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ARTIFICIAL INTELLIGENCE IN THE URBAN ENVIRONMENT: EXAMPLES OF TECHNOLOGY APPLICATIONS. Part I

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Overview of report materials based on the Global Initiative on AI and Virtual Worlds – Disco ering the Citiverse [1-6]

ABSTRACT

This overview is based on the document "The AI-Enabled Citiverse: Use Cases for Cities in the Age of AI" and focuses on a critical phase in urban development. Across the globe, major cities are transitioning from pilot projects and proof-of-concept initiatives to the full-scale implementation of artificial intelligence, digital twins, and immersive technologies. These tools are reshaping approaches to urban planning and management, while also transforming how people interact with the urban environment. This process is examined through the lens of both existing and prospective use cases. The authors propose a methodology for identifying and evaluating AI applications within urban settings, providing an overview of the underlying approaches and specific examples of technology deployment. The review covers key domains, including urban planning, infrastructure, governance, economic development, education, tourism, transport, and mobility. Separate sections address public safety, healthcare, and disaster resilience. The overview presents AI use cases across five urban sectors and outlines the potential for scaling, the level of impact, feasibility, and the risks associated with integrating AI into the urban environment. The first part of the review examines the application of artificial intelligence in the urban environment within the scope of the "Services and Public Participation" area.

KEYWORDS: *Artificial intelligence, Strategic Blueprint, Digital twins, Urban planning, City administration services, Economic development, Transport and mobility.*

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Introduction



Cities that view the concept of an "AI-enabled citiverse" merely as a theoretical possibility risk finding themselves in a situation where their management systems have already been predetermined by someone else. The convergence of artificial intelligence, spatial computing, digital twins, and immersive environments has reached a level of maturity that allows for their integration into urban infrastructure. This overview outlines the methodology for identifying and evaluating examples of the "AI-enabled citiverse" concept being implemented around the world [1-6]. These examples are examined in detail across five thematic sections, compiled in the collection titled "The AI-Enabled Citiverse: Use Cases for Cities in the Age of Artificial Intelligence." The areas covered include:

• Urban planning, the creation of high-quality urban environments, and infrastructure: this area focuses on the use of AI technologies to transform approaches to developing livable spaces and urban environments.

• Urban overnance and public participation.

• Economic development, education, and tourism: focused on leveraging AI-driven digital urban environments to provide immersive, personalized learning, foster sustainable urban economic development, and promote sustainable tourism.

• Transport and mobility

• Public safety, healthcare, and disaster resilience.

The use cases presented were selected by an international working group of experts, including representatives from academia, municipal governments, NGOs, small and medium-sized enterprises (SMEs), and industry specialists. This is not merely a catalog of technological solutions, but a structured tool for assessing the opportunities, risks, and maturity levels of innovative technologies. It will help cities identify scenarios that are already implemented, solutions currently undergoing pilot testing, and concepts that are still in the exploratory phase.

These use cases are intended to:

• Identify innovative solutions based on technologies such as artificial intelligence (AI), augmented and virtual reality (AR/VR), digital twins, the Internet of Things (IoT), and the metaverse, while highlighting their vast potential across a wide range of sectors.

• Showc se international best practices.

• Establish a foundation for developing other aspects of this initiative – for instance, in areas such as emerging technologies, security and trust, as well as digital inclusion and accessibility.

The collection of examples presented here offers a snapshot of current innovations and serves as a cornerstone for future collaboration.

Methodology

The methodology combined literature review, expert assessments, stakeholder input, and prospective analysis to select and classify use cases across key thematic areas. During the initial phase of the work, the primary focus was on gathering a wide range of use cases for each thematic area from various sources.

A list of use cases covering five thematic areas was compiled. To create a shortlist for each area (consisting of approximately 10 cases), the working group evaluated them based on four key criteria approved by the "Global Initiative on AI and Virtual Worlds – Citiverse Concept Exploration" community: alignment with the Sustainable Development Goals (SDGs), scalability, significance of impact, and feasibility (Table 1).

Table 1

AI-Enabled Citiverse Use Case Scoring Criteria

Scoring Criteria	Key Questions
1. Alig ent with SDGs	To what extent does this use case contribute to one or more SDG targets?
2. Scal ility	How relevant is this use case for multiple cities and how easily can it be replicated and scaled?
3. Impa	How impactful will the case study be for social, economic and environmental outcomes?
4. Feasi lity	What are the long-term maintenance and resource requirements? What is the time to value?

Each expert assigned a score for each criterion on a scale from 1 to 10. The cases with the highest scores were included in the final shortlist for each thematic group, while also ensuring a diverse range of examples that cover key focus areas.

To illustrate the level of maturity and the implementation timelines for various use cases, each has been assigned to one of three horizons:

1: Mature solutions that are already being deployed in real-world urban environments.

2: Emerging use cases for which successful pilot projects or initial implementation phases already exist.

3: Conceptual or experimental use cases that hold significant long-term potential but are not yet ready for practical application. No specific implementation examples (case studies) are provided for this horizon, as these solutions are still in the "discovery" phase.

This classification enables cities to distinguish between opportunities for short-term implementation, projects that should be incorporated into innovation and pilot-testing roadmaps, and forward-looking innovations that require further research.

Each use case was also evaluated across four risk dimensions, helping cities identify implementation challenges and the measures required to mitigate them:

• Public safety.

• Stake older acceptance.

• Privacy a d data security.

• Fina cial and operational risks.

Risk levels were classified as low, medium, or high, based on available data and expert assessments. This analysis enables cities to proactively identify key issues that must be addressed prior to implementation.

For each use case, key technologies were also selected, and a preliminary list was compiled (Table 2).

Table 2

Definitions

Technology	Definition	Reference
Metaverse	An integrative ecosystem of virtual worlds offering immersive experiences to users, that modifies pre-existing and creates new value from economic, environmental, social and cultural perspectives. NOTE – A metaverse can be virtual, augmented, representative of, or associated with, the physical world.	FGMV-20
Digital twin	A digital twin network is a digital representation of an object of interest.	ITU-T Y.4600
Augmented reality (AR)	An environment containing real and virtual sensory components. The augmented reality continuum runs from virtual content that is clearly overlaid on a real environment (assisted reality) to virtual content that is seamlessly integrated and interacts with a real environment (mixed reality).	ITU-T P.1320
Virtual reality (VR)	An environment that is fully generated by digital means. To qualify as virtual reality, the virtual environment should differ from the local environment.	ITU-T P.1320
Mixed reality (MR)	An environment containing real and virtual components that are seamlessly integrated and interact with each other in a natural way (one end of the augmented reality continuum).	ITU-T P.1320
Internet of Things (IoT)	A global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies.	ITU-T Y.4000
Artificial intelligence (AI)	Computerized system that uses cognition to understand information and solve problems.	ITU-T M.3080
Generative AI (GAI)	GAI refers to a broad field of research and development that focuses on creating intelligent systems that can generate new, original content such as images, videos, music, text and even entire conversations. These systems use machine learning algorithms to learn patterns and structures within the data they are trained on and then use this knowledge to generate new content that resembles the original data, but is not necessarily identical to it.	FGMV-22

Overall use cases for cities in the age of AI

This section provides an overview of practical examples covering five key topics relevant to municipal authorities and stakeholders.

