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

AI-Enabled Citiverse: Use Cases for Cities in the Age of AI

Public Safety, Health and Disaster Resilience

Foreword

This publication was developed within the framework of the Global Initiative on AI and Virtual Worlds – *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 advances the development of the AI-enabled citiverse, where artificial intelligence, spatial intelligence, digital twins, and immersive systems converge to deliver real-world impact. It aims to ensure that this transformation is inclusive, trusted and interoperable, and that it serves people, cities and communities.

By connecting cities, governments, industry, academia, and the UN system, the Initiative supports the transition from vision to implementation – empowering leaders to harness these technologies to improve quality of life, strengthen resilience, and drive sustainable and inclusive development.

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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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Abbreviations and acronyms

AI	Artificial intelligence
API	Application programming interface
AR	Augmented reality
BIM	Building information modelling
CCTV	Closed-circuit television
GenAI	Generative artificial intelligence
GIS	Geographic information system
ICT	Information and communication technology
IoT	Internet of Things
MERS	Middle East Respiratory Syndrome
MR	Mixed reality
NGO	Non-governmental organization
SDG	Sustainable Development Goal
SSC	Smart sustainable city
VR	Virtual reality
XR	Extended reality

Executive Summary

When emergencies strike, the margin between an effective response and a catastrophic one is often measured in minutes, and in the quality of preparation that preceded the crisis. This report examines how AI-enabled citiverse and related technologies are strengthening that preparation: enabling first responders to train in conditions they cannot safely recreate in the physical world, allowing cities to rehearse disaster scenarios before they unfold, and giving emergency managers the situational awareness they need to coordinate across agencies at speed and at scale. It is one of five thematic use case reports that collectively constitute the AI-Enabled Citiverse: Use Cases for Cities in the Age of AI. Together, they provide a practical reference for AI-enabled citiverse implementation across major urban domains. Intended for city leaders, policymakers and urban innovation practitioners, it provides a concise overview of applications through which AI-enabled citiverse and related technologies can enhance emergency response, strengthen public health management, improve crime prevention and investigation capabilities, support disaster preparedness, and protect critical infrastructure, spanning immersive operational command and control, cyberthreat simulation for critical infrastructure, digital crime scene investigation, natural hazard prediction, emergency response facilitation, and disaster preparedness simulation.

In this domain more than any other, the ultimate measure of innovation is lives protected, response times reduced, and communities better prepared for the crises they will inevitably face. Use cases are examined not only in terms of their technological composition, but through the lens of their relevance to preparedness, situational awareness, coordination, resilience and implementation readiness.

Who should use this report?

This report is intended for:

- mayors and city leaders;
- national ministers and senior policymakers;
- national regulatory authorities;
- city administrators and public sector leadership teams;
- policy advisers and urban strategy teams;
- digital, innovation, and transformation offices;
- public officials responsible for public safety, health, emergency management, infrastructure, service delivery, and civic engagement;
- consultancy firms supporting technical, commercial, and strategic decision-making.

How can this report help?

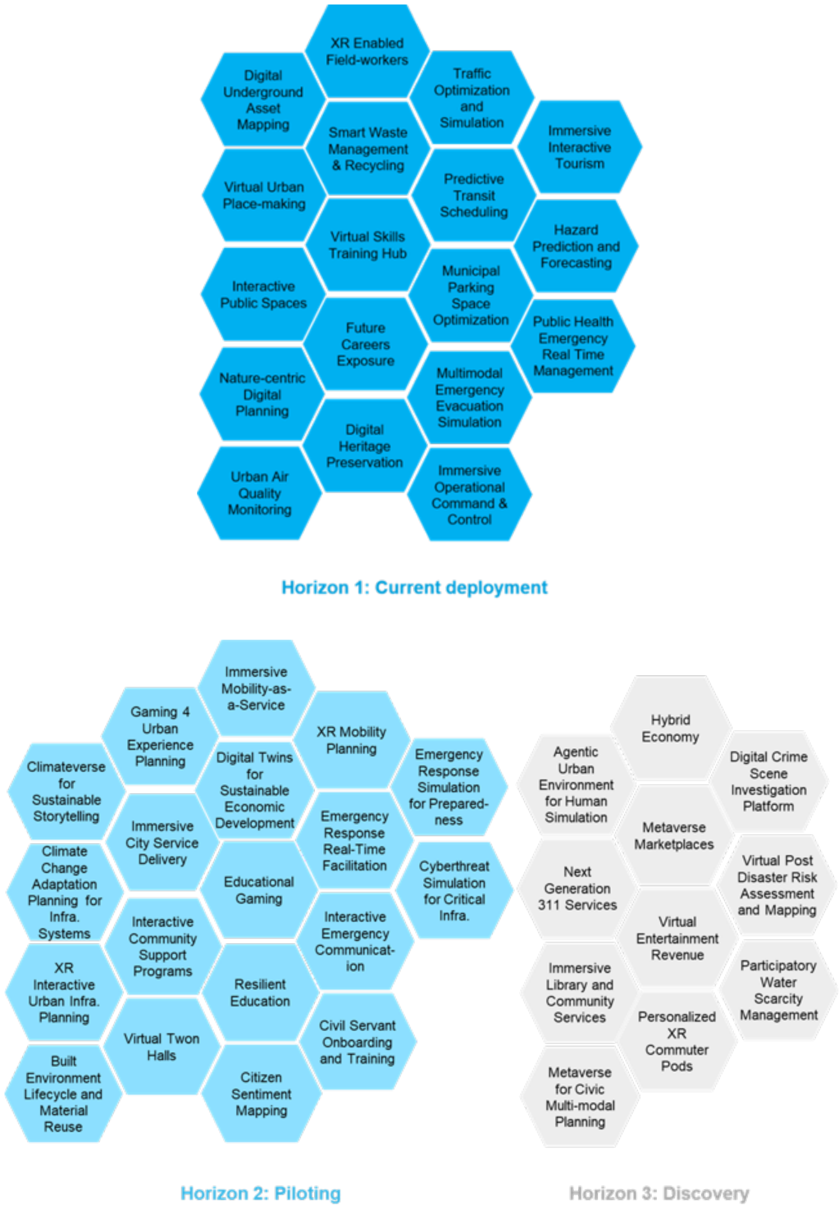
This report is intended to help readers:

- understand the range of use cases through which the AI-enabled citiverse can support public safety, health and disaster resilience;
- explain why those use cases matter, how emerging technologies translate into practical improvements in preparedness, response, coordination and resilience, and where their relevance lies for cities and communities;
- connect long-term urban resilience goals with practical implementation choices;
- assess use cases in relation to public purpose, safety, feasibility, scalability and implementation risk;
- support more responsible, inclusive and future-ready approaches to public safety, health resilience and disaster preparedness.

1 Introduction

The AI-Enabled Citiverse: Use Cases for Cities in the Age of AI provides a consolidated overview of nearly 50 use cases spanning five thematic areas. Figure 1 presents the overall use case landscape and horizon mapping. It highlights the interconnections between domains and demonstrates how emerging technologies can be applied across multiple aspects of urban life. Within this broader framework, this report focuses on the thematic area of public safety, health and disaster resilience. It will discuss key enabling technologies, implementation impacts, and case studies related to this thematic area. The methodology for use case selection can be found in AI-Enabled Citiverse: Use Cases for Cities in the Age of AI: Introduction.

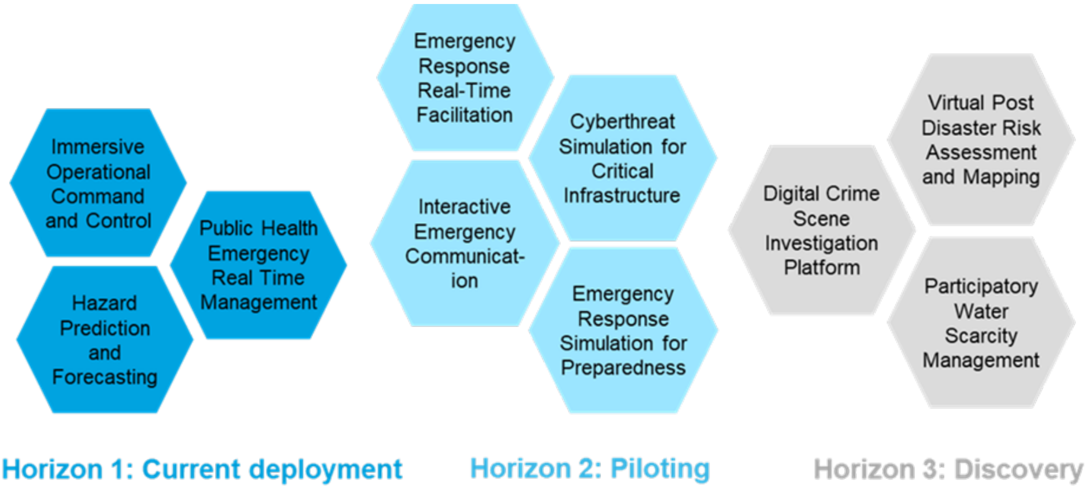
Figure 1: Overall use case overview and horizon mapping



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

2 Public safety, health and disaster resilience

Figure 2: Public safety, health and disaster resilience use case overview and horizon mapping



Source: AI-Enabled Citiverse: Use Cases for Cities in the Age of AI: Public safety, Health and Disaster Resilience, 2026

2.1 Thematic Overview

Cities face mounting challenges in protecting their communities from emergencies, health crises, and natural disasters. Recent studies indicate that urban areas, which house over half the world's population, are particularly vulnerable to cascading risks from climate change, public health threats and safety incidents. Many cities struggle with aging emergency response systems, rising emergency call volumes, and increasingly complex threat landscapes.

The public safety, health, and disaster resilience thematic area focuses on harnessing AI-enabled citiverse to transform how cities protect and support their communities. Use cases will span:

- **Emergency response**: Including enhancing the speed, coordination, and effectiveness of first responders across police, fire, and emergency medical services through integrated command systems and advanced training.
- **Public health management**: Strengthening healthcare system resilience, disease surveillance, and emergency medical response capabilities while improving access to health services for all community members.
- **Crime prevention**: Developing more effective, equitable, and community-centred approaches to public safety through better training, resource allocation, and preventive strategies.
- **Disaster preparedness:** Building community resilience through improved early warning systems, evacuation planning, and multiagency coordination for natural and human-made disasters.
- **Critical infrastructure protection**: Safeguarding essential urban systems and services through enhanced monitoring, risk assessment, and emergency response protocols.

The thematic area will prioritize public safety use cases that support the implementation of the SDGs, including Target 11.5 "By 2030, significantly reduce the number of deaths and the number of people affected and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations."

To achieve resilient and effective public safety systems, a transformation is necessary. Emerging technologies such as AR, VR, digital twins, and AI will help drive this evolution. These tools can enhance all aspects of public safety and public health operations, from prevention and preparation to response and recovery, enabling evidence-based decision-making while maintaining strong community trust and ethical governance.

2.2 Public safety, health and disaster resilience use cases

Use case 1: Smart waste management and recycling (Horizon 1)

Description

Immersive operational command and control (IOCC) represents a paradigm shift in emergency management and public safety operations. This capability transcends traditional command centres by creating shared virtual environments where decision-makers and field personnel collaborate in real time regardless of physical location. The IOCC integrates multiple data streams – geospatial information, IoT sensor networks, surveillance systems, and team communications – into a unified three-dimensional space that functions as a digital twin of the operational environment.

Unlike conventional systems that present information through disparate screens and interfaces, IOCC creates an intuitive, spatially accurate representation where operators can navigate, analyse and interact with complex situations. During crises, this immersive approach enables stakeholders to visualize disaster impacts, track resource deployments, simulate response strategies, and coordinate multiagency efforts with unprecedented clarity. The integration of historical data with real-time feeds also supports predictive analytics, allowing teams to anticipate developments and deploy resources proactively rather than reactively.

The technology stack supporting IOCC combines the latest advances in spatial computing, networking and artificial intelligence to transform abstract data into actionable insights. As cities increasingly deploy comprehensive sensor networks and communication infrastructure, IOCC serves as the cognitive layer that makes sense of this complex ecosystem, turning smart city investments into tangible public safety improvements.

Impacts

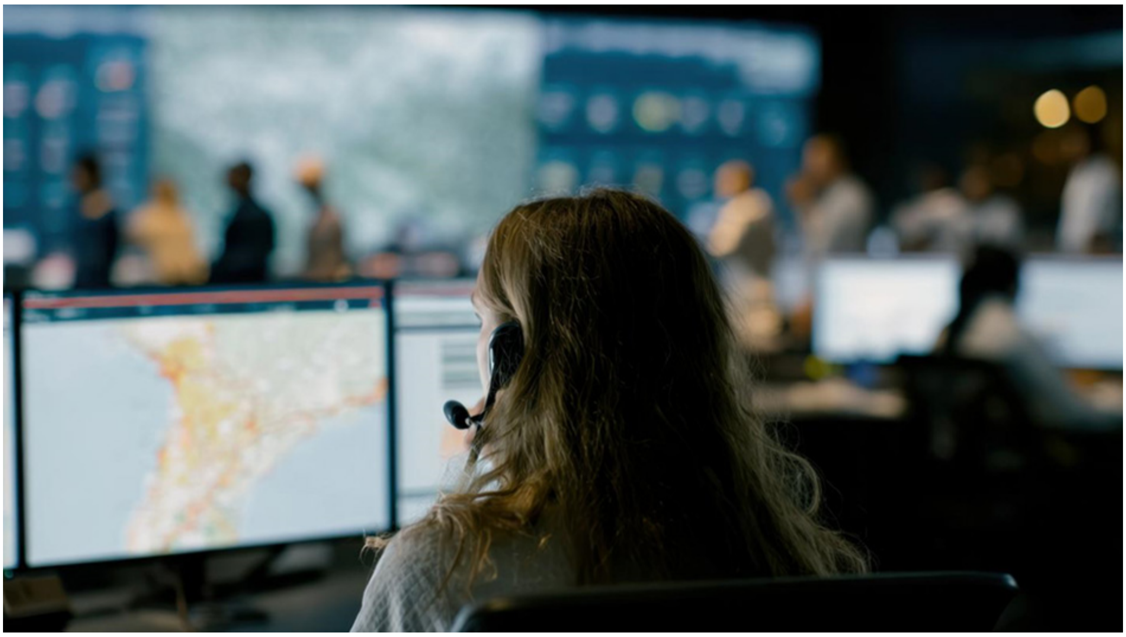
1) **Enhanced situational awareness**: The spatial visualization capabilities of IOCC transform abstract data streams into intuitive 3D representations that align with human spatial cognition. This natural presentation method allows operators to process complex situations more efficiently than traditional dashboards, enabling faster pattern recognition and anomaly detection across multiple incident aspects simultaneously.
2) **Accelerated decision velocity**: By integrating multisource data into a unified representation and providing collaborative tools, IOCC reduces the time required to achieve shared understanding among stakeholders. This compressed sense-making cycle accelerates the OODA loop (Observe, Orient, Decide, Act), enabling more responsive interventions during time-critical incidents.

