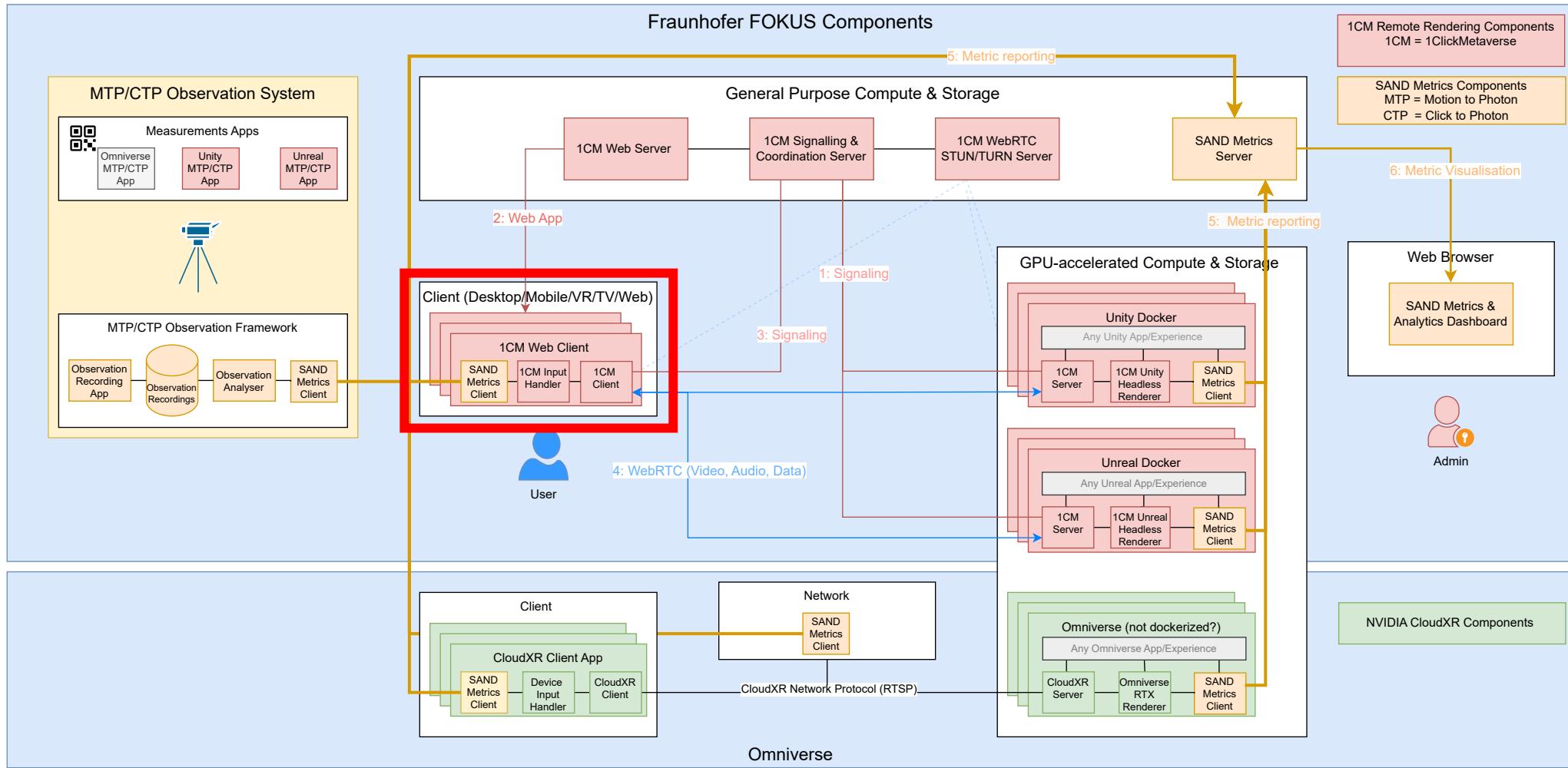
## Computation – 1ClickMetaverse Remote Rendering Architecture



<https://www.fokus.fraunhofer.de/go/metaverse>

# Metaverse Enablers

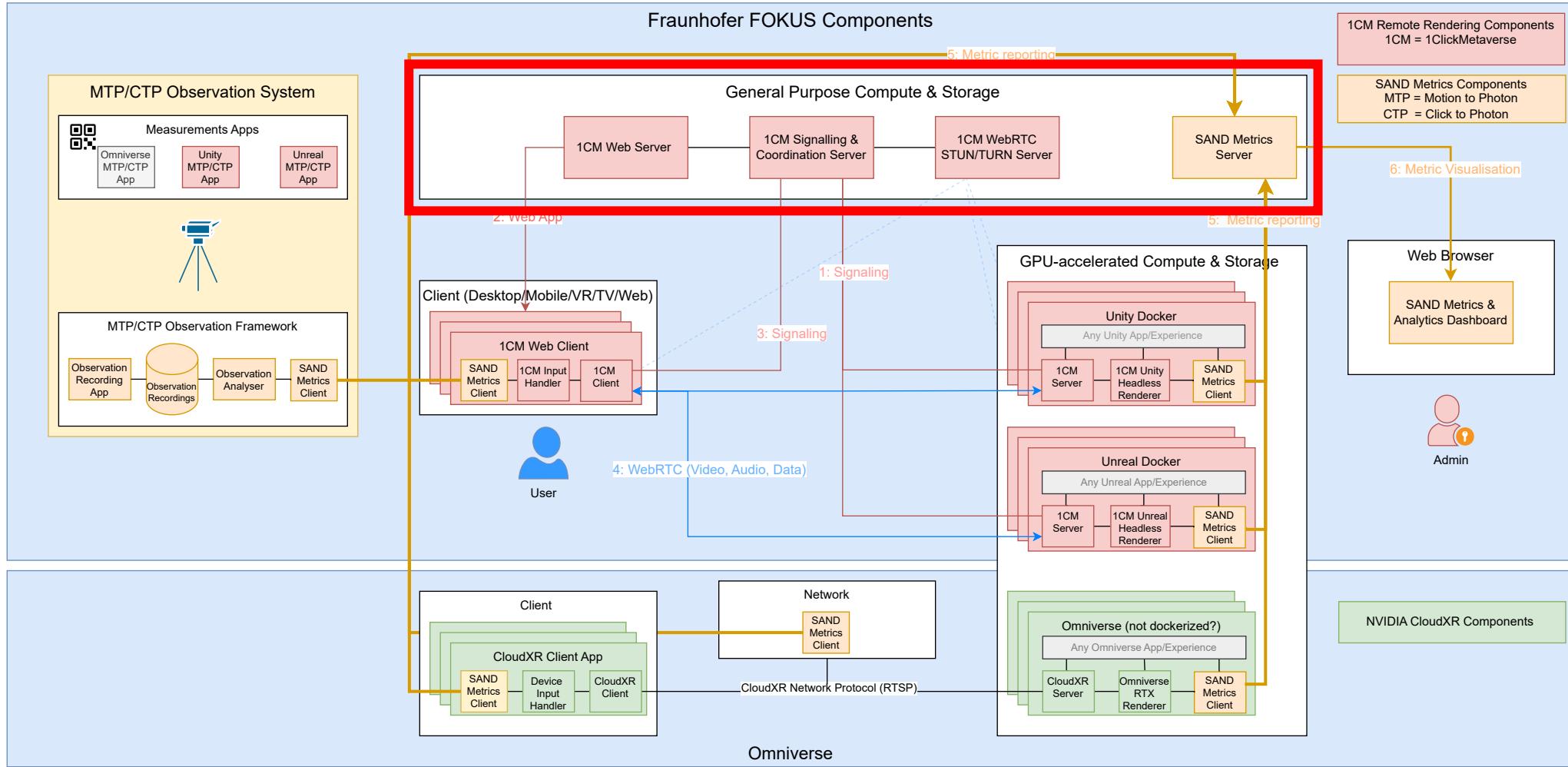
## Computation – 1ClickMetaverse Remote Rendering Architecture



<https://www.fokus.fraunhofer.de/go/metaverse>

# Metaverse Enablers

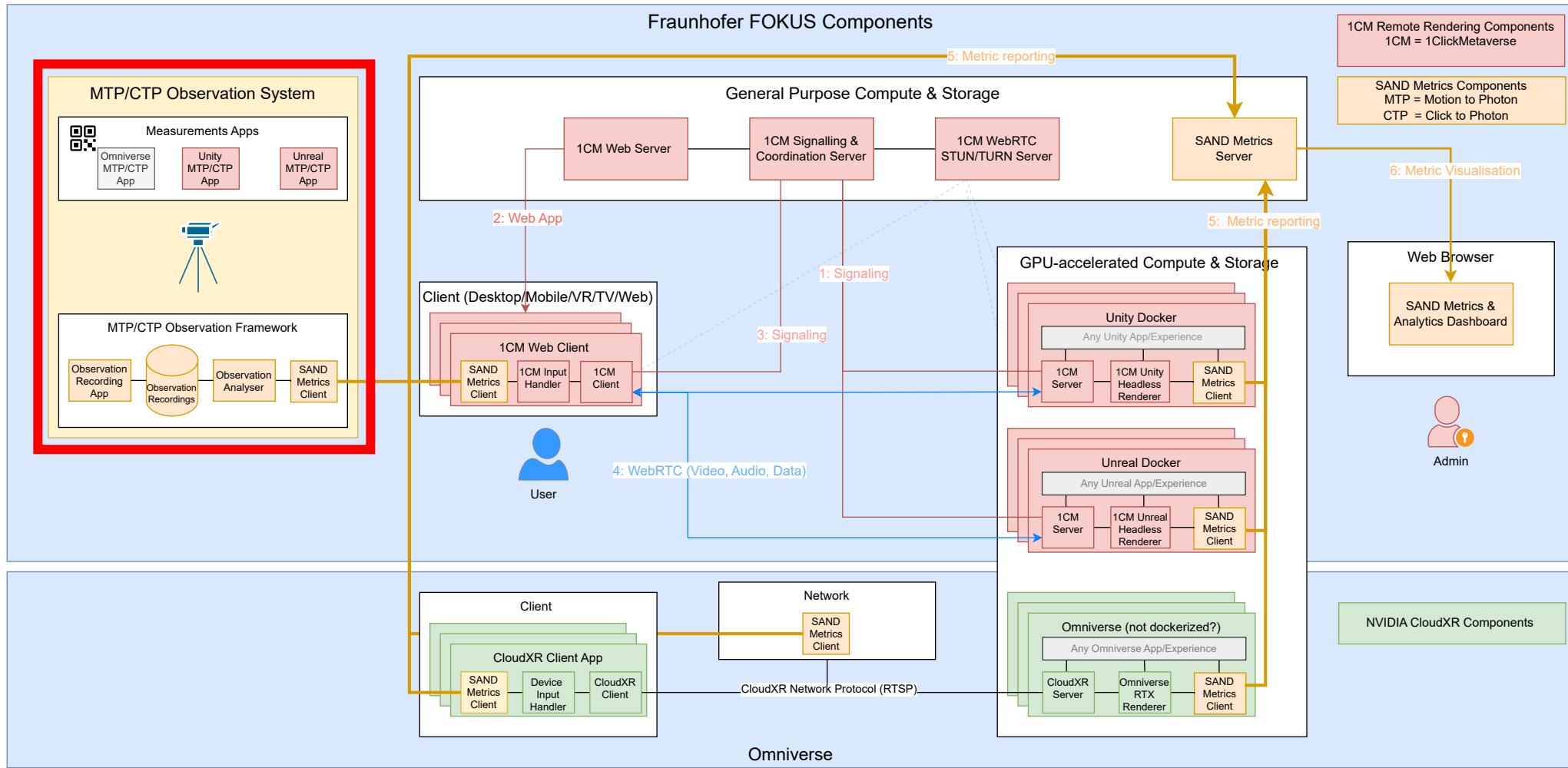
## Computation – 1ClickMetaverse Remote Rendering Architecture