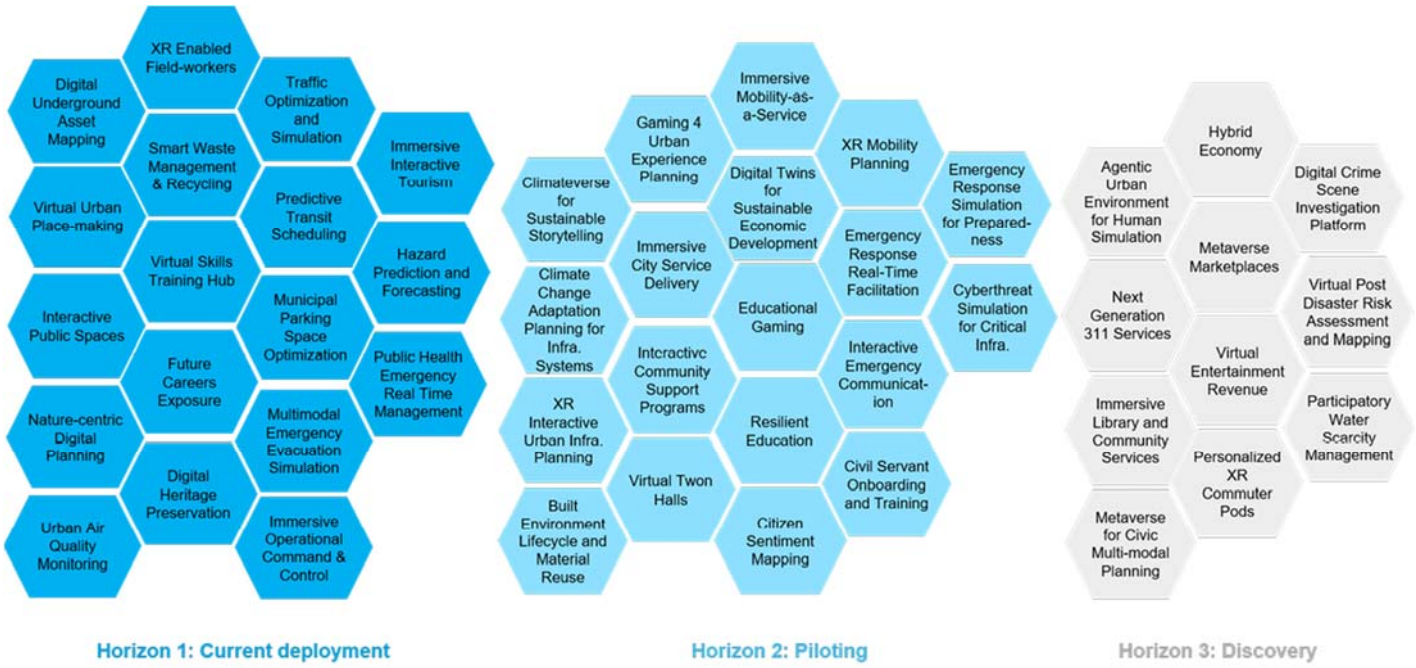


Fig. 1. Overall use case overview and horizon mapping [1]

Source: AI-enabled Citiverse: Use Cases for Cities in the Age of AI: Introduction, 2026

The "cityverse" concept enables cities to create immersive digital representations of their urban environments, bridging the physical and virtual worlds through technologies such as the metaverse, digital twins, augmented and virtual reality (AR/VR), artificial intelligence (AI), and the Internet of Things (IoT). AI – particularly generative AI – increasingly serves as a foundational technology that drives innovation, enhances user experience, and facilitates the creation of interactive, immersive virtual environments. As autonomous intelligent agents ("Agentic AI") continue to evolve, it is also essential to examine their impact on virtual-world technologies and their potential use cases.

Research indicates that AI-powered "cityverses" are not merely a technological novelty, but a fundamental infrastructure for managing cities in the 21st century. Cities that have implemented such solutions are already seeing tangible results: in Seoul, a digital-twin-based traffic management system has reduced emergency response times by 20%; the "Virtual Helsinki" project attracted over 1 million users during the COVID-19 lockdowns; and the UK's National Underground Asset Register now integrates data from 267 infrastructure owners, covering more than 40% of the entire national infrastructure network. These examples confirm that AI-enabled "cityverses" are a vital tool for addressing complex urban challenges on a large scale.

In every domain, AI-enabled Citiverse is used to address unique challenges – ranging from climate change adaptation and circular economy initiatives to citizen engagement and emergency management. The cross-sectoral nature of these applications demonstrates the versatility of AI-enabled Citiverse as a platform for problem-solving. For instance, digital twins serve urban planners in visualizing infrastructure, emergency responders in simulating natural disasters, and citizens in accessing immersive educational and cultural experiences.

Cities must balance risks and opportunities when implementing artificial intelligence use cases on a citywide scale. A systematic risk library – covering public safety, stakeholder acceptance, data privacy/security, and financial/operational risks – enables cities to prioritize use cases that strike a balance between innovation and manageable risk. This approach supports informed decision-making, ensuring that high-impact, scalable solutions are prioritized for early adoption, while more experimental or higher-risk concepts are piloted or studied in greater depth before being deployed across the entire city.

Research indicates that most risks to public safety are low to moderate; in fact, virtual environments often enhance rather than diminish safety by improving training, simulation, and coordination capabilities. However, data privacy and cybersecurity risks require ongoing attention, particularly for applications that process sensitive infrastructure-related, personal, or financial data.

Experience gained from various initiatives in the realm of digital urban spaces highlights several key success factors, including:

Implementing open standards and ensuring interoperability: The success of projects in this field depends on the development and adoption of unified data models, APIs, and semantic structures that enable seamless information exchange across different platforms. The UK's NUAR project clearly demonstrated the effectiveness of using a common international data model for underground infrastructure (MUDDI), which brought together 267 asset owners and numerous agencies into a single "digital twin." Focusing on open standards from the early stages helps cities avoid data silos, accelerates the replication of solutions, and reduces dependency on specific technology vendors. ITU-T Study Group 20 – which focuses on the Internet of Things, digital twins, and smart, sustainable cities and communities – is developing international standards for an AI-driven "cityverse." These standards serve as a global framework for ensuring interoperability, trust, and scalability for solutions across cities, industries, and government entities.

Establishing robust and flexible governance mechanisms: Beyond the technological aspects, it is essential to develop governance structures that effectively allocate roles, responsibilities, and risks throughout a project's entire lifecycle. The success of the digital twins within Copenhagen's "Street Lab" initiative stems from active collaboration among municipal services, private operators, and academic partners, who jointly make decisions and share responsibility for data management. Establishing clear governance rules – covering issues such as data ownership, quality control, and change management – Is fundamental to the long-term sustainability of such projects. Developing multilateral cooperation and engagement: No single organization can create a "cityverse" on its own. The success of the Metaverse Seoul project was made possible through the collaborative efforts of city authorities, public associations, technology companies, and civil society.

