Citiverse Initiative
Global Initiative on Virtual Worlds and AI – Discovering the Citiverse

Citiverse Use Case Taxonomy: Transport and Mobility

Foreword

This publication was developed within the framework of the [Global Initiative on Virtual Worlds and AI – *Discovering the Citiverse*], which is a global multistakeholder platform launched by the International Telecommunication Union (ITU), the United Nations International Computing Centre (UNICC), and Digital Dubai, and supported by more than 70 international partners.

The Initiative aims to shape a future where AI-powered virtual worlds are inclusive, trusted, and interoperable. By connecting people, cities, and technologies, it empowers meaningful progress through AI-powered virtual worlds.

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Disclaimers

The opinions expressed in this publication are those of the authors and do not necessarily represent the views of their respective organizations, Executive Committee members or Steering Committee members of the Initiative. The findings presented in this report are based on a comprehensive review of existing literature and voluntary written contributions submitted by a diverse range of stakeholders.

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Citiverse Use Case Taxonomy: Transport and Mobility

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Abbreviations and acronyms

AI	Artificial intelligence
API	Application programming interface
AR	Augmented reality
CCTV	Closed-circuit television
GAI	Generative artificial intelligence
GenAI	Generative artificial intelligence
GIS	Geographic information system
GPS	Global positioning system
ICT	Information and communication technology
IoT	Internet of Things
MERS	Middle East Respiratory Syndrome
MR	Mixed reality
SDG	Sustainable Development Goal
TOPIS	Transport Operation and Information Service
VR	Virtual reality
XR	Extended reality

1 Introduction

This report is part of a series produced under the Use Case Identification Track of the Global Initiative on Virtual Worlds and AI – Discovering the Citiverse. To make the taxonomy more accessible and user-friendly, the material has been presented as one overarching report and five thematic reports.

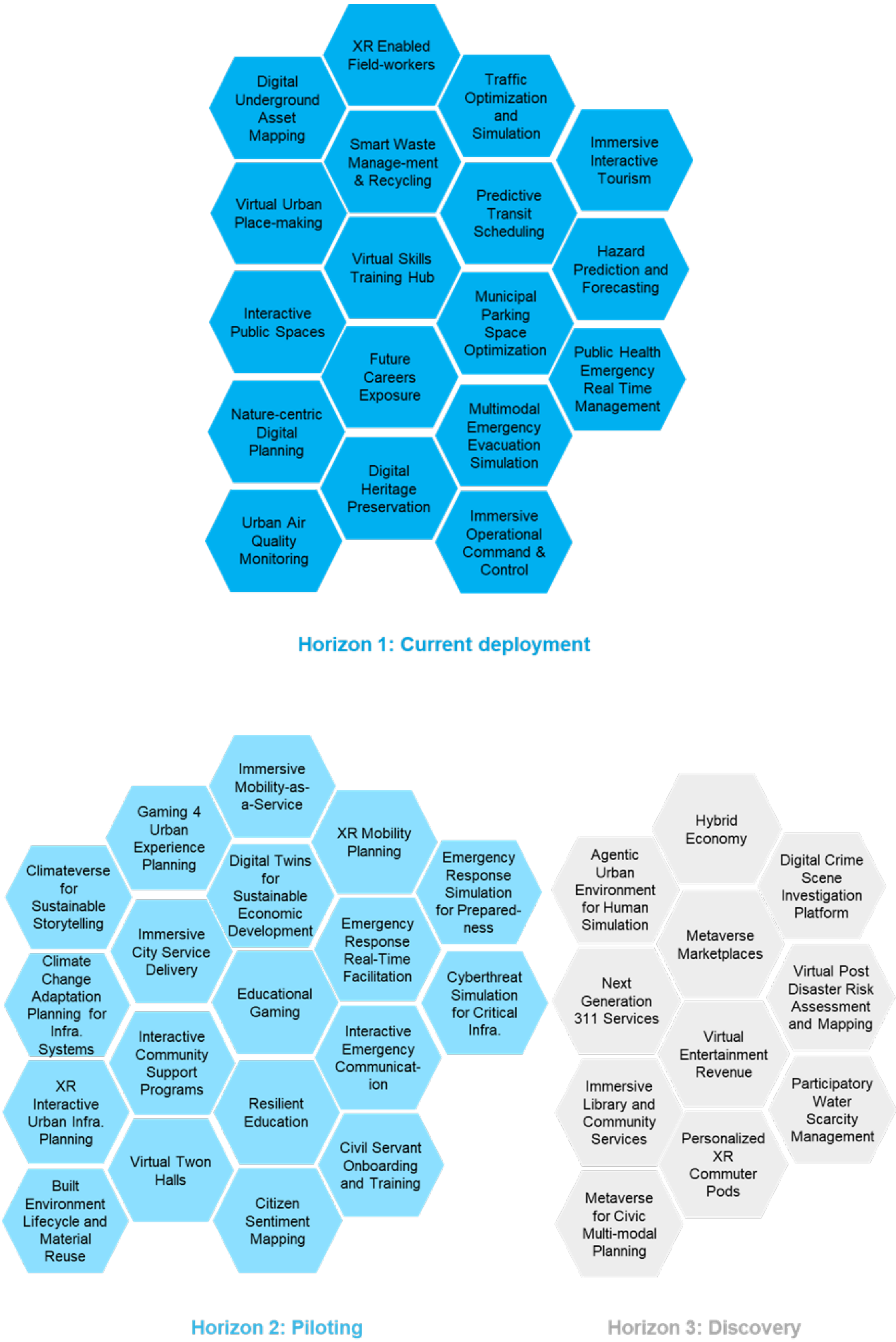
This thematic report focuses on transport and mobility. It includes the overall taxonomy for reference, a thematic overview, detailed use cases, and concluding information about the Initiative and references.

The Global Insights and Implementation Pathways report provides the overarching framework, while the other thematic reports cover the remaining four areas. Together, these reports provide both a global framework and sector-specific insights, supporting decision-making for policymakers, industry leaders, and city practitioners.

2 Overall use case taxonomy

The Citiverse Use Case Taxonomy provides a consolidated overview of nearly 50 use cases spanning five thematic areas. Figure 1 presents the overall use case landscape and horizon mapping. This overarching taxonomy highlights the interconnections between domains and demonstrates how emerging technologies can be applied across multiple aspects of urban life. Within this broader framework, the following section focuses on the thematic area of transport and mobility.

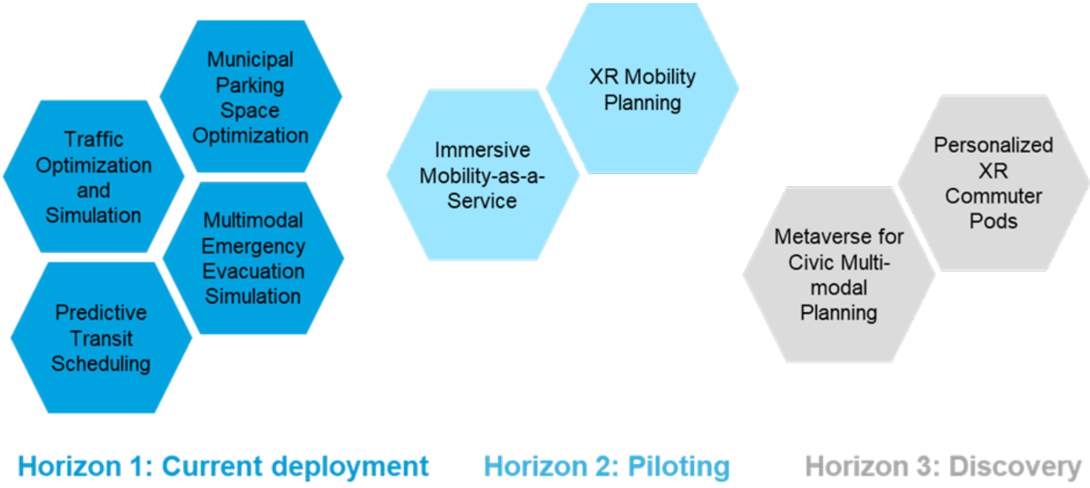
Figure 1: Overall use case overview and horizon mapping



Source: Citiverse Use Case Taxonomy: Global Insights and Implementation Pathways, 2025

3 Transport and mobility

Figure 2: Transport and mobility use case overview and horizon mapping



Source: Citiverse Use Case Taxonomy: Transport and Mobility, 2025

3.1 Thematic area description

Cities are grappling with high levels of GHG emissions and air pollution linked to transport. Estimates suggest that urban areas are responsible for 70 per cent of global $C0_2$ emissions, with transport and buildings being among the largest contributors (IPCC 2022). Many cities are also facing high levels of traffic congestion, ageing infrastructure, and growing populations.