<https://www.fokus.fraunhofer.de/go/metaverse>

# Metaverse Enablers

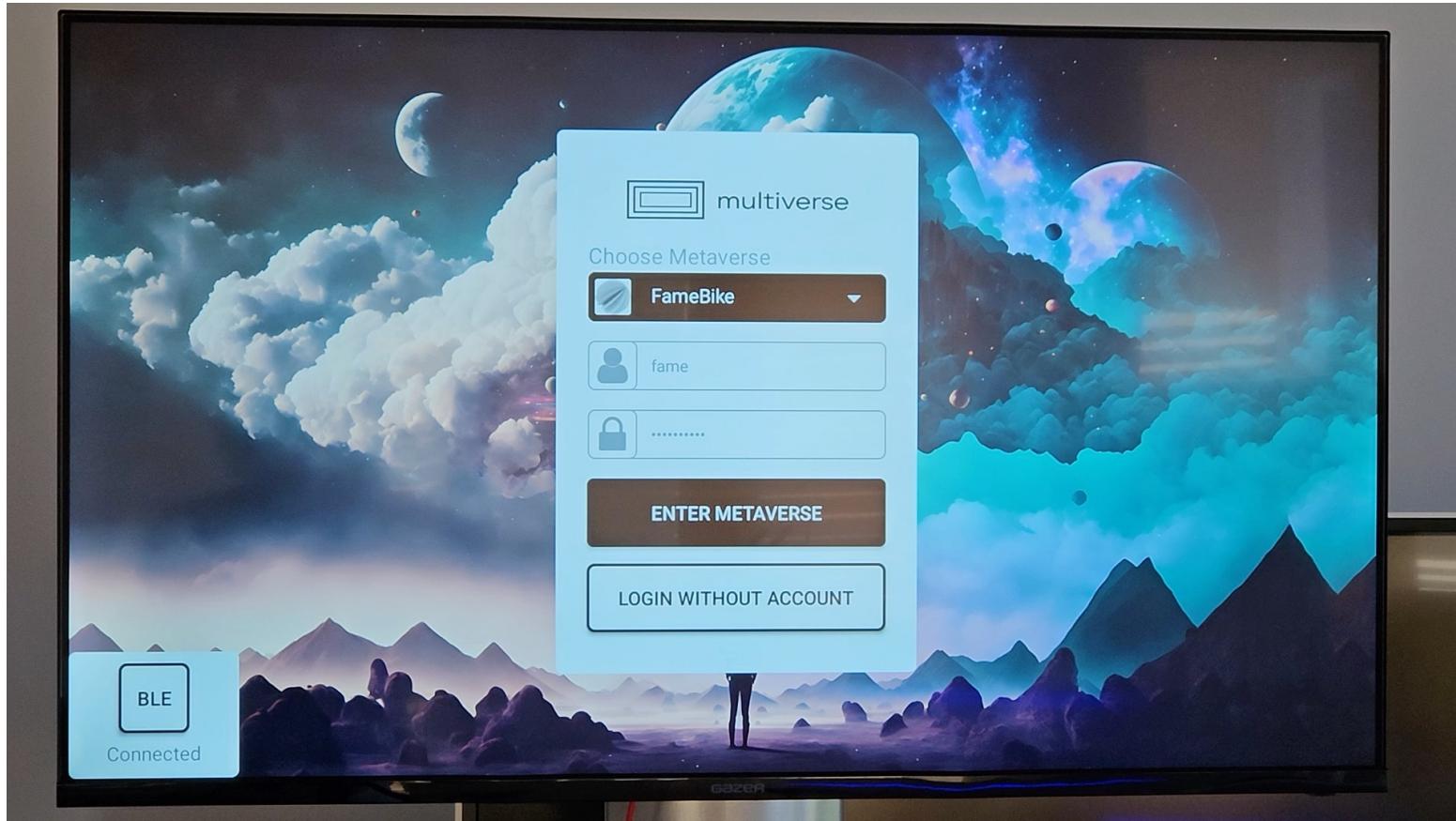
## Computation – 1ClickMetaverse Remote Rendering Architecture