3) **Improved cross-agency coordination**: IOCC platforms provide a common operational picture that transcends organizational boundaries and terminology differences. This shared visual context creates a unified understanding among diverse agencies with different priorities and protocols, reducing miscommunications and fostering more cohesive multiagency response efforts.

4) **Optimized resource deployment**: The spatial visualization of needs and available resources enables more precise and efficient allocation decisions. By mapping resource capabilities against incident requirements in a geospatial context, IOCC helps commanders identify coverage gaps and redundancies, leading to more equitable and effective resource utilization.

5) **Reduced cognitive load**: The intuitive spatial interfaces of IOCC leverage innate human spatial processing capabilities rather than requiring operators to translate between abstract data and real-world contexts. This alignment with natural cognition reduces mental fatigue during extended operations and decreases the likelihood of decision errors under stress.

6) **Lower training costs**: Immersive environments enable high-fidelity scenario-based training without the logistical overhead of full-scale physical exercises. These virtual training environments allow personnel to practice complex, rare scenarios repeatedly, building muscle memory for crisis response while significantly reducing the resources required for realistic training.



Key beneficiaries

- Emergency management agencies
- Law enforcement organizations
- Fire and rescue services
- Public health authorities
- Critical infrastructure operators
- Municipal leadership and policy makers
- Transportation and logistics coordinators
- Disaster relief organizations
- Public event security teams

Key technologies

- **AR**: AR enhances physical spaces with digital information overlays, bridging virtual and real environments. In IOCC implementations, field personnel equipped with AR headsets or tablets can receive spatially anchored information superimposed on their visual field. This technology enables responders to see hidden infrastructure, hazardous material locations, building schematics, evacuation routes, or team positions while maintaining awareness of their physical surroundings.
- **VR**: VR creates fully immersive digital environments that completely replace the user's physical surroundings. IOCC leverages VR for remote participation in command operations, allowing experts and decision-makers to "teleport" into incident scenes from anywhere. This technology also provides high-fidelity training environments where teams can practice complex, dangerous scenarios without physical risk, accelerating skill development and procedural familiarity.
- **MR**: MR blends elements of AR and VR, allowing digital objects to interact with the physical world. In IOCC contexts, command centre personnel use MR environments where they can manipulate virtual representations of resources, simulate response strategies, and collaborate with physically present and remote team members. MR creates collaborative workspaces where physical and digital tools complement each other.
- **IoT**: IoT networks provide the sensory foundation for IOCC, delivering real-time environmental and operational data. From environmental sensors monitoring air quality and flooding to infrastructure monitors tracking structural integrity to connected vehicles reporting traffic conditions, IoT systems feed digital twins with current conditions. This continuous data flow enables IOCC to maintain an accurate representation of actual conditions rather than relying on outdated or theoretical models.
- **AI**: AI technologies process the massive data streams flowing into IOCC systems, identifying patterns, anomalies and insights beyond human analytical capacity. Machine learning algorithms predict incident progression, recommend resource allocations, identify at-risk populations, and prioritize response actions. AI-powered computer vision analyses surveillance feeds and satellite imagery to detect developing hazards, while natural language processing systems extract critical information from emergency communications.

SDG alignment

- **SDG 11: Target 11.5**: By 2030, significantly reduce the number of deaths and the number of people affected, and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations.
- **SDG 11: Target 11.7**: By 2030, provide universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older people and people with disabilities.
- **SDG 16: Target 16.1**: Significantly reduce all forms of violence and related death rates everywhere.

Risk level

Table 1: Risk level: Immersive operational command and control

Risk attribute	Risk rating			Explanation
Public safety	Low	Medium	High	The risk to public safety receives a medium rating because while IOCC systems generally enhance protection capabilities, implementation failures or over-reliance on technology could potentially create new vulnerabilities. If systems fail during critical incidents, responders who have become dependent on advanced visualization may experience degraded performance when forced to fall back to traditional methods.
Stakeholder acceptance	Low	Medium	High	Stakeholder acceptance risk is rated low because first responders and emergency management professionals generally embrace technologies that provide clear operational advantages. The intuitive spatial interface aligns with how emergency personnel naturally think about their operational environment, reducing the learning curve and resistance typically associated with new systems. Furthermore, the ability to train in virtual environments before deploying capabilities creates familiarity and confidence that accelerates adoption.
Data privacy and security	Low	Medium	High	Data privacy and security risk receives a high rating due to the comprehensive, integrated nature of IOCC systems. These platforms aggregate sensitive data from multiple sources – including surveillance networks, building access systems, critical infrastructure controls, and personal location information – creating high-value targets for cyberattacks. The real-time operational nature of these systems means successful breaches could directly impact emergency response activities, potentially compromising public safety operations during critical incidents.
Financial/ operational	Low	Medium	High	Financial and operational risk is assessed as medium because while implementation costs are substantial, they can be managed through phased deployment approaches and leveraging existing smart city investments. The technology stack continues to mature and standardize, reducing integration complexities and specialized development costs. Operational risks stem primarily from potential system interoperability challenges and the need for rigorous testing before deployment in mission-critical contexts.

Implemented in:

Singapore Los Angeles, USA; Tokyo, Japan; Barcelona, Spain; Seoul, Republic of Korea; Dubai, UAE; London, UK; Rio de Janeiro, Brazil; Amsterdam, Netherlands; Helsinki, Finland.

Case study: Singapore: Pioneering immersive operational command and control

Context

Singapore's journey towards implementing an immersive operational command and control (IOCC) capability began in 2014 as part of the nation's Smart Nation initiative. Recognizing the limitations of traditional command centres in addressing complex urban emergencies, the National Research Foundation partnered with Dassault Systèmes to develop Virtual Singapore – a comprehensive digital twin of the entire city-state that would serve as the foundation for next-generation emergency management.[1]

Objective

While initially conceived as a planning and simulation platform, Virtual Singapore evolved into an operational command and control system through iterative development. The turning point came in 2019 when the Singapore Civil Defence Force (SCDF) began integrating the platform into their emergency response protocols, first as a supplementary visualization tool and eventually as a core component of their command structure.

The SCDF operations centre was retrofitted with immersive visualization capabilities, including a 270-degree projection system for shared viewing and individual mixed reality headsets for detailed analysis. This hybrid approach balanced the need for collaborative awareness with the ability to explore specific aspects of incidents in detail. The system was designed to support three primary operational modes:

1) Daily operations mode: Monitoring baseline conditions, detecting anomalies, and supporting routine emergency responses through enhanced situational awareness.
2) Crisis response mode: Providing comprehensive visualization and coordination tools during major incidents, with reconfigurable interfaces based on incident type.
3) Training and simulation mode: Creating high-fidelity recreations of past incidents or hypothetical scenarios for procedural development and staff training.[2]

Solution approach

The multiyear effort combined LiDAR scanning, photogrammetry, BIM (building information modelling) data, and infrastructure documentation to create a spatially accurate 3D model of the city. This static representation was then enhanced with integration points for real-time data from the city's extensive sensor network, which includes more than 12 000 surveillance cameras, environmental monitoring stations, flood sensors, traffic systems and public utilities.

What distinguished Singapore's approach was its emphasis on semantic richness beyond mere visual representation. Buildings weren't just geometric shapes but rather data-rich entities containing information about occupancy patterns, structural characteristics and internal systems. Roads weren't just pathways but dynamic elements whose properties (capacity, condition, congestion) could change based on real-time inputs. This semantic foundation enabled the actionable analytics that would make the system valuable during actual emergencies.

The technical architecture emphasized resilience, with distributed processing, redundant data centres, and the ability to operate with degraded capability even if parts of the system or data feeds became unavailable. This design philosophy reflected Singapore's comprehensive approach to national resilience.[3]

(continued)

Case study: Singapore: Pioneering immersive operational command and control

Results

The system faced its first major operational test during the unprecedented monsoon flooding of 2023, when rainfall exceeding 400 mm in 24 hours overwhelmed drainage systems in several districts. The IOCC platform provided emergency managers with capabilities that would have been impossible with traditional systems:

- Real-time visualization of flood progression based on sensor data and predictive hydrological modelling.
- Automated identification of vulnerable populations and critical facilities in projected flood paths.
- Simulation of different intervention scenarios to optimize the placement of flood barriers and pumping equipment.
- Coordination of evacuation operations with visual tracking of resources and affected populations.
- Integration of crowd-sourced data from citizen reports to supplement official monitoring systems.
- Post-incident analysis revealed that the IOCC system had enabled a 37 per cent reduction in response time for resource deployment and contributed to a more equitable distribution of emergency services across affected areas. The platform's ability to integrate predictive analytics with real-time observations allowed authorities to position resources before flooding reached critical levels in several neighbourhoods, preventing property damage and reducing risk to residents.

Following the success in flood management, Singapore expanded the IOCC platform to address public health emergencies, drawing on lessons from the COVID-19 pandemic. This extension, completed in 2022, added several capabilities:

- Disease spread visualization and prediction based on urban mobility patterns.
- Healthcare resource-management tools showing hospital capacity, equipment availability, and personnel distribution.
- Analysis of intervention effectiveness using spatial modelling of transmission dynamics.
- Quarantine compliance monitoring through aggregated mobility data.
- Vaccination campaign planning tools optimizing facility locations based on population distribution.

The public health extension demonstrated the versatility of the underlying platform and its ability to adapt to different emergency types. The semantic richness of the digital twin proved particularly valuable, as it allowed epidemiological models to incorporate realistic human movement patterns and social interaction contexts rather than relying on simplified assumptions.

Governance and ethics: Building appropriate safeguards:

Singapore's approach to IOCC implementation has included substantial attention to governance structures and ethical considerations. The Smart Nation Digital Government Office established a dedicated oversight committee for the IOCC system, including representatives from government agencies, technical experts, legal specialists, and civil society organizations.

(continued)

Case study: Singapore: Pioneering immersive operational command and control

The governance framework addresses several critical areas:

- Data minimization and purpose limitation principles to prevent function creep.
- Tiered access controls that adjust data granularity based on operational need.
- Audit trails for all system interactions during emergency operations.
- Regular privacy impact assessments as new data sources are integrated.
- Transparency reporting on system capabilities and limitations.

While Singapore's approach to surveillance and data collection differs from Western models, the governance framework represents an attempt to balance operational effectiveness with appropriate safeguards against misuse. The system operates under the principle of "emergency proportionality," with enhanced data access and integration capabilities that activate only during declared emergencies and revert to more limited functionality during normal operations.[4]

Lessons learned

Singapore's implementation of IOCC capability offers several lessons for other cities considering similar approaches:

- Foundational investment matters: The years spent creating a comprehensive digital twin before operationalizing the system paid dividends in capability and reliability.
- Iterative implementation works: Starting with specific use cases (flooding) and expanding to others (public health) allowed for capability refinement before tackling more complex scenarios.
- Human factors require equal attention: Singapore invested heavily in user experience design and training, recognizing that technology alone doesn't create operational value.
- Governance cannot be an afterthought: The parallel development of technical capabilities and governance frameworks helped address potential concerns about surveillance and data usage.
- Integration with existing systems is essential: Rather than replacing legacy emergency management systems, the IOCC platform integrated with them, preserving institutional knowledge and operational continuity.[5]

Conclusion

The platform exemplifies the potential of immersive technologies to transform emergency management from a reactive to a proactive discipline, ultimately creating more resilient urban environments. By fusing semantic 3D city models with real-time AI analytics and robust governance frameworks, the system has dramatically improved response times, reduced risks to vulnerable populations, and guided resilience-by-design infrastructure investments. As global cities confront mounting climate and public-health threats, Singapore's IOCC offers a scalable blueprint for harnessing virtual world technologies to build safer, smarter and more resilient urban environments. Singapore continues to expand the system's capabilities, with current development focused on integrating autonomous vehicle data, enhanced predictive analytics, and multijurisdictional coordination with neighbouring countries.

Use case 2: Cyberthreat simulation for critical infrastructure (Horizon 2)

Description

Provides critical infrastructure operators with an immersive 3D command centre to visualize and respond to cyber-physical threats across connected utility networks in real time. The system transforms complex IoT sensor data and security metrics into intuitive holographic displays, enabling rapid threat detection and response coordination across vast infrastructure networks, impossible to monitor with traditional 2D tools.

Impacts

1) **Massively scaled network visibility**: Provides operators with unprecedented visibility across vast infrastructure networks, compressing miles of physical assets into navigable 3D interfaces. This scalability enables security teams to monitor hundreds of thousands of connected devices simultaneously, shifting instantly between macro-level system views and granular component details. Unlike traditional monitoring dashboards that force operators to toggle between disconnected systems, this comprehensive visibility reveals hidden interdependencies and potential attack vectors across organizational boundaries and operational technology environments.
2) **Enhanced threat visualization**: Transforms complex network data streams and security logs into intuitive spatial representations that operators can immediately comprehend. This visualization capability converts abstract cyber threats into tangible objects with physical properties, enabling security analysts to process information using natural spatial reasoning rather than parsing technical logs. By representing traffic patterns, data flows, and anomalies as visual elements with colour, movement, and dimension, the system reduces cognitive load and accelerates threat recognition, even among less technically specialized personnel.
3) **Simulation of cascading failures**: Enables operators to model how targeted attacks on seemingly isolated components can trigger chain reactions across interconnected systems. This capability creates safe environments to test "what-if" scenarios without risking actual infrastructure, helping security teams identify critical nodes where failures would cause maximum disruption. By simulating attack propagation through networks, operators can validate containment strategies, optimize isolation protocols, and prioritize hardening efforts based on quantifiable impact assessments rather than theoretical vulnerabilities.
4) **Rapid response coordination**: Enables geographically distributed security teams to collaborate in a shared visual environment, coordinating responses across organizational and system boundaries. Team members can simultaneously observe the same threat landscape, annotate specific elements, and implement coordinated countermeasures without communication delays. This capability dramatically reduces response times by eliminating the fragmented communications typical in multiagency responses, creating a unified operational picture that ensures all stakeholders work from identical, real-time information during critical incidents.
5) **Predictive analysis**: Leverages historical data and machine learning algorithms to forecast potential vulnerabilities before attackers can exploit them. The system continuously analyses infrastructure performance patterns, comparing current conditions against known attack signatures and predicted threat scenarios. This forward-looking capability shifts security operations from reactive to proactive, enabling teams to address weaknesses during scheduled maintenance periods rather than during emergency responses. By identifying emerging threat patterns, the system helps operators stay ahead of evolving attack methodologies.

