Yerevan's transformation into a smart city: Innovating infrastructure and driving sustainable urban development

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Abstract

Objectives: The research explores how Yerevan is developing into a smart city, emphasising strategies for dealing with challenges including aging infrastructure, budgetary limitations, and equal access while encouraging sustainable urban growth. Prior Work: In line with research that has examined at sustainable urban development in emerging countries, this paper builds on the frameworks of smart city development, namely those related to geographic information systems (GIS), digital public services, and energy-efficient infrastructure. Additionally, it makes use of earlier studies on digital governance models and public-private partnerships that facilitate citizen involvement. As primary resources, the Yerevan Municipality's strategic documents that directly address the city's transition to a smart city have also been used in this research. Approach: Using a case study methodology, the study examines Yerevan's current projects, including GPS-enabled public transportation systems, energy-efficient street lighting, and e-governance platforms, and assesses how well strategic planning techniques, public-private partnerships, and community involvement can help the city overcome its financial and infrastructure obstacles. Results: Although Yerevan has made great progress towards becoming a smart city, challenges including antiquated infrastructure, a lack of funding, and digital inequality still exist. Initiatives in sustainable infrastructure and digital governance, however, show encouraging promise for enhancing waste management, public safety, energy efficiency, and intelligent traffic control. Implications: Researchers interested in sustainable urban development, politicians, and urban planners will find this research useful. In towns with ageing infrastructure and little funding, the study offers insights on how to overcome obstacles to smart city development. Value**:** The article provides a thorough case study of Yerevan, which adds to the larger conversation on smart cities. By highlighting the need of strategic alliances and public involvement in overcoming urban obstacles, it offers a distinctive viewpoint on the possibilities for sustainable development in cities undergoing transition.

Keywords: infrastructure, e-governance, public-private partnerships.

1. Introduction

The rapid development of information and communication technologies (ICTs) has transformed urban management and paved the way for the emergence of smart cities. These cities leverage digital tools to improve public services, optimize resource usage, and reduce environmental impacts. Defined broadly, a smart city connects physical, digital, and social infrastructures to enhance quality of life while addressing economic, social, and environmental challenges. This integration allows cities to operate more efficiently and sustainably, benefiting residents and fostering long-term urban resilience.

As urbanization accelerates, with projections indicating that 70% of the global population will reside in cities by 2050, the role of smart cities becomes increasingly critical. Currently, cities consume 75% of global resources and generate 80% of greenhouse gas

emissions, intensifying environmental challenges. Smart city initiatives, such as energy-efficient infrastructure, intelligent transport systems, and digital governance platforms, offer solutions to mitigate these impacts while supporting urban growth [1].

Despite their potential, implementing smart city projects presents challenges, particularly in resource-limited contexts. Issues such as outdated infrastructure, budget constraints, and digital inequality hinder progress, highlighting the need for inclusive and strategic approaches. By addressing these challenges, smart cities can become models for sustainable development, ensuring equitable access to technology-driven advancements while balancing economic growth and environmental preservation [2].

Yerevan, Armenia's capital and one of the world's oldest cities, is transforming into a smart city to modernize infrastructure, address challenges like congestion and digital inequality, and promote sustainability. Despite progress with innovations such as GPS-enabled transport and e-governance platforms, the city faces significant challenges, including outdated infrastructure, limited financial resources, and digital inequality. These issues hinder the implementation of advanced technologies and risk excluding vulnerable groups, offering valuable insights into balancing tradition with smart urban development in resource-limited contexts.

So, the purpose of the research is to explore Yerevan's transformation into a smart city, focusing on strategies to overcome challenges such as aging infrastructure, budgetary limitations, and digital inequality while promoting sustainable urban growth. The study aims to provide insights into effective planning and implementation of smart city initiatives, with lessons drawn from global practices to enhance infrastructure, governance, and public services.