The transport and mobility thematic area focuses on leveraging virtual worlds to transform the way people and goods move through cities. Use cases will span:

- **Public transportation:** Including enhancing the access, sustainability, efficiency, customer experience and modal share of public transport from railways to bus networks.
- **Active transport and micro-mobility:** Increasing opportunities and reclaiming urban spaces for safe and attractive walking, cycling and micro-mobility such as scooters.
- **Private vehicles:** Reducing traffic congestion and safety and enabling EV adoption through better urban infrastructure systems.
- **Urban logistics and freight:** Optimizing the movement of goods within cities through smarter and more intelligent systems from supply management to last-mile delivery.
- **Transportation hubs:** transforming stations, city ports and airports into seamlessly integrated multimodal transport hubs.

The thematic area will prioritise transport and mobility use cases that support the implementation of the SDGS, including Target 11.2 "*By 2030, provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities and older persons.*

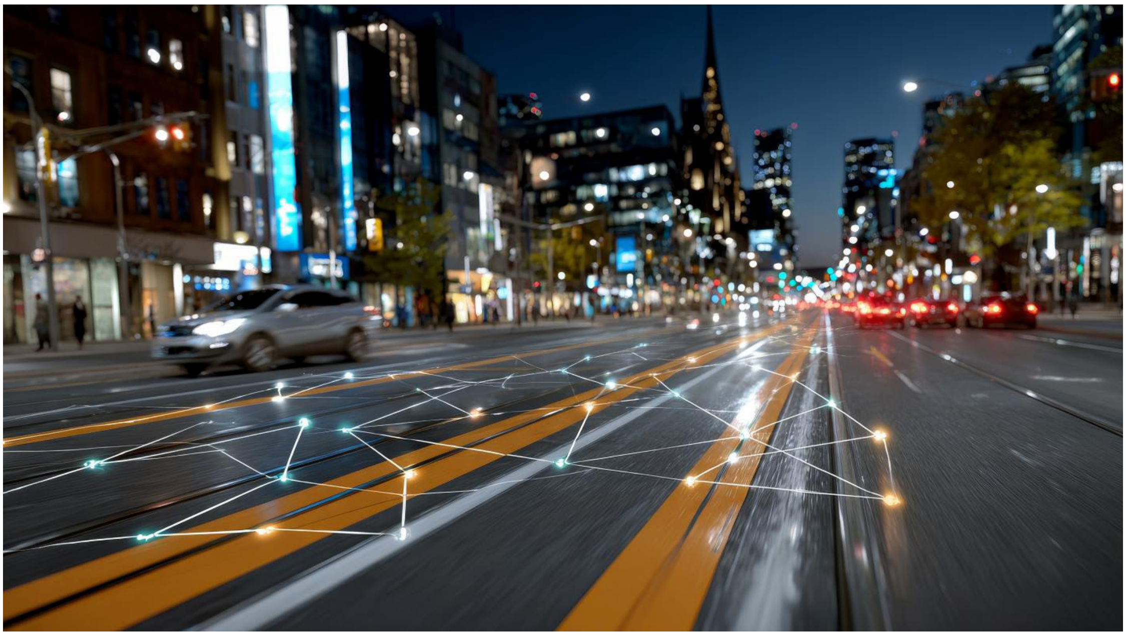
To achieve intelligent and sustainable transportation and mobility systems, a paradigm shift is required. Emerging technologies such as AR, VR, digital twins and AI will be essential for this transformation. These tools can be applied across all phases of transportation operations, from planning and design to real-time monitoring and management, enabling data-driven decision making.

3.2 Transport and mobility use cases

Use case 1: Traffic optimization and simulation (Horizon 1)

Description

Virtual world technologies such as digital twins can be used to create a real-time simulation of traffic flows across cities. City stakeholders such as transport planners, traffic management authorities, and public safety departments can use this platform to monitor mobility patterns, model different traffic scenarios, and adjust infrastructure operations to optimize flow and enhance safety. IoT devices such as sensors and connected traffic signals feed live data into the digital twin, enabling continuous updates to the virtual model. AI can be leveraged to predict congestion hotspots, dynamically adjust traffic signal timings, and recommend rerouting strategies to minimize delays, reduce emissions, and improve travel experience.



Impacts

1) **Reduced traffic congestion:** Real-time data analysis and adaptive signal control have led to smoother traffic flow and decreased travel times.
2) **Enhanced public safety:** Improved monitoring and rapid response capabilities have contributed to a reduction in traffic accidents and fatalities.
3) **Environmental benefits:** Optimized traffic flow has resulted in lower vehicle emissions, contributing to better air quality.
4) **Informed urban planning:** Traffic optimization and simulation can provide valuable insights for infrastructure development and policymaking.
5) **Economic benefits:** Reducing travel time can lead to overall increases in economic productivity, through reduce commute times and improving access to local businesses, retail and recreational areas.

Key beneficiaries

- Commuters and residents
- Emergency services
- Urban planners and policymakers
- Environmental agencies

Key technologies

- **Digital twin:** A 3D simulation platform that models the city's infrastructure and environment.
- **AI:** Analyse traffic data to predict congestion and optimize signal timings.
- **C-ITS:** Enables vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) communication for coordinated traffic management.
- **IoT Sensors:** Collect real-time data on traffic conditions, vehicle speeds and environmental factors.

SDG alignment

- **SDG 3: Target 3.6** By 2020, halve the number of global deaths and injuries from road traffic accidents.
- **SDG 9: Target 9.1** Develop quality, reliable, sustainable and resilient infrastructure, including regional and transborder infrastructure, to support economic development and human well-being, with a focus on affordable and equitable access for all.
- **SDG 11: Target 11.2** By 2030, provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, people with disabilities and older people.
- **SDG 11: Target 11.3** By 2030, enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries.
- **SDG 11: Target 11.6** Strengthen efforts to protect and safeguard the world's cultural and natural heritage.

Risk level

Table 1: Risk level: Traffic optimization and simulation

Risk attribute	Risk rating			Explanation
Public safety	Low	Medium	High	The system enhances safety through improved traffic management and emergency response capabilities.
Stakeholder acceptance	Low	Medium	High	Public and institutional support is strong due to visible improvements in traffic conditions.

Table 1: Risk level: Traffic optimization and simulation (continued)

Risk attribute	Risk rating			Explanation
Data privacy and security	Low	Medium	High	Handling of real-time data requires robust cyber-security measures to protect against breaches.
Financial/ operational	Low	Medium	High	Significant investment is needed for infrastructure and maintenance, but long-term benefits are substantial.

Implemented in:

Seoul, Republic of Korea; Aachen, Germany; Zurich, Switzerland; Boston, USA; Dubai, UAE; Singapore

Case study: AI-powered traffic optimization using digital twins in Seoul

Context

Seoul, Republic of Korea, is one of the most densely populated cities in the world, home to more than 9 million residents within its metropolitan boundary.[1] The city has long grappled with severe traffic congestion, rising greenhouse gas emissions, and the need for more efficient and resilient public infrastructure. Historically, Seoul's traffic management relied on siloed systems and manual control protocols, which were insufficient to meet the growing complexity of mobility demands in a megacity. The COVID-19 pandemic and increasing incidents of extreme weather added urgency to the city's efforts to modernize its transportation ecosystem. In response, Seoul implemented a pioneering digital twin solution called the Smart Traffic Management System, designed to simulate, predict, and control urban traffic patterns in real time. This digital twin integrates with the city's Transport Operation and Information Service (TOPIS) and is powered by AI, IoT sensors, and geospatial mapping technologies.[2]

Objective

The primary goal of Seoul's digital twin initiative is to reduce congestion and improve public safety by predicting and managing traffic conditions more effectively. It aims to provide a real-time model of the city's transport network, which can help optimize traffic signal timings, reroute emergency vehicles, and support long-term infrastructure planning.

Key objectives include:

- Reducing average commute times across core corridors.
- Improving safety by reducing traffic-related fatalities and emergency response times.
- Lowering carbon emissions through better traffic flow and mode shift.
- Supporting predictive planning to prevent future bottlenecks.
- Facilitating cross-agency coordination and data sharing in real time.[3]

(continued)

Case study: AI-powered traffic optimization using digital twins in Seoul

Solution approach

The project is spearheaded by the Seoul Metropolitan Government in collaboration with technology partners including LG CNS, MORAI, and academic institutions such as KAIST. Seoul's solution is built on a city-scale digital twin known as the "S-Map" that mirrors traffic conditions using data collected from more than 5 000 sensors, 1 200 CCTV cameras, and GPS-enabled vehicles. Key technologies involved include:

- AI and Machine Learning to analyse traffic data, detect anomalies, and provide predictive analytics.
- Digital twins for real-time simulation and visualization of traffic patterns under various scenarios.
- IoT Devices such as smart traffic lights and speed detectors that feed data into the digital platform.
- GIS Mapping to correlate traffic flows with spatial infrastructure and demographics.
- Emergency Routing Algorithms to prioritize ambulances and fire trucks in congested areas.