# 1ClickMetaverse

## FameBike

---



<https://www.fokus.fraunhofer.de/go/metaverse>

# 1ClickMetaverse

## Decentraland



<https://www.fokus.fraunhofer.de/go/metaverse>

## Remote Warehouse

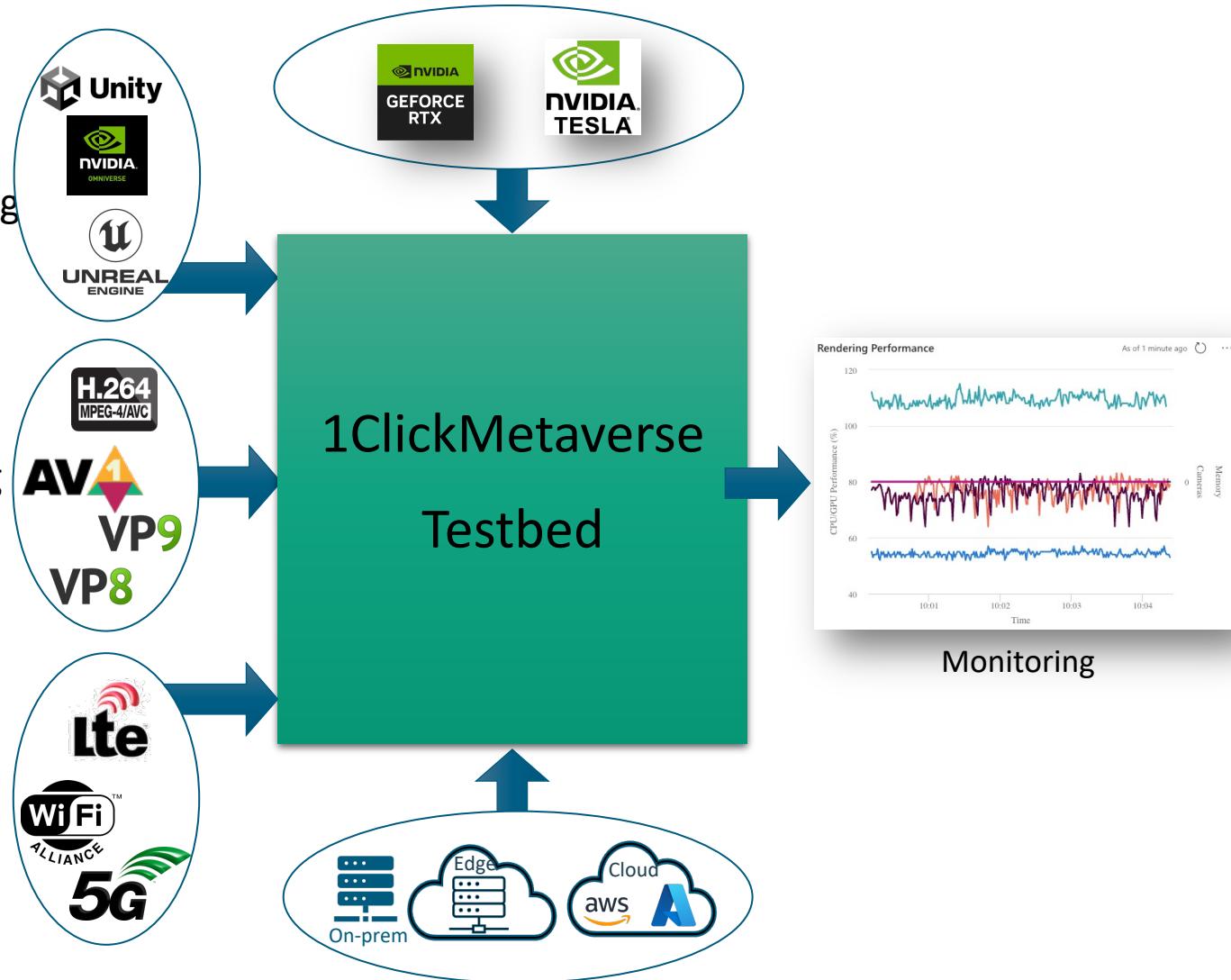
---



<https://www.fokus.fraunhofer.de/go/metaverse>

# 1ClickMetaverse (1CM) Testbed

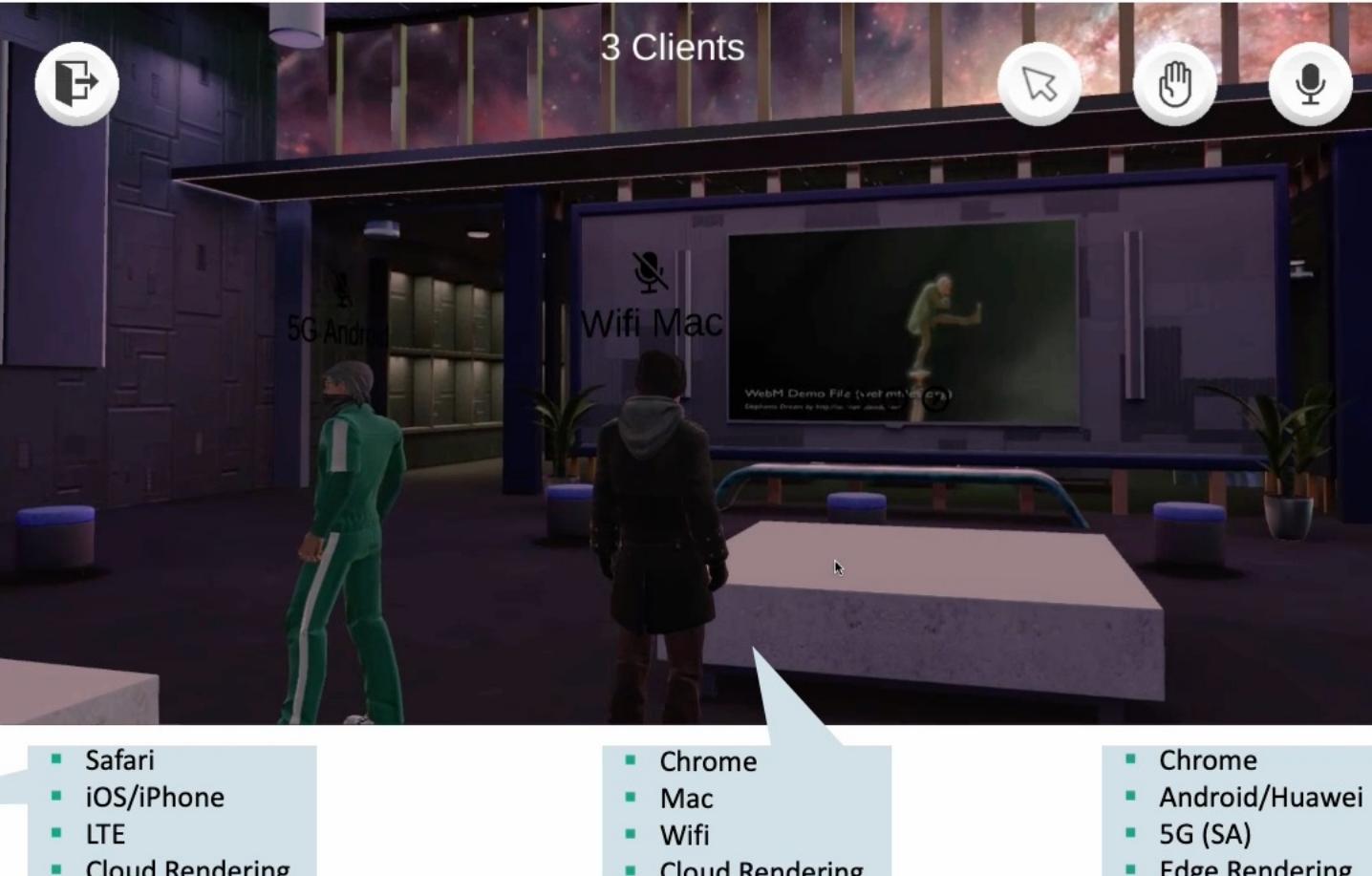
- Metaverse test environment (Testbed) for evaluating real-time rendering, encoding, and streaming of (industrial) Metaverse experiences under various QoS network configurations and computation capabilities (CPU/GPU/Memory)
- Leveraging 5G Edge Computing and Network Slicing Capabilities for enabling seamless experience
- Integration of industrial Metaverse experience developed in cutting edge graphics engines such as Unity, Unreal Engine and Omniverse
- Define, report and collect metrics (performance, network, rendering) for further evaluation



## 1ClickMetaverse Testbed

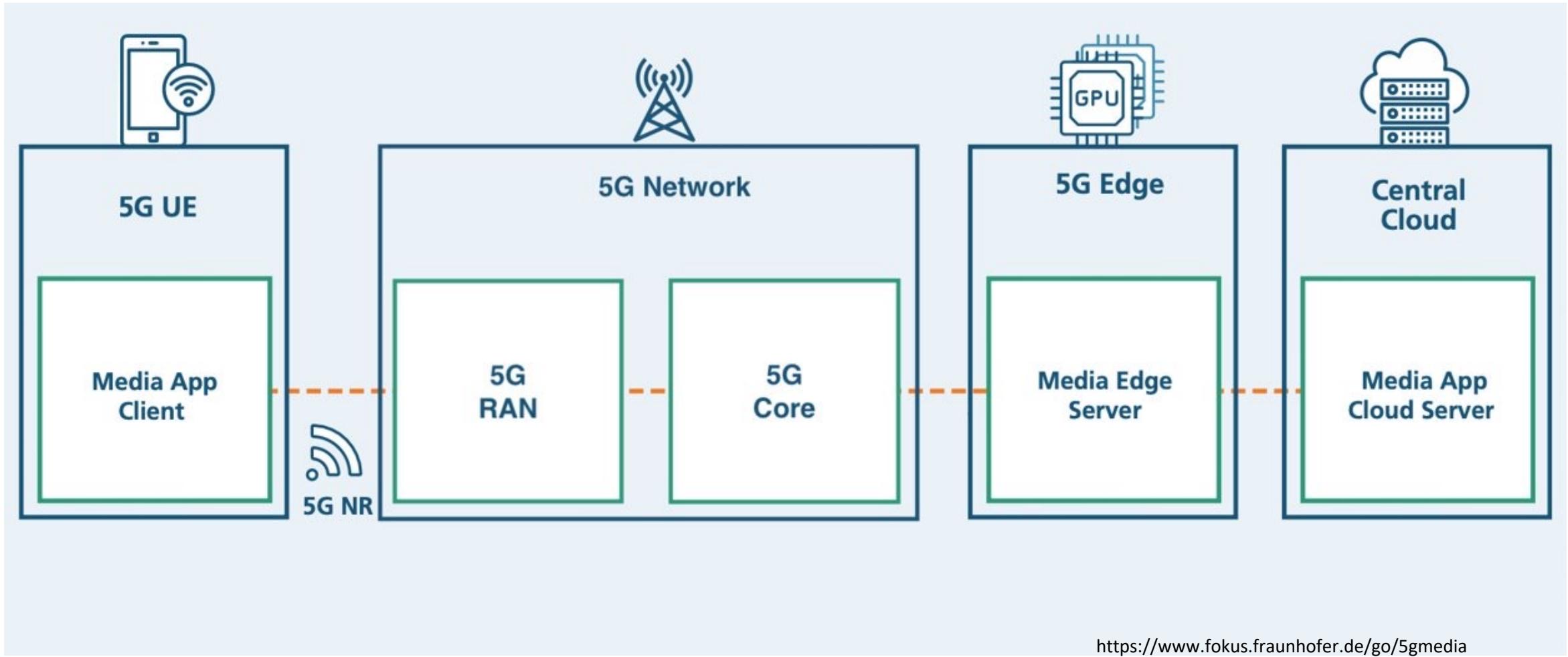
## 5G/Android/Chrome/Edge - LTE/iOS/Safari/Cloud - Wifi/Mac/Chrome/Cloud

99944/F5GMT 82% 10:59

[fameverse.fokus.fraunhofer.de](https://fameverse.fokus.fraunhofer.de)<https://www.fokus.fraunhofer.de/go/metaverse>

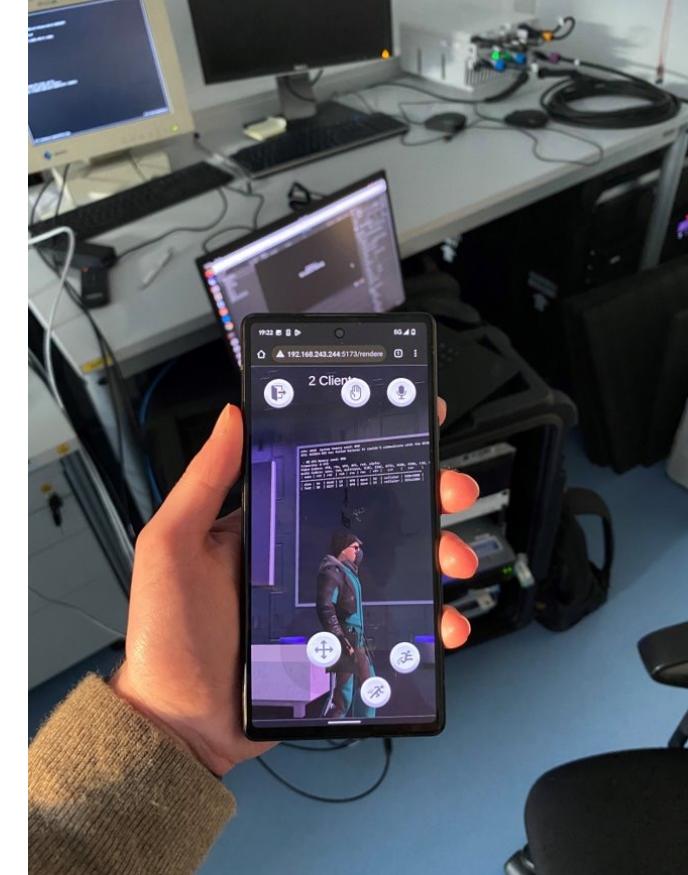
## Metaverse Enablers

### Communication – 5G Media Testbed meets Open5GCore



## Metaverse Enablers

# Communication – 5G Media Testbed meets Open5GCore



<https://www.fokus.fraunhofer.de/go/5gmedia>

# Metaverse Enablers

## Communication – Towards 6G

---

- **6G NeXt**
  - Develop a scalable infrastructure enabling use cases requiring capabilities exceeding the ones offered by 5G
  - Facilitate remote and split-processing
- **HoloCom Use Case**
  - Holographic communication over 6G
  - Real-time photorealistic 3D representation of participants