2. Smart cities: Components and characteristics

Smart cities encompass a diverse range of components, with eight critical elements commonly identified: smart infrastructure, smart buildings, smart transportation, smart energy, smart healthcare, smart technology, smart governance, and smart education, as well as the role of smart citizens (Fig. 1). These elements collectively contribute to the creation of an integrated, sustainable urban ecosystem. However, the specific emphasis placed on each component varies across cities, depending on their particular socio-economic conditions, developmental priorities, and the unique challenges they face [3].
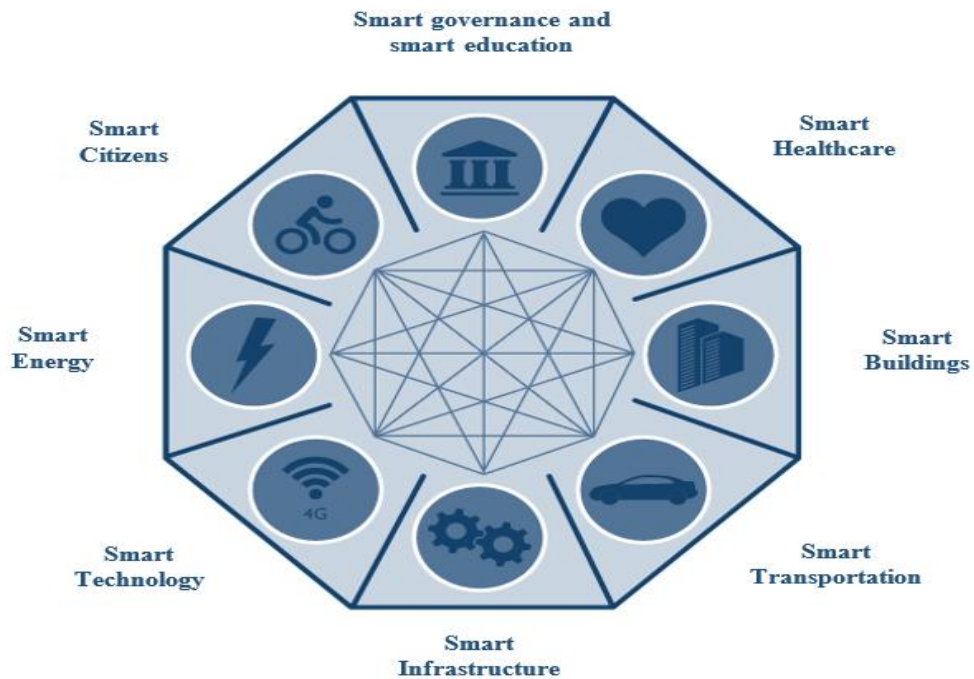
Fig. 1. Components of a smart city
Source: https://www.flexpostinc.com/blog/smart-city/

The concept of "smartness" refers to a city's ambition to enhance its economic, social, and environmental standards. Common dimensions of smartness include smart economy, smart people, smart governance, smart mobility, and smart living. A smart city operates under four core themes: society, economy, environment, and governance. The society theme emphasizes that the city exists for its citizens, prioritizing their needs and well-being. The economy theme underscores continuous job creation and sustained economic growth. The environment theme reflects a city's commitment to ecological sustainability, ensuring functionality for both current and future generations. Finally, the governance theme highlights the city's ability to implement effective policies and coordinate the other components cohesively [4].

The infrastructure of a smart city can be categorized into three main types:
- physical,
- ICT (information and communication technology),
- service infrastructure.

Smart city infrastructure integrates physical, ICT, and service components to create a seamless urban environment that enhances the quality of life for its residents. Physical infrastructure consists of traditional elements like buildings, roads, bridges, and utilities, which provide the essential framework for city operations. However, in a smart city, the concept of infrastructure expands to include both electrical and digital systems, which support more efficient and sustainable urban management. ICT infrastructure acts as the

core enabler, connecting various systems and serving as the city's central nervous system. Through the integration of technologies such as fiber optics, Wi-Fi, and wireless networks, ICT infrastructure allows real-time data exchange and ensures that the city's services are optimized for efficiency, security, and adaptability [5].