The platform is accessible to city officials via the TOPIS dashboard and used by multiple agencies for coordination. While it currently operates in 2D, development towards a 3D simulation model is underway for advanced visualization of multilevel infrastructure such as bridges, tunnels, and underground expressways.[4]

Results

- Travel times decreased by 15–25 per cent in key districts following the introduction of AI signal optimization.
- Emergency vehicle response times improved by up to 20 per cent due to adaptive routing.
- Vehicle emissions decreased by an estimated 11.3 per cent in trial zones as a result of reduced idling.
- Real-time traffic predictions with 92 per cent accuracy allowed pre-emptive adjustments to signal systems.
- The digital twin has become a foundational tool for Seoul's future plans to integrate autonomous vehicles.
- The public dashboard has enhanced transparency and trust among citizens.
- According to Seoul's Digital Foundation Division, citizen satisfaction with transport services increased by 18 per cent post-implementation.[5]

Conclusion

Seoul's AI-powered digital twin demonstrates how real-time simulation, AI analytics and IoT integration can transform urban traffic management. By enabling predictive control and cross-agency coordination, the Smart Traffic Management System delivered measurable reductions in congestion, emissions, and emergency response times. As other megacities face similar mobility challenges, Seoul's experience offers a blueprint for leveraging digital twin technology to create more efficient, resilient, and citizen-centric transport ecosystems.

Use case 2: Predictive transit scheduling (Horizon 1)

Description

Digital twins can be used to support AI-powered predictive transit scheduling by simulating and visualizing real-time passenger demand, traffic conditions, and operational scenarios across city-wide transport networks. City stakeholders such as fleet operators and transport planners can use these platforms to dynamically adjust transport schedules, optimize vehicle dispatching, and reduce service gaps based on live and forecasted data. IoT sensors across vehicles, stations, and road networks can feed real-time information into digital replicas of the transit system to enable continuous performance monitoring. AI could be leveraged to anticipate surges in demand, recommend fleet adjustments, and optimize resource allocation.

Impacts

1) **Improved punctuality:** AI models help align schedules with real-world conditions, reducing lateness and missed transfers.
2) **Operational cost reduction:** Buses are deployed more efficiently based on dynamic demand modelling.
3) **Increased passenger satisfaction:** Riders experience more consistent wait times and reliable service.
4) **Lower emissions:** Optimized routing and idling reduction contribute to environmental improvements.
5) **Improved accessibility:** Transport planners can use AI-powered predictive transit scheduling to plan and test routes for disabled people to improve accessibility across the network.

Key beneficiaries

- Commuters, including shift workers and students
- Public transport authorities and fleet managers
- Municipal environmental and mobility departments

Key technologies

- **Digital twins:** Can be used to support AI-powered predictive transit scheduling by simulating and visualizing real-time passenger demand, traffic conditions, and operational scenarios across city-wide transport networks.
- **AI:** Forecast demand using historical, real-time, and contextual data.
- **Fleet management systems:** Integrate AI outputs into dispatch and routing.
- **IoT sensors:** Monitor location, vehicle health, and occupancy levels.
- **Open data APIs:** Share information with the public and MaaS platforms for transparent access.

SDG alignment

- **SDG 9: Target 9.1** Develop quality, reliable, sustainable and resilient infrastructure, including regional and transborder infrastructure, to support economic development and human well-being, with a focus on affordable and equitable access for all.
- **SDG 11: Target 11.2** By 2030, provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, people with disabilities and older people.

Risk level

Table 2: Risk level: Predictive transit scheduling

Risk attribute	Risk rating			Explanation
Public safety	**Low**	Medium	High	Optimizing schedules and reducing crowding improves user safety.
Stakeholder acceptance	**Low**	Medium	High	Passengers and operators generally welcome improvements in reliability.
Data privacy and security	Low	**Medium**	High	Passenger travel data must be anonymized and protected.
Financial/ operational	Low	**Medium**	High	Upfront investment in infrastructure and training is required.

Implemented in:

Singapore; Madrid, Spain; Helsinki, Finland; Zurich, Switzerland; Boston, USA

Case study: AI-powered predictive transit scheduling in Madrid

Context

Madrid, the capital of Spain, has a public transport network that serves more than 4 million daily commuters across buses, metro and suburban rail. While the system is one of the most extensive in Europe, growing demand, traffic congestion, and sustainability goals have created new challenges.

The city faces significant variation in transport demand due to commuting patterns, special events, and weather conditions, leading to inefficiencies in bus scheduling and fleet management. The Empresa Municipal de Transportes (EMT Madrid), responsible for operating more than 2 000 buses on 200+ routes, recognized the need for more responsive, data-driven scheduling to address operational inefficiencies and improve passenger experience. This led to the deployment of an AI-based predictive scheduling system that uses real-time and historical data to anticipate ridership and allocate transit resources dynamically.[6]

Objective

The main objective of EMT Madrid's AI-powered transit optimization project is to improve the efficiency and reliability of the public bus network. Specifically, the project aims to:

- Enhance service reliability by reducing delays and improving bus availability.
- Forecast short-term demand to optimize route frequency during peak hours.
- Improve passenger satisfaction through reduced wait times and crowding.
- Contribute to Madrid's air quality and climate goals by reducing unnecessary vehicle deployment.
- Improve response to unexpected events (e.g., road closures, extreme weather, or public demonstrations).[7]

Solution approach

EMT Madrid implemented an AI-powered transit scheduling solution in partnership with local universities and technology companies. The approach combines multiple data streams – such as ticket validations, GPS signals, traffic patterns, and event calendars – to feed predictive algorithms trained on machine learning models. The key technologies and components include:

- **AI and machine learning models** trained to detect demand trends across time, geography, and demographics.
- **IoT sensors and AVL systems** (Automatic Vehicle Location) for real-time fleet tracking and system performance monitoring.
- **GIS Mapping and simulation tools** to visualize and test alternative routing and frequency plans.
- **Data integration platforms** to unify datasets from Madrid's mobility ecosystem, including road traffic, pollution levels, and metro ridership.
- **A command centre dashboard** provides planners with predictive insights 24–48 hours ahead, enabling adjustments to scheduling and fleet deployment. The solution is integrated with EMT Madrid's legacy control systems, ensuring minimal disruption during rollout.[8]

(continued)

Case study: AI-powered predictive transit scheduling in Madrid

Results

- Reduced bus waiting times on priority lines by 12–18 per cent during morning and evening peaks.
- Decreased service gaps by improving allocation of reserve buses in response to real-time conditions.
- Improved average bus punctuality by 15 per cent compared with 2019 baselines.
- Enabled route-specific emissions tracking to identify and reduce carbon hotspots.
- Passengers reported increased satisfaction with service frequency and reliability in user feedback surveys conducted by EMT.
- EMT estimates that dynamic scheduling has contributed to operational savings of approximately EUR 2.3 million annually.[9]

Lessons learned

- **User-centric KPIs** (like wait time and punctuality) were key to evaluating system effectiveness.
- **Integration with legacy systems** required early collaboration between IT and operations teams.
- **Change management and staff training** were vital for control room operators to adapt to AI-guided decision making.
- **Data privacy and system interoperability** emerged as future focal points for scale-up and MaaS integration.
- **Proactive engagement with passengers** through feedback loops strengthened public trust in automated decisions.[10]

Conclusion

EMT Madrid's AI-driven predictive scheduling system has transformed bus operations by integrating real-time ticket validations, GPS, traffic, and event data into machine learning forecasts that reduced peak-hour wait times by up to 18 per cent, improved punctuality by 15 per cent, and enabled reserve-bus allocation that cut service gaps and saved EUR 2.3 million annually. This high-impact initiative also delivered route-specific emissions tracking aligned with Madrid's Air Quality and Mobility Plan 2025, while partnerships under the EIT Urban Mobility Madrid Innovation Hub ensured seamless legacy-system integration and staff training that underpinned trust in AI recommendations. By focusing on user-centric KPIs and continuous passenger feedback, EMT built public confidence and laid the groundwork for scaling dynamic scheduling across routes and modes, exemplifying the EU Smart Cities Marketplace's AI for Smart Transport Management guidelines and positioning Madrid as a leader in sustainable, data-driven urban mobility.