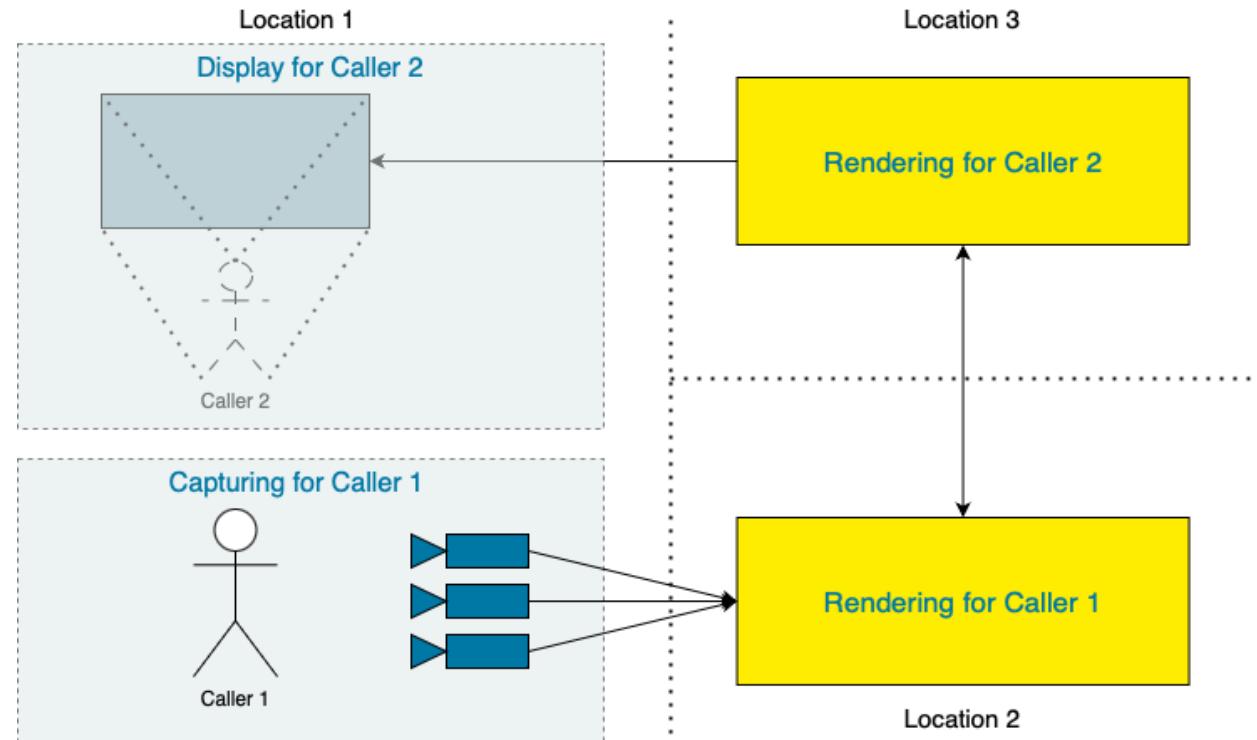


source: <https://6gnext.de/>

More Info → <https://www.fokus.fraunhofer.de/en/fame/projects/6Gnext>

## Communication – Towards 6G – XR Split Rendering

- Viewport Rendering and AI Processing tasks are crucial components affecting the 3D experience. Rendering photorealistic content requires advanced graphical processing which is not available on most consumer devices.
- Split Rendering solves this issue by offloading complex rendering and processing task to the network.
- Workloads must run efficiently on-device at low latency
  - Minimizing motion to photon latency is crucial for immersion



### QoS/QoE - 1ClickMetaverse

---

- Issue

- A high degree of separation between real-world movements and their virtual counterparts can cause motion sickness and headaches

- Metric Types

- Application Metrics
  - Rendering performance, Encoding/Decoding Speed
- Platform Metrics
  - CPU/GPU/Memory Utilization
- Network Metrics
  - Bandwidth, Jitter, Latency, Packet Loss
- Observed End-to-End Metrics
  - Click-to-Photon (CTP) and Motion-to-Photon (MTP) Latency

### QoS/QoE - 1ClickMetaverse

---

- **Motion-to-Photon Latency**

“The lag between a user making a movement and the movement being displayed within the display”

<https://pubmed.ncbi.nlm.nih.gov/36217006>

- Latency perception threshold: 23ms

- **Click-to-Photon Latency**

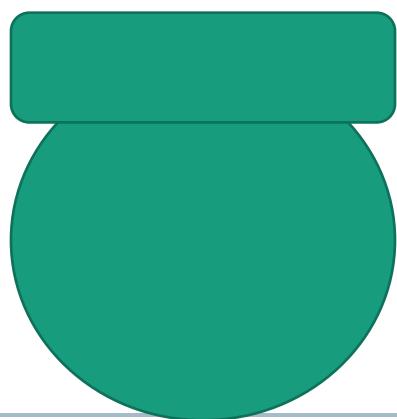
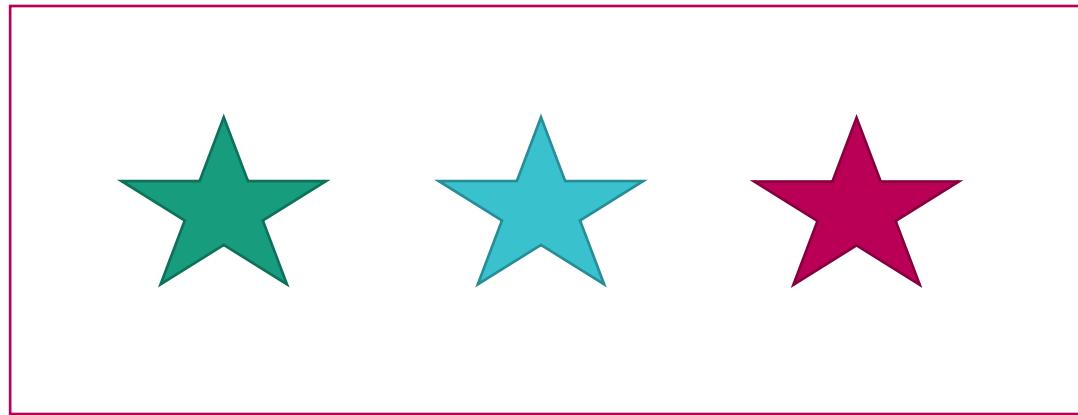
“The total latency between a user's input and the resulting visual output on the screen”

<https://www.go-euc.com/measuring-input-latency-in-virtual-desktops-introduction-and-baselines-of-the-nvidia-lvat-research>

## Metaverse Enablers

### MTP Latency – Visualization - Ideal

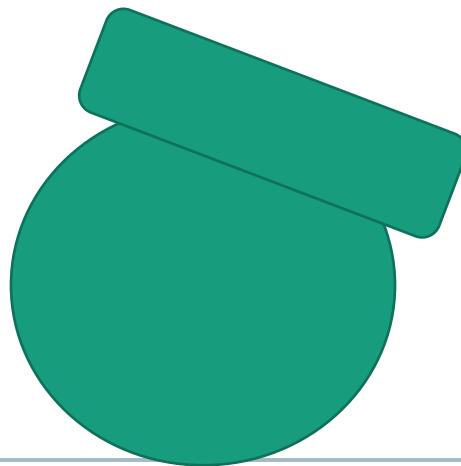
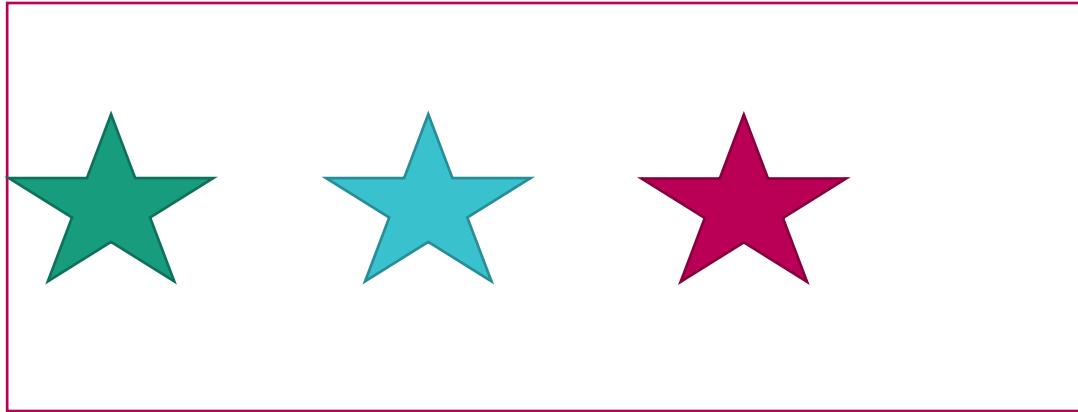
---



## Metaverse Enablers

### MTP Latency – Visualization - Ideal

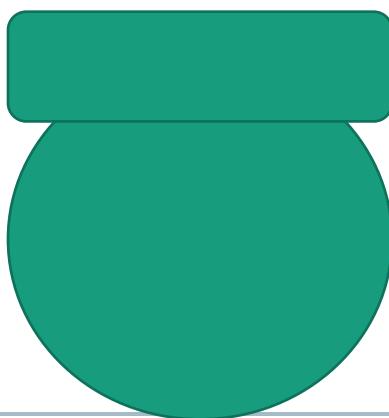
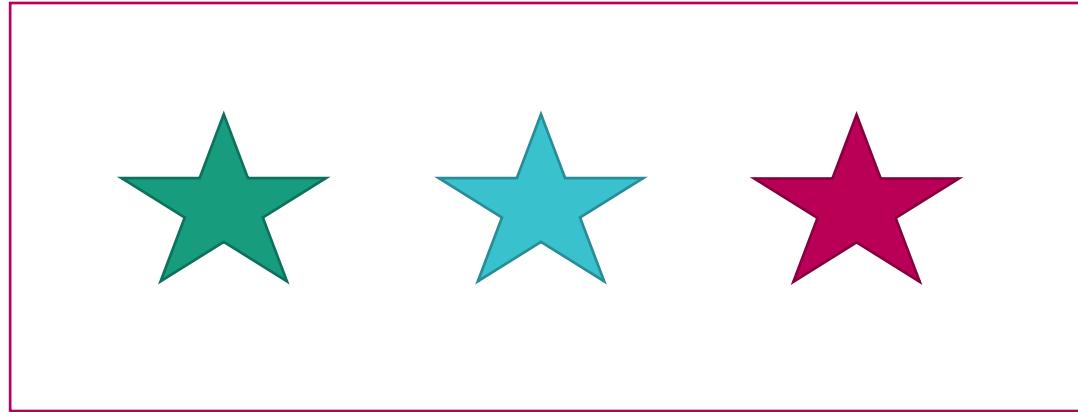
---