Service infrastructure builds upon the physical and ICT frameworks, enabling the delivery of enhanced services to residents. By incorporating technologies like sensors and automated systems, service infrastructure enables better management of public services such as waste collection, traffic flow, and energy usage. For instance, smart waste management systems use sensors to track the fill levels of bins, ensuring that they are only collected when necessary, reducing both operational costs and environmental impact.

In smart cities, infrastructure also includes key systems such as transportation networks, energy grids, water distribution, and healthcare services. Smart transportation systems, powered by ICT, enable seamless integration across various modes of transport. Intelligent Transport Systems (ITS) leverage real-time data to optimize traffic flow, reduce congestion, and improve overall mobility. For example, vehicles can communicate with each other and with traffic lights to reduce wait times and enhance safety. Similarly, smart energy systems integrate renewable energy sources, such as solar and wind, into the city's power grid, optimizing energy distribution and reducing reliance on non-renewable resources [6].

One of the most important components of smart infrastructure is smart buildings, which integrate advanced technologies like IoT sensors, smart appliances, and automated systems to optimize energy consumption, security, and operational efficiency. Unlike traditional buildings that focus solely on physical structure, smart buildings dynamically interact with other buildings, technologies, and environmental systems, creating a connected ecosystem. For example, a smart building connected to a smart grid can adjust its energy consumption based on real-time demand, reducing energy costs and supporting sustainability goals [7]. Traditional city infrastructure, while functional, operates in isolation and lacks the integration required for smart city efficiency. However, the evolution towards smart cities presents the opportunity to break down these silos and create systems that communicate with each other, leading to more efficient urban operations. By connecting transportation, energy, healthcare, and other systems, smart cities can address modern challenges such as traffic congestion, environmental degradation, and inadequate healthcare [8].

Furthermore, a key aspect of smart city infrastructure is the role of Big Data. Cities generate massive amounts of data through sensors, devices, and social media, and this data can be analyzed to optimize city operations and improve services. For example, real-time traffic data can inform public transport schedules, while energy consumption data can guide the deployment of renewable resources. The ability to process and act on this data allows smart cities to adapt quickly to changing conditions and ensure the efficient use of resources [9]. To sum up, the integration of physical, ICT, and service infrastructure is what defines a smart city. By combining traditional elements with advanced technologies, cities can achieve greater efficiency, sustainability, and quality of life for residents. However, the successful implementation of smart infrastructure requires a holistic approach that

addresses challenges such as digital inequality, funding constraints, and the need for public engagement. By overcoming these hurdles, smart cities can unlock their full potential and set the stage for a more sustainable and equitable urban future.

3. Critical analysis of smart cities

Smart cities represent a transformative approach to urban development, offering significant benefits while posing critical challenges that need careful analysis. Among the most impactful benefits is the enhancement of resource efficiency. Through the integration of IoT and advanced data analytics, smart cities can optimize energy consumption, water usage, and waste management systems. For example, smart grids and renewable energy integration not only reduce carbon emissions but also lower costs for both cities and residents. Waste management technologies, as seen in Singapore, further highlight the capacity of smart cities to minimize environmental and financial burdens.

Urban transportation is another key area where smart cities excel. Intelligent Transport Systems (ITS) improve traffic flow, reduce congestion, and lower emissions by leveraging real-time data and AI-driven optimization. Cities like Seoul and Dublin showcase these advancements, creating safer and more efficient mobility networks. Moreover, the introduction of autonomous vehicles and shared mobility services has the potential to significantly decrease private car ownership and associated urban challenges [10].

Economic growth in smart cities is driven by innovation ecosystems and the collaboration between public and private sectors. Open data initiatives empower startups and enterprises to develop innovative solutions tailored to local challenges, fostering economic dynamism. Initiatives such as Dublin's Smart Dublin platform illustrate how such collaborations can lead to widespread socio-economic benefits. The emphasis on technological solutions also extends to healthcare, where smart systems facilitate early disease detection, improve hospital resource allocation, and expand access to care, particularly in underserved areas. The sustainability benefits of smart cities are equally noteworthy. By prioritizing the integration of renewable energy sources and enhancing the energy efficiency of buildings, cities can significantly reduce their environmental impact. The use of ICT to monitor and control emissions and energy consumption underscores the role of technology in fostering environmental responsibility [11].