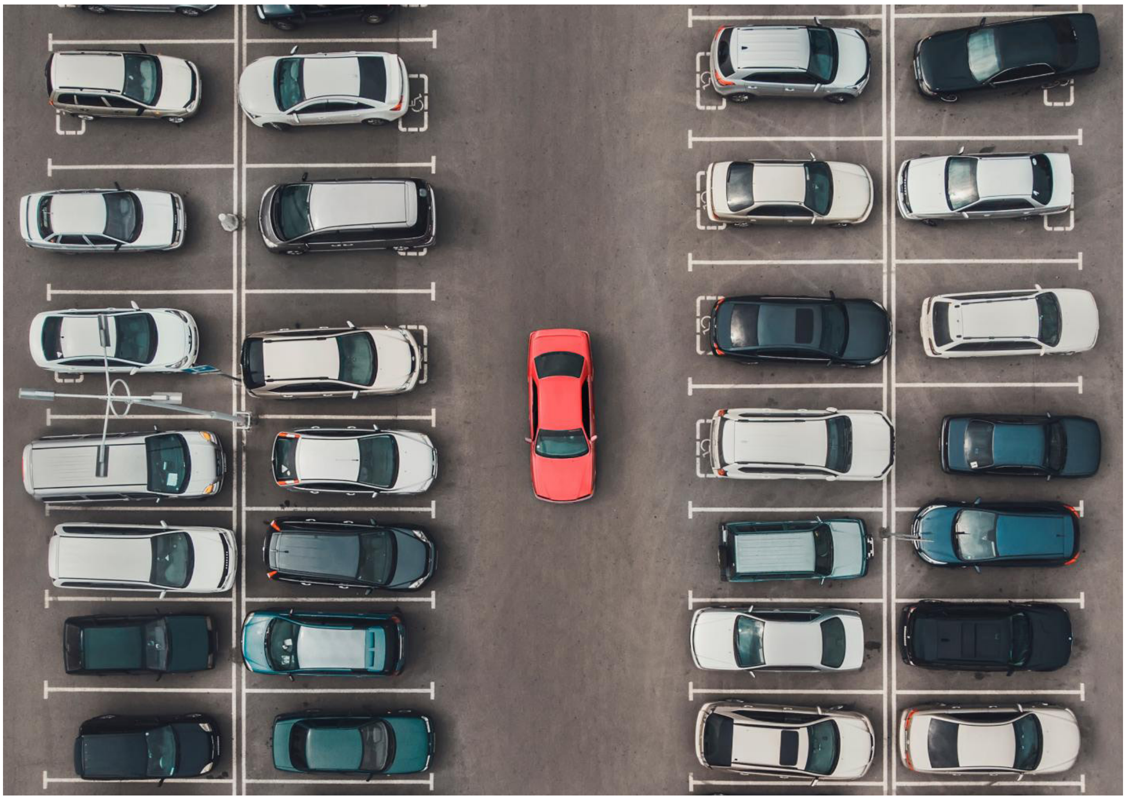
Use case 3: Municipal Parking Space Optimization (Horizon 1)

Description

Digital twins can be used to create detailed, dynamic models of municipal parking infrastructure that monitor real-time space availability, usage patterns, and future demand across cities. Transport planners can use these platforms to identify parking pressure points, inform policy decisions, and plan more efficient resource allocation. This is particularly valuable for dense urban environments in which optimizing space utilization directly impacts traffic congestion and accessibility. AI can be leveraged to automate the detection of parking occupancy using aerial and street imagery, predict future demand fluctuations, and recommend dynamic management strategies to improve mobility outcomes for residents and visitors.

Impacts

1) **Reduced congestion**: Dynamic reallocation of available parking spaces and adaptive pricing reduces cruising for parking and associated vehicle emissions.
2) **Improved quality of life**: Greater parking availability lowers stress and travel time for drivers, leading to less noise and safer streets.
3) **Improved visitor/resident experience**: Real-time parking guidance via apps directs users to available spaces, reducing frustration and supporting local businesses.
4) **Operational efficiency**: Automated occupancy detection and demand forecasting cut labour costs for enforcement and reduce revenue losses from underutilized spaces.
5) **Economic development**: Better parking management supports commercial activity by improving turnover rates and making city centres more accessible.



Key beneficiaries

- Citizens and residents (car users)
- Urban planning/transport planning departments

Key technologies

- **Digital twin:** Real-time virtual replica of on street and off-street parking assets, ingested from IoT sensors and imagery.
- **AI**: AI can classify parking occupancy from aerial and street-view cameras, while time-series models forecast demand.

- **IoT:** Ground sensors, smart meters, and connected cameras can feed live occupancy and usage data into the digital twin.

SDG alignment

- **SDG 11: Target 11.2** By 2030, provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, people with disabilities and older people.
- **SDG 11: Target 11.3** By 2030, enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries.

Risk level

Table 3: Risk level: Municipal Parking Space Optimization

Risk attribute	Risk rating			Explanation
Public safety	Low	Medium	High	Parking guidance reduces illegal stopping and double-parking, improving vehicular and pedestrian safety.
Stakeholder acceptance	Low	Medium	High	Drivers generally appreciate improved convenience; clear communication and user-friendly apps support uptake.
Data privacy and security	Low	Medium	High	Real-time location data and camera feeds must be protected to prevent misuse and ensure citizen trust
Financial/ operational	Low	Medium	High	Significant upfront investment in sensors, AI models, and digital twin infrastructure is required.

Implemented in:

San Francisco, USA; Leipzig, Germany; Singapore

Case study: Curb Space Management in San Francisco

Context

As a dense urban centre with growing e-commerce, ride-hailing, micromobility, and delivery services, San Francisco has faced significant curbside congestion. Traditional curb regulations – often static, paper-based, and difficult to enforce – have proven insufficient in managing the city's dynamic mobility needs. Double-parking, delivery delays, and pedestrian safety concerns prompted the San Francisco Municipal Transportation Agency (SFMTA) to seek smarter approaches to curb space management. In response, SFMTA piloted a smart curb platform in partnership with private sector technology providers to digitize curb rules, enable dynamic pricing, and provide real-time curb availability data to logistics companies and drivers.[11]

Objective

The Smart Curb Management initiative was designed to:

- Reduce double-parking and illegal loading activity.
- Improve curb access for delivery, paratransit, and service vehicles.
- Support equity by prioritizing curb space near affordable housing and social infrastructure.
- Use data to inform policy and pricing mechanisms for flexible curb usage.
- Provide detailed information for the public and provide real-time communication with users via APIs and mobile apps.
- Integrate the Digital Curb Program with Muni Mobile, the bike share system, and scooter share providers to give people better alternatives to get around.
- Encouraging drivers to use loading zones in places and at times where they are more likely to get safely to the curb and out of the way of people on bikes and scooters.
- Improve staff efficiency: Staff knowing, with confidence, what is out on the street is critical to more efficient internal operations.[12]

Solution approach

SFMTA partnered with Coord (a Sidewalk Labs spin-off) and other curb tech startups to create a digital curb inventory and test dynamic curb allocations in pilot zones. The project involved:

- **High-resolution curb mapping** and digitization of curb regulations (e.g., hours, vehicle type permissions, and pricing).
- **Web map-based tool** to visualize all curb data.
- **IoT sensors and cameras** deployed to monitor occupancy, dwell times, and violations.
- **Digital signage and mobile apps** for real-time curb availability and driver guidance.
- **API integration** with delivery fleets such as UPS, FedEx, and shared mobility providers.
- **Dynamic pricing algorithms** to adjust rates based on time of day, demand, and vehicle emissions profile.

The pilots focused on commercial corridors such as the Mission District and SoMa, where curb competition was most intense.[13]

(continued)

Case study: Curb Space Management in San Francisco

Results

- Double-parking incidents decreased by 25 per cent in pilot areas.
- Commercial loading zone turnover improved by 19 per cent.
- Dwell time for delivery vehicles fell by 18 per cent, contributing to operational efficiency for logistics partners.
- SFMTA gained new insights into usage patterns, informing future policy around equitable access and emissions reduction.
- Surveys from delivery drivers showed improved satisfaction and clarity around permitted curb use.
- Approximately five additional staff members, and upfront (about USD 1 million) and ongoing (about USD 200 000 annual) investments in consulting and software, would be needed to fully fund this programme. However, it will save thousands of staff hours and lays the groundwork for more effective curb pricing, good governance practices, and improved communications.[14]

Lessons learned

- **Curb digitization is foundational** for any dynamic management system; initial data collection took longer than expected.
- **Stakeholder trust is critical:** early engagement with logistics providers, advocacy groups, and local businesses reduced resistance.
- **Dynamic pricing requires transparency**: users want to understand why rates change.
- **Interoperability with multiple systems**: (apps, fleets, city databases) must be prioritized to scale solutions.
- **Equity concerns must be addressed** to prevent exclusion of smaller operators or underserved neighbourhoods.
- **Most curb users are not private citizens looking for a parking spot:** they are TNC drivers, delivery drivers, and package delivery companies. The city cannot effectively regulate, price, or give them incentives to modify their operations without the Digital Curb.[15]