## Metaverse Enablers

### MTP Latency – Visualization - Reality

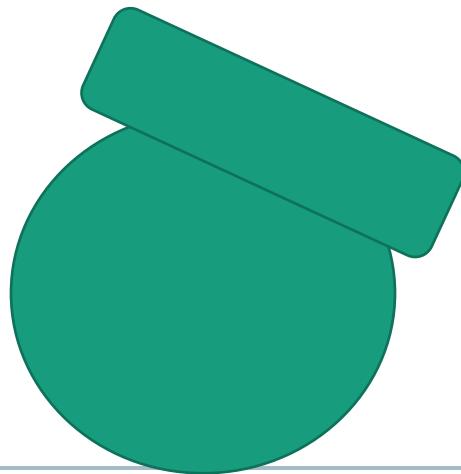
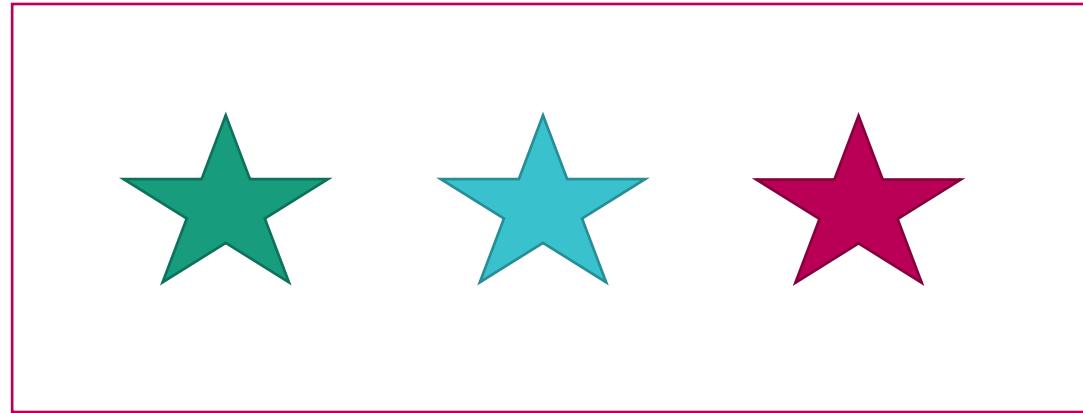
---



## Metaverse Enablers

### MTP Latency – Visualization - Reality

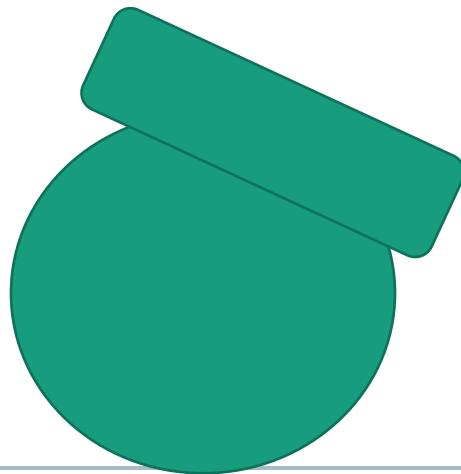
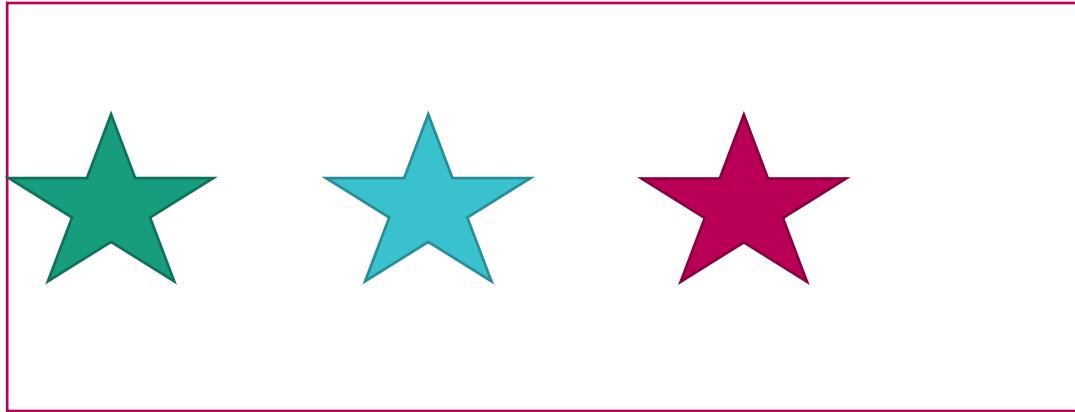
---



## Metaverse Enablers

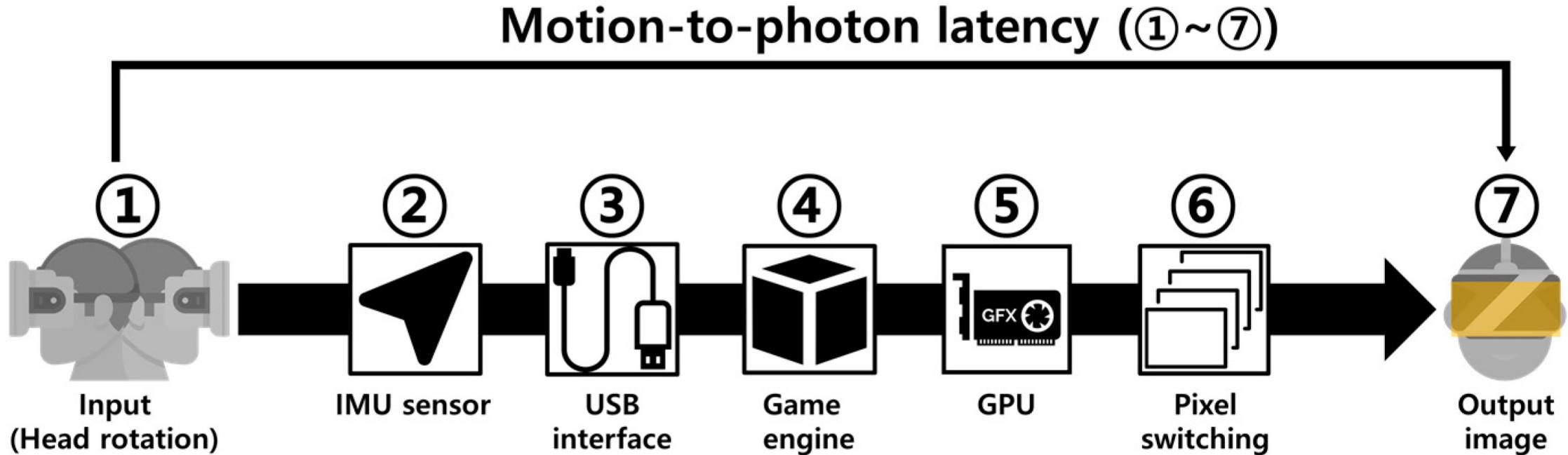
### MTP Latency – Visualization - Reality

---



### MTP Latency - Cause

---

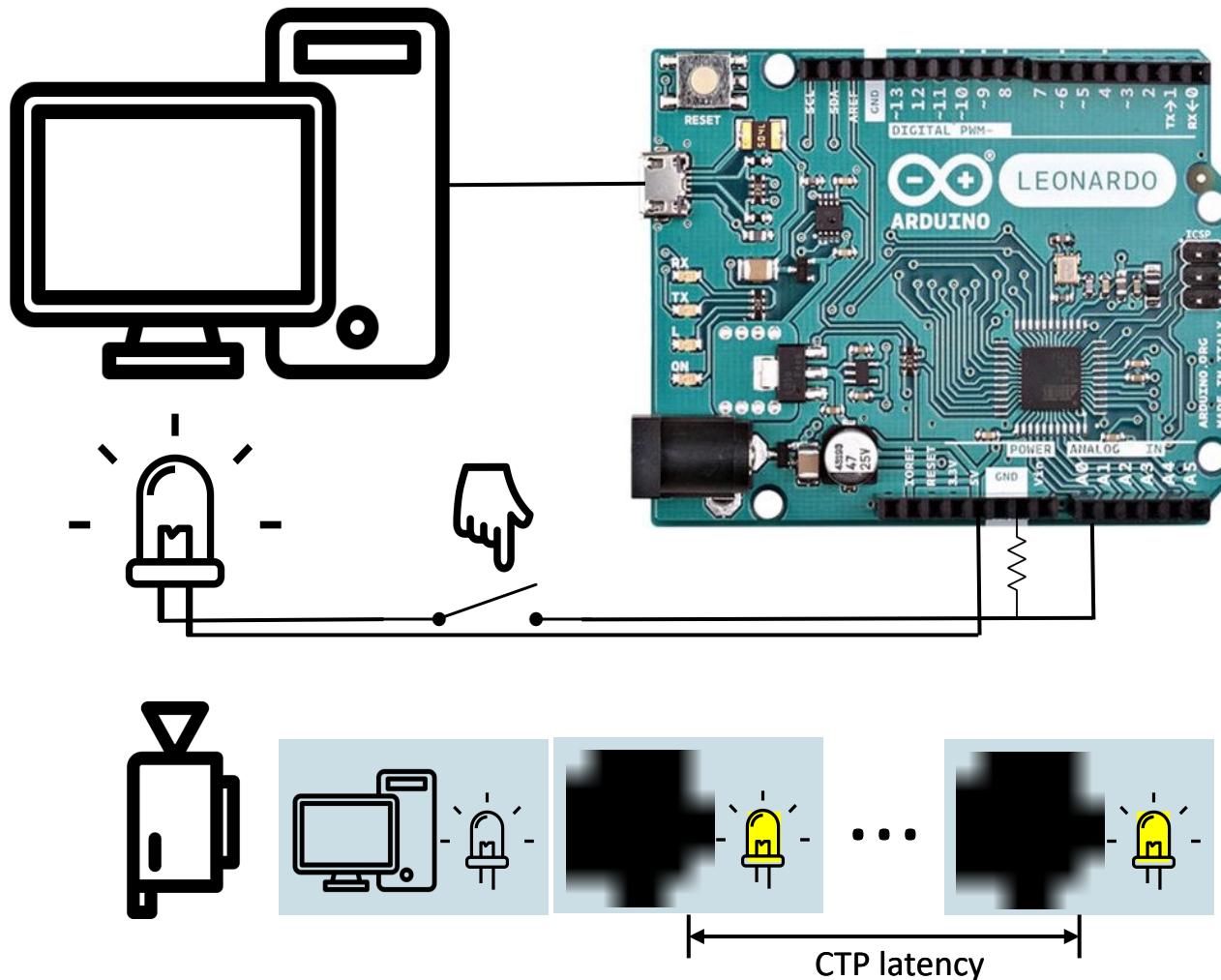


## Metaverse Enablers

### QoS/QoE – Measuring Click-to-Photon Latency in 1ClickMetaverse

#### Measure delay between LED and display

- Arduino simulating keyboard connected to PC
- LED connected to button on Arduino
- Button turns green when button pressed is
- Screen turns green when button is pressed
- LED + screen captured by camera with high frames per second
- Script counts how many frames between LED turning green and screen turning green
- Result is Click-to-Photon Latency