However, the implementation of smart cities is not without its limitations. The most immediate challenge is the high cost of deploying advanced technologies. Developing nations, in particular, face barriers to investing in the infrastructure required for IoT devices, data centers, and communication networks. This financial disparity risks widening the gap between affluent and less affluent cities. Additionally, digital inequality persists within smart cities, excluding marginalized groups from accessing or benefiting from these advancements. This lack of equitable access reinforces societal divisions, underscoring the need for targeted interventions such as digital literacy programs.

Privacy and security concerns also emerge as significant challenges. The reliance on pervasive surveillance technologies, while enhancing safety, raises ethical questions about the balance between security and individual freedoms. Smart city systems are also

vulnerable to cyberattacks, which can disrupt essential services like energy and transportation, with potentially catastrophic effects. Furthermore, while aiming for sustainability, the production and disposal of IoT devices and other high-tech components contribute to environmental degradation through e-waste and energy-intensive manufacturing processes [12].

Another critical limitation lies in the overdependence on technology. Urban systems built around ICT and IoT are susceptible to failures that can paralyze entire sectors, from healthcare to public transit. The rapid pace of technological obsolescence adds to this vulnerability, requiring continuous investment and upgrades (McKinsey, 2024). Additionally, smart city designs often prioritize efficiency and technological sophistication over inclusivity, creating "smart enclaves" that cater primarily to affluent populations while neglecting the needs of lower-income residents.

In conclusion, while smart cities promise enhanced efficiency, economic growth, and sustainability, they also face significant challenges related to costs, equity, security, and environmental impact. Achieving their full potential requires inclusive policies that address digital and social divides, ensure privacy protections, and incorporate sustainable lifecycle management for technologies. By balancing innovation with equity and sustainability, smart cities can serve as models for the future of urban development.

4. The Digital Transformation Strategic Plan for Yerevan

The Digital Transformation Strategic Plan for 2024–2028 is a bold and forward-looking blueprint for addressing the challenges of rapid urbanization and technological evolution in Yerevan. The strategy outlines a comprehensive framework aimed at modernizing governance, enhancing infrastructure, and fostering sustainability. By leveraging cutting-edge digital tools, it seeks to position Yerevan as a leading smart city. While the plan reflects ambition and innovation, it requires closer analysis to assess its feasibility, inclusivity, and long-term viability [13].

- **A foundation rooted in technological modernization**

At the core of the plan is a vision to transform Yerevan through a three-tier digital architecture. This system integrates citizen-facing platforms for public services, automated municipal operations for process efficiency, and data analytics for informed decision-making. The Municipality aims to digitize 95% of its services by 2028, significantly improving accessibility and responsiveness. However, the heavy reliance on digital systems raises concerns about disparities in digital literacy among residents and municipal staff. Without targeted training programs and public education, these advanced systems risk underutilization, particularly among marginalized groups.

- **Challenges in bridging inclusivity and access**

The strategy's emphasis on inclusivity, particularly through e-government portals and mobile applications, reflects its commitment to accessibility. Yet, Yerevan's socio-economic realities present barriers to achieving this goal. As of 2023, nearly 20% of the population lacks consistent access to the internet or digital devices. If these disparities are

not addressed, marginalized groups may be left behind, undermining the inclusivity objectives of the plan. Investments in physical infrastructure, affordable internet access, and widespread digital literacy programs are critical for ensuring equitable access to the proposed digital systems [14].

- **Environmental sustainability as a cornerstone**

Sustainability plays a pivotal role in the plan, with a focus on transitioning from non-renewable to renewable energy sources. The Municipality intends to reduce reliance on non-renewables from 40% in 2023 to 25% by 2028 through initiatives such as solar panel installations and LED lighting. These efforts are complemented by smart waste management and recycling systems, targeting a 50% reduction in landfill waste. However, achieving these goals depends on external factors, including funding availability, public compliance, and access to renewable energy technology. The strategy could benefit from deeper exploration of ecological challenges such as water conservation, biodiversity protection, and the mitigation of urban heat islands, which are not sufficiently addressed [13].