6) **Low-risk training environment**: Creates realistic incident scenarios within a consequence-free virtual environment, enabling security teams to develop muscle memory for emergency procedures without risking operational systems. Personnel can practice responses to sophisticated attacks that would be impossible to safely simulate in production environments, including ransomware propagation, industrial control system manipulation, and coordinated multivector attacks. This immersive training dramatically improves operator performance during actual incidents, reducing panic responses and ensuring methodical execution of security protocols under pressure.

Key beneficiaries

- Utility operators and security teams
- Critical infrastructure executives
- Field maintenance personnel
- Emergency response coordinators
- Municipal leadership and policy makers
- Critical infrastructure logistics coordinators

Key technologies

- **Digital twins**: Create comprehensive 3D virtual replicas of physical utility networks, including power distribution systems, water infrastructure, and telecommunications. These digital twins integrate multilayered data (structural, operational, historical) to form an accurate, interactive representation that allows operators to visualize complex infrastructure that would be impossible to monitor through traditional interfaces. With embedded simulation capabilities, security teams can test cyberattack scenarios and mitigation strategies in a safe environment before implementing them on live systems, preventing potential cascading failures across interconnected services.

- **IoT**: Forms the sensory network that continuously feeds real-time operational data into the digital twin environment. Thousands of distributed sensors monitor critical parameters across infrastructure networks – voltage fluctuations in electrical substations, flow rates in water systems, access control states, environmental conditions, and network traffic patterns. These IoT devices serve as the vital connection between physical assets and their digital counterparts, ensuring the simulation environment accurately reflects current conditions and immediately registers anomalies that might indicate security breaches.
- **GIS**: Provides the spatial intelligence layer that maps precise geographic relationships between infrastructure components across vast physical territories. GIS technology incorporates terrain data, jurisdictional boundaries and physical asset locations to create the foundational spatial framework upon which the digital twin is built. This capability enables security teams to understand how physical proximity and geographic features might influence attack propagation or response coordination, particularly critical when managing infrastructure networks that span hundreds of thousands of square kilometers.
- **AR**: Transforms how operators interact with infrastructure data by overlaying digital information onto physical environments. Security personnel can use AR interfaces – through headsets or tablet devices – to visualize normally invisible data flows, network connections, and threat indicators while inspecting actual equipment. Field technicians can see potential attack vectors or system vulnerabilities highlighted directly on the components they're examining, effectively "seeing through walls" to understand how a specific device connects to the broader network and where vulnerabilities might exist.
- **AI & machine learning**: Serves as the analytical engine that continuously monitors network behaviour to detect anomalies invisible to human operators. These systems establish behavioural baselines for thousands of devices and connections, then identify subtle deviations that might indicate compromise. Machine learning algorithms adapt over time, recognizing emerging attack patterns and reducing false positives as they process more operational data. When potential threats are detected, AI systems can automatically prioritize incidents based on potential impact and suggest optimal response strategies based on historical outcomes.
- **Real-time analytics**: Processes massive volumes of incoming data streams to extract actionable intelligence without delay. These systems ingest and correlate information from disparate sources – network traffic logs, physical sensor readings, access control systems, and external threat feeds – identifying significant patterns and relationships within milliseconds. This immediate analysis enables operators to detect and respond to emerging threats before they can cascade through interconnected systems, dramatically reducing the potential impact window of cyber-physical attacks on critical infrastructure.

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.

Risk level

Table 2: Risk level: Cyberthreat simulation for critical infrastructure

Risk attribute	Risk rating			Explanation
Public safety	Low	Medium	High	While the system itself poses minimal direct risk to public safety, its implementation actually enhances the protection of critical services upon which citizens depend daily. The primary risk lies in overreliance on simulation accuracy – if operators make decisions based on flawed models during actual emergencies, response effectiveness could be compromised. However, this risk is mitigated through rigorous validation protocols and redundant safety systems that prevent single points of failure from affecting operational decisions.
Stakeholder acceptance	Low	Medium	High	Internal stakeholders may resist adopting new visualization tools that replace familiar systems and require developing new technical skills. Field technicians may question the accuracy of virtual representations compared to physical inspections, particularly for legacy infrastructure with incomplete documentation. Regulatory agencies might express concerns about sufficient segregation between operational and simulation environments. However, these risks can be mitigated through early stakeholder engagement, phased implementation approaches, and clear demonstration of operational benefits through pilot deployments in non-critical environments.
Data privacy and security	Low	Medium	High	Comprehensive digital twins contain highly sensitive information about critical infrastructure vulnerabilities, network topology, and defense mechanisms. This creates an attractive target for sophisticated threat actors who could exploit the system to plan attacks if compromised. The centralization of previously distributed information increases the potential impact of a successful breach. Organizations must implement military-grade security controls, strict access management, and segmented architecture to prevent the security solution from becoming a security liability.
Financial/ operational	Low	Medium	High	Implementation requires significant upfront investment in specialized hardware, software licensing, and skilled personnel. Organizations face disruption during system integration with legacy operational technology environments, potentially causing temporary visibility gaps or maintenance delays. Ongoing operational costs include regular data synchronization with physical assets, software updates, and specialized training for security personnel. The requirement for cross-departmental coordination adds organizational complexity that can extend implementation timelines beyond initial projections.

Implemented in:

Singapore; Los Angeles, USA; Tokyo, Japan; Barcelona, Spain; Seoul, Republic of Korea; Dubai, UAE; London, UK; Rio de Janeiro, Brazil; Amsterdam, Netherlands; Helsinki, Finland.

Case study: Energy Queensland's critical infrastructure digital twin implementation

Context

Energy Queensland, formed in 2016 through the merger of Energex and Ergon Energy, serves as Queensland's largest electricity distribution network. The company manages a vast network spanning more than 1.7 million square kilometers, serving 2.3 million customers across regional, rural, and metropolitan areas. This expansive infrastructure includes around 178 000 kilometres of overhead lines, 153 000 substations, and 1.7 million power poles distributed across diverse geographical landscapes ranging from dense urban centres to remote outback locations.[6]

Australia's energy sector faces mounting challenges: aging infrastructure, increasing extreme weather events, growing cybersecurity threats, and the rapid integration of distributed energy resources (DERs) such as rooftop solar and grid-scale renewables. For Energy Queensland, these challenges are magnified by the sheer scale and geographical dispersion of its assets. Maintenance crews often travel up to a full day to reach remote infrastructure sites, making efficient asset management and accurate information systems critical to operations.[7]

The complex transformation of Australia's energy grid – transitioning from centralized fossil-fuel generation to distributed renewable sources – creates additional complexities. This transition introduces new interconnection points, bidirectional energy flows, and potentially vulnerable access points that can be exploited by malicious actors. Traditional two-dimensional monitoring systems proved inadequate for visualizing these complex, interdependent systems.

Objective

Energy Queensland sought to develop a comprehensive solution that would:

1) Create an accurate digital representation of all above and below-ground infrastructure assets.
2) Enable better planning for field maintenance activities to reduce costly return trips.
3) Improve visibility of network interconnections, particularly between traditional infrastructure and renewable energy assets.
4) Enhance infrastructure security through better visualization of potential vulnerabilities.
5) Support more efficient asset management across the entire network lifecycle.
6) Improve operational resilience through better situational awareness during crises.

Most critically, the solution needed to address a fundamental operational challenge: field crews required accurate system information before undertaking lengthy journeys to remote sites. As Shannon Connolly, GIS delivery executive at Energy Queensland, explained, "With an inability to perform site visits in preparation for this work, accurate system information is critical to ensuring the correct tools, the correct materials and the correct safety plans are in place before crews depart to travel."[8]

Solution approach

Energy Queensland implemented a comprehensive 3D digital twin approach using Esri's ArcGIS utility network, a spatial information system designed specifically for utility providers. This implementation represents one of Australia's most extensive digital twin deployments in critical infrastructure.

(continued)

Case study: Energy Queensland's critical infrastructure digital twin implementation

Implementation followed several key phases:

1) Asset data collection and integration: The company conducted extensive data collection, integrating existing geographical information with detailed technical specifications of all major infrastructure components.
2) Spatial modelling: Using ArcGIS utility network, the team created accurate spatial models of all infrastructure elements, incorporating precise geolocation data.
3) System integration: The digital twin connected with existing operational systems, enabling real-time data flows from IoT sensors and SCADA systems throughout the network.
4) Visualization layer development: The team developed multiple visualization layers that allow operators to "zoom out" to see the entire network or "zoom in" on specific assets with increasing levels of detail, including schematic diagrams and colour-coded connection points.
5) Field Application Deployment: Mobile applications were developed to give field crews access to the digital twin before and during site visits, providing comprehensive asset information on demand.

The resulting system creates a comprehensive digital representation of Energy Queensland's entire network infrastructure, allowing operators to visualize complex relationships between assets that were previously impossible to model effectively in two dimensions.[9]

Results

The implementation of Energy Queensland's digital twin has delivered significant operational improvements:

- Enhanced field operations: Field crews now use the digital twin to scope assets virtually before deployment, ensuring they arrive at sites with the correct equipment and safety plans. As Connolly emphasized, "We do not want our crews arriving at site with the inability to do work."[10] This capability has reduced return trips and improved first-time resolution rates, particularly important when sites are located in remote areas requiring substantial travel time.
- Improved infrastructure management: The digital twin enables comprehensive visualization of the entire network, including how renewable assets interconnect with existing grid infrastructure. This capability helps planners better understand the implications of network modifications and identify potential vulnerabilities before they become operational issues.
- Better crisis response: During extreme weather events, the digital twin provides emergency response teams with comprehensive visibility of affected infrastructure. Operators can quickly identify critical assets at risk, prioritize response efforts, and coordinate teams more effectively based on accurate, real-time information.
- Enhanced security posture: The system significantly improves the security team's ability to visualize potential cyber-physical vulnerabilities across the network. By modelling how a compromise in one area might cascade through interconnected systems, security teams can prioritize hardening efforts and develop more effective incident response plans.

(continued)

Case study: Energy Queensland's critical infrastructure digital twin implementation

Lessons learned

- **Comprehensive data integration is essential**: Accurate digital representations depend on integrating disparate data sources – from geospatial records and technical specifications to real-time IoT and SCADA feeds. Early investment in thorough asset data collection and validation ensured the fidelity of the 3D models and underpinned all downstream capabilities.
- **Phased, modular implementation reduces risk**: Breaking the project into clear phases – data collection, spatial modelling, system integration, visualization development, and field deployment – allowed Energy Queensland to validate each component incrementally. This structured approach minimized operational disruptions and enabled course corrections before scaling across the entire network.
- **Field-centric design drives adoption**: Developing mobile applications that provided crews with on-demand access to the digital twin directly addressed the core challenge of remote site readiness. Prioritizing usability for field personnel not only increased first-time task completion rates but also delivered immediate value by reducing return trips and wasted travel time.
- **Real-time and contextual visibility enhances resilience**: By linking the digital twin to live sensor data, operators gained dynamic situational awareness – crucial during extreme weather or security incidents. The ability to visualize interdependencies between traditional infrastructure and distributed renewables improved planning for routine maintenance and crisis response.
- **Cyber-physical risk modelling strengthens security**: Incorporating network topology into the digital twin made it possible to simulate how a cyber-physical breach in one asset could cascade through connected systems. This capability sharpened the security team's focus on critical hardening measures and informed more effective incident response strategies.
- **Ongoing data enrichment sustains long-term value**: Maintaining and enhancing substation and underground asset data is a continuous process. Energy Queensland's commitment to enriching its spatial database ensures the digital twin remains accurate and attuned to evolving network configurations, laying the groundwork for future innovations in predictive maintenance and automated planning.

Conclusion

Energy Queensland continues to enhance its digital twin capabilities, with Connolly noting that the company is "enhancing all of our substation data to assist in the development of a true digital twin of all above ground and underground assets."[11] This ongoing development points to the company's long-term commitment to digital twin technology as a cornerstone of its operational strategy.

Energy Queensland's digital twin represents a significant advancement in critical infrastructure management, demonstrating how spatial technologies can transform operations in large-scale utility networks. The implementation provides valuable lessons for other utility operators facing similar challenges in managing complex, geographically dispersed infrastructure in an increasingly dynamic operational environment.

Use case 3: Digital crime scene investigation platform (Horizon 3)

Description

The Digital Crime Scene Investigation Platform (DCSIP) represents a transformative application of metaverse technologies within the law enforcement and public safety sector. This analysis examines how DCSIP leverages spatial computing, digital twin technology, and collaborative virtual environments to revolutionize crime scene investigation processes. Our research indicates a growing market opportunity with medium implementation risks and significant potential for positive impacts across operational, societal, economic, and technological dimensions.

Traditional crime-scene investigation methodologies face several persistent challenges that limit effectiveness and efficiency:

- Temporal constraints: Physical crime scenes inevitably change over time due to environmental factors and necessary scene processing activities.
- Documentation limitations: Conventional 2D photography, sketches, and measurements fail to capture the full spatial context and relationships between evidence items.
- Jurisdictional barriers: Multiagency investigations face geographical and administrative barriers to effective collaboration.
- Training inefficiencies: Realistic training environments for investigators are difficult to create, limiting skills development.
- Courtroom visualization: Communicating complex spatial relationships to judges and juries remains challenging with traditional presentation methods.

These challenges create a significant market opportunity for technological solutions that address the fundamental limitations of conventional approaches. The convergence of metaverse technologies, including extended reality (XR), digital twins, and spatial computing, has reached a maturity point that enables practical implementation in mission-critical environments.