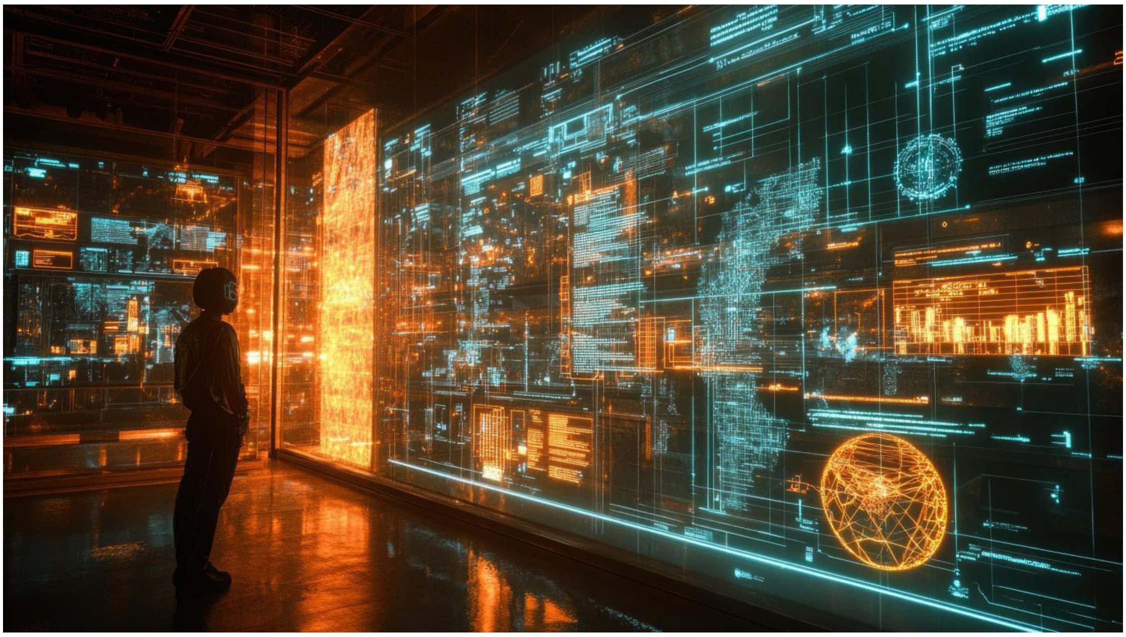
Conclusion

The San Francisco Smart Curb Management initiative demonstrates the transformative potential of combining digital technology with urban infrastructure to address complex mobility challenges. By digitizing curb regulations, deploying real-time sensor data, and implementing dynamic pricing algorithms, SFMTA successfully reduced congestion, improved curb access, and enhanced operational efficiency for delivery and mobility services. The project not only delivered measurable reductions in double-parking and improved loading zone turnover but also established a scalable foundation for equitable and transparent curb space governance. Key lessons around stakeholder engagement, system interoperability, and the importance of transparency in dynamic pricing provide valuable guidance for future smart city programmes. While the upfront investment and organizational effort are significant, the system's ability to save staff time and inform adaptive policymaking underscores its long-term value. This case exemplifies how data-driven digital management of urban assets can support safer, more efficient, and more inclusive city operations in an era of rapidly evolving transportation demands.

Use case 4: Multimodal emergency evacuation simulation (Horizon 1)

Description

Virtual world technologies such as digital twins can be used to create detailed, dynamic models of transport systems that simulate disaster scenarios, evacuation routes, and emergency service deployment in real time. City stakeholders such as emergency management agencies, urban planners, and public safety departments can use these platforms to identify vulnerabilities, optimize evacuation strategies, and plan resource allocation before and during critical events. This is particularly valuable for complex multimodal, multiprovider transport systems. AI could be leveraged to predict the spread of hazards, optimize response routes, and recommend real-time adjustments to improve public safety outcomes and reduce response times during emergencies.



Impacts

1) **Disaster resilience:** Can enables authorities to stress-test evacuation plans under a wide range of simulated hazard scenarios, strengthening community preparedness and infrastructure robustness.
2) **Faster emergency response:** AI-driven route optimization and real-time traffic simulation can speed ambulance, fire, and police deployments, reducing critical response times.
3) **Citizen safety:** By pre-planning safe corridors and dynamic rerouting around hazards, digital twin simulations can help minimize exposure to danger and protect vulnerable populations.
4) **Optimized evacuation:** Simulation of multimodal flows – combining road, rail, pedestrian, and water-borne transport – ensures a balanced use of all available assets for orderly mass egress.
5) **Improved mobility during crises:** Simulation can be used to stress test multimodal mobility routes to avoid bottle necks and improve the number of evacuation routes, including testing for accessible routes.

Key beneficiaries

- Citizens and visitors
- Urban emergency services and civil defence teams
- Disaster planning and resilience authorities
- Public transport operators and city planners

Key technologies

- **Digital twin:** A real-time, high-fidelity virtual replica of the city's transport infrastructure – roads, rails, stations, and pedestrian networks – that ingests live sensor and telemetry data.
- **AI:** Machine learning models that forecast hazard progression, identify at-risk zones, and optimize multimodal evacuation routes under evolving conditions.
- **IoT Networks:** Ubiquitous deployment of connected sensors – traffic detectors, BLE beacons, environmental monitors – and mobile device data feeds to update the digital twin with current system status.
- **GIS & 3D City modelling:** Geospatial information systems coupled with 3D terrain and building models to visualize floodplains, structural damage extents, and clearance pathways for emergency vehicles and evacuees.
- **Metaverse:** Shared virtual environments where stakeholders can collaborate on emergency planning scenarios, conduct immersive drills, and integrate real-time data streams into a cohesive operational picture.

SDG alignment

- **SDG 3: Target 3.D** Strengthen the capacity of all countries, in particular developing countries, for early warning, risk reduction and management of national and global health risks.
- **SDG 11: Target 11.B** By 2020, substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion, resource efficiency, mitigation and adaptation to climate change, resilience to disasters, and develop and implement, in line with the Sendai Framework for Disaster Risk Reduction 2015–2030, holistic disaster risk management at all levels.

Risk level

Table 4: Risk level: Multimodal Emergency Evacuation Simulation

Risk attribute	Risk rating			Explanation
Public safety	Low	Medium	High	Designed to prevent loss of life and reduce response times.
Stakeholder acceptance	Low	Medium	High	Generally supported by the public and institutions due to clear life-saving potential.

Table 4: Risk level: Multimodal Emergency Evacuation Simulation (continued)

Risk attribute	Risk rating			Explanation
Data privacy and security	Low	Medium	High	Emergency data must be secured from misuse.
Financial/ operational	Low	Medium	High	Requires significant cross-agency coordination and system integration.

Implemented in:

Singapore; Venice, Italy; New Orleans, USA

Case study: Digital twin-enabled emergency evacuation simulation in Singapore

Context

Singapore is a densely populated island city-state vulnerable to a range of environmental risks including flash floods, fires, and structural hazards. The complexity of its urban infrastructure – much of which is interconnected and vertically layered – poses challenges for traditional evacuation planning methods. To enhance urban resilience and public safety, Singapore's government launched a national-scale digital twin initiative that includes simulation of emergency evacuation scenarios. The Urban Redevelopment Authority (URA), in collaboration with GovTech and A*STAR, has developed a comprehensive 3D digital model of the city to test, evaluate, and optimize emergency response plans. The system enables authorities to simulate hazards and evaluate infrastructure resilience in real time and in predictive modes.[16]

Objective

The evacuation simulation platform aims to:

- Enhance urban emergency preparedness across flood, fire, and other scenarios.
- Improve coordination between multiple agencies during emergencies.
- Protect vulnerable populations by identifying accessibility gaps and bottlenecks.
- Inform the design of new infrastructure with resilience-by-design principles.
- Support long-term planning for climate adaptation and public safety policy.[17]

Solution approach

Singapore's digital twin platform, part of the "Virtual Singapore" initiative, integrates data from more than 20 agencies and includes:

- **3D spatial models** of all buildings, transport systems, drainage, and utilities across the island.
- **AI algorithms** trained to simulate crowd dynamics, hazard spread, and evacuation bottlenecks.
- **GIS-based decision tools** to overlay social, demographic, and environmental data for targeted responses.
- **Real-time sensor feeds** from IoT-enabled storm drains, traffic systems, and emergency services.
- **Simulation interfaces** that allow planners to run drills and visualize outcomes under multiple-risk scenarios.

The platform is used by agencies including the Singapore Civil Defence Force (SCDF), Land Transport Authority (LTA), and Building and Construction Authority (BCA).[18]

(continued)

Case study: Digital twin-enabled emergency evacuation simulation in Singapore

Results

- Simulation trials reduced estimated evacuation times by 25–30 per cent in high-risk zones.
- Authorities improved their ability to plan emergency vehicle routes, coordinate shelter capacity, and stage personnel and supplies.
- Infrastructure upgrades such as elevated footpaths and barrier-free access points, were implemented based on digital twin findings.
- Cross-agency communication improved through shared dashboards and scenario-planning tools.
- Singapore was ranked in the top three globally in the 2022 Smart Cities Index for resilience planning and emergency readiness.[19]

Lessons learned

- **Centralized data governance** is critical for aligning inputs from multiple ministries and agencies.
- **High-fidelity modelling** requires frequent updates and collaboration with industry and academia.
- **Community involvement** in emergency drills ensures that digital simulations align with real-world behaviour.
- **Scenarios must reflect diverse populations** including elderly, disabled, and migrant communities – to build inclusive response plans.
- **Integration with education and training** builds trust and usage among frontline responders.[20]

Conclusion

Singapore's digital twin – enabled evacuation simulation represents a pioneering model of how integrated virtual world technologies can strengthen urban resilience and public safety. By drawing on the comprehensive 3D spatial datasets orchestrated by the Urban Redevelopment Authority and GovTech under the Virtual Singapore project, and leveraging A*STAR's advanced crowd-dynamics and hazard-spread algorithms alongside real-time IoT sensor feeds, authorities such as the SCDF have cut evacuation times by up to 30 per cent, optimized emergency vehicle routing, and pinpointed critical accessibility gaps for vulnerable populations. The platform's GIS-based decision tools have directly informed next-generation infrastructure designs – such as elevated footpaths and barrier-free access – and fostered seamless multi-agency coordination via shared dashboards. Singapore's success, affirmed by its top-three ranking in the 2022 Smart Cities Index for emergency readiness, underscores the importance of centralized data governance, industry-academia collaboration, and community involvement in drills. As climate risks intensify and urban systems grow ever more complex, Singapore's holistic digital twin approach offers a replicable blueprint for cities worldwide to build resilient, inclusive, and data-driven emergency response capabilities.