- **Reimagining urban mobility**

Transportation reforms form a key pillar of the strategy, with a focus on reducing congestion and promoting sustainable travel. Yerevan's congestion, which causes annual economic losses of $50 million, is targeted through real-time traffic management systems, unified ticketing platforms, and infrastructure for cycling and walking. These measures aim to increase public transport usage by 15% and reduce congestion by 20% by 2028. However, such transformations require significant upfront investments, and their success hinges on public adoption. Behavioral change incentives, such as subsidies for public transport and awareness campaigns, are needed to encourage the transition to sustainable mobility options [13].

- **Public safety and the role of AI**

The strategy's safe city initiatives stand out for their use of advanced technology, including AI-driven surveillance and predictive analytics. These systems promise to enhance emergency response times, reduce crime rates, and improve overall safety. By 2028, an additional 10,000 surveillance cameras with AI capabilities will be deployed, while emergency response times are projected to decrease by 30%. However, these advancements raise ethical concerns about data privacy and potential misuse. Without robust data protection protocols and transparent governance, the public may resist such surveillance systems, undermining the effectiveness of these safety measures.

- **Strengthening digital infrastructure amid risks**

Digital infrastructure serves as the backbone of the transformation strategy, with a focus on integrating data from municipal departments, IoT devices, and GIS systems. The creation of a centralized big data repository will enhance resource allocation and policy decisions. While this integration offers immense potential, it also presents risks of system fragmentation and vulnerabilities to cyberattacks. The plan includes cybersecurity measures, such as SIEM systems and endpoint protections, but it lacks detailed strategies

to address evolving threats. Ensuring the reliability and security of digital systems is critical to maintaining public trust and operational efficiency [15].

- **Economic and social impact: Promises and challenges**

The strategy projects substantial economic gains, including $100 million in savings over five years through improved efficiency and a 10% increase in tech-sector employment. Socially, it aims to enhance citizen engagement through expanded digital services, potentially benefiting marginalized communities. However, these benefits are contingent on sustained political support, effective public-private partnerships, and careful financial management. If these conditions are not met, the strategy risks becoming an aspirational framework with limited tangible outcomes.

- **Implementation feasibility and timelines**

The plan outlines a phased implementation approach, beginning with foundational systems in 2024–2025, scaling up through IoT and public engagement platforms in subsequent years, and concluding with evaluations in 2028. While ambitious, this timeline may be overly optimistic given Yerevan's current resource and capacity constraints. Key performance indicators, such as increasing public adoption of digital services and reducing congestion-related economic losses, provide measurable goals but require clearer mechanisms for accountability. A more detailed roadmap would enhance the strategy's credibility and improve its chances of success [13].

So, to sum up, Yerevan positions as a trailblazer in smart city development. By focusing on governance, sustainability, mobility, safety, and digital infrastructure, it aspires to create a safer, greener, and more efficient urban environment. However, the plan must address critical gaps in inclusivity, cybersecurity, funding, and implementation planning to realize its full potential. By refining its approach and ensuring that the necessary resources and frameworks are in place, Yerevan can transform into a model city for innovation and sustainability. Without these adjustments, the strategy risks falling short, leaving the city vulnerable to inefficiencies and unmet expectations.

5. Examples of smart cities illustrate how these concepts are applied in practice

International smart city experiences are crucial in understanding how technology can address urban challenges and enhance quality of life. By integrating technologies in transportation, energy, governance, and public safety, smart cities optimize resources, improve sustainability, and foster inclusivity. These global examples provide valuable data-driven solutions that can be tailored to meet specific urban needs.

The analysis of cities like Seoul, Dublin, and Tallinn is particularly important for Yerevan as it offers insights into effective strategies for managing similar challenges such as traffic congestion, environmental sustainability, and public service efficiency. By learning from these successful cases, Yerevan can adapt proven solutions to its own context, ensuring a more sustainable and resilient urban future.