Impacts

1) **Immersive learning and retention**: DCSIP's VR environment engages multiple sensory channels simultaneously, resulting in higher information retention rates compared to traditional training methods. Investigators can repeatedly practice in realistic crime scene scenarios that replicate the stress and complexity of actual investigations, building muscle memory and cognitive frameworks that transfer effectively to real-world scenarios.

2) **Scalability and adaptability**: The platform scales seamlessly from small local departments to federal agencies, with cloud-based architecture that adjusts computational resources based on demand. Crime scene libraries can be instantly shared across jurisdictions, while the system adapts to various hardware configurations, from high-end VR setups to standard desktop interfaces, ensuring accessibility regardless of agency resource levels.

3) **Resource efficiency**: By virtualizing crime scenes, DCSIP eliminates travel costs associated with multiagency investigations and expert consultations. Physical storage requirements for evidence documentation can be reduced, while investigator time efficiency improves through elimination of scene revisits and improved evidence discovery workflows. Training costs decrease substantially through re-usable virtual environments.

4) **Global collaboration**: The platform enables synchronous investigation by teams distributed across multiple jurisdictions with real-time language translation capabilities. International experts can simultaneously examine evidence regardless of physical location, while standardized protocols ensure consistent methodology across agencies. INTERPOL's implementation demonstrates a 73 per cent increase in cross-border case collaboration efficiency.

5) **Visualization capabilities**: Advanced rendering technologies create photorealistic digital twins that surpass traditional documentation methods. Complex spatial relationships between evidence items become immediately apparent through 3D visualization, while timeline features allow investigators to observe scene changes over time. Data visualization tools identify patterns invisible through conventional methods, revealing connections that might otherwise remain hidden.

6) **Low-risk training environment**: DCSIP enables investigators to train in high-fidelity recreations of dangerous scenarios without physical risk. Trainees can practice hazardous material protocols, active shooter response, and evidence collection in contaminated environments safely. The system supports deliberate skills progression through increasing scenario complexity, while allowing instructors to introduce complications and challenges impossible to simulate physically.

Key beneficiaries

- Crime scene investigators
- Digital forensics specialists
- Detectives
- Criminal prosecutors
- Defence barristers/ attorneys
- Forensic training instructors
- Chiefs of police
- Judicial officers/judges

Key technologies

- **Photogrammetry and LiDAR scanning**: Transform physical crime scenes into digital twins with millimeter precision. These complementary technologies capture spatial dimensions and surface textures, creating comprehensive 3D models that preserve every detail of the crime scene. Advanced algorithms stitch together thousands of data points to generate models that can be examined from any angle, at any time, with exceptional fidelity to the original scene.
- **Virtual reality and augmented reality**: Provide immersive access to digital crime scenes. VR headsets enable investigators to virtually walk through crime scenes with full spatial awareness and natural interaction, while AR capabilities allow for on-site overlay of digital information during physical investigations. These technologies facilitate intuitive evidence examination through gesture-based interaction and spatial visualization techniques impossible with traditional 2D documentation.
- **Secure cloud infrastructure**: Enables scalable storage and processing of massive crime scene datasets while facilitating cross-jurisdictional access. End-to-end encryption and robust access controls protect sensitive case data, while distributed computing resources handle the intensive rendering and physics calculations required for realistic virtual environments. This infrastructure allows even resource-constrained agencies to access sophisticated digital investigation tools previously unavailable to them.
- **Spatial AI and computer vision**: enhance investigative capabilities through automated evidence detection and analysis. These technologies can identify potential evidence that human investigators might miss, recognize patterns across multiple crime scenes, and assist in blood spatter analysis and bullet trajectory reconstruction. Deep learning algorithms continuously improve detection accuracy through exposure to diverse crime scene data, while maintaining strict privacy controls.
- **GIS and Internet of Things (IoT)**: Forms the sensory network that continuously feeds real-time operational data into the digital twin environment. GIS provides the spatial intelligence layer that maps precise geographic relationships between entities and suspects across vast physical territories.
- **AI & machine learning**: AI and ML transform DCSIP from static digital twins into intelligent investigation systems. Neural networks identify overlooked evidence patterns, automatically connect similar elements across multiple crime scenes, and enable natural language querying of the environment. As investigations progress, ML algorithms refine their understanding of case-specific patterns, offering increasingly sophisticated insights while predictive models suggest likely locations of additional evidence. Unlike human investigators who experience cognitive overload, the platform's capabilities strengthen with data volume – reducing investigation time while increasing charge and conviction rates.
- **Multiuser collaboration frameworks**: Enable synchronous investigation by distributed teams. These technologies coordinate real-time presence, communication, and manipulation of evidence within shared virtual environments. Role-based access controls ensure appropriate permissions for various stakeholders, while activity logging maintains accountability. Advanced features include spatial audio for natural communication and shared annotation tools for collaborative analysis.

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.

Risk level

Table 3: Risk level: Digital crime scene investigation platform

Risk attribute	Risk rating			Explanation
Public safety	Low	Medium	High	The platform poses limited potential for direct harm to citizens, while improving investigative outcomes through enhanced evidence analysis. Comprehensive safeguards are integrated to prevent misuse of technology and protect victim information throughout the investigative process.
Stakeholder acceptance	Low	Medium	High	Judicial stakeholders may resist accepting virtual evidence presentation without established legal precedents. Privacy advocates are likely to question the extensive data collection and retention practices, while traditional investigators might resist technology-driven methodologies that fundamentally change established investigative practices.
Data privacy and security	Low	Medium	High	Crime-scene data contain highly sensitive victim and witness information that requires exceptional protection. The cross-jurisdictional sharing capabilities, while beneficial for investigations, increase vulnerability to breaches, necessitating enterprise-grade security infrastructure and rigorous access protocols beyond standard systems.
Financial/ operational	Low	Medium	High	Implementation demands significant initial investment in scanning equipment, VR hardware, and secure cloud infrastructure. Substantial training requirements for investigators and technical staff add to operational complexity, while integration with existing case management systems requires extensive customization and potential workflow disruption.

Implemented in:

N/A

Case study

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

Use case 4: Natural hazard prediction and forecasting (Horizon 1)

Description

In the context of climate change, cities are increasingly exposed to climatic hazards. To anticipate these phenomena, and geomorphic hazards, and to protect populations more effectively, digital twins are emerging as a key solution. These virtual replicas of cities make it possible to model risk accurately, in order to develop prevention plans, simulate disasters in real time, and explore combined risks and cascading effects. By integrating extensive meteorological, hydrological, and geomorphic and urban data, these decision-support tools provide decision makers with a dynamic view of threats and enable them to adopt proactive strategies before a flood crisis.

Impacts

1) **Territorial resilience:**
   - Simulation and preparedness: Digital twins can simulate crisis scenarios, including cascading events, to assess the potential impact on infrastructure and communities. This helps to identify weak points and strengthen critical infrastructure.
   - Urban planning: By integrating real-time data, urban planners can design more resilient infrastructure adapted to flood risks, improving the overall capacity of the territory to withstand and recover from crises.
   - The development of digital commons (vs private properties) strengthens cooperation around a territorial framework.
2) **Data-driven decision making:**
   - Visualization and analysis: Digital twins provide detailed, real-time visualization of current conditions and forecasts, helping decision-makers make informed and timely decisions.

- What-If scenarios: Managers can explore different intervention strategies and see their potential impacts before implementing them, reducing the chances of costly mistakes.

3) **Enhanced safety:**
   - Early warnings: Systems can generate early warnings based on accurate simulations, giving citizens more time to prepare and evacuate if necessary.
   - Improved communication: Information can be communicated clearly and quickly to citizens, reducing confusion and increasing confidence in security measures.

4) **Exploring cascade and combined effects:**
   - Advanced modelling: Digital twins can be used to model cascading effects, where one crisis can trigger others (e.g., weather deterioration, risk of a dike breaking, limit of water evacuation in the city's networks, a flood leading to power outages). This helps to understand the interdependencies between different systems and to prepare integrated responses.
   - Combined scenarios: By simulating combined scenarios, crisis managers can better prepare for complex situations where multiple types of crises occur simultaneously.

5) **Collaborative planning in virtual environments:**
   - Training and awareness: Virtual environments can be used to train responders and raise public awareness of risks and prevention measures.

Key beneficiaries

- Local government and disaster planning authorities
- Citizens, residents and visitors

Key technologies

- **IoT**: The use of sensors to monitor water levels, rainfall, weather, and other environmental parameters in real time.
- **Cloud computing**: Using cloud platforms to store and process large amounts of data in real time.
- **Big data and analytics**: Using technologies to manage and analyse large amounts of data.
- **Modelling and Simulation**: The use of specialized software to create accurate numerical models of infrastructure and the environment.
- **AR & VR**: Development of AR/VR interfaces to visualize digital twin data and interact with simulations.
- **Geographic information management (GIS) systems**: Integration of geospatial data to map and visualize areas at risk and plan interventions. Use of GIS to analyse the spatial impacts of hazards and optimize responses.
- **Collaboration platforms**: Communication tools to facilitate collaboration and data sharing between different agencies and stakeholders.
- **AI**: Development of algorithms to analyse simulation results in real-time and provide data-driven recommendations, and to improve the accuracy of forecasts and simulations.

SDG alignment

- **SDG 9: Target 9.1**: Develop innovative, reliable, and sustainable infrastructure that integrates cutting-edge technologies to drive economic growth and enhance human well-being. Focus on regional and transborder connectivity, ensuring equitable access to digital and technological advancements, and fostering resilient, future-ready industries.
- **SDG 11: Target 11.5**: Strengthen resilience and innovation in critical infrastructure to limit the impacts of disasters. Integrate advanced technologies to ensure the continuity of education, health, and other vital services, thereby ensuring sustainable and secure development.
- **SDG 13: Target 13.1**: Reduce disaster mortality and impact by strengthening prevention, innovation and community resilience. Despite a decline in the disaster-related death rate, the absolute number of deaths remains high, and the number of people affected is growing. Integrating advanced technologies and tailored strategies is essential to better anticipate and mitigate these crises.

Risk level

Table 4: Risk level: Natural hazard prediction and forecasting

Risk attribute	Risk rating			Explanation
Public safety	Low	Medium	High	This use case does not pose a threat to public safety; indeed, it can enhance public safety by preventing damage from potential disasters.
Stakeholder acceptance	Low	Medium	High	Stakeholder acceptance of improved disaster preparedness measures is generally low if stake-holders are informed of its value.
Data privacy and security	Low	Medium	High	The risk to data privacy and security was classi-fied as low due to the data not being sensitive.
Financial/ operational	Low	Medium	High	Financial and operational risks were assessed as moderate, primarily due to the complexity of collaborating with various public and private stakeholders to establish and sustain this use case.

Implemented in:

Bordeaux, France; Quebec, Canada.

Case study: Digital Twin of the Port de Bordeaux

Context

While climate change is already noticeable, the IPCC's 6th report indicates that the impacts are occurring more quickly than expected and that the Anthropocene CO_2 reduction targets will be achieved later, and only partially. After the Xynthia storm in 2010, which devastated homes and forests, the coastal erosion that led to the expropriation of the occupants of the Signal building in the Médoc region in 2014, and then the Claus storm in 2015, the Nouvelle-Aquitaine region suffered historic fires in 2022, due to a water shortage combined with the hottest summer on record. In 2013, the Water Agency published a press release on the impacts expected in 2050 on Europe's largest estuary: a strengthening of the silt plug, a deterioration in the situation of aquatic life, and conflicts over water use, particularly related to agricultural activities. The Grand Port Maritime de Bordeaux began its first digital modelling work on the river in 2015 and included in its 2021– 2025 strategic plan objectives addressing port challenges, particularly climate adaptation, and research and development to support and sustain changes in the region. However, digital modelling required complex computing resources, teams of IT specialists, and experts to implement it. Until now, only scientists and major design firms have had such resources and expertise.[12]

Objective

In a context of accelerating transitions, the Grand Port Maritime de Bordeaux aims to structure the port of tomorrow and, in particular, to participate in the construction of a sustainable port. In 2015, work began on a digital model of the Gironde estuary designed to secure and improve navigation and daily dredging operations, in order to accommodate larger vessels. It was decided to use collaborative decision-support tools to improve knowledge of the river and to test climate and anthropogenic scenarios, based on digital replicas of the real world. This is called digital twins. The Grand Port Maritime de Bordeaux wanted to facilitate and democratize this approach by creating LISOS, a generic platform for hosting digital twins. It then created the first digital twin of the river, based on the Gironde XL 3D digital model hosted on the LISOS platform, which reproduces the functioning of the Gironde estuary (a total area of 13 800 km^2).[13]

Solution approach

The Grand Port Maritime de Bordeaux has brought together all the water stakeholders around this project ,in order to co-develop tools to accelerate the resilience of territories to the impacts of climate change: Adour-Garonne Water Agency; the three territorial public basin establishments (EPIDOR, SMEAG, SMIDDEST); the public establishment in charge of the river part (Voies Navigables de France); and the Oceanographic Service of the French Navy (SHOM). The above are being assisted by various experts: French Office for Biodiversity, CEREMA; EPOC Laboratory of the University of Bordeaux; and Pilotage de Gironde.

An innovation partnership was launched at the end of 2021 to oppose four consortia of experts under the aegis of a jury made up of water stakeholders. A hackathon was launched in January 2022 to remind everyone of the key elements of predicting the impact of climate change, the benefits of open source, and the importance of communities. This has made it possible to develop tools in record time. Indeed, the first operational version was launched on 25 April 2023, just 15 months after the launch of the hackathon, and the latest version of the digital model of the estuary is already available in open access on the repository of the Nouvelle-Aquitaine Open-Source regional cluster (NAOS).

The Grand Port Maritime de Bordeaux, a pioneer in this field for its own needs, has decided to make its digital model of the estuary public, to pool the simulation platform to use this model and integrate other models. It's also working on the public sharing of daily forecasts, in conjunction with the International Office for Water (SANDRE label) for interoperability.[14]

(continued)

Case study: Digital Twin of the Port de Bordeaux

Results

First results

Since 2023, the LISOS platform developed by the port to animate digital twins has made it possible to use a first digital model of the Gironde estuary in order to monitor and predict the evolution of the river level and currents on a daily basis. This model also makes it possible to simulate many other parameters, including salinity, temperature, turbidity, oxygen, organic charge and plastic particles.

These tools, digital twin of the river, are already being used by engineer offices to carry out river-sea works (e.g., France-Spain electricity interconnection via the Bay of Biscay, and the installation of the future Atlantic wind farm). And they already allow parallel simulations, each of which requires significant computing resources, to be run in real time to explore cascade and combined effects.