Phased implementation through pilot projects: a step-by-step rollout reduces risks and builds momentum. The CReDo project in the UK began with targeted pilot projects focused on addressing the impacts of flooding, later expanding to include resilience planning for various infrastructure assets.

Balancing technical infrastructure with organizational change management: technologies such as digital twins and immersive XR platforms may require significant infrastructure investment – including 3D modeling, cloud services, and sensor networks – but technology alone is not enough to achieve results. The Nottingham City Council's digital twin initiative integrated specialized organizational change management teams to help developers, planners, and the public adapt to new workflows. Dedicated resources

for change management – such as training, communication plans, and feedback channels – are j st as essential as servers and software.

Prioritizing security, privacy, and trust by design: several AI use cases within the "Citiverse" integrate personal data, infrastructure data, and Internet of Things (IoT) data. Embedding security and privacy at every level – through network segmentation, end-to-end encryption, consent-based data sharing, and role-based access control – ensures resilience against breaches.

Iterative improvement relies on real-time performance data and structured evaluations. Seoul's traffic digital twin reduced emergency response times by 20 percent by continuously refining its AI models based on feedback from real-time sensors. An inclusive and accessible approach to design: while an AI-enabled urban environment has the potential to democratize participation, it also risks excluding individuals with low digital literacy, limited access to devices, visual impairments, or neurodivergence. Implementing universal design principles – such as supporting multiple input methods, low-bandwidth modes, and multilingual interfaces, among other design considerations – can help mitigate these issues.

Virtual environments can democratize participation by removing the geographical, temporal, and accessibility constraints that have traditionally excluded vulnerable populations from urban planning processes. Seoul's "Metaverse Seoul" platform and initiatives in Barcelona focused on mapping citizen sentiment demonstrate how digital platforms can amplify the voices of previously marginalized groups within municipal decision-making.

Digital twins and AI-driven analytics are transforming maintenance from a reactive approach to predictive management, thereby reducing costs and enhancing service reliability.

Climate adaptation is emerging as a critical area of application; digital twins allow cities to simulate flood scenarios, optimize the placement of green infrastructure, and coordinate the responses of various departments to extreme weather events. The CReDo project in the United Kingdom illustrates how cross-sectoral data sharing via digital twins strengthens collective resilience to climate risks, while simultaneously facilitating more effective capital investment decisions.

Immersive educational platforms prove particularly effective in complex, high-risk, or costly learning environments. Such applications support formal education systems as well as the continuous professional development of municipal staff.

They foster economic diversification and cultural preservation; an AI-enabled urban environment opens new avenues for economic growth through virtual marketplaces, immersive tourism, digital heritage conservation, and support for creative industries. These use cases contribute to local economic resilience, cultural continuity, and global accessibility, while simultaneously reducing the environmental impact associated with physical tourism and commerce.

Virtual tourism platforms show significant potential for cultural sites facing the pressures of overtourism or climate-related threats. Digital heritage preservation projects create permanent records of vulnerable sites while generating new revenue streams through virtual experiences. Global digital heritage initiatives and various virtual museums demonstrate how cities can preserve cultural assets while expanding global access to local

heritage – creating sustainable tourism models that benefit communities without overburdening physical infrastructure.

They promote sustainable development across all facets of urban life: from nature-inclusive mapping and design, the advancement of a circular economy, and waste management, to the provision of educational opportunities – including the gamification of sustainable behaviors and the simulation of climate change adaptation strategies.

Educational gaming platforms, such as Scubaverse, illustrate how immersive experiences can enhance environmental awareness and drive behavioral change on a large scale. Digital twins support circular economy initiatives by tracking material flows, optimizing waste collection routes, and enabling collaborative planning to improve resource efficiency.

Art and culture programs in virtual environments enable the creation of new forms of creative self-expression while preserving traditional cultural practices. The integration of live musical performances in a virtual version of Helsinki – combined with interactive city exploration – and experiments in the virtual creation of public spaces at the Burning Man festival demonstrate how digital environments can complement, rather than replace, physical cultural experiences. These initiatives foster hybrid models that expand access while maintaining authentic community connections.

In the future, the convergence of an AI-powered virtual universe with emerging technologies – such as advanced artificial intelligence and quantum computing – will pave the way for even more sophisticated applications.

City Administration and Services

This section examines how an AI-enabled "citiverse" – and related technologies - can help cities deliver services more quickly, make them more accessible, and better tailor them to the needs of diverse population groups [2]. It provides a brief overview of solutions that leverage AI and allied technologies to improve public service delivery, enhance civic engagement, support the sustainable functioning of a city, and strengthen transparency and accountability.

Figures 2 and 3 illustrates the overall landscape of potential use cases and their future development. It highlights the interconnections between various sectors and demonstrates how advanced technologies can be applied across a wide range of aspects of urban life. Within this broad framework, this report focuses on thematic areas such as urban governance, service delivery, and public engagement. It examines key technologies that drive innovation, the implications of their implementation, and specific real-world examples.

Cities are increasingly adopting digital technologies to transform governance, improve public and municipal services, and expand citizen participation in urban life.



Fig. 2. Overall use case overview [2]

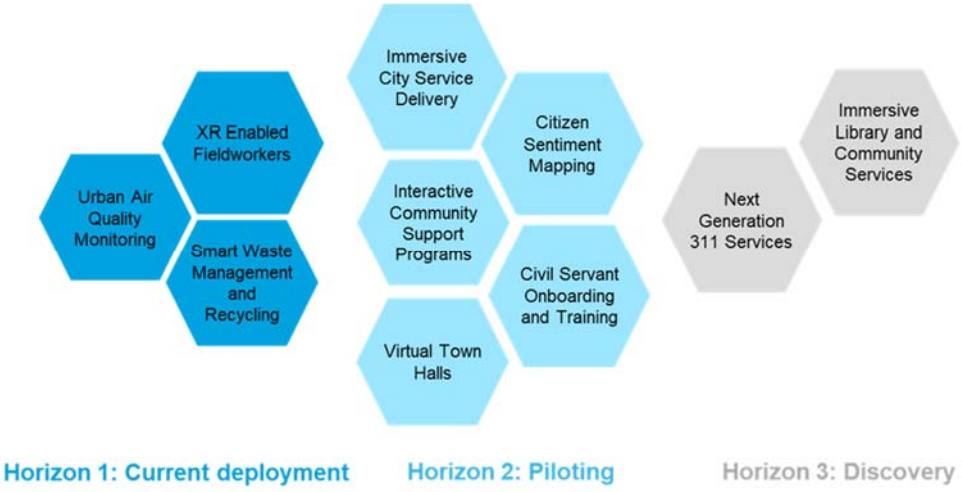


Fig. 3. City Administration, Services and Public Participation Use Case Overview and Horizon Mapping [2]

The thematic area of "Urban Governance, Services, and Citizen Participation" focuses on the use of digital technologies – such as artificial intelligence (AI), virtual reality (VR), augmented reality (AR), and digital twins – to reshape city management, enhance service quality, and foster active resident engagement. Practical applications include:

• Delivery of public and municipal services: increasing the accessibility and efficiency of processes such as tax administration, permit issuance, licensing, and social support.