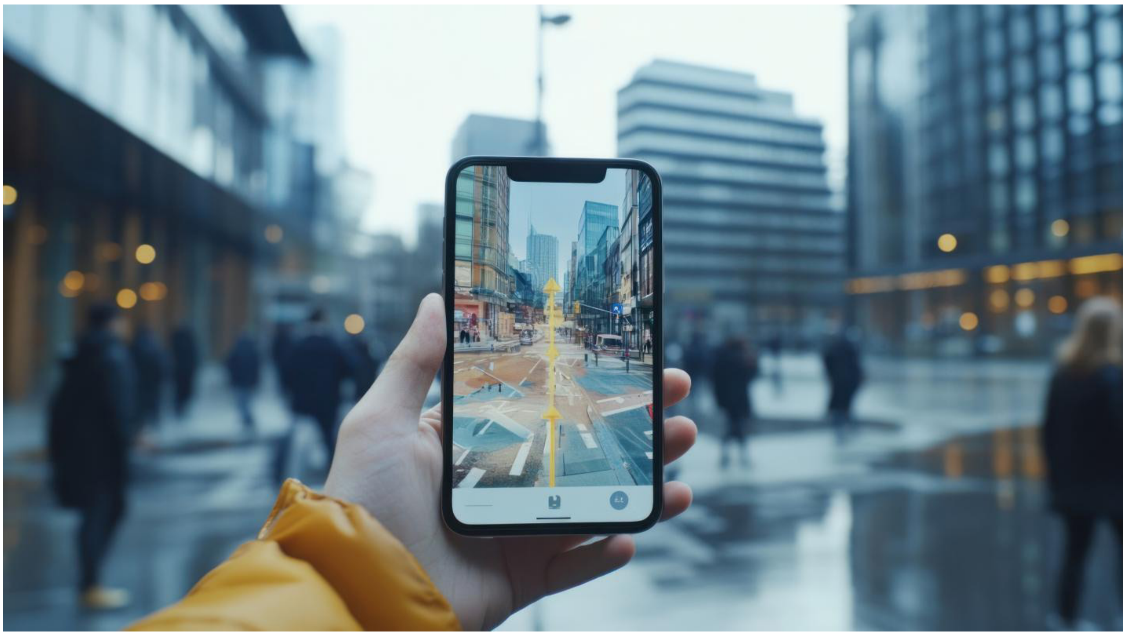
Use case 5: Immersive mobility-as-a-service (Horizon 2)

Description

Virtual world technologies such as AR can be integrated into MaaS platforms to create immersive wayfinding experiences and enhance multimodal journey planning for users navigating urban transport networks. Transport operators and city authorities can use these platforms to deliver real-time virtual overlays that guide travelers through stations and city streets while personalizing routes based on preferences and accessibility needs. IoT devices can provide live transport data to continually update the AR environment and improve accuracy. AI could be leveraged to predict service delays, optimize intermodal transitions, and offer adaptive journey recommendations and GenAI could support a multilingual personalized interface.

Impacts

1) **Improved transit adoption:** AR navigation reduces confusion and increases public transport usage.
2) **Enhanced accessibility:** Supports users with disabilities or unfamiliarity with the city through intuitive visual aids.
3) **Personalized mobility:** AI tailors route suggestions based on travel history and preferences.
4) **Reduced congestion:** Intelligent routing helps distribute passenger flows during peak hours.



Key beneficiaries

- Daily commuters and tourists
- Mobility-impaired and neurodiverse users
- Urban transport providers and mobility planners

Key technologies

- **AR:** Visual overlays assist users in real-world navigation within transport hubs.
- **AI:** Learns behaviour and adjusts route recommendations in real time.
- **MaaS platforms:** Integrate journey planning, ticketing, and routing across transport modes.
- **Geospatial intelligence:** Supports precision location services within indoor and outdoor environments.

SDG alignment

- **SDG 9: Target 9.1** Develop quality, reliable, sustainable and resilient infrastructure, including regional and transborder infrastructure, to support economic development and human well-being, with a focus on affordable and equitable access for all.
- **SDG 11: Target 11.2** By 2030, provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, people with disabilities and older people.

Risk level

Table 5: Risk level: Immersive mobility-as-a-service

Risk attribute	Risk rating			Explanation
Public safety	Low	Medium	High	AR improves wayfinding and reduces the chance of passengers getting lost. However, measures need to be taken to ensure safe use, including limiting disorientation and decreased attention to physical surroundings.
Stakeholder acceptance	Low	Medium	High	Adoption may be slower among less digitally skilled populations or those without access to compatible devices.
Data privacy and security	Low	Medium	High	Real-time tracking and personal data raise privacy concerns.
Financial/ operational	Low	Medium	High	Requires significant technical infrastructure and ongoing app updates.

Implemented in:

London, UK; Madrid, Spain; Hong Kong, Special Administrative Region of China

Case study: Immersive MaaS interfaces with AR navigation in London

Context

London's extensive multimodal transport system spans underground, bus, rail, walking, and cycling networks, managed in large part by Transport for London (TfL). With more than 4 billion passenger journeys per year, navigating the complexity of London's transport landscape can be particularly challenging for tourists, first-time users, and people with disabilities.

Traditional static signage and mobile route planners often fall short in stations with multiple levels or unfamiliar exit configurations. To address these accessibility and wayfinding issues, TfL and tech partners launched pilots integrating augmented reality (AR) navigation features into Mobility-as-a-Service (MaaS) apps. These AR interfaces are designed to offer real-time visual directions layered onto the physical world, supporting seamless multimodal journeys and enhancing confidence among users unfamiliar with the network.[21]

Objective

The main objective of introducing AR interfaces into MaaS platforms in London is to improve the user experience by making the public transport system more intuitive and navigable. The project specifically aims to:

- Improve wayfinding in complex transit stations and interchanges.
- Increase adoption of public transport among tourists and occasional riders.
- Support accessibility for visually impaired and neurodiverse users.
- Reduce congestion and station dwell times by optimizing passenger movement.
- Test new digital engagement tools that can scale across TfL's broader digital strategy.[22]

Solution approach

TfL collaborated with Citymapper, Google Maps, and AR-focused startups like Pointr and NaviLens to pilot immersive navigation features in selected stations. The approach integrates:

- AR overlays using smartphones and wearable devices to provide directional prompts, visual signage, and real-time alerts.
- Indoor Positioning Systems (IPS) based on Bluetooth beacons, Wi-Fi triangulation, and geomagnetic data.
- AI-based route personalization to suggest optimal routes based on walking ability, congestion levels, or user preferences
- MaaS app integration to combine route planning, ticketing, and AR navigation in one interface. Early deployments were focused on key stations such as King's Cross, Liverpool Street and Stratford, with localized content rendered in AR as users moved through the space.

Results

- AR trials showed a 30 per cent reduction in passenger confusion and wrong exits in complex stations.
- Increased user satisfaction scores in participating MaaS apps (notably Citymapper) by 22 per cent.
- Station dwell times dropped by eight per cent among tourists during trial periods.
- Feedback from neurodiverse users highlighted improved comfort and independence when navigating.
- The project has informed ongoing efforts within TfL's Digital Strategy to expand AR and immersive engagement.[23]

(continued)

Case study: Immersive MaaS interfaces with AR navigation in London

Lessons learned

- **Multilingual and inclusive design** was key to reaching all user groups effectively.
- **Integration with legacy systems** such as TfL's open data APIs was crucial for real-time accuracy.
- **Battery and connectivity limitations** for AR apps require further hardware optimization.
- **Usability testing with diverse user groups** yielded vital insights for interface improvements.
- **Combining AR with tactile signage** and audio instructions can further enhance accessibility.[24]

Conclusion

The integration of augmented reality navigation into London's MaaS platforms represents a landmark step in Transport for London's Digital Strategy, demonstrating the potential of immersive technologies to transform wayfinding across one of the world's most complex transit networks. By leveraging partnerships with Citymapper, NaviLens, and Pointr, TfL has validated that AR overlays and indoor positioning systems can significantly reduce passenger confusion, shorten station dwell times, and enhance the independence of visually impaired and neurodiverse users. The positive outcomes underscore AR's capacity to streamline passenger flows and elevate the visitor experience in multimodal interchanges.