The outlook ahead

The integration of a digital model integrating cities, streets and buildings around the river and other data of the territory (e.g., sanitation networks, dam conditions) within the LISOS platform will make it possible to constitute a powerful decision-making tool for the real-time management of submersion crises. Discussions are underway with stakeholders who already have the necessary data.

Lessons learned

Digital twins of the river are become now exploration tools for transitions with a lot of applications:

- **Climate resilience**
  - Tools to support strategic and urban planning of land use.
  - Facilitate the management of submersion crises by promoting the real-time approach.
  - Accelerates studies and reduces costs (community tools).
  - Promote hydro-diplomacy based on a common and inclusive framework.
- **Decarbonization**
  - Facilitate the citizens acceptance of new industrial uses with open sand common tools.
  - Studies of the impacts of industrial projects in the context of climate change (abstraction/ discharges).
  - Study of the new renewable energy deposits in the territory: wave energy, osmotic energy.
- **Daily forecast (river weather)**
  - Environmental preservation: temperature, turbidity, oxygen, organic load, etc.
  - Economic activities: navigation, mooring lines, etc.
- **Other SD objectives**
  - Modelling of drifting plastics (macro/micro) to facilitate their collection and identify their source.[15]

(continued)

Case study: Digital Twin of the Port de Bordeaux
Conclusion The digital twins of the river represent a significant step forward in predicting and managing the risks of natural disasters such as land submersion. Since their commissioning in April 2023, their first version has laid the foundations for an innovative approach to anticipate and better respond to these extreme events. By pooling efforts and developing training, this initiative aims to strengthen the resilience of territories to disasters and facilitate the sharing of essential know-how for large-scale natural risk management. This open-source approach will promote the replication of the approach on other rivers to accelerate territorial resilience and better prepare them for the management of natural risks on a large scale.

Use case 5: Emergency response real time facilitation (Horizon 2)

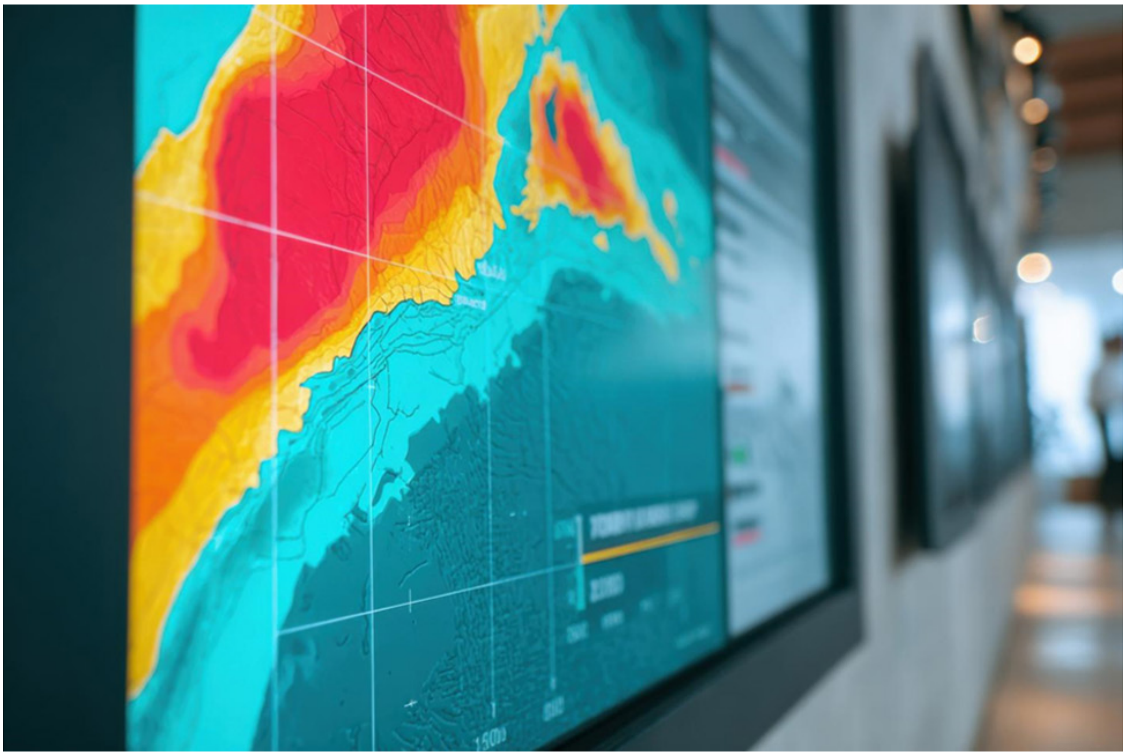
Description

Simulation exercises involving multiple organizations and roles are already a crucial aspect of planning and preparedness for disaster events. In their form as "tabletop" exercises they have been limited by lack of data and the latency of interactions. As new AI and virtual world technologies are integrated into training exercises there are new opportunities emerging for digital twinning as part of humanitarian preparation. These platforms can be used to simulate disaster scenarios with real-time environmental changes, communication challenges, and infrastructure disruptions. Participants can practice coordinated response activities, test resource deployment strategies, and evaluate decision-making processes.

Impacts

1) **Disaster risk reduction**: By improving the means for rapid real-time coordination, humanitarian planning and coordination efforts can drastically reduce the risk exposure of communities to hazards.
2) **Early warning**: Global alerting systems are not effectively tied into means of digital coordination. Geo-messaging tools for real-time spatial coordination can link early warnings to real-time response and coordination capacity, so shortening the time between alerting and action.
3) **Inclusion**: Official emergency coordination mechanisms often suffer from information bottlenecks by concentrating capacity and knowledge in small groups and organizations. This is despite abundant evidence that the vast majority of assistance during emergencies is delivered by neighbours, community members and local institutions. Expansion of digital real-time coordination opens up the range of actors and communities who can play a specific role in allocation and other aid decisions.
4) **Health and wellbeing**: Reduction of risk exposure to hazards and improvement of direct coordination efforts to agencies and communities has the ability to reduce harm from disasters, so improving health related to event shocks.
5) **Climate adaptation**: Rapidly emerging climate shocks pose fundamental challenges to the ability of communities and response agencies to adapt behaviours and infrastructures in ways that are likely to minimize harm and increase protection. Real-time spatial communications tied to improved analytical understanding of climate shocks allows for coordinated behaviours that improve adaptation to changing risks and events.

6) **Citizen engagement**: Participation in humanitarian response is largely predicated upon information and communications flows, including the ability to send specific information about local impacts and to receive guidance from public agencies and others regarding safe actions. Flexible spatio-temporal messaging expands the scope of participation.



Key beneficiaries

- Emergency management and public health nonprofits, NGOs, and multilaterals
- Public sector emergency management at national, regional, and municipal levels
- Researchers and scientists
- Impacted communities
- Emergency data providers

Key technologies

- **AR**: Real-time spatial information such as localized alerting of a hazard, needs to be accessible to responders and community members in the form factor most likely to enable its effective use during a disaster event. Augmented reality overlays of spatial information within geospatial messaging tools – such as seeing the direction of evacuation flows in a heads-up form – allow for understanding, reaction and coordination based upon visual information.
- **GenAI**: Large amounts of spatially and temporally specific information can lead towards negative outcomes if they produce a kind of information overload effect on people acting within crisis contexts. Generative AI integrations can help to add meaningful information synthesis and intelligence layers onto real-time feeds, which improves the ability to process data into actionable information at speed.
- **AI**: Computer vision and other forms of AI, which allow for things like rapid segmentation of satellite or oblique imagery, can integrate with geo-messaging applications in order to

improve the ability to rapidly extract and communicate alerting information in a way that allows others to respond and communicate quickly during crisis events.

- **IoT**: Sensor information such as, for instance, river gauges or vehicle monitors, produce significant amounts of real-time spatial alerting, which can be integrated effectively into geo-messaging platforms in order to improve situational coordination and comprehension. Likewise, an individual using a geo-messaging application becomes a kind of field sensor, capable of generating and communicating new information quickly about dynamic situations. Geo-messaging in turn improves the integration of IoT data within crisis response environments.

SDG alignment

- **SDG 1: Target 1.5**: By 2030, build the resilience of the poor and those in vulnerable situations and reduce their exposure and vulnerability to climate-related extreme events and other economic, social and environmental shocks and disasters.
- **SDG 11: Target 11.5**: By 2030, significantly reduce the number of deaths and the number of people affected and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations.

Risk level

Table 5: Risk level: Emergency response real time facilitation

Risk attribute	Risk rating			Explanation
Public safety	Low	Medium	High	This use case does not pose a direct threat to public safety except insofar as malicious actors may find ways to use geo-messaging coordination platforms for the purpose of misinformation or other negative outcomes.
Stakeholder acceptance	Low	Medium	High	Geo-messaging in general builds upon the familiarity and ease of use of many other digital messaging platforms such as WhatsApp or Facebook Messenger. Establishment of operational networks tends to be fast, within minimal training or socialization requirements
Data privacy and security	Low	Medium	High	High-resolution spatial and temporal information pertinent to individuals has the potential, if not appropriately managed and secured, to reveal significant amounts of personal identifying information.
Financial/ operational	Low	Medium	High	Operational costs for geo-messaging networks tend to be low on a per-user basis. They do however, require bandwidth in crisis zones for full operational status, which can secondarily raise costs.

Implemented in:

Ukraine; Colombia; Mexico; Haiti

* While not all of these were not implemented at the city level, municipal authorities were heavily involved during the COVID-19 outbreak. The value from this use case comes from multiple local and regional authorities collaborating to provide interoperable data sharing mechanisms.

Use case 6: Emergency response simulation for preparedness (Horizon 2)

Description

Humanitarian coordination requires precise information about relevant risks and events to decision makers of many kinds in rapidly changing environments, and immersive technologies such as digital twins, as well as AI, can significantly enhance the speed, clarity and effectiveness of communication. New spatially and temporally specific communications tools are already shaping the landscape of rapid and flexible humanitarian coordination. Virtual world technologies can facilitate real-time communication, task management, and spatial awareness among staff, enabling efficient public service delivery and better operational oversight. XR features allow for enhanced visualization of locations and tasks, improving workflow coordination.

Impacts

1) **Disaster risk reduction**: By improving the use of data-driven workflows and providing a safe space for reflection on the relationships between hazards, vulnerabilities, infrastructures, communities, events, and other factors, simulations provide rich testing grounds for steps to proactively reduce disaster risks.
2) **Anticipatory action**: Accurate simulation exercises based on high quality data allow for the improvement of systems and analytical workflows aimed at improving predictions of disaster events and potential effective actions based on those predictions.
3) **Health and wellbeing**: Improvement of disaster management overall leads to a reduction in lives lost and, ideally, to a more specifically needs-driven response.
4) **Strategic planning**: Disaster response, particularly across rather than within organizations, perpetually suffers from limitations to the capacity to plan strategically for what sorts of investments, actions and operating procedures are likely to bear the most significant positive results. Simulation exercises provide frameworks for the development of those types of planning frameworks, and for testing planning frameworks which may exist in order to measure their utility and benefit.
5) **Inclusion**: While disaster response at all levels remains disproportionately dominated by a handful of large organizations, governments and funders, best practices in the field routinely point towards the need for localization of actions to achieve the best results. Simulation exercises, especially those carried out in relatively low-cost environments, can play the role of deliberately fostering local inclusion, improving training and education for local responders, and in measuring the effectiveness of localized response strategies.
6) **Stakeholder engagement**: While data-driven workflows in disaster management involve coordination across not only response agencies themselves but also researchers, data scientists, public policy makers, and data providers, these types of stakeholders are challenging to coordinate in the context of actual events. Simulation exercises based on high quality data therefore provide the useful grounds for building these types of enhanced or expanded partnerships and working dynamics.

Key beneficiaries

- Emergency management and public health nonprofits, NGOs and multilaterals
- Public sector emergency management at national, regional, and municipal levels
- Researchers and scientists
- Impacted communities
- Emergency data providers

Key technologies

- **Digital twin**: The simulation exercise requires the use of data to create an accurate response context for decision making. Digital twin technologies can improve upon what are now commonly understood by incompletely integrated data streams.
- **Metaverse**: Virtual simulation events rely upon videoconferencing, chat, and real-time mapping technologies to create a perception of presence which is required for immersion in decision-making scenarios. Metaverse technologies can build upon these foundations to enhance the perception of distributed presence.
- **VR**: Virtual reality is among the key metaverse technologies which may be foundational to future scenarios, building in particular upon roles which may require simulation of potentially unfamiliar contexts.
- **GenAI**: Analytics workflows built in part from generative AI can be an effective part of the simulation environment. Likewise, generative AI plays a role in creation of compelling character roles, which enhance the learning value of the simulation.
- **AI**: Apart from generative AI, geospatial AI technologies, particularly for the extraction of useful information from imagery, are at the forefront of enhanced disaster analytics, and at the core of the leading edge of simulation exercises.

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 16: Target 16.7**: Ensure responsive, inclusive, participatory and representative decision making at all levels.

Risk level

Table 6: Risk level: Emergency response simulation for preparedness

Risk attribute	Risk rating			Explanation
Public safety	Low	Medium	High	This use case does not pose a direct threat to public safety. Rather, it can enhance public safety through the avoidance of accidental strikes of underground pipes and cables.
Stakeholder acceptance	Low	Medium	High	High stakeholder acceptance is predicated upon the ability to create meaningful simulations across a wide variety of roles and backgrounds, while still maintaining the practical ability to complete the exercise in reasonable time. The intersecting challenges make this a medium risk.
Data privacy and security	Low	Medium	High	Effective and accurate simulation exercises require the use of some data which may be sensitive to communities and critical public infrastructure. This is not an actual event but nevertheless the risk to privacy is medium.
Financial/ operational	Low	Medium	High	High quality simulation exercises require expert inputs, substantial infrastructure, and extensive time commitments. Sustainably financing these types of exercises is at least reasonably significant.

Implemented in:

Democratic Republic of Congo.

Case study: NASA Lifelines Virtual Simulations for Disaster Preparedness in the DRC

Context

Complex humanitarian emergencies require significant amounts of practice and reflection in order to improve upon key workflows even in marginal ways. Tabletop exercises have traditionally been one of the main types of practice exercises designed to allow for reflection upon humanitarian workflows and ways to understand novel emergency situations. Tabletop simulations, however, have been limited by access to real-time data, engagement with distributed communities, and effective emulation of actual response conditions. They have been limited to the use of turn-based gaming techniques as a result, and confined primarily to spatially proximate colleagues.