• Citizen interaction, participation, and co-creation: establishing platforms for more inclusive, interactive, and meaningful resident involvement in city life.

• Sustainable urban functioning: initiatives to monitor and support the transition toward "net-zero" emissions, as well as promoting the efficient use of resources and the implementation of circular economy principles – for instance, measures to improve air quality and enhance waste management systems.

• Transparency and accountability.

City Administration, Services, and Public Participation

Case 1: Smart Waste Management and Recycling

AI-enabled urban environment technologies, such as digital twins, can be used to create an interactive digital platform for managing the collection and recycling of urban waste in residential and commercial areas.

Impact

1) Emission reduction: Optimizing waste collection routes and schedules using AI and real-time digital twin data significantly lowers fuel consumption for waste collection vehicles. More efficient waste collection leads to a cleaner, better-maintained urban environment, with fewer overflowing bins, less litter, and reduced unpleasant odors. This makes areas less attractive to pests and eases traffic congestion caused by collection vehicles, contributing to safer and more pleasant public spaces.

2) Biodiversity: Reducing illegal dumping and increasing recycling rates helps decrease pollution and the disruption of habitats within urban green spaces.

3) Pedestrian accessibility: Keeping sidewalks and public spaces clean, while minimizing the presence of waste collection vehicles through dynamic route planning, fosters a more pedestrian-friendly environment.

4) Health and well-being: Lowering the accumulation of waste reduces exposure to harmful bacteria, pests, and airborne pollutants.

5) Citizen engagement: Interactive digital twin platforms empower residents by providing real-time feedback on their recycling efforts, the status of waste containers, and available incentives.

Key Technologies

• GenAI: Generative AI can enhance smart waste management by simulating scenarios, optimizing collection routes, and developing targeted citizen engagement campaigns – even when direct data is limited or rapidly changing. It can also generate accessible, multilingual content and summaries within tools such as digital twins, improving understanding and participation among city staff and residents.

• AI: Artificial intelligence can be used to analyze waste generation patterns, predict peak collection times, optimize collection routes, and forecast whether containers are becoming overfilled or underutilized. Machine learning can automate scheduling, suggest resource allocation strategies, and continuously refine routing as urban conditions evolve.

• IoT: Fill-level sensors – utilizing ultrasonic, lidar, or optical technologies – can be embedded in containers to monitor volume, temperature, and tilt status in real time. This enables dynamic data collection on container usage, reduces the need for manual inspections, and provides waste management operators with immediate insights. These

sensors transmit data at frequent intervals and trigger automated alerts in the event of overfilling or unusual activity.

• Computer Vision: Cameras and computer vision systems can be integrated into advanced containers to automatically recognize and separate recyclable materials from general waste.

• Digital Twin: Digital twins offer a centralized, interactive visualization of all waste management assets. This fosters operational efficiency and cross-departmental urban planning by integrating waste streams with other urban infrastructure systems.

Implemented in:

Copenhagen, Denmark; Edinburgh, UK; Bratislava, Slovakia; Nicosia, Cyprus; Barcelona, Spain; Singapore; San Francisco, USA; Amsterdam, Netherlands

Case study: A digital twin including waste management in Copenhagen

Copenhagen (Denmark) is advancing its smart city strategy through a large-scale "digital twin" project, implemented in partnership with Cisco and TDC (Tele Danmark Communications).

As a European capital of "green" digitalization, Copenhagen has launched an ambitious initiative: the creation of an integrated digital platform that aggregates and manages data from various urban infrastructure systems – ranging from lighting and parking to air quality monitoring and waste management. Centered around the Danish Outdoor Living Lab (DOLL) and the Copenhagen Street Lab, the project spans an urban area of over 11 kilometers (7 miles) in the western part of Copenhagen.

This initiative brings together more than 40 different smart city solutions, deployed as a "living laboratory" for testing and demonstrating intelligent urban technologies. Copenhagen's goal of becoming the world's first carbon-neutral capital by 2025 has driven city authorities to adopt data-driven solutions. These enable the optimization of operational processes, cost reduction, and the improvement of public services, all while contributing to the achievement of ambitious climate targets.

The primary objective of the Copenhagen "digital twin" project was to develop a comprehensive, real-time digital model of the city's infrastructure.

The project aimed to deliver several key outcomes:

• Smart city innovation: Strengthening Copenhagen's position as a global leader in smart city technologies by establishing Europe's largest outdoor testing ground for intelligent urban solutions. • Support for carbon neutrality: development of digital tools and analytical capabilities for monitoring, measuring, and optimizing carbon emissions across various municipal services.

• Operational efficiency: implementation of data-driven decision-making processes across various municipal services.

• Economic growth and improved quality of life for residents: creation of new business models and investment opportunities, while simultaneously reducing operational costs. The broader "Copenhagen Connecting" initiative is projected to generate a socio-economic impact of €600 million over the course of its implementation.

The creation of a "digital twin" of Copenhagen was based on a multi-layered architecture that integrates advanced network infrastructure, Internet of Things (IoT) sensors, data analytics tools, and unified management platforms.

• Foundation of the digital infrastructure: The project established a robust digital framework, with the Cisco Smart+Connected Digital Platform serving as the central integration layer. This cloud-based system aggregated data streams from sensors and end-user devices across the city, forming an ecosystem of applications for managing the urban environment via open APIs. TDC provided carrier-grade Wi-Fi and cellular connectivity, ensuring stable data transmission throughout the seven-mile pilot zone.

• Deployment of a sensor network: The project involved the implementation of an extensive network of IoT sensors covering various urban systems. Specifically, for waste management purposes, ultrasonic fill-level sensors were installed in waste containers throughout the area; these monitor the volume, temperature, and orientation (tilt) of the containers in real time. Data from these devices were transmitted via energy-efficient, long-range networks (LoRaWAN, NB-IoT), which minimized power consumption while maintaining reliable connectivity.

• Integrated Analytical Platform: Data from all connected systems flowed into a centralized analytical platform capable of real-time monitoring and predictive analysis. The system integrated environmental monitoring (air quality, noise, temperature), traffic management, parking sensors, smart lighting control, and waste management data into a unified operational view.

• Waste Management Integration: The waste management component utilized smart bin sensors to monitor fill levels and optimize collection routes. When sensors revealed that only 30 percent of traditionally scheduled waste pickups actually involved full bins, the system enabled Copenhagen to shift from a fixed schedule to on-demand waste collection. This data-driven approach was designed to reduce unnecessary collection trips, lower fuel consumption, and decrease CO_2 emissions.