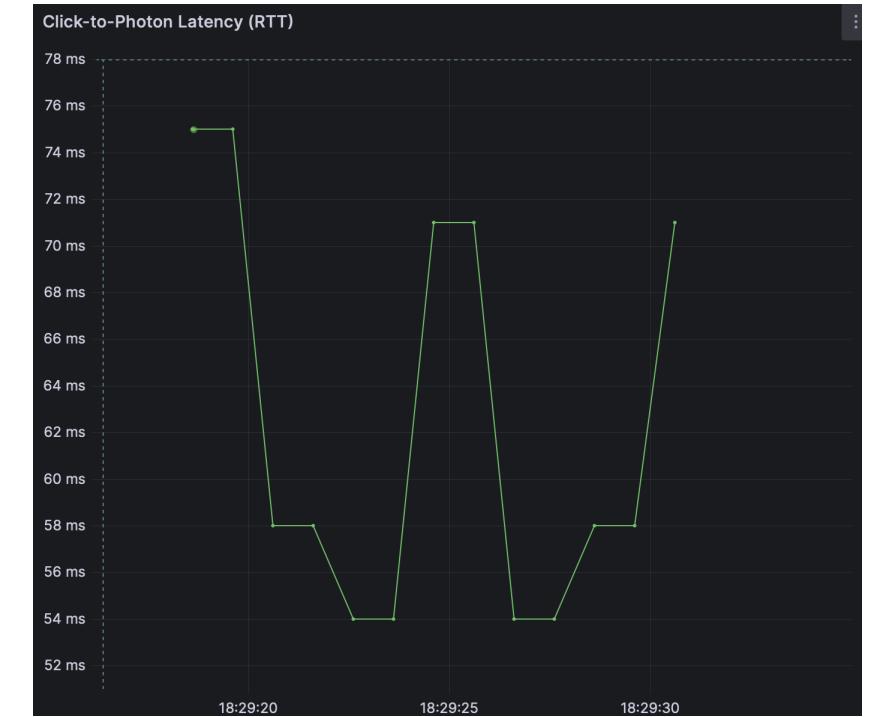


## Metaverse Enablers

### QoS/QoE – Measuring Click-to-Photon Latency in 1ClickMetaverse

#### Measure delay between LED and display

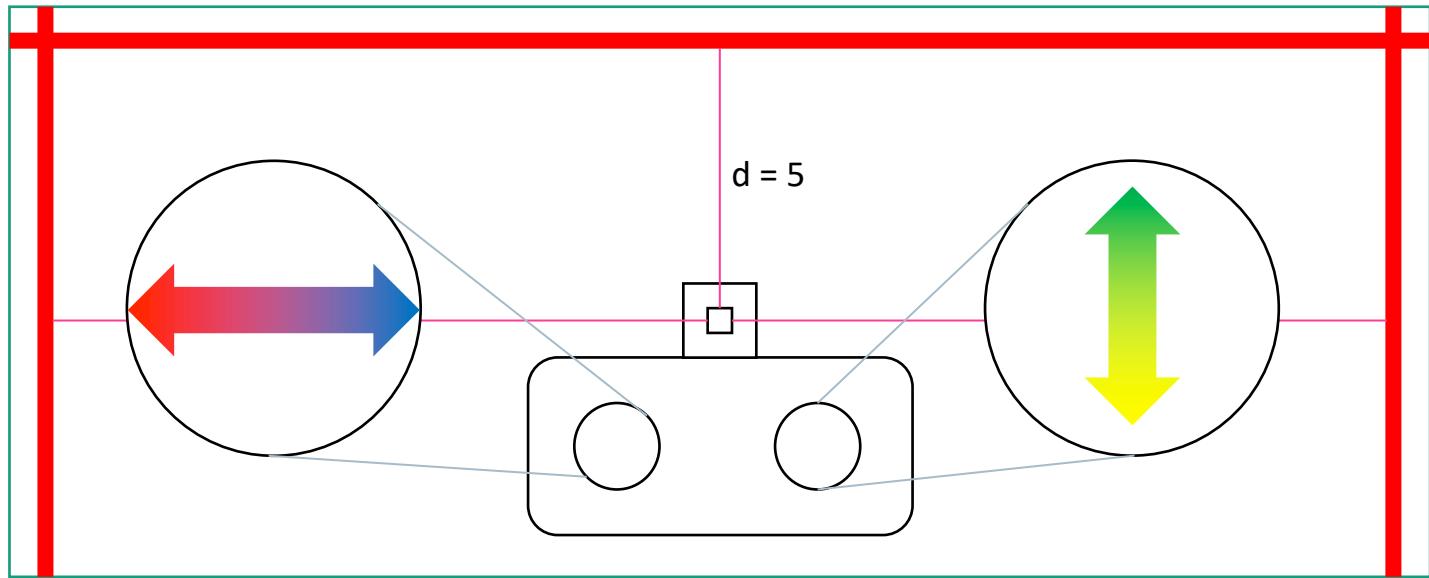
- Arduino simulating keyboard connected to PC
- LED connected to button on Arduino
- Button turns green when button pressed is
- Screen turns green when button is pressed
- LED + screen captured by camera with high frames per second
- Script counts how many frames between LED turning green and screen turning green
- Result is Click-to-Photon Latency



### QoS/QoE – Measuring Motion-to-Photon Latency in 1ClickMetaverse

Measure delay between real and virtual movement

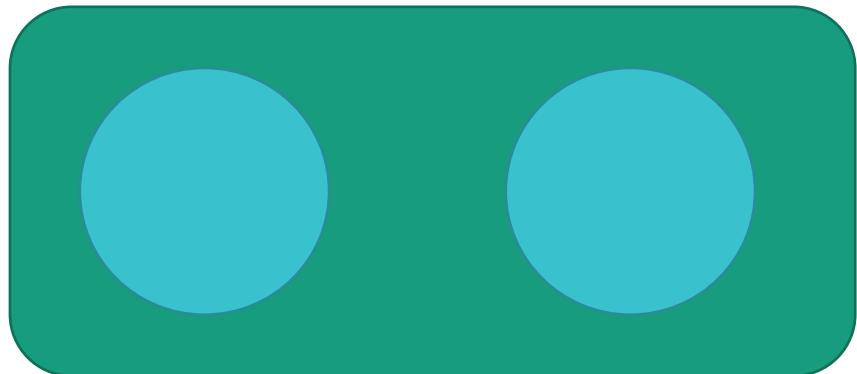
- Custom background
- Custom VR Application running on the head-mounted display (HMD)
- Movement of the HMD recognized by change in distance to borders on the background
- Virtual movement recognized by change of color of the HMD screen
- HMD + Background captured by camera with high frames per second
- Script counts how many frames between real movement and color change
- Result is Motion-to-Photon Latency