"*Simulations are effective tools for learning, engagement, and community building. Beyond community and awareness building, simulations can help train experts in use of satellite data in humanitarian crises.*" Rhiannon Price, NASA Lifelines

This particular simulation exercise focused on a multistage event in eastern Democratic Republic of Congo. At the outset participants were faced with a conflict event, which, in turn, prompted a large-scale displacement and human rights crisis. These were followed by a widespread disease outbreak and the eruption of a nearby volcano, which added the dimension of a nature-based disaster to the dynamics of the social crisis.[16]

Objective

The shift at the NASA Lifelines programme towards virtual, global simulation conditions was prompted by the need to find ways around the data limitation of tabletop exercises, and the need to integrate novel data sources based on remote sensing, in order to foster learning and innovation towards improvement of future field practices.

The key objective was to produce a working virtual model of a complex humanitarian emergency such that a large number of people working in different places throughout the world could collaborate to use remote sensing and other data to develop rapid solutions to sudden onset crises. In this context, key learning focused on the creation and testing of operational workflows, as well as on communications between diverse participants, and learning about the use of datasets and sources which may not have already been broadly understood or experienced by the majority of participants.[17]

Solution approach

In late October 2024, the NASA Lifelines Program convened a group of 328 individual participants from 53 countries to work in 20 different teams on the first-ever virtual global humanitarian data simulation exercise. Most participants were online, but there were also five in-person teams distributed across the world who collaborated with the virtual teams. The principal goal of the simulation was to enable and explore work streams associated with the use of satellite imagery and derived data products for response to a complex humanitarian crisis.

The core communications technologies at the heart of the exercise were Zoom and Discord, which allowed for the creation of segmented team structures and rapid online coordination mechanisms. The NASA Lifelines team curated a large number of satellite and satellite-derived data products, which were provided to teams ahead of the simulation in order to encourage their use for specific problem-solving needs during the exercise. Teams were given specific roles common to a UN cluster-based humanitarian response, as well as roles for journalists, government, local NGOs, community leaders, and others, so as to fill out the spectrum of actions and questions that would drive insight into the decision-making needs of the response.

Media production was utilized throughout the event to produce a sense of urgency and immersive presence for participants. Products ranged from simulated newscasts to press conferences and other live coverage, which, in turn, fed into data and decision workflows for participants.[18]

(continued)

Case study: NASA Lifelines Virtual Simulations for Disaster Preparedness in the DRC

Results

The three-day simulation exercise was considered to be an important watershed in the development and implementation of novel types of humanitarian training and collaborations.

"We are confident that we met our goal of fostering this community of the future where experts from various backgrounds meaningfully connect, learn from each other, and grow together. Across the board, people reported that they learned something new and met a new potential collaborator. Even better, everyone wants to stay involved with this incredible community to do more of this together and find other likeminded changemakers using satellite data for humanitarian action." Rhiannon Price, NASA Lifelines[19]

Lessons learned

The *NASA Lifelines* Program surfaced several critical lessons relevant to advancing remote, collaborative crisis response:

- **Technology integration** – Seamless coordination depended on robust digital infrastructure and intuitive platforms. The combined use of Zoom for structured meetings and Discord for real-time, segmented communications enabled rapid decision making. However, pre-deployment testing and standardizing tools for all participants would further reduce friction and learning curves during the exercise.
- **Immersive engagement** – The production of simulated newscasts, press conferences, and urgent situation updates added emotional and operational pressure that mirrored real-world humanitarian stressors. This level of immersion exposed strengths and gaps in communication pipelines under time pressure.
- **Global participation dynamics** – Having 328 participants from 53 countries fostered diverse perspectives and knowledge exchange. However, varying levels of Internet bandwidth, time zone differences, and language considerations underscored the need for flexible scheduling, multilingual support, and low-bandwidth communication options in future exercises.
- **Community building and continuity** – Beyond technical and operational learning, the simulation succeeded in forming lasting connections among participants. Many reported meeting future collaborators, underscoring the value of maintaining networks between exercises to reinforce skills and promote sustained innovation.
- **Teams made great use of the data** – Teams utilized a wide range of datasets, enhancing the realism and impact of their analyses. There was a wide variety of analysis and visualization software used.
- **The simulation could have been more equitable** – Speaking roles tended to be dominated by Westerners. There are some inherent biases in the game design – playing in English, using two different online platforms in Zoom and Discord, time zone differences, and so on, that likely influenced this.[20]

(continued)

Case study: NASA Lifelines Virtual Simulations for Disaster Preparedness in the DRC
Conclusion The first virtual global humanitarian data simulation by NASA Lifelines marks a significant milestone in evolving humanitarian training from traditional tabletop exercises to globally connected, data-driven collaboration. By integrating satellite-derived datasets, role-based scenario play and immersive media elements, the exercise successfully replicated the pressures, complexity, and multi-actor decision environments of real-world crises. The event demonstrated that virtual simulations can rapidly scale participation, diversify expertise, and foster innovation in crisis workflows – provided that robust connectivity, intuitive communication tools, and clear data access protocols are in place. The integration of immersive storytelling amplified engagement, while the diversity of roles ensured a multidimensional understanding of humanitarian response dynamics. Most critically, this initiative reinforced that simulations are not only about technical proficiency but also about forging resilient, interdisciplinary networks. As complex emergencies increasingly demand globally coordinated responses, exercises like this will be pivotal for preparing responders to integrate remote sensing, collaborative platforms, and real-time decision making in operational contexts. Continued investment in such simulations – paired with structured follow-up, community-building activities, and iterative refinement – will expand the global humanitarian community's capacity to respond effectively to the crises of the future.

Use case 7: Virtual post-disaster assessment and risk mapping (Horizon 3)

Description

The Virtual Post-Disaster Assessment and Risk Mapping (VP-DARM) use case applies metaverse and digital twin technologies to emergency management. By fusing satellite and UAV imagery with geospatial AI and collaborative virtual environments, VP-DARM can generate high-fidelity 3D replicas of disaster-affected areas in near real time. These immersive digital twins enable stakeholders – from municipal authorities to humanitarian NGOs – to assess damage, prioritize interventions, and coordinate response efforts without physical site visits. The market is nascent but growing rapidly, driven by advances in image analytics, cloud computing, and participatory mapping.

Impacts

1) **Rapid damage visualization**: 3D digital twins update within hours of imagery acquisition, enabling responders to identify collapsed structures, blocked routes, and flooding extents faster than ground teams.
2) **Optimized resource allocation**: AI-driven risk heatmaps overlay critical infrastructure locations and vulnerable population data, guiding the deployment of search-and-rescue, medical and relief assets with precision.
3) **Inclusive community engagement**: Web-based VR portals allow affected residents to annotate hazards and service gaps directly onto the digital twin, integrating local knowledge into response planning.
4) **Cross-agency coordination**: Cloud-hosted environments support simultaneous access by UN agencies, national authorities, and NGOs, with role-based permissions and real-time translation tools to streamline multijurisdictional collaboration.
5) **Cost and safety efficiency**: Virtual assessments reduce the need for repeated dangerous site visits, lowering field operations costs and minimizing responder exposure to aftershocks, landslides, or hazardous materials.

Key beneficiaries

- National and local emergency management agencies
- International humanitarian organizations
- First responders and search-and-rescue teams
- Urban planners and infrastructure operators
- Community-based organizations and volunteer groups
- Disaster-impacted populations

Key technologies

- **Digital twin**: Rapid ingestion of aerial and satellite imagery enables creation of up-to-date 3D replicas of disaster-affected areas, preserving structural and topographical details. These virtual models support real-time overlay of damage assessments, resource tracking, and scenario simulations to inform priority response decisions.
- **AR**: Mobile AR applications overlay hazard maps, evacuation routes, and infrastructure status onto live camera views, guiding field responders with contextual geospatial insights. Community volunteers can use AR to annotate damaged sites in situ, feeding local knowledge directly into the shared digital twin.
- **VR**: Immersive VR environments allow remote experts to "walk" through 3D disaster twins, inspect structural failures, and collaborate on response planning without physical site visits. Interactive measurement and visualization tools in VR support training simulations and rapid risk-scenario rehearsals for emergency teams.
- **GenAI**: Generative models synthesize missing terrain or structure data where imagery is obscured by clouds, smoke, or debris, producing plausible reconstructions to maintain situational continuity. These AI-generated fill-ins accelerate mapping completeness and support predictive mapping of secondary hazards such as landslides or flooding.
- **AI**: Computer vision algorithms automatically detect and classify damage features – collapsed buildings, impassable roads, and flood extents – from multispectral imagery, expediting large-scale damage quantification. AI-driven risk heatmaps combine infrastructure vulnerability data with population density layers to optimize allocation of relief assets.
- **IoT**: Deployable ground sensors (structural strain gauges, water-level monitors) and fixed urban IoT networks feed real-time telemetry into the digital twin, alerting responders to evolving hazards such as aftershocks or rising floodwaters. Integration of IoT data streams into collaborative mapping dashboards enhances dynamic situational awareness and decision support.

SDG alignment

- **SDG 1: Target 1.5**: By 2030, build the resilience of the poor and those in vulnerable situations and reduce their exposure and vulnerability to climate-related extreme events and other economic, social and environmental shocks and disasters.
- **SDG 11: Target 11.5**: By 2030, significantly reduce the number of deaths and the number of people affected and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations.
- **SDG 13: Target 13.1**: Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries.

Risk level

Table 7: Risk level: Virtual post-disaster assessment and risk mapping

Risk attribute	Risk rating			Explanation
Public safety	Low	Medium	High	Virtual assessments minimize field hazards, but errors in reconstruction or connectivity failures could misdirect relief operations, posing safety risks. However, public safety can be increased through increased disaster awareness and reduced need for on the ground deployment of humanitarian actors.
Stakeholder acceptance	Low	Medium	High	Requires alignment among government bodies, NGOs, and communities; data-sharing reluctance or governance disputes can slow adoption.
Data privacy and security	Low	Medium	High	Aggregating geolocated and socio-economic data creates high-value targets for cyber-attacks; robust encryption, access controls, and compliance frameworks are essential.
Financial/ operational	Low	Medium	High	High costs for imagery procurement, AI model training, cloud infrastructure, and XR hardware; integration complexity and maintenance add to operational burden. However, costs saved through remote versus in person deployment.

Implemented in:

N/A

Case study

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

Use case 8: Participatory water scarcity management (Horizon 3)

Description

Cities are increasingly exposed to water shortages. Digital twins and IoT can be used to create virtual replicas of city water systems including manmade and natural water bodies, as well as water infrastructure and networks. Water demand and supply can be monitored and forecasted, and decision makers can conduct scenario planning. When necessary, mitigation measures can be introduced to promote participatory climate action. An open digital twin and XR can demonstrate to citizens why and when to limit usage through an interactive environment and provide an open environment to debate public policies.

Many new industrial needs require large quantities of water; for example, using green hydrogen instead of methane to produce fertilizers and water cooling for data centres. To anticipate citizen acceptance, it will be necessary to demonstrate that public policies will not adversely harm the water balance of the city and adjoining territories. The public sharing of the hypotheses and an open digital twin can bring unprecedented transparency to public debates and promote citizen participatory democracy.

Impacts

1) **Transparency and public trust**

- **Facilitating transitions**: Digital twins are valued as a common territorial reference system. They allow open and transparent access to environmental and hydrological data. Citizens can consult the results of the simulations, the hypotheses, alternative scenarios, and have all the information to redo the simulations; water level flows, withdrawals, discharges, impacts on biodiversity, etc.
- **Citizen engagement**: By making data accessible, citizens can better understand the issues and participate actively in discussions about water management. This strengthens trust in public policies.

2) **A common repository for resolving conflicts**

- **Efficient water management**: Digital twins make it possible to simulate different scenarios of available water resources and adapted uses, facilitating discussions between stakeholders around water resource conflicts.

3) **Climate resilience**

- **Evaluation of public policies**: Digital twins make it possible to model the impacts of climate change and political decisions, thus facilitating the adaptation of public policies to territorial specificities and the quantitative evaluation of future trajectories and the impacts of support actions (e.g., release of water from hydroelectric dams).

4) **Innovation and sustainable development**

- **Improved crisis management**: Offers the opportunity to perform real-time simulations, and thus explore what-if scenarios that will make it possible to anticipate in a few moments cascade and combined effects during a crisis.

5) **Democratic participation**

- **Informed debates**: Digital twins provide real-world data that can enrich public debates and help inform decisions.
- **Stakeholder inclusion**: By involving various stakeholders (citizens, businesses, NGOs), digital twins promote an inclusive approach to water management.

6) **Education and awareness**

- **Citizen training**: Digital twins can be used as educational tools to raise awareness of water and climate change issues.
- **Promoting good practices**: By sharing examples of good practices, digital twins can encourage more responsible behaviours.

Key beneficiaries

- Local governments and water management authorities
- Industry
- Citizens

Key technologies

- **Digital twin**: City-wide water systems – including reservoirs, distribution networks and natural waterways – are modelled as dynamic digital twins that integrate real-time and historical hydrological data. These replicas enable stakeholders to visualize current water levels, forecast demand and supply imbalances, and test the impact of alternative policy scenarios (e.g., industrial withdrawals or drought restrictions) in a transparent, endlessly replayable environment.
- **AR**: AR mobile and wearable apps overlay water network schematics, consumption metrics, and conservation prompts onto physical infrastructure during public demonstrations or field inspections. Citizens and decision-makers alike can point their devices at local pipelines, treatment plants, or rivers to view animated flow simulations, projected stress points, and recommended usage limits in situ, thus fostering immediate understanding and engagement.
- **VR**: Immersive VR experiences transport users into a fully rendered 3D model of the city's water cycle – from catchment and treatment to distribution and re-use – allowing participants to "walk" through treatment facilities or observe aquifer recharge processes. Scenario-based VR modules guide policymakers and community groups through interactive crisis simulations (e.g., sudden reservoir depletion), enabling rehearsals of allocation strategies and collaborative decision making in risk-free virtual spaces.
- **Internet of Things (IoT)**: A network of smart flow meters, soil-moisture sensors, and weather stations continuously streams telemetry into the digital twin, providing granular visibility of water consumption patterns and environmental conditions. Automated alerts

flag anomalies – such as leaks, unauthorized withdrawals, or drought thresholds – while dashboards aggregate this data for experts and the public, underpinning data-driven dialogue and rapid response.