• Stakeholder Engagement: The project involved extensive collaboration among municipal authorities (Copenhagen, Frederikssund, and Albertslund), technology providers (Cisco, TDC), and research institutions. The DOLL Living Lab served as a neutral testing ground where various vendors could showcase their solutions side-by-side, facilitating informed procurement decisions.

Results

The implementation of a "digital twin" in Copenhagen has led to measurable improvements across various operational and environmental areas.

The integrated platform enabled real-time monitoring and management of urban infrastructure within a seven-mile (approximately 11 km) pilot zone. Through a unified dashboard, municipal services gained access to detailed data on lighting systems, parking space utilization, air quality, and the fill levels of waste containers. In practice, the system demonstrated the technical feasibility of consolidating diverse urban infrastructure systems onto a single digital platform.

Although detailed quantitative metrics from the sensors installed in Copenhagen's waste containers are not available, the overall outcomes in waste management indicate significant potential. Approximately 600 waste containers in the city center were equipped with sensors, facilitating predictive waste collection planning and route optimization. Similar projects utilizing Nordsense technology in other cities have resulted in an 80%

reduction in overflowing containers, a 66% decrease in street-cleaning service requests, and a 64% drop in illegal dumping.

The platform contributed to Copenhagen's broader environmental objectives, though specific CO_2 emission reductions attributable solely to the "digital twin" were not separately quantified. Between 2009 and 2022, Copenhagen succeeded in reducing its total CO_2 emissions by 80%. A significant role in this was played by the waste management system developed as part of the city's "Circular Copenhagen" program, which aims to reduce CO_2 emissions by 59,000 tonnes by 2024.

Lessons Learned

• Integration complexity necessitates strong partnerships: The success of Copenhagen's digital twin relied heavily on close collaboration between the municipal government, technology providers, and telecommunications companies. The partnership between Copenhagen, Cisco, and TDC demonstrated that complex "smart city" initiatives require an ongoing commitment from multiple stakeholders, with clearly defined roles and responsibilities.

• Pilot-scale implementation facilitates learning: A seven-mile test zone provided a sufficient scale for verifying technologies while remaining manageable for deployment and troubleshooting. This approach allowed the city to test and refine solutions prior to broader rollout, thereby mitigating the risks associated with a citywide implementation.

• Data quality and sensor maintenance: Maintaining sensor functionality and data quality within diverse urban environments requires constant attention. The success of waste management optimization depends on reliable sensor performance, regular calibration, and robust data management systems.

• Scalability considerations: While the pilot project demonstrated technical feasibility, scaling to larger urban areas requires significant infrastructure investment and organizational change management. The platform architecture developed for DOLL served as a foundation for expansion into other parts of Copenhagen; however, full-scale, citywide implementation remains a multi-year undertaking.

Copenhagen's initiative to create a "digital twin" of the city – focused on waste management and the monitoring of complex urban systems – demonstrates the transformative potential of integrating IoT sensors, data analytics, and cloud platforms into municipal governance. The project has laid a technical foundation for data-driven urban operations, while simultaneously supporting the achievement of Copenhagen's ambitious climate goals. A key strength of this initiative lies in its comprehensive approach.

Case 2: field staff supported by XR technologies

Extended reality (XR) technologies, such as augmented reality (AR) and virtual reality (VR), have the potential to significantly enhance the capabilities of government field personnel – for instance, building or environmental inspectors. Through XR, these staff members can receive real-time remote consultations from experts who are "virtually present" at the site via digital twins and data streams. XR headsets or smart glasses allow critical information – such as schematics, troubleshooting tips, or safety instructions – to be overlaid directly into the user's field of view, enabling them to perform tasks efficiently

while keeping their hands free. VR simulations facilitate staff training in a realistic, immersive environment, where high-risk tasks can be practiced without any actual danger. Furthermore, the integration of artificial intelligence (AI) provides professionals with access to real-time analytics and recommendations, which helps optimize workflows, improve safety, and boost productivity.

Benefits

1) Efficiency: Using augmented/mixed reality (XR) headsets allows field technicians to access equipment documentation – such as manuals for water pumps or valves – directly on-site. This documentation includes detailed repair or replacement instructions, as well as instructional videos. XR technology significantly reduces the time required for equipment repairs and replacements by minimizing the time spent traveling or working in the office.

2) Quality of Life: Implementing this technology improves the quality of life for both technicians and local residents. Staff spend less time commuting between the office and job sites, while residents benefit from faster restoration of services.

Furthermore, XR technology enables municipalities to onboard less experienced staff by providing hands-on, on-the-job training.

3) Increased Operational Readiness: The ability to instantly access essential information when encountering new or unforeseen issues facilitates faster repairs, thereby maximizing the uptime of critical infrastructure.

4) Knowledge Sharing: XR technology allows a more experienced specialist to virtually "join" colleagues working at various locations across the city, regardless of the specific nature of the task at hand.

Key Technologies

• Digital Twins: Infrastructure, along with its associated documentation and video materials, can be stored within a digital twin. This allows users to access precise information about the location of assets and all related data from any remote site.

• R/VR (Augmented and Virtual Reality): To effectively utilize these technologies, cities will require the necessary hardware – such as AR headsets and supporting systems – to ensure that field personnel have access to the data they need while performing tasks on-site.

• IoT (Internet of Things): By integrating IoT devices into critical infrastructure, personnel working on-site can receive real-time updates on the current status of that infrastructure.

Table 3

Risk level: XR-enabled fieldworkers

Risk attribute	Risk rating			Explanation
Public safety	Low	Medium	High	The use case presents a low impact on public safety. However, it can improve the outcomes for public safety due to lower disruption of infrastructure.
Stakeholder acceptance	Low	Medium	High	This use case will have newer training methods, which may reduce acceptance rates at first. Through training and champions, the technology has the potential to have a high acceptance.
Data privacy and security	Low	Medium	High	With the data being stored locally and consists of commonly found documents, and the AR glasses not connecting to a network, reduce the data privacy risks.
Financial/ operational	Low	Medium	High	With all new technologies, costs are still higher than more commonly available technologies on the market. However, adoption is growing which will reduce costs.

Implemented in: Vienna, Austria; Coral Gables, USA; Chandler, USA.

Case study: Vienna AR-enabled building permitting

Every year, more than 13,000 building permit applications are submitted in Vienna; however, due to an outdated, paper-based workflow, the average time to issue a single permit was twelve months. Approximately 200 tons of archived blueprints and a fragmented collection of regulatory requirements made the review process extremely labor-intensive for municipal authorities and opaque for citizens. To address rapid population growth – the number of residents increased by an average of 21,000 per year between 2012 and 2021 – city authorities launched a research project called BRISE Vienna (Building Regulations Information for Submission Envolvement). The project, which received €4.8 million in funding through the EU's "Urban Innovative Actions" program, aimed to create a fully digital, end-to-end permitting process that integrates Building Information Modeling (BIM), artificial intelligence (AI), and augmented reality (AR).