Looking ahead, these pilots have laid the groundwork for scaling AR navigation across additional stations and integrating tactile and audio cues to ensure truly inclusive mobility. Ongoing optimization of hardware and battery management, combined with rigorous usability testing, will be essential to refine the end-to-end experience. As TfL continues to expand its open data ecosystem and MaaS offerings, AR-powered wayfinding promises to play a central role in making London's transport network more intuitive, accessible, and resilient for all users.

Use case 6: XR mobility planning (Horizon 2)

Description

Urban planners can use immersive XR environments to simulate proposed changes in transit routes, station placement, and pedestrian impact before construction begins. Urban planners, transport authorities and community engagement teams can use these platforms to visualize design impacts, assess accessibility improvements, and integrate public feedback into infrastructure projects. These tools allow residents to virtually walk through redesigned transport infrastructure and give feedback before construction begins. These tools also enable public participation and equity-focused design.

Impacts

1) **Inclusive urban planning:** XR environments can democratize the design process by making complex planning concepts accessible to diverse communities, allowing underrepresented groups to actively participate in shaping their neighbourhoods.
2) **Improved urban design:** Immersive 3D visualizations can enable planners to identify design flaws and test multiple scenarios before construction, leading to more effective and user-centred infrastructure solutions.
3) **Active mobility:** VR simulations of cycling routes, pedestrian pathways, and transit connections can help optimize active transportation networks while allowing users to experience proposed improvements first hand.
4) **Stakeholder engagement:** XR platforms can increase participation rates across demographic backgrounds by providing intuitive, engaging ways for citizens to visualize and provide feedback on transport proposals.
5) **Increased transit adoption:** By helping users understand and experience new transport infrastructure before construction, XR can reduce resistance to change and builds community support for sustainable mobility solutions.
6) **Improved accessibility:** Virtual walkthroughs enable planners to test accessibility features from the perspective of mobility-impaired users, ensuring inclusive design from the outset.

Key beneficiaries

- Residents and commuters
- Underrepresented and mobility-impaired communities
- Urban designers and architects
- City transportation agencies and planning departments

Key technologies

- **AR/VR/MR:** Combines GIS with immersive 3D simulation.
- **GIS mapping:** Provides the spatial foundation for VR modelling.

- **Game engines:** Unity and Unreal Engine are used for rendering interactive environments.
- **User testing interfaces:** Capture behavioural and experiential data during virtual walkthroughs.
- **Digital twins:** Create virtual replicas of existing transport infrastructure that can be modified and tested in real time, enabling evidence-based decision making.
- **Metaverse:** Provides virtual environments where global communities can participate in local transport planning, breaking geographical barriers to civic engagement.
- **AI/GenAI:** Powers generative design tools that can create multiple transport scenarios based on policy requirements, user preferences, and local constraints, while analysing citizen feedback to identify common themes and priorities.

SDG alignment

- **SDG 11: Target 11.3** By 2030, enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries.
- **SDG 16: Target 16.7** Ensure responsive, inclusive, participatory and representative decision making at all levels

Risk level

Table 6: Risk level: XR mobility planning

Risk attribute	Risk rating			Explanation
Public safety	Low	Medium	High	Used during planning phase only; improves outcomes before construction.
Stakeholder acceptance	Low	Medium	High	Generally, well received as a tool for inclusive planning. However, it assumes a level of digital access and literacy.
Data privacy and security	Low	Medium	High	Low risk if anonymized user feedback data is collected.
Financial/operational	Low	Medium	High	Requires technical teams and investment in VR equipment and development.

Implemented in:

Boston, USA; Watford, UK; Bristol, USA

Case study: Immersive Transport Planning in Boston

Context

Boston is undergoing significant infrastructure upgrades across its public transportation system, including redesigning more than 1 000 bus stops and enhancing accessibility in key subway stations. Historically, planning for such infrastructure projects has been technical and inaccessible to the public, particularly marginalized communities. Low levels of engagement from communities affected by transit changes often lead to late-stage resistance, costly redesigns, or inequitable outcomes. To bridge the gap between planners and the public, the City of Boston and Massachusetts Bay Transportation Authority (MBTA) adopted Geospatial virtual reality (VR) tools to provide immersive planning experiences. These tools allow residents to virtually walk through redesigned transport infrastructure and give feedback before construction begins.[25]

Objective

The main goal of Boston's VR-based participatory planning programme is to make infrastructure projects more inclusive, accessible, and informed by real community input. Specific objectives include:

- Enhancing early-stage public engagement in transit projects.
- Improving accessibility outcomes for people with disabilities.
- Reducing late-stage design changes and project delays.
- Using immersive tools to make technical proposals understandable to the public.
- Building trust in planning authorities through transparency and responsiveness.[26]

Solution approach

Boston's Transportation Department partnered with researchers from MIT's Urban Studies Lab and private firms to develop VR simulations of key infrastructure projects. The solution includes:

- **3D GIS models** generated from LIDAR and spatial data, imported into Unity or Unreal Engine to create walkable VR environments.
- **On-site VR kiosks** deployed in libraries, community centres, and transit hubs for broad public access.
- **Interactive feedback mechanisms** within the VR experience, allowing users to comment on design elements like shelter height, curb alignment, or signage placement.
- **Accessibility simulations** allowing users to experience a station as someone in a wheelchair, with vision impairments, or pushing a stroller.

The immersive environments are co-developed with accessibility advocates and tested by real users from affected communities.[27]

Results

- More than 2 000 residents participated in VR walkthroughs of redesigned stations and stops.
- 84 community-generated recommendations were adopted into final designs.
- Public satisfaction with the engagement process improved by 32 per cent compared to previous consultation methods.
- Accessibility scores (as measured by independent audits) improved significantly in pilot projects.
- The MBTA reported fewer change orders during construction, saving an estimated USD 1.1 million across four stations.[28]

(continued)

Case study: Immersive Transport Planning in Boston

Lessons learned

- Immersive visualization increases empathy and clarity for users unfamiliar with planning documents.
- Partnerships with local advocates (e.g., disability rights groups) ensured relevance and representation in simulations.
- Technology access must be democratized by offering mobile, in-person, and low-tech alternatives to VR headsets.
- Staff training in facilitation and digital tools was essential for smooth user experiences.
- VR can be a catalyst for civic dialogue but needs continuous iteration and funding to scale city-wide.[29]

Conclusion

Boston's use of virtual reality for participatory transit planning has demonstrated that immersive XR environments can transform public engagement, equity and project efficiency within urban infrastructure programmes. By enabling more than 2 000 residents to virtually navigate redesigned bus stops and subway stations – complete with accessibility simulations for wheelchair users, visually impaired riders, and parents with strollers – the City of Boston and MBTA not only improved public satisfaction by 32 per cent and adopted 84 community-driven recommendations, but also reduced late-stage design changes and saved approximately USD 1.1 million in construction change orders. These outcomes underscore VR's unique capacity to make technical proposals comprehensible, foster empathy, and build trust among marginalized communities. Crucially, the programme's success hinged on strategic partnerships with MIT's Urban Studies Lab and local disability advocates, the deployment of accessible VR kiosks across neighbourhoods, and robust staff training, illustrating a replicable blueprint for cities seeking to leverage digital twin and XR technologies to deliver more inclusive, cost-effective, and transparent transit solutions.

Use case 7: Metaverse for civic multimodal planning (Horizon 3)

Description

A metaverse environment can allow stakeholders – from city planners to residents – to interact with different 3D models of mobility systems, going beyond simulating proposed changes to individual infrastructure assets, to enabling citizens to explore the impacts on multimodal connections. This can be used to simulate routes for active travel such as cycling and micro-mobility to test safety and experience. In a metaverse environment, citizens can also interact and vote on policy proposals. AI and GAI can be leveraged to generate different design options and support multilingual and personalized interaction interfaces for users to navigate the virtual environment.

Impacts

1) **Transparent & inclusive planning:** XR environments can democratize planning by making complex proposals accessible, empowering diverse communities to shape mobility solutions.
2) **Increased trust:** Immersive visualizations and real-time data can build confidence in infrastructure investments and decision-making transparency.
3) **Higher transit adoption:** Virtual previews of intermodal connections can reduce change resistance and foster support for sustainable transport options.
4) **Active mobility:** VR simulations of bike, walk, and micromobility routes allow users to experience and refine active transport networks before build-out.
5) **Improved accessibility:** Virtual walkthroughs can test ramps, signage, and wayfinding from diverse user perspectives, ensuring inclusive design from day one.