Seoul

Seoul, South Korea, stands out as one of the most advanced smart cities globally, leveraging technology to improve everyday life for its citizens. One of the most remarkable features of Seoul's smart city approach is its highly efficient public transportation system. The Seoul TOPIS (Transportation Operation and Information Service) platform is an integrated system that provides real-time traffic updates, public transport schedules, and information on road conditions. This system helps residents plan their commutes more effectively, reducing time spent in traffic. Additionally, Seoul has developed the T-money card, which facilitates seamless travel across buses, subways, and taxis. As of 2020, approximately 80% of the city's population uses the T-money card, which has significantly streamlined public transport access and fare payments. Seoul has become a shining example of what a smart city can achieve, using technology to make life easier and better for its people. One of its standout features is the public transportation system. With the Seoul TOPIS platform, residents can check real-time traffic updates and public transport schedules, making commuting much more convenient. The city's T-money card allows seamless travel across buses, subways, and taxis, simplifying daily commutes [128].

In terms of public safety, Seoul has deployed AI-powered CCTV cameras in high-risk areas to monitor potential crimes. To keep the city safe, Seoul has installed AI-powered CCTV cameras in areas prone to crime, which can alert authorities when something seems wrong. These cameras are connected to a central command system that can alert authorities when unusual activities, such as potential crimes, are detected. The city's investment in AI technology for crime prevention has contributed to a decrease in crime rates over the years. According to Seoul Metropolitan Police, crime rates dropped by 10% between 2019 and 2021, largely due to the proactive use of AI surveillance. Seoul also prioritizes environmental concerns, particularly air quality. The city uses smart air quality monitoring systems that provide real-time pollution updates via apps, helping residents track the levels of particulate matter and take necessary precautions. These efforts have led to an improvement in air quality, with fine dust levels dropping by 12% between 2018 and 2020. Beyond environmental monitoring, Seoul's commitment to inclusivity is evident in its digital literacy programs. These programs are designed to ensure that senior citizens, who may be less familiar with new technologies, are given access to the skills needed to navigate modern digital services. As of 2022, more than 60,000 seniors had participated in digital literacy programs across the city. Furthermore, Seoul fosters civic engagement through the mVoting app, which enables citizens to vote on local issues, ensuring that all residents, regardless of their technological proficiency, can have a voice in the city's decision-making processes. It uses smart air quality monitoring systems to provide real-time pollution updates through apps, helping people stay informed. On top of that, Seoul makes sure everyone can join in its digital advancements, offering programs to teach senior citizens how to use modern technology. The mVoting app even lets residents have a say in local decisions, ensuring everyone's voice is heard. With ongoing projects in renewable energy, disaster preparedness, and telemedicine, Seoul is constantly pushing the boundaries of what a sustainable, inclusive, and innovative city can be. This inclusive approach, coupled with ongoing efforts in renewable energy, disaster preparedness, and telemedicine, shows how Seoul is constantly pushing the boundaries of what a sustainable, innovative, and inclusive smart city can achieve.

Tallinn

Tallinn, the capital of Estonia, beautifully blends cutting-edge technology with its rich historical charm. As part of Estonia's advanced digital ecosystem, Tallinn makes life easier for its residents with its e-government services. From registering businesses to accessing healthcare, almost everything can be done online. One of the city's unique features is its free public transportation system for registered residents, making it both inclusive and eco-friendly. One of Tallinn's standout features is its e-government services. In 2020, over 99% of public services in Estonia, including those in Tallinn, were available online, making it one of the most digitally advanced countries globally. These e-services include everything from business registration to tax filing and access to healthcare services. Tallinn's commitment to digital government has streamlined bureaucracy and improved accessibility to essential services, particularly for busy citizens who may otherwise struggle with in-person visits to government offices [17].

In terms of sustainability, Tallinn has implemented several innovative solutions. The city offers free public transportation to all registered residents, making it the first European capital to do so. This initiative not only encourages the use of public transport but also reduces the number of private vehicles on the road, contributing to a decrease in air pollution. Tallinn also employs real-time data to manage traffic flow, reducing congestion and cutting down on carbon emissions. In 2020, Tallinn's traffic management system was credited with reducing traffic jams by 15%, helping make commuting more efficient for its 450,000 residents.