Objectives

The BRISE project pursues four strategic goals:

• To reduce approval times by at least 50% - from 6-12 months down to 3-6 months for standard residential projects.

• To automate regulatory compliance checks by comparing BIM models submitted by applicants against a 3D master model of the city, which incorporates all site-specific building codes and zoning regulations.

• To increase transparency and public trust through augmented reality (AR) visualizations, allowing residents to see exactly what a planned development will look like and how it will affect lighting (e.g., shadows cast) before construction begins.

• Enable regulatory authority specialists to use AR visualizations to gain a deeper understanding of the scale and impact of planned construction work.

• Adapt municipal workflows to future requirements and develop an open BIM data standard.

Approach to the Solution

• OpenBIM-based submission plugin: The municipal authorities provide an IFC plugin that allows architects to export a 3D model of a project – a "building permit application model" – ready for automated compliance checking against building regulations. This eliminates the need for professionals to learn new software tools.

• AI-driven verification system: Machine learning algorithms analyze the submitted model, compare it against Vienna's building codes, and identify non-compliance issues (such as violations regarding the length of evacuation routes or the required number of parking spaces).

• Reference 3D Model (REM): A "digital twin" is created for every cadastral plot within the system, containing data on height restrictions, protected heritage zones, and transport corridors. This enables the immediate detection of conflicts between design proposals and permitted development parameters.

• Augmented Reality (AR) module: Inspectors and local residents can use tablets or HoloLens headsets to overlay approved project volumes onto the actual construction site. This facilitates compliance verification and makes the project more accessible and understandable to the public.

• Pilot project implementation: Between June and December 2022, 13 architectural firms submitted 17 real-world projects through the new system. Concurrently, the relevant municipal department (MA 37) established a dedicated working group to expedite the review of applications and the preparation of feedback.

Results

• Time savings: The review process for digital applications – up to the point of a final decision – took 3-4 months, compared to approximately 8 months for equivalent paper-based submissions. Consequently, the goal of reducing processing time by 50% was achieved.

• Scaling the pilot project: positive feedback from participants prompted 13 additional companies to join the system, demonstrating clear demand for it.

• Scaling potential: internal estimates indicate that a full transition to this system – covering all 13,000 annual requests – would result in savings of 50,000 man-hours and 7 million euros per year.

BRISE Vienna demonstrates how BIM, AI, and augmented reality can be integrated into a unified digital workflow that cuts permit processing times in half, reduces errors, and simplifies planning-related decision-making for citizens. By digitizing applications, automating regulatory compliance checks, and using augmented reality to overlay approvals directly on-site, Vienna has transformed a bureaucratic hurdle that once took a year into a transparent, data-driven service.

Case 3: Next generation 311 Services

"311" services provide citizens with a way to interact with the municipal administration and report issues related to local services and infrastructure. Technologies from the virtual realm are enabling a new generation of "311" services. Digital twins – virtual replicas of the urban environment – are updated in real time using data from sensors, citizen reports, and other incoming information. Mixed reality (MR) technologies allow residents to use smartphones or augmented reality (AR) headsets to scan their surroundings and access information regarding submitted service requests, maintenance schedules, or the progress of repair work.

Key technologies: Digital twin, AR, GenAI and IoT.

Table 3

Risk level: Next generation 311 Services

Risk attribute	Risk rating			Explanation
Public safety	Low	Medium	High	This use case enhances public safety by enabling faster non-emergency response coordination (e.g., addressing potholes and waste accumulation) and proactive infrastructure monitoring, with minimal direct safety risks.
Stakeholder acceptance	Low	Medium	High	While citizens generally welcome improved services, some citizens may resist process/service changes. Many users will also be unfamiliar with MR technologies and require upskilling and public engagement to encourage adoption.
Data privacy and security	Low	Medium	High	Service requests contain location and personal data requiring robust protection. Integration with IoT sensors expands potential attack surfaces needing security measures.
Financial/ operational	Low	Medium	High	This solution requires up-front cost of creation of the front end and backend system but also ongoing maintenance of the solution and new workstreams to process a new channel of citizen engagement.

For this use-case, no relevant case study has been identified due to the horizon 3 level.

Case 4: Citizen sentiment mapping

"Digital city" (citiverse) technologies, including artificial intelligence and digital twins, can be used to collect and analyze the sentiments of city residents, enabling authorities to make informed decisions that take public opinion into account. AI algorithms are capable of processing this data to identify patterns, trends, and emerging issues, which are then visualized within dynamic models of the city.

Results

1) Resource Allocation: Using real-time data on public sentiment allows city authorities to prioritize the allocation of resources toward the neighborhoods or issues that are of greatest concern.

2) Quality of Life: Visualizing trends in public sentiment helps identify areas characterized by social tension, dissatisfaction, or unmet needs.

3) Effective Policymaking: Integrating the results of public sentiment analysis enables decision-making based on empirical data, citizens' preferences, and their current priorities.

4) Improvement of Urban Services: The feedback mechanism created by mapping public sentiment facilitates the continuous improvement of municipal services. By identifying the strengths and weaknesses of city services – from the perspective of the citizens themselves – authorities can adjust and refine their operations to better align with the public's expectations.

5) Citizen Engagement: Interactive visualization tools allow residents to see how their feedback influences the actions and policies of city authorities.

Key technologies: Digital twin, AR & VR, AI, GenAI, IoT.

Implemented in: Helsinki, Finland; New York, USA: Barcelona, Spain; Singapore; London, UK; Dublin, Republic of Ireland; Tallinn, Finland; Aachen; Germany Leicester, UK.

Case study: Citizen sentiment mapping and engagement platform in Patras, Greece

The city of Patras – Greece’s third-largest urban center and the administrative capital of the Western Greece region – has emerged as a leading example of integrating public opinion analysis tools into municipal governance through "digital twin" technology.

Home to approximately 214,000 residents, Patras faces challenges typical of mid-sized European cities: aging infrastructure, the need for environmental monitoring, complex traffic management issues, and an urgent requirement for meaningful citizen participation in decision-making processes. In 2020, building on experience gained through the EU’s "Intelligent Cities Challenge," the municipality of Patras began developing an "Urban Resilience Digital Twin." This solution fundamentally transforms how public opinion is gathered, analyzed, and incorporated into urban planning and the delivery of municipal services. The project represents a significant advancement over traditional management methods: it creates a dynamic, AI-driven digital model that continuously "learns" from interactions with citizens, providing real-time data on the needs and priorities of the local community.

The "Urban Resilience Digital Twin" project in Patras was aimed at transforming the city's governance system. At its core is a comprehensive, AI-driven platform that continuously collects, analyzes, and visualizes public sentiment, enabling data-informed decision-making and enhancing urban resilience. The primary objective was to create a dynamic system capable of converting fragmented citizen feedback into actionable insights for municipal authorities, facilitating a shift from reactive to proactive governance.