Key beneficiaries

- Commuters and visitors
- Transit operators
- Tourism agencies

Key technologies

- **Digital twin:** For this use case, digital twins can model and visualize multimodal networks in 3D, linking real-world assets (e.g., roads, bike lanes, transit stops) with simulated scenarios. Advanced twins integrate AI-driven analytics for scenario testing – such as reconfigured intersections or new bus routes – allowing planners and citizens to explore impacts before implementation.
- **AR:** For this use case, AR overlays proposed infrastructure changes directly onto physical environments via mobile devices or smart glasses, helping stakeholders see new bike lanes or curb reallocations in context and compare alternatives on-site.

- **VR:** For this use case, VR creates fully immersive simulations of future streetscapes – letting users "walk," "cycle," or "ride "virtual transit to assess comfort, sightlines, and connections, and to vote on design options in a shared, cloud-hosted environment.
- **MR:** For this use case, MR blends real-world views with 3D infrastructure models in the field, enabling planners and community members to simultaneously see existing conditions and proposed changes, facilitating collaborative workshops and live adjustments.
- **GenAI:** For this use case, GenAI generates diverse design proposals and narrative walkthroughs on demand – automatically creating alternative street layouts, pricing strategies, or accessibility features – and provides multilingual support to guide users through the metaverse.
- **AI:** For this use case, AI analyses historical and real-time mobility data – identifying usage patterns, predicting demand shifts, and optimising multimodal connections. AI-based scenario planning can flag potential safety or congestion risks and recommend data-driven policy tweaks.
- **IoT:** For this use case, IoT sensors on streets, transit vehicles, and shared-mobility assets feed live occupancy, speed and emissions data into the digital twin, enabling dynamic updates and real-time performance monitoring of proposed infrastructure changes.

SDG alignment

- **SDG 11: Target 11.2** By 2030, provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention paid to the needs of those in vulnerable situations, women, children, people with disabilities and older people.
- **SDG 11: Target 11.3** By 2030, enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries.
- **SDG 11: Target 11.6** By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management.
- **SDG 16: Target 16.7** Ensure responsive, inclusive, participatory and representative decision making at all levels.

Risk level

Table 7: Risk level: Metaverse for civic multimodal planning

Risk attribute	Risk rating			Explanation
Public safety	Low	Medium	High	Virtual testing poses minimal physical risk and can highlight safety issues before real-world implementation.
Stakeholder acceptance	Low	Medium	High	Success depends on digital literacy and community trust in virtual engagement; requires outreach and training.

Table 7: Risk level: Metaverse for civic multimodal planning (continued)

Risk attribute	Risk rating			Explanation
Data privacy and security	Low	Medium	High	Use of location and mobility data in a shared virtual space necessitates robust anonymization and access controls.
Financial/ operational	Low	Medium	High	High initial investment in 3D modelling, platform development, and ongoing maintenance may challenge budgets.

Implemented in:

N/A

Case study

For this use-case, no relevant case study has been identified due to the horizon 3 level. However, Kaunas Municipality is discussing a participatory planning pilot using Unreal-powered 3D models and VR environments to visualize tram alignments. Citizens can walk through proposed tram stations virtually, explore multimodal connections, and vote on key choices – a Baltic-first approach to deep civic engagement in transport infrastructure planning.

Use case 8: Personalised XR commuter pods (Horizon 3)

Description

Virtual world technologies such as AR, VR and MR can be used to create personalized immersive environments inside shared autonomous pods, transforming the travel experience into a dynamic, user-centric space. Travelers can be provided with real-time navigation assistance, wellness programmes, entertainment, or productivity tools customized to individual needs during their journey. IoT sensors embedded in the vehicle interior monitor environmental and user data to dynamically adapt the XR environment to optimize comfort, safety, and engagement. AI could be leveraged to analyse biometric feedback, predict traveler preferences, and generate personalized immersive content.

Impacts

1) **Passenger experience:** XR pods can transform rides into personalized journeys by adapting visuals, soundscapes, and interfaces in real time to passenger preferences, reducing stress and enhancing comfort.
2) **Increased shared transit:** Immersive in-ride experiences can incentivize commuters to choose shared pods over private cars by offering entertainment, productivity, and wellness features tailored to individual needs.
3) **Visitor experience and tourism:** XR overlays within pods can deliver location-based storytelling and contextual information.
4) **Workforce productivity:** Integrated productivity tools and dynamic XR environments allow passengers to conduct meetings, review documents, or receive briefings seamlessly while en route.

Key beneficiaries

- Commuters and visitors
- Transit operators
- Tourism agencies
- Employers

Key technologies

- **Metaverse:** Metaverse platforms can host interconnected virtual pod environments and transit networks, allowing passengers to seamlessly move between shared pod lounges, virtual meeting rooms, and real-world map overlays – all within a persistent cloud-based XR world.
- **AR:** AR overlays can add personalized route guidance, safety alerts, and contextual information onto pod windows or staff tablets, enabling passengers and operators to see live directions, vehicle status, and nearby points of interest superimposed on the external view.
- **VR:** VR headsets can immerse passengers in fully customized environments – such as calming natural landscapes or productivity-focused virtual offices – synced precisely with pod movement to reduce motion discomfort and enhance engagement.
- **MR:** MR headsets can allow pod operators and maintenance staff to view real-time diagnostic overlays – highlighting sensor readings, component health, and spatial positioning – directly on the physical vehicle interior and exterior.
- **GenAI:** GenAI can craft bespoke in-ride experiences on demand – automatically generating wellness programmes, interactive narratives, or multilingual assistance UIs based on passenger profiles and trip context.
- **AI:** AI algorithms can analyse biometric feedback, ride metrics, and historical user data to predict discomfort triggers, adjust environmental controls (lighting, temperature), and suggest optimal content sequencing for each journey.
- **IoT:** IoT sensors embedded in pods can continuously stream data on air quality, seat pressure, acceleration, and passenger vitals into the AI engine, enabling real-time comfort optimization and safety monitoring throughout the ride.

SDG alignment

- **SDG 8: Target 8.2** Achieve higher levels of economic productivity through diversification, technological upgrading and innovation, including through a focus on high-value added and labour-intensive sectors
- **SDG 11: Target 11.2** By 2030, provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, people with disabilities.

Risk level

Table 8: Risk level: Personalised XR commuter pods

Risk attribute	Risk rating			Explanation
Public safety	Low	Medium	High	XR devices may distract passengers or obscure emergency cues; rigorous safety validations and fail-safes are required.
Stakeholder acceptance	Low	Medium	High	Novel biometric monitoring and immersive experiences may face user hesitancy; demonstration pilots and outreach needed.
Data privacy and security	Low	Medium	High	Continuous collection of biometric and location data poses high privacy risks; strong encryption and consent mechanisms are essential.
Financial/ operational	Low	Medium	High	Significant investment in hardware, software, and maintenance may strain budgets and require public–private partnerships.

Implemented in:

N/A

Case study

For this use-case, no relevant case study has been identified due to the horizon 3 level. However, Holoride has developed a VR entertainment system that synchronizes with real-time vehicle movement, aiming to transform passenger experiences in vehicles, particularly autonomous ones. Their platform, dubbed the "Motorverse", integrates games and apps with live ride information to provide immersive experiences. By aligning visual stimuli with the car's motion, the technology aims to reduce motion sickness and enhance in-car entertainment. Early demonstrations have begun in cities such a LA, New York and in Germany, however, city-level pilots have not yet occurred.[30]

About the Global Initiative on Virtual Worlds and AI – *Discovering the Citiverse*

Launched by ITU, UNICC, and Digital Dubai, the Global Initiative on Virtual Worlds and AI – *Discovering the Citiverse* is a multistakeholder platform dedicated to shaping the next generation of AI-powered virtual worlds[31].

These immersive digital environments are transforming how people live, learn, govern, and interact. The Initiative ensures that AI-powered virtual worlds evolve in ways that are inclusive, interoperable, and human-centric – and that they help deliver on the Pact for the Future and its Global Digital Compact.

Serving as a neutral and action-oriented platform, the Initiative brings together cities, governments, UN agencies, private sector companies, academia, and civil society to collaboratively shape the responsible development and deployment of these technologies.

The Initiative advances its mission through three strategic pillars, each supported by dedicated tracks that address the most urgent challenges and promising opportunities in AI-powered virtual worlds. This comprehensive structure enables the Initiative to deliver both high-level global guidance and practical implementation in cities worldwide.

The Initiative is supported by over 70 international partners.

For more information, please visit: https://www.itu.int/metaverse/virtual-worlds/.

Meet the Champions

Champions are entities that demonstrate leadership by providing financial contributions in support of the Initiative. This may include funding for events, challenges, research outputs, communication activities, trainings, travel grants, or other related efforts.

Meet the Founding Partners

Founding Partners are the organizations that launched the Initiative. They serve as the core convening entities and contribute to shaping its long-term vision. The Founding Partners are:

Meet the Supporters

Supporters are organizations that have expressed endorsement of the Initiative and actively participate in its activities. This includes, but is not limited to, participation in tracks, contribution of use cases, co-organization of events, provision of expertise, or public advocacy of the Initiative.

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