SDG alignment

- **SDG Target 9.4**: By 2030, upgrade infrastructure and modernize industries to make them sustainable, increasing resource use efficiency and adopting more clean and environmentally friendly industrial technologies and processes, with all countries acting according to their respective capabilities.
- **SDG 11: Target 11.1**: By 2030, enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries.
- **SDG 13: Target 13.1**: Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries.

Risk level

Table 8: Risk level: Participatory water scarcity management

Risk attribute	Risk rating			Explanation
Public safety	**Low**	Medium	High	This use case does not pose a threat to public safety; on the contrary, it strengthens citizen participation.
Stakeholder acceptance	Low	**Medium**	High	Water usage can be a very political matter, engaging with the public in this format may receive some resistance. However, participation of public and policy creation is often well received. Participation may be dependent on digital skills, literacy and access to devices.
Data privacy and security	Low	**Medium**	High	Some of the data included may be considered sensitive by local authorities.
Financial/ operational	Low	**Medium**	High	Financial and operational risks were assessed as moderate, primarily due to the complexity of collaborating with various public and private stakeholders to establish and sustain this use case. The first open technological building blocks are now in operation (e.g., in the Gironde estuary). This requires strong and sustainable governance structures to ensure long-term success.

Implemented in:

N/A

Case study

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

Use case 9: Interactive emergency communication (Horizon 2)

Description

In an emergency, city governments can use AR to provide real-time guidance to citizens through mobile apps (e.g., identifying safe evacuation routes, locating shelters, avoiding crowdy spaces during outbreaks). The metaverse can host virtual town halls or press conferences or other virtual rooms in which city officials provide updates and guidance, discuss strategies, and engage citizens in disaster-related decision making. Moreover, alternative virtual spaces can offer separate and thematic communication spaces, based on either the target audience (i.e., civil protection stakeholders' coordination compared to vulnerable communities' communication, and so on) or the guiding material (i.e., how to use equipment, how to navigate to shelters, how to perform vaccination, and so on). Furthermore, smart city IoT equipment can collect real-time data, and integrate physical and virtual space via positioning determination.

AI can be leveraged to classify users in communication groups and allocate them to the appropriate communication rooms/spaces. Moreover, AI can be utilized to identify collaboration opportunities between public and private stakeholders that could coordinate people during emergencies.

Impacts

1) **Transparency**: Users are expected to use the official virtual spaces to navigate updates about the emergency, receive detailed guidance, explore corresponding references and engage with the crisis decision making. In such virtual spaces it's expected that Internet censorship will be limited or fully unavailable.
2) **Enhanced safety**: Real-time guidance provided through digital channels can reduce risks such as accidental damage during evacuation, missing safe shelters, avoiding crowdy spaces during outbreaks, and so on, can be reduced leading to safer construction practices.
3) **Quality of life**: Digital real-time guidance safeguards live during emergencies. With precise data on safe shelters evacuation can be performed more efficiently, leading to fewer accidents and traffic disruptions, and less panic, ultimately enhancing the overall quality of life in urban areas.
4) **Cost savings**: The use of digital mapping helps minimize resources' losses by providing precise asset locations, while optimizing civil protection HR allocation, and corresponding operational costs. Furthermore, improved asset management and reduced resource losses generate cost savings for utilities and municipalities.
5) **Operational efficiency**: Virtual rooms, digital dashboards and digital mapping enables real-time data access, streamlining operations by improving coordination of people and between teams and stakeholders. With this information, municipal and utility response can be optimized, so ensuring more effective resource allocation and safeguarding lives. They also ensure quicker decision making and reduce delays, allowing for more efficient response to the emergency.
6) **Regulatory compliance**: The overall real-time emergency provision and communication ensure compliance with safety, environmental, and openness regulations by providing accurate records that can be easily accessed for audits and by minimizing censorship.

It also supports proactive management of assets in accordance with national and local policies.

Key beneficiaries

- Residents and visitors
- Local businesses
- Civil protection
- Public health systems
- City departments such as civil protection, urban planning, infrastructure, transport and housing
- Utilities companies such as energy (e.g., electricity, gas), water, waste and sewage
- Telecommunications companies
- ICT companies

Key technologies

- **Digital twins**: Digital twins can be leveraged to capture, analyse and visualize data on civil protection assets. For more advanced digital twins, 3D visualizations of shelters and necessary response equipment can provide users with a more user-friendly interface to interact with and analyse the data. Digital twins can also support more advanced analysis through the integration of AI capabilities for users' classification to virtual rooms (i.e., based on their location or their vulnerability).
- **Metaverse**: Metaverse will enable virtual-room generation where city officials provide updates, discuss strategies, and engage citizens in disaster-related decision making.
- **IoT**: IoT device data can be integrated into the digital twin to enable real time monitoring of underground pipes and cables, for example, real-time leak detection for water pipes.

- **AR/VR/MR**: AR/VR/MR can be leveraged to provide civil protection staff with an interactive view of the different material to be used against the crisis, citizens to get access to safe shelter, access vaccination, ensure distancing, and do on.
- **AI**: AI can be leveraged to AI can be leveraged to classify users in communication groups and allocate them to the appropriate communication rooms/spaces.

SDG alignment

- **SDG 9: Target 9.c**: Significantly increase access to information and communications technology and strive to provide universal and affordable access to the Internet in least developed countries by 2020.
- **SDG 11: Target 11.5**: By 2030, significantly reduce the number of deaths and the number of people affected and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations.

Risk level

Table 9: Risk level: Interactive emergency communication

Risk attribute	Risk rating			Explanation
Public safety	Low	Medium	High	Virtual community support programmes pose moderate public safety risks related to potential misuse of platforms for harmful activities or inadequate crisis response mechanisms. However, proper moderation, professional oversight, and emergency protocols can mitigate these concerns while enhancing overall community safety through improved mental health support.
Stakeholder acceptance	Low	Medium	High	Implementation faces significant resistance from traditional service providers, community members unfamiliar with digital platforms, and those preferring face-to-face interactions. Success requires extensive community engagement, digital literacy training, and demonstrable benefits to overcome scepticism and build trust in virtual support systems.
Data privacy and security	Low	Medium	High	Collection and processing of sensitive personal, mental health, and behavioural data creates substantial privacy risks requiring robust cybersecurity measures, strict data governance protocols, and compliance with healthcare privacy regulations. Potential breaches could have severe consequences for vulnerable community members.

Table 9: Risk level: Interactive emergency communication (continued)

Risk attribute	Risk rating			Explanation
Financial/ operational	Low	Medium	High	Moderate implementation costs include technology infrastructure, staff training, ongoing platform maintenance, and professional oversight. However, potential cost savings from reduced physical infrastructure, improved wellbeing and mental health outcomes, and improved service efficiency can offset initial investments, making long-term sustainability achievable.

Implemented in:

Seoul, Republic of Korea; Singapore; India

* While not all of these were not implemented at the city level, municipal authorities were heavily involved during the COVID-19 outbreak. The value from this use case comes from multiple local and regional authorities collaborating to provide interoperable data sharing mechanisms.

Case study: Proposed interactive emergency communication virtual ecosystem

Context

Cities are complex systems that consist of infrastructure, including utilities such as water, gas, electricity, telecommunications, and transportation systems, organizations like the municipality and the local stakeholders, and the community. During emergencies (i.e., earthquakes, tsunami, flood, forest fires), the efficient emergency response, resource and asset management, stakeholders' and community engagement and guidance are crucial to maintain public safety, safeguard lives and ensure the social cohesion. The available safe shelter and resource accurate positioning, the continuous and transparent communication about the emergency, and even the training of stakeholders and people (i.e., about how to vaccinate during a pandemic), are important to respond and mitigate properly.

On 21 November 2016, Seoul's Mayor Park joined 100 or more mayors from around the world in the Healthy Cities Mayors Forum at the 9th Global Conference on Health Promotion in Shanghai; reaching a Healthy Cities Consensus that placed emphasis on promoting health at the neighbourhood and community levels for all groups, highlighting the importance of local leadership and citizen engagement in achieving the goal to proactively respond against public health emergencies, like MERS.

Following the first confirmed case in Seoul, a state of emergency was declared, and an evolving strategy was devised to contain the virus and protect the economy and society. It included the early and widespread adoption of temporary testing sites such as the drive-through, the testing booth, and use of diagnostic test kits, producing quick results. This enabled moving faster to tracing and detecting of infection hot-spots, and equally swift in alerting the public through the various government websites and through phone applications. Tracing and tracking in-particular have relied largely on data already collected from phone records, credit card transactions and CCTV sources. These data are repurposed for use during the coronavirus pandemic, by government and the public, as mandated by the 2013 Act on Promotion of the Provision and Use of Public Data. Seoul citizens have played an instrumental role in designing apps (Corona Map, Corona 100, Self-diagnosis and Mask Apps) that allow real-time tracking of the virus by creating maps of hotpots, with regular updates of the number of infected, quarantined and expired.

(continued)

Case study: Proposed interactive emergency communication virtual ecosystem

Objective

The primary objective of this use-case is to define and demonstrate and interactive emergency communication virtual space ecosystem, which can be enabled during an emergency such as a public health crisis. Transparent communication without censorship is crucial during public health emergencies for people's trust and engagement, while the appropriate guidance can safeguard lives and enhance coherency.

The key objectives of the project are to promote safety, resilience, sustainability, and improve the quality of public health services. Creating a digital ecosystem that integrates city digital twin (i.e., real-time maps), metaverse (i.e., to generate virtual rooms for communication, training and guidance) and AI (i.e., to classify users based on their location, vulnerability and other criteria) can safeguard lives and streamline municipal response against emergencies:

1) Safe evacuation routes: This project can coordinate map applications (i.e., street maps); for example, to facilitate evacuation, social distancing and resource mobility.
2) Resilience: In terms of social coherency, people will gain trust from their governments since they will have access to virtual rooms for direct, updated and continuous communication about the emergency, thereby avoiding Internet censorship.
3) Asset Management: Asset owners need to identify the state and attributes of the required equipment for dealing with the emergency. This project will speed up infrastructure positioning and improve access, management and use.
4) Communication: Real-time, transparent, up-to-date communication and focused communication (the appropriate message to the appropriate receiver) is crucial to safeguarding lives, and maintaining community trust and engagement for efficient response and mitigation.
5) Training: Government needs to train the involved civil protection stakeholders to apply measures.
6) Engagement: Stakeholders' and community engagement in decision making is necessary to enhance coherency and maintain trust during and at the post-emergency period.

Solution approach

The solution will be built upon Geographic Information System (GIS) technology, which allows for the mapping of shelters and equipment on a shared platform. Public and private sector asset owners can upload their data digitally or via API for others to access. Authorised users will be able to view the digital map and search assets via street name and geographical references such as postcodes.

While the current digital asset map is in 2D, there is an opportunity to increase the maturity of the digital twin in future iterations by creating a 3D version to improve the visualisation capabilities and level of detail available to users. The need to do so should be informed by concrete applications where 3D visualizations will improve use case outcomes, while AR can provide real-time guidance to citizens through mobile apps (e.g., identifying safe evacuation routes, locating shelters, avoiding crowdy spaces during outbreaks).

Moreover, virtual spaces can generate virtual town halls or press conferences or other virtual rooms where city officials provide updates, discuss strategies, and engage citizens in disaster-related decision making.

Crucially, because of the sensitive nature of the data, the platform is not open and has high security standards. Data access is role based and granted according to defined use cases and legally enforceable agreements.

(continued)

Case study: Proposed interactive emergency communication virtual ecosystem
Conclusion The proposed project is based on the experiences from the Seoul response against the COVID-19 outbreak. The local government used a dashboard for daily updates, timeline of events, countermeasures. Seoul's media outlets were used by SMG to keep the public informed. Furthermore, innovative applications like the Smart map of Seoul were launched: the Corona Map, Corona 100, Self-diagnosis and Mask Apps in Seoul allow real-time tracking of the virus by creating maps of hotpots, with regular updates. An example of how cities can implement virtual world technologies such as digital twins of safe shelter, evacuation paths, response equipment, hospitals, and so on, in order to strengthen public safety and improve resilience in terms of social coherency. The use case demonstrates how AI-enabled citiverse can enhance people's understanding of the crisis, gain access to real-time communication, and get guidance about how to respond to the emergency. The importance of stakeholder collaboration, a well-established data model, and the need for regulatory and legislative support to mainstream these solutions. Going forward, and for other cities implementing this use case, other complementary technologies such as AI and IoT networks should also be considered to provide further capabilities and support additional complementary applications.

Use case 10: Public health emergency real-time management (Horizon 1)

Description

During an emergency, city governments can use digital twins and metaverse to visualize real-time outbreak and perform the appropriate decision making. Real-time data will be collected from, for example, the city IoT, hospitals and research centres, and smart city platforms. Public health officials can visualize and analyse the data, perform decision making regarding policies to control the emergency, while they can utilize the virtual spaces to post early alerts, call resources for action, simulate how to apply measures and depict the outbreak figures to the community.

AI algorithms, on the other hand, can estimate an outbreak, enable early alerting to the officials, perform predictions and enable automatic notifications and guidance based on these decisions (i.e., hospital preparation and routes' automation for affected people).

Impacts

1) **Transparency**: Digital underground asset mapping ensures accurate, up-to-date information about infrastructure, which can drive data-driven decision making for better asset management. This contributes to the development and maintenance of high-quality, resilient infrastructure that can be efficiently monitored and upgraded.

2) **Enhanced safety**: By real-time guidance digitally, risks such as accidental damage during evacuation, missing safe shelters, avoiding crowdy spaces during outbreaks, and so on, can be reduced leading to safer construction practices.

3) **Quality of life**: Digital real-time guidance safeguards live during emergencies. With precise data on safe shelters evacuation can be performed more efficiently, leading to fewer accidents and traffic disruptions, and less panic, ultimately enhancing the overall quality of life in urban areas.

4) **Cost savings**: The use of digital mapping helps minimize resources' losses by providing precise asset locations, while it optimizes civil protection HR allocation, and corresponding operational costs. Furthermore, improved asset management and reduced resource losses generate cost savings for utilities and municipalities.