## Metaverse Enablers

### QoS/QoE – Measuring Motion-to-Photon Latency in 1ClickMetaverse

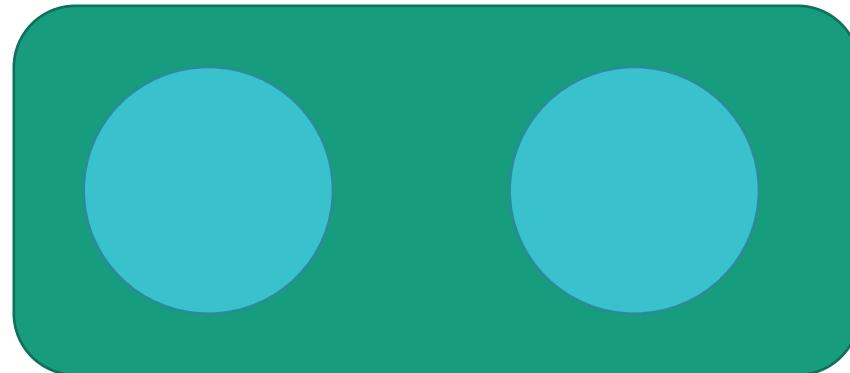
---



## Metaverse Enablers

### QoS/QoE – Measuring Motion-to-Photon Latency in 1ClickMetaverse

---

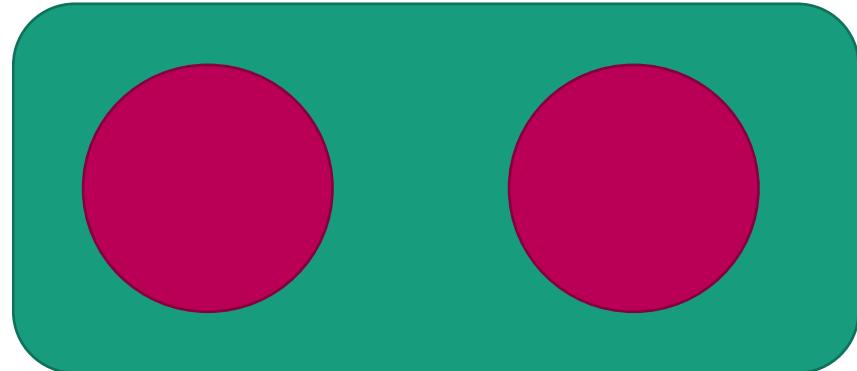


Start of real movement at: 1698244749

## Metaverse Enablers

### QoS/QoE – Measuring Motion-to-Photon Latency in 1ClickMetaverse

---



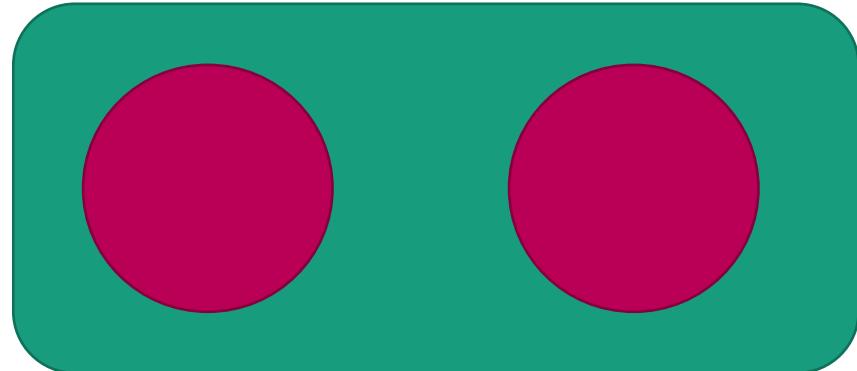
Start of real movement at: 1698244749

Change in application at: 1698244849

## Metaverse Enablers

### QoS/QoE – Measuring Motion-to-Photon Latency in 1ClickMetaverse

---



Start of real movement at: 1698212444749

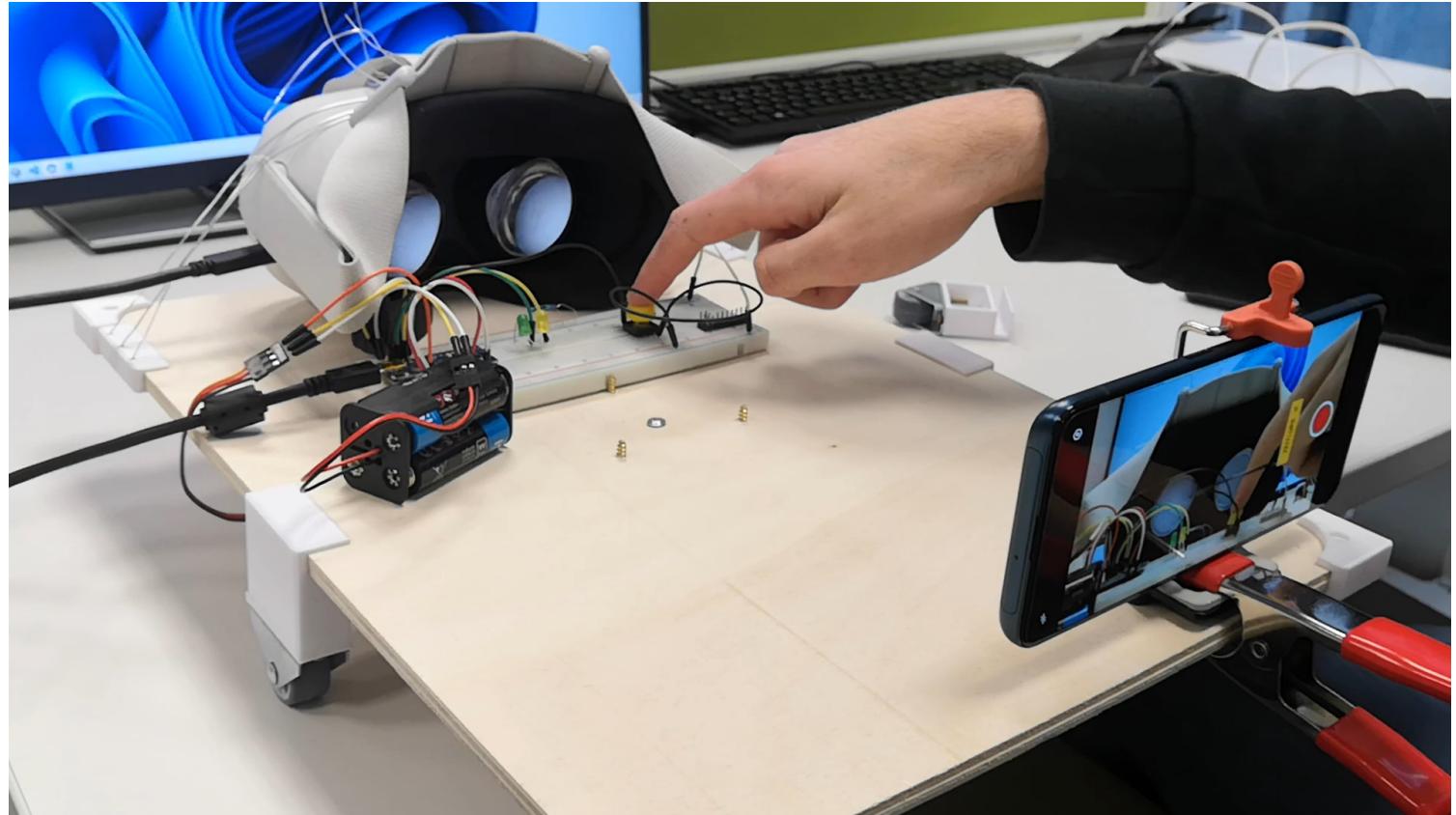
Change in application at: 1698212444849

Delay: 100ms

### QoS/QoE – Measuring Motion-to-Photon Latency in 1ClickMetaverse

Measure delay between real and virtual movement

- Custom background
- Custom VR Application running on the head-mounted display (HMD)
- Movement of the HMD recognized by change in distance to borders on the background
- Virtual movement recognized by change of color of the HMD screen
- HMD + Background captured by camera with high frames per second
- Script counts how many frames between real movement and color change
- Result is Motion-to-Photon Latency



# Metaverse Enablers

## Generative AI

---

Generative AI contributes to the creation of realistic and dynamic virtual environments, characters, content and 3D virtual spaces in the Metaverse:

- 3D Asset Generation of 3D Models, Environments, Terrains and Avatars
- Texture Synthesis for creating high-quality textures for surfaces adding more realism
- Realistic Animations to generate lifelike movements and behaviours for characters
- Natural Language Processing enabling more realistic and dynamic communication between users and virtual entities
- AI-Generated NPCs (Non-Player Characters)



source: <https://www.youtube.com/watch?v=4sCwf2VGdfc>



# Metaverse: developing an Unreal Engine experience using MetaHuman

Final Presentation

Emil Balitzki, Tarek El Tamimi, Mehmet Karagülle | Project Advanced Web Technologies | SS23



recolor both cylinder covers green and hide the two intake

# Metaverse Enablers

## Photorealistic 3D Assets

Photorealistic 3D Assets are of high relevance for Metaverse applications contributing to a more immersive and engaging virtual experience:

- Realism and Presence
- User Engagement
- Emotional Connection
- Enhanced Storytelling
- Increased User Adoption
- Create Synthetic Data for AI training



source: Unreal Engine 5



source: sordi.ai



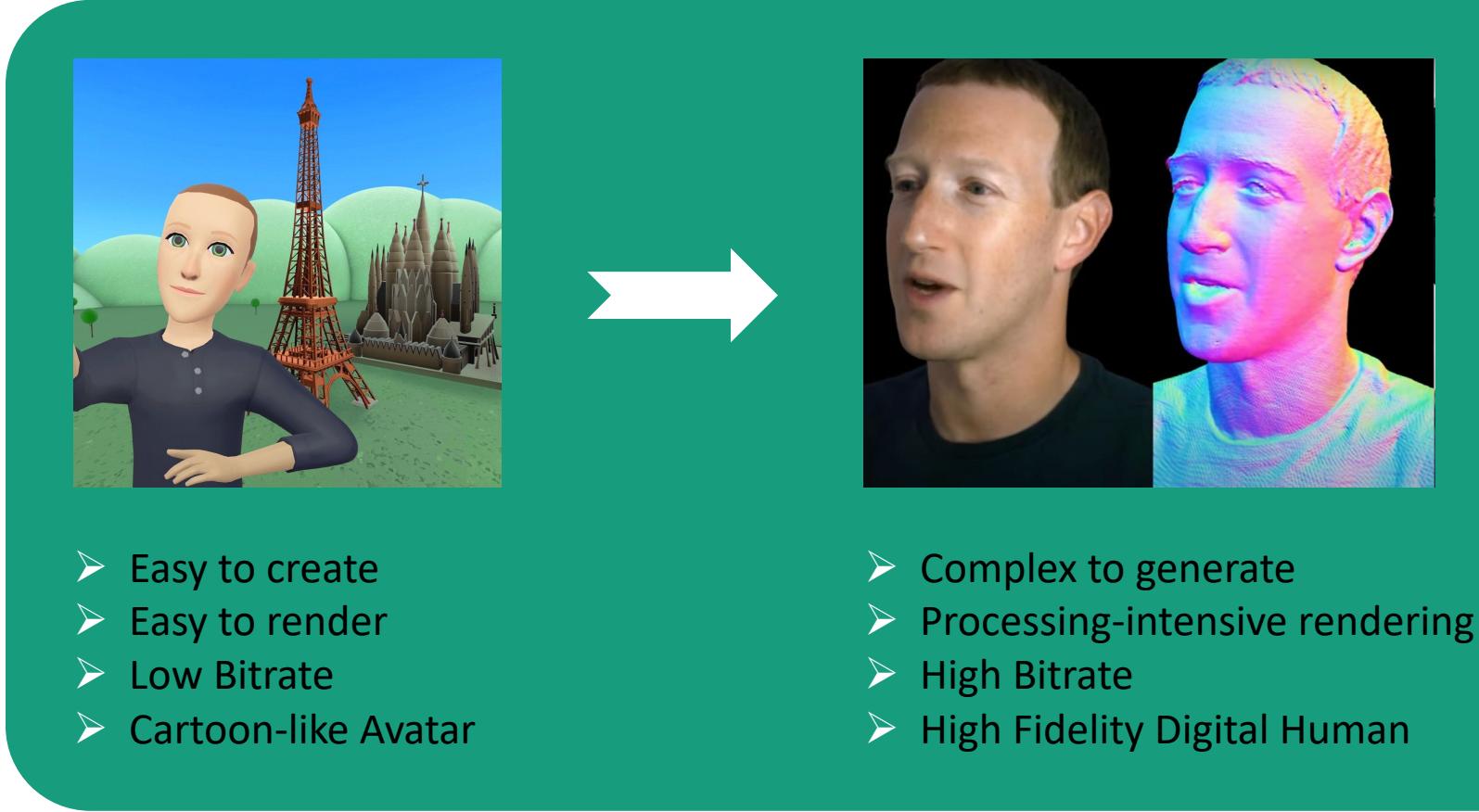
source: MetaHuman



source: Meta Codec Avatar

## Metaverse Enablers

### 3D Assets - Photorealistic 3D Avatars



Source: <https://www.youtube.com/watch?v=So8GdQD0Qyc>

## FACE BLEND SPACE ? X

Studio Face Epic (Ray Traced) LOD 0

**FACE**  
Blend Space  
Skin  
Eyes  
Teeth  
Makeup**HAIR**  
Head  
Eyebrows  
Eyelashes  
Beard  
Mustache**BODY**  
Body Shape  
Tops  
Bottoms  
Shoes