A key feature of the approach implemented in Patras is its granular, neighborhood-level focus. This allows city officials to understand how residents in different parts of the city perceive the quality of urban services and to identify localized issues that might otherwise go unnoticed when assessing the situation on a city-wide scale. The system serves as a tool for urban planning rooted in the actual priorities of citizens, rather than in assumptions about the needs of the public.

To implement this solution, the project utilized Sense.City – a versatile digital tool for citizen engagement, developed and maintained by the University of Patras. Sense.City establishes a direct link between residents and municipal services; through an intuitive mobile or web application, citizens can report urban issues in real time. The platform collects georeferenced data on a wide range of concerns – from malfunctioning streetlights and damaged traffic signals to abandoned vehicles and various environmental issues. Users can attach photographs to their reports, and each submission is categorized to ensure more efficient processing. This data is further supplemented by information gathered from social media.

Citizens have access to a citywide portal that allows them to track reported issues, monitor the progress of their resolution, and evaluate the performance of various municipal services. Municipal authorities use analytical dashboards that display trends in the emergence of issues, response times, and metrics regarding successful resolution.

To process and analyze citizen reports, the platform in Patras leverages the capabilities of modern smartphones – such as GPS, accelerometers, cameras, and microphones – effectively turning residents into "live sensors" of the urban environment. The system's backend manages data related to geofencing and critical infrastructure, providing municipal officials with a comprehensive overview of urban issues. The platform is open-source, which facilitates its adaptation and implementation in other cities worldwide; furthermore, it includes an open API for integration with other urban management systems.

Integrating real-time feedback from citizens with predictive analytics methods opens up significant opportunities for the proactive management of the urban environment, making it possible to address issues before they escalate into large-scale systemic failures.

Case 5: Virtual town halls

Virtual public meetings, based on metaverse and extended reality (XR) technologies, offer an innovative way for citizens to engage with local government authorities and community leaders. Such events create an immersive 3D environment where residents can participate in open discussions, ask questions, and share their opinions in real time – regardless of their physical location.

Key technologies: Metaverse, VR, AI, GenAI. Implemented in Seoul, Republic of Korea. Seoul's Metaverse Seoul initiative exemplifies how metaverse technology can be effectively utilized to enhance public service delivery and citizen engagement. By creating

an immersive and interactive virtual environment, the Seoul Metropolitan Government has paved the way for innovative digital governance, setting a benchmark for other cities to follow.

Case 6: Civil servant onboarding and training

Creating immersive learning environments allows new employees to interact with digital replicas of government buildings, enabling them to familiarize themselves with the work environment, internal policies, and procedures within a safe, virtual setting. In a space reminiscent of a metaverse, new hires can simulate real-world work scenarios – such as processing citizen inquiries, responding to emergencies, or collaborating with colleagues from other departments. AI-powered virtual assistants can guide employees through the training process, offering personalized learning paths and assessing their knowledge. This approach not only accelerates onboarding but also facilitates better information retention, boosts employee engagement, and enhances preparedness for job responsibilities, ultimately helping civil servants integrate into the workflow more effectively.

Key technologies: Metaverse platforms, VR, GenAI, Digital twins. Implemented in: San Diego County, USA; Sharjah, UAE; Dubai, UAE.

San Diego County determined that new staff members require more hands-on experience to conduct eligibility interviews and make informed decisions regarding the provision of benefits – decisions that determine families' access to food, healthcare, and housing support.

San Diego County, in collaboration with Accenture, has implemented the Accenture Virtual Experience Solution (AVEnueS) – a comprehensive VR training platform designed specifically for the needs of the public sector.

By leveraging immersive technologies and AI-driven interactive elements, the program has successfully addressed key challenges inherent in traditional training methods, while simultaneously enhancing staff readiness and the quality of services provided. As digital tools become increasingly accessible and sophisticated, this model offers a scalable framework for modernizing workforce development within the public sector across various jurisdictions and service areas.

Case 7: Immersive library and community services

The metaverse and XR have the potential to transform the delivery of library services by creating virtual libraries and public spaces. Libraries can develop immersive environments where users can explore various genres, attend author meet-and-greets, or join book clubs – all within a fully interactive setting. Through XR technologies, users can also engage with digital versions of books, interacting with multimedia content such as videos, audio, or interactive exhibits. Artificial intelligence can be integrated to provide personalized recommendations and support virtual librarians, who can guide users in navigating and utilizing resources. Furthermore, libraries can host virtual or XR-based educational sessions, facilitating easier access to workshops, research activities, and even remote study groups.

Key technologies: Digital twin, Metaverse, AR, VR, GenAI, IoT. For this use-case, no relevant case study has been identified due to the horizon 3 level.

Case 8: Interactive community support programmes

Virtual world technologies – including metaverses, combined with AI-powered chatbots and immersive environments – have the potential to transform community support programs by offering residents interactive and accessible platforms through which they can obtain assistance, guidance, and resources.

Key technologies: Metaverse, AR, VR, MR, GenAI, AI. Implemented in: Westminster, UK; Seoul, Republic of Korea; Manchester, UK.

Westminster Council, operating within one of London's most diverse and complex urban environments, has faced significant challenges in providing support to communities affected by youth violence. Traditional community engagement programs often failed to reach the most hard-to-engage groups of residents. High levels of youth violence, combined with low levels of trust between citizens and local authorities, created obstacles to the effective implementation of support measures. Community practitioners in Westminster concluded that innovative approaches were required – ones that could foster meaningful connections and deliver psychological support in a way that was both accessible and truly relevant to the affected populations.

Westminster Council partnered with The FRED Company to implement a comprehensive three-year programme (2021-2023) spanning eight distinct projects, each running 6-12 weeks.

The VR-RAW program, implemented in Westminster, demonstrates the significant potential of immersive technologies to transform public support systems – particularly for hard-to-reach populations facing social challenges. The success of this initiative led to the establishment of the Westminster VR Service, which has facilitated the broader integration of virtual reality technologies into public support strategies. This example illustrates how the thoughtful application of advanced technology can open new avenues for strengthening social ties, supporting mental health, and fostering social cohesion within complex urban environments.

Case 9: Immersive city service delivery

Creating virtual spaces and experiences that digitally recreate the real world will allow citizens to interact more freely with the government and members of their communities – leveraging technologies such as the metaverse, augmented/mixed/virtual reality, and blockchain – to submit applications and access comprehensive services and benefits. Government services, including permit applications, the receipt of benefits, and non-emergency services, can be delivered through these environments.

Key technologies: Metaverse, AR, VR, MR, GenAI/AI, IoT. Implemented in Seoul, Republic of Korea.

The Seoul Metropolitan Government serves approximately 10 million people within a complex urban environment, a task that entails thousands of daily administrative operations – ranging from processing permit applications to managing social welfare assistance. Traditional service centers face several challenges, including limited capacity, long wait times, and accessibility issues – particularly for the elderly, individuals with disabilities, and those who work shifts.