5) **Operational efficiency**: Virtual rooms, digital dashboards and digital mapping enables real-time data access, streamlining operations by improving coordination of people and between teams and stakeholders. With this information, municipal and utility response can be optimized, ensuring more effective resource allocation and safeguarding lives. They also ensure quicker decision making and reduced delays, allowing for more efficient response to the emergency.

6) **Regulatory compliance**: The overall real-time emergency provision and communication ensure compliance with safety, environmental, and openness regulations by providing accurate records that can be easily accessed for audits and by minimizing censorship. It also supports the proactive management of assets, in accordance with national and local policies.

Key beneficiaries

Residents and visitors

- Local businesses
- Civil protection
- Public health system
- City departments such as civil protection, urban planning, infrastructure, transport and housing
- Utilities companies such as energy (e.g., electricity, gas), water, waste and sewage
- Telecommunications companies
- ICT companies

Key technologies

- **Smart and sustainable city (SSC)**: City IoT, smart city platforms and city dashboards are integrated to synthesize a smart public health ecosystem. IoT sensing from sewage, hospitals and research centres can generate the appropriate data streams to feed early predictions via smart city platforms and the appropriate interfaces, while it can generate and broadcast notifications to the stakeholders and the community. City dashboards can enable real-time outbreak visualizations that will be open to the public. Moreover, the smart and sustainable city infrastructure interoperates with the national public health control centre's dashboard, the national e-health system, the civil protection system, other city platforms (e.g., health platforms) and external dashboards.
- **Digital twins**: Digital twins can be leveraged to capture, analyse and visualize data on civil protection assets. For more advanced digital twins, 3D visualizations of shelters and necessary response equipment can provide users with a more user-friendly interface to interact with and analyse the data. Digital twins can also support more advanced analysis through the integration of AI capabilities for users' classification to virtual rooms (i.e., based on their location or to their vulnerability).
- **Metaverse**: Metaverse will enable the integration of a smart city with existing virtual worlds, where city officials can provide updates, provide remote assistance as required with limited human interaction, explain measures, and engage citizens in measure definition and decision making.
- **IoT**: for this use case, IoT device data can be integrated with smart city platforms and dashboards. IoT devices include cameras, environmental sensors, new types of sensors (e.g., for sewage analysis) and biosensors.
- **AI**: AI algorithms on the other hand, can estimate an outbreak, enable early alerting to the officials, perform predictions and enable automatic notifications and guidance based on these decisions (i.e., hospital preparation and routes' automation for affected people).

SDG alignment

- **SDG 9: Target 9.c**: Significantly increase access to information and communications technology and strive to provide universal and affordable access to the Internet in least developed countries by 2020.
- **SDG 11: Target 11.5**: By 2030, significantly reduce the number of deaths and the number of people affected and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations.

Risk level

Table 10: Risk level: Public health emergency real-time management

Risk attribute	Risk rating			Explanation
Public safety	Low	Medium	High	Virtual channels may be exploited for misin-formation or unauthorized access; robust verification and monitoring needed.
Stakeholder acceptance	Low	Medium	High	Resistance from officials and citizens accustomed to traditional in-person services; requires training and outreach.
Data privacy and security	Low	Medium	High	Handling sensitive personal and financial data demands stringent encryption, governance, and regulatory compliance.
Financial/ operational	Low	Medium	High	Significant initial investment and staff training required; long-term efficiencies justify costs.

Implemented in:

Seoul, Republic of Korea; Singapore; Ghana; Israel; Germany; London, UK; Indonesia; Poland; India

* while these were not implemented at the city level, municipal authorities were heavily involved. The value from this use case comes from multiple local and regional authorities collaborating to provide interoperable data sharing mechanisms.

Case study: Framework for smart public health emergency management in smart and sustainable cities

Context

SSCs are capable of fostering data-driven smart applications to manage limited resources and implement them to thwart the advent of future pandemics of a similar magnitude to the COVID-19 pandemic. Linking SSCs with public health frameworks to manage future pandemics and epidemics and to the attainment of the SDGs, and to the Sendai Framework for Disaster Risk Reduction is a challenge and serves a dual purpose. With the utilization of appropriate emergency communication and public health frameworks, it will become easier to develop models to predict the spread of diseases, ascertain the source of illnesses, coordinate lockdowns, detect and report symptoms, identify viral strains and provide remote assistance as required with limited human interaction, through an infrastructure based on the Internet of Things.

On 21 November 2016, Seoul's Mayor Park joined 100 or more mayors from around the world in the Healthy Cities Mayors Forum at the 9th Global Conference on Health Promotion in Shanghai; reaching a Healthy Cities Consensus that placed emphasis on promoting health at the neighbourhood and community levels for all groups, highlighting the importance of local leadership and citizen engagement in achieving the goal to proactively respond against public health emergencies, like MERS.

Following the first confirmed case in Seoul, a state of emergency was declared, and an evolving strategy was devised to contain the virus and to protect the economy and society. It included the early and widespread adoption of temporary testing sites such as the drive-through, the testing booth, and use of diagnostic test kits, producing quick results. Seoul citizens have played an instrumental role in designing apps (Corona Map, Corona 100, Self-diagnosis and Mask Apps) that allow real-time tracking of the virus by creating maps of hotpots, with regular updates of the number of infected, quarantined and expired. Moreover, although the Korean health system was efficient, a patient management system (C40) was installed to streamline hospital bed capacity and achieve fast control without putting any pressure on the hospitals with the use of AI estimations.

Objective

The COVID-19 pandemic has exposed the global risks and threats posed by unpreparedness, thus lending urgency to the need to build a robust system for early warning, risk reduction and health management. It's believed that the "worst" epidemics (single outbreaks) are most likely to occur in cities where individuals mix randomly (proportionate mixing). Pandemics impact countries and communities, may cause national laws to be rewritten, initiate a restructuring of public health infrastructure and encourage the application of modified methods of combatting disease in the areas of epidemic surveillance and lockdowns.

Despite improvements in urban conditions and the emergence of SSCs, the incidence of infectious diseases continues to be on the rise. Therefore, ICTs should play a greater role in predicting pandemics and identifying early warning signals. Epidemic surveillance has become ICT-based with the use of satellites, drones and cutting-edge technologies such as cameras, sensors, actuators and the IoT combined with emerging applications (e.g., dashboards, analytics and AI-based estimations).

SSCs are in the process of leveraging cutting-edge technologies to become greener and more autonomous and homogeneous. In this respect, cities form strategies and follow frameworks to adopt ICT innovation, especially in the field of data management, big data analytics and AI, to make cities autonomous or, in other words, enable them to make informed political and management decisions.

(continued)

Case study: Framework for smart public health emergency management in smart and sustainable cities

The key objectives of the project are to promote safety and resilience in terms of social coherence and improve the efficiency of public health services. Creating a digital ecosystem that integrates SSC, smart city platforms, city digital twin (i.e., real-time maps), metaverse (i.e., to generate virtual rooms for communication, remote assistance, training and guidance) and AI (i.e., to perform estimations, raise alerts and coordinate the health system) can safeguard lives and streamline public health system's response against emergencies:

1) Social distancing in open spaces: This project can coordinate map applications (i.e., street maps) for lockdowns and social distancing.
2) Resilience: in terms of social coherency people will gain trust from their governments since they will have access to virtual rooms for direct, updated and continuous communication about the emergency, avoiding Internet censorship.
3) Public health asset Management: engaged stakeholders need to identify the location, the state and attributes of necessary public health equipment. This project will speed up equipment deployment and reduce risks.
4) Communication: real-time, transparent, up-to-date communication and focused communication (the appropriate message to the appropriate receiver) is crucial to safeguard lives and maintain community trust and engagement for efficient response and mitigation.
5) Training: Government needs to train the involved public health staff to apply measures (i.e., lockdowns, vaccination).
6) Engagement: stakeholders' and community engagement in decision making is necessary to enhance coherency and maintain trust during and at the post-outbreak period.

Solution approach

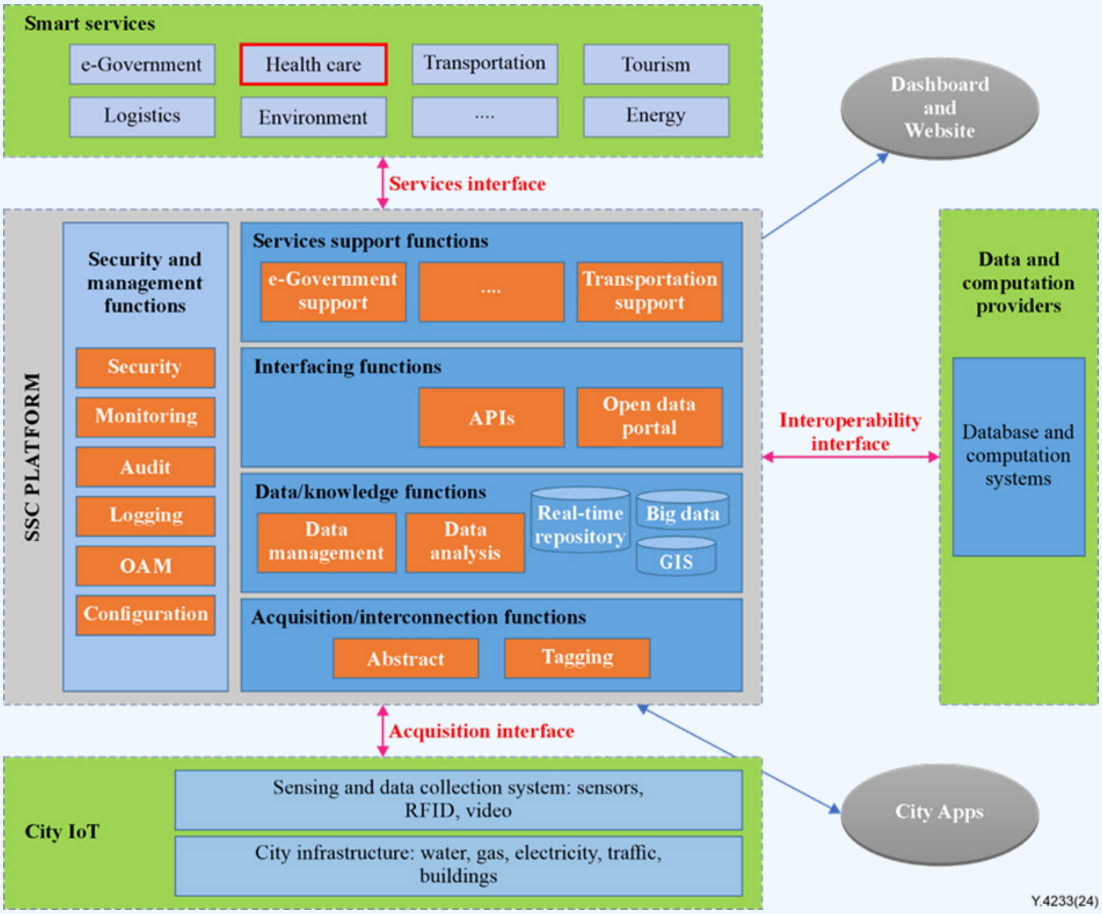
The SSC components depicted in Figure 3, where the reference framework of a smart city platform (Recommendation ITU-T Y.4201) is shown with extensions represented by the dashboard and website and city apps, are required for the implementation of the smart public health emergency management framework.

The proposed smart public health framework is applied in the health care smart service group of the reference framework and uses all the smart city platform components and expands them with the incorporation of the component's dashboard and website for public information release to the community, and the city apps that are developed by the community to support dealing with the emergency.

(continued)

Case study: Framework for smart public health emergency management in smart and sustainable cities

Figure 3: SSC components required for the ICT implementation of the smart public health emergency management framework



Source: ITU-T Y.4233

The "Dashboard and website" and "city Apps" applications are required to be integrated with the SSC platform via appropriate interfaces.

Information related to the public health emergency is collected from the urban space (IoT, hospitals and research centres, crowdsourcing applications) and feeds into the public health threat analysis system and the epidemic curves of corresponding dashboards. Moreover, information is required to be generated and offered to the community via city dashboard, website and city apps.

Interoperability (organizational, semantic and technological) among the SSC stakeholders via the SSC platform is required to support a city when it faces pandemics or other public health emergencies. To facilitate interoperability, standards are required to be used for communication and exchanging data; for example, gateways and APIs might act as a glue between the components of the SSC platform.

ICT-based services are required to be offered to the community to ensure its public health conditions, which are labelled smart services and generate alerts before and during the crisis (e.g., call social services or the security services in the city to respond to an incident).

(continued)

Case study: Framework for smart public health emergency management in smart and sustainable cities
Conclusion The proposed project is based on the recommendation ITU-T Y.4233 "Framework for smart public health emergency management in smart and sustainable cities" and on the experiences from the Seoul response against the COVID-19 outbreak. The local government used a dashboard for daily updates, timeline of events, countermeasures. Seoul's media outlets were used by the local government to keep the public informed. Furthermore, innovative applications were launched: the Corona Map, Corona 100, Self-diagnosis and Mask Apps. Moreover, although the Korean health system was efficient, a patient management system (C40) was installed to streamline hospital bed capacity and achieve fast control without putting any pressure on the hospitals with the use of AI estimations.

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

Launched by ITU, UNICC, and Digital Dubai, the Global Initiative on AI and Virtual Worlds – *Discovering the Citiverse* is a multistakeholder platform dedicated to shaping the next generation of AI-enabled citiverse[21].

A global coalition of more than 70 partners, including cities, governments, UN agencies, standards bodies, industry, academia and civil society, the Initiative is building the governance architecture of the AI-enabled citiverse.

The Initiative ensures that these technologies evolve in ways that are inclusive, interoperable, and human-centric, while contributing to the implementation of the Pact for the Future and its Global Digital Compact.

Serving as a neutral and action-oriented platform, it brings together public and private stakeholders to advance the responsible development and deployment of the AI-enabled citiverse. It provides blueprints, capacity-building resources, and a global peer network to support cities in moving from vision to scaled implementation.

The Initiative advances its mission through three strategic pillars, supported by dedicated tracks addressing key challenges and opportunities. This structure enables both high-level global guidance and practical implementation across cities worldwide.

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.

Ministry of Internal Affairs and Communications

دبـــي الرقمية DIGITAL DUBAI

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:

ITU

UNICC

دبـــي الرقمية DIGITAL DUBAI

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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XRSI Human Intelligence In The Loop

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