## BLEND TARGETS

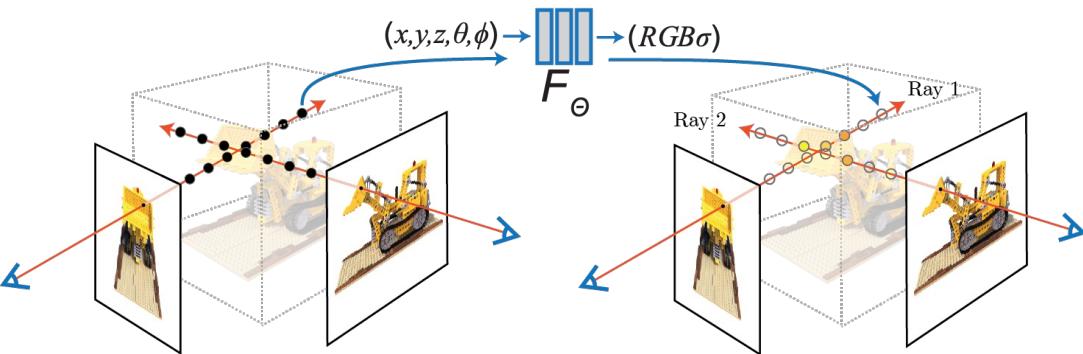


## Metaverse Enablers

### 3D Assets - Neural Radiance Fields (NeRF) & 3D Gaussian Splatting (3DGS)

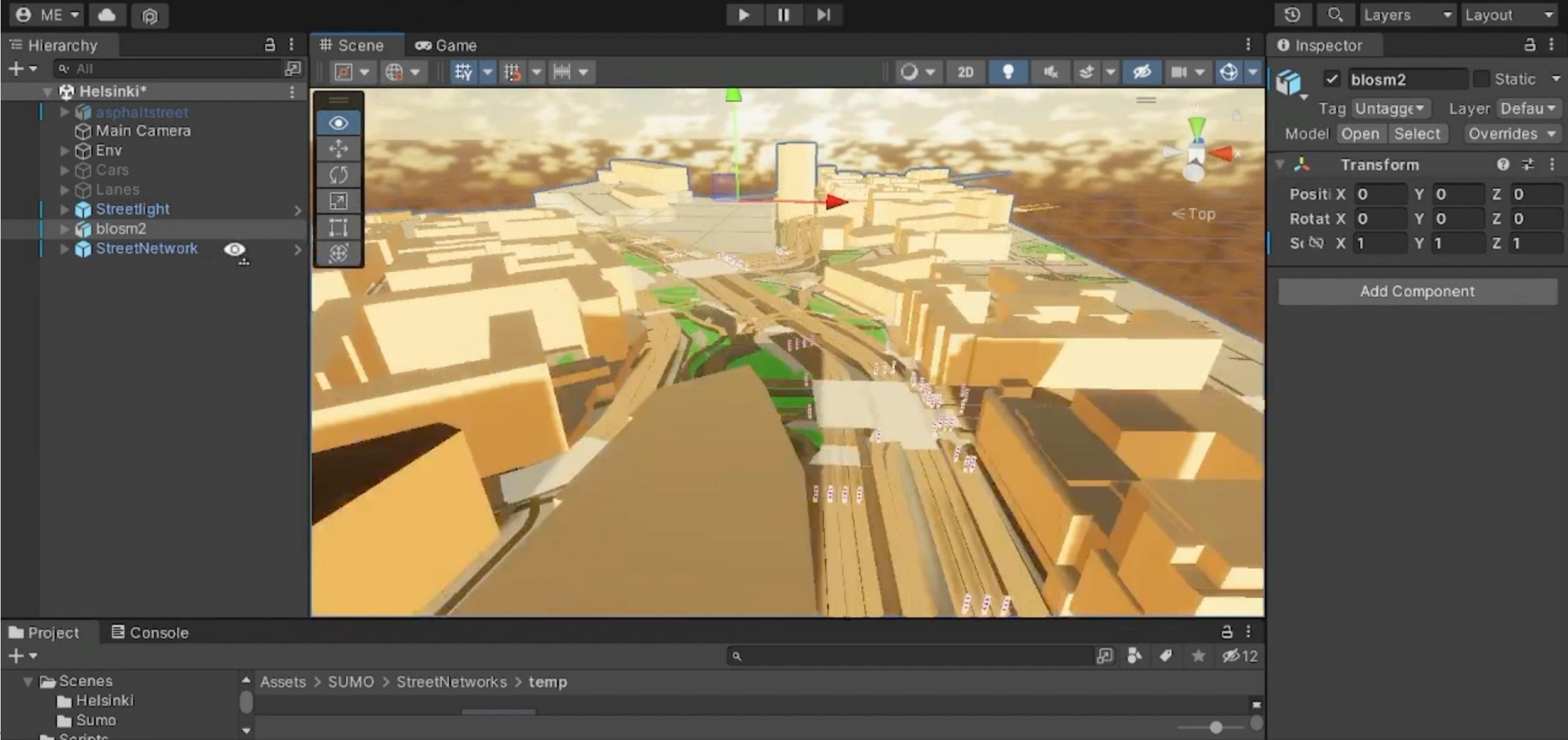
Neural Radiance Fields (NeRF) and 3D Gaussian Splatting (3DGS) are two techniques for synthesizing novel views of complex 3D scenes by learning a volumetric scene representation directly from images.

- **NeRF:** A neural network is trained to approximate the volumetric scene representation. This network takes 3D coordinates as input and outputs radiance values, effectively learning to model the complex lighting and geometry of the scene.





File Edit Assets GameObject Component Animation Rigging Jobs Test Window Help



# Standardization

# Standardization

## Metaverse Standards Forum - 2500 Global Members and Counting...



Wide diversity of organizations, including...

### Standards Organizations

Khronos, W3C, Open Geospatial Consortium, IEEE, Web3D Consortium, OMI, ASWF, Spatial Web Foundation, VRM Consortium, XRSI, ...

### Platforms

Meta, Microsoft, Sony, Google, Baidu, Huawei, General Motors, RedHat, Siemens, Tencent, Mozilla, Paramount ...

### Tools and Engines

Epic, Unity, Adobe, Autodesk, Otoy, Maxon, Cesium, ESRI, Blackshark.ai, Croquet, Lamina1, Niantic, Ready Player Me, DGG, Manticoore ...

### XR

HTC, Magic Leap, Nreal, Panasonic, Tobii, zSpace ...

### Hardware

NVIDIA, Intel, AMD, HP, Acer, Dell, Qualcomm, Samsung, Sony, MediaTek, Oppo, Lenovo, ZTE, LG ...

### Wireless and Networking

China Telecom, Deutsche Telekom, T-Mobile, Verizon, NTT, AT&T, Telefónica, Juniper, Comcast ...

### 3D Commerce

Alibaba, Alvanon, Avataar, CLO, Browzwear, IKEA, VNTANA, Metaverse Fashion ...

### Universities and Institutes

Stanford, John Hopkins, Yale (XRP), Queens University Belfast, University Salford, Fraunhofer, ...

### Advocacy

XRSI, AREA, XR Association, VRAR Association, XR Guild, Web3 Marketing ...

Global participation gathers diverse requirements and expertise  
Strong industry involvement drives pragmatic projects and deliverables



<https://metaverse-standards.org/>

# Standardization

## Metaverse Standards Forum - Domain Group Pipeline

↑  
Continuously Evolving  
Pipeline

### Metaverse Standards Register

Publicly available database mapping the landscape of metaverse-relevant standardization activities

### Privacy, Cybersecurity & Identity

Recommendations for responsible innovation that mitigates human and societal harm from objective and subjective privacy risks – including cybersecurity and identity risk management

### gITF/USD 3D Asset Interoperability (visuals, behaviors)

Cooperation between USD and gITF to increase synergy and reduce duplication of effort, gaps, fragmentation and industry confusion

### Asset Management (web3, protection, digital rights)

Digital rights, protection, portability, access, availability

### Interoperable Avatars

Cross-platform avatars and characters for film, gaming, fashion and social platforms

### 3D Web Interoperability

Enable the broadest possible interoperability of Metaverse Content using the Web

### Real/Virtual World Integration (digital twins, IOT)

Constructs to describe and integrate the physical world and created representations

### Network Requirements and Capabilities to Support Metaverse Applications

Industry requirements for seamlessly transitioning traffic on multiple wireline and wireless technologies for deploying metaverse applications at scale

### Technical Interoperability and End-User Troubleshooting

Enabling end-users to ensure reliable metaverse experiences

### Digital Fashion/Wearables

Clothing (including layering), shoes, hats, accessories

### The Industrial Metaverse

#### Accessibility

#### Academia & Research and the Metaverse

#### Ethical principles for the metaverse and their implementation

#### Ownership and Identity

#### Best Practices for Living and Working in the Metaverse

**Any Forum member can propose and participate in Domain Groups**

**There are often multiple Domain Group meetings each day**

**Key Working Groups**  
**Exploratory Groups**  
**Exploratory Group Proposals**

**Forum Domain Group activities**  
<https://metaverse-standards.org/domain-groups/>



**Metaverse**  
**STANDARDS FORUM™**

Thank you!!



Louay



Alex