In November 2022, Seoul launched "Metaverse Seoul" – the world's first government-run metaverse – designed to transition municipal administrative functions, public consultations, and economic services into a digital format, delivered through an immersive 3D environment.

The Seoul Metropolitan Government, in partnership with leading technology companies, launched a phased pilot project involving 3,200 users, including municipal employees, youth groups, and governance experts. Key elements included:

• Virtual City Hall and Plazas: 3D reconstructions of Seoul City Hall and Gwanghwamun Plaza, recreated within the metaverse, allowing users to navigate to information points via avatars.

• Integrati n of AI-powered chatbots and the "Seoul Wallet" service.

• C nsultation rooms for young people.

• Blockchain-based identification and documentation: Distributed ledger technology serves as the foundation for user authentication and the issuance of digital certificates, minimizing fraud and streamlining record-keeping.

• Metaverse Startup Zone: A dedicated area featuring virtual booths for fintech startups and small-to-medium-sized enterprises, enabling them to present projects to investors, attend workshops, and conduct real-time product demonstrations.

Results

• Service Usage: 85% of pilot project participants completed at least one municipal transaction (such as renewing a permit or applying for social assistance) via the metaverse platform.

• Engagement: Attendance at virtual city meetings was twice as high as that of comparable in-person events; furthermore, 78% of participants actively took part in real-time polls and Q&A sessions.

• Operational Efficiency: AI-powered chatbots handled 72% of standard inquiries, reducing the workload on staff (operators) by an average of 55%.

• Economic Impact: Over 150 virtual startup pitches attracted the interest of 20 international investors, leading to the initiation of funding negotiations totaling approximately 2 million USD.

• User Satisfaction: Pilot project participants rated their experience 4.6 out of 5, highlighting convenience and reduced wait times as the primary benefits.

The Metaverse Seoul project demonstrates that immersive virtual platforms can significantly enhance the delivery of municipal services, civic engagement, and local economic development. Seoul has created a scalable model for other cities looking to modernize their public services. Future plans include deepening integration with smart city IoT networks, launching multilingual virtual support services, and incorporating environmental monitoring data to bolster sustainability initiatives.

Case 10: Urban air quality monitoring

Cities are increasingly adopting "digital twin" technologies to visualize and monitor air pollution in real time. By integrating data from IoT sensor networks, meteorological information, and details on traffic flow and land use into a unified 3D model, stakeholders can identify pollution hotspots, evaluate the effectiveness of implemented measures, and engage the public in initiatives to improve air quality. Machine learning algorithms make it

possible to forecast the dispersion of pollutants under various weather conditions and traffic intensity levels, while generative artificial intelligence enables users to query the data using natural language.

Key technologies: Digital twin, Mixed reality (MR), AI, GenAI, IoT. Implemented in: Jakarta, Indonesia; Shenzhen, China; London, UK.

Rapid urbanization and an increasing number of vehicles in Jakarta have led to a serious air pollution problem. The city is home to over 11.6 million people. According to research, air pollution in Jakarta causes more than 10,000 deaths and 5,000 hospitalizations annually due to cardiovascular and respiratory diseases, in addition to resulting in over 7,000 adverse health outcomes for children. The economic damage from this exceeds 2.9 billion USD per year (equivalent to 2.2% of Jakarta's gross regional product).

Traditional air quality monitoring relies on a limited network of stationary observation stations. Such a system fails to track local fluctuations in pollution levels across specific neighborhoods or short-term emission spikes near busy thoroughfares, making it difficult to develop effective interventions tailored to particular urban areas.

An initiative by BINUS University aims to overcome the primary shortcomings of traditional air quality monitoring in Jakarta by creating a "digital twin" (DT) of the city, integrated with mixed reality (MR) technologies.

The project's key objectives are to:

• D velop a comprehensive, data-rich 3D model of Jakarta's urban environment.

• Incorporate real-time data from air quality sensors, meteorological information, traffic flow data, and infrastructure characteristics into this virtual model.

• Enable decision-makers and stakeholders to visualize air pollution within a spatiotemporal context, identify "hotspots," and test various intervention measures within an interactive, immersive environment.

• Increase the transparency of processes, foster public engagement, and ensure support for science-based urban policy aimed at sustainable development and the protection of public health.

Results

The digital twin prototype provided city authorities and stakeholders with a comprehensive, real-time view of air quality in Jakarta. Key initial outcomes include:

• Precise identification of persistent pollution hotspots in densely built-up urban areas and near major transport hubs, enabling the prioritization of interventions.

• Robust scenario-modeling capabilities, demonstrating the potential impact of changes in transport policy, industrial restrictions, or the creation of new green spaces on local air quality.

• More effective decision-making: data visualization supported the allocation of resources for pollution control, the planning of traffic management measures, and the development of targeted public health recommendations.

• Engagement with a diverse range of stakeholders, which fostered greater transparency and strengthened trust in the city government's efforts to manage air quality.

The "digital twin" air quality system developed by BINUS University represents a significant advancement in the toolkit for environmental management in Jakarta. By integrating real-time sensor data, AI-driven analytics, immersive 3D visualization, and user interaction mechanisms powered by mixed reality (MR) technology, this project demonstrates how cities can develop adaptive, data-informed strategies to address complex urban challenges – such as air pollution. This approach serves as a replicable model for other megacities seeking to improve environmental conditions, bolster public health, and enhance stakeholder engagement in the governance of "smart" cities.

Conclusion

The concept of a "citiverse" – an urban ecosystem powered by artificial intelligence – should not be viewed as a single technological platform, but rather as a long-term development trajectory for cities. It serves as a framework for enhancing urban management, planning, operations, and civic engagement. The true value of this approach lies not in the mere accumulation of digital tools, but in the opportunities they create to deliver outcomes that are meaningful to residents.

A governance transformation for impactful civic outcomes achieving real public value. Not a technology project.

The AI-enabled citiverse is the convergence of artificial intelligence, digital twins, spatial computing and immersive environments into a coherent, sovereign urban intelligence platform designed to serve human potential, not replace it. It is not a future scenario. It is an emerging reality. Cities that treat it as speculative will find themselves governing systems already shaped by others.

Before a city can meaningfully build, four foundations must be in place. These are non-negotiable prerequisites.

- Vision: A formally endorsed strategy with at least one use case.
- Governance: Legal review + ethical and AI governance principles formally adopted.
- Data oundation: A funded plan for data collection, storage, and city sovereignty.
- C alition: Named champions.

AI capabilities and spatial computing are advancing exponentially. The rules of the new digital urban economy are being written today by cities that act, not by cities that wait.

Abbreviations and acronyms

AI	Artificial intelligence
API	Application programming interface
AR	Augmented reality
BIM	Building information modelling
GenAI	Generative artificial intelligence
GPS	Global positioning system
ICT	Information and communication technology
IoT	Internet of Things
MR	Mixed reality
NIS2	EU Directive on Security of Network and Information Systems 2
ROI	Return on investment
SDG	Sustainable Development Goal
SSC	Smart sustainable city
VR	Virtual reality
XR	Extended reality

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