Tallinn's smart waste management system uses IoT sensors to monitor the fill levels of waste containers, ensuring that trash is collected only when necessary. This system has led to a reduction in waste collection costs by 25% and has minimized the city's environmental impact by reducing the number of collection trucks on the roads. Additionally, Tallinn uses smart technology to promote tourism, with the Tallinn Card App offering visitors personalized recommendations and access to attractions based on their preferences.

The city also encourages resident involvement in urban planning through feedback platforms that allow citizens to share their opinions on development projects and city policies. This participatory approach has made Tallinn one of the most transparent cities in Europe, with public trust in local governance consistently high. Tallinn's focus on cybersecurity, energy efficiency, and green innovation continues to set a high standard for smart cities around the world, proving that digital advancement and sustainability can go hand-in-hand. The city encourages community involvement by involving residents in urban planning through feedback platforms. Tallinn's focus on cybersecurity, energy efficiency, and green innovation shows its dedication to being a forward-thinking smart city while keeping its rich heritage alive.

Dublin

Dublin, Ireland, has embraced technology and collaboration as part of its Smart Dublin Initiative, which brings together government agencies, businesses, and universities to create innovative solutions for the city's urban challenges. Dublin has embraced technology and collaboration to solve urban challenges and make life better for its people. Through the

Smart Dublin Initiative, the city has brought together government agencies, businesses, and universities to create innovative solutions. For example, its smart mobility system uses real-time traffic data to improve public transport and reduce congestion, with apps providing commuters with live updates.

One of Dublin's key innovations is its smart mobility system, which uses real-time traffic data to improve public transport and reduce congestion. As of 2021, Dublin's public transportation system, which includes buses, trams, and trains, saw over 300 million passenger journeys annually, with smart ticketing and mobile apps making it easier for commuters to navigate the system.

Dublin has also incorporated sensor-enabled waste bins into its urban landscape. These bins use sensors to track fill levels, enabling waste collection services to operate more efficiently and reduce unnecessary trips. This system has contributed to a 20% reduction in waste collection costs since its implementation [18].

Given its coastal location and flood risks, Dublin has implemented smart flood monitoring systems that use sensors to detect and manage potential threats. It has also introduced sensor-enabled waste bins to track fill levels, making garbage collection more efficient and eco-friendly.

Dublin actively involves its residents by sharing city data through an open platform, empowering developers, researchers, and citizens to create new solutions. Tools like the "Dublin Dashboard" provide real-time information about the city, helping people make informed decisions. The city also supports innovation and entrepreneurship, offering spaces like the Guinness Enterprise Centre for startups working on smart city technologies. By focusing on mobility, sustainability, and digital engagement, Dublin is setting an example of how technology and data can transform a city into a thriving, inclusive, and forward-looking community.

Dublin has also fostered an environment for entrepreneurship by providing spaces like the **Guinness Enterprise Centre**, where startups working on smart city technologies can thrive. Through these efforts, Dublin has set a compelling example of how data and technology can be used to improve urban life while engaging citizens in the process.

6. Conclusions and recommendations

Yerevan's transformation into a smart city has seen considerable progress, marked by initiatives such as GPS-enabled public transportation, e-governance platforms, and energy-efficient infrastructure. However, challenges remain, including aging infrastructure, budgetary constraints, and digital inequality. Drawing from international experiences, several key conclusions can be highlighted. First, citizen engagement is essential. Cities like Seoul and Dublin demonstrate that participatory governance tools and digital platforms enhance inclusivity and foster public trust in smart city projects. Second, leveraging technology, such as IoT, AI, and GIS, effectively addresses urban challenges like waste management, public safety, and traffic congestion, as evidenced by examples from Tallinn and Seoul. Third, sustainability must remain central, with renewable energy adoption,

efficient waste management, and air quality monitoring playing critical roles, as seen in Tallinn's free public transport and Seoul's air quality initiatives. Finally, while technological advancements are transformative, they also risk excluding marginalized populations due to digital inequalities, making inclusivity a priority.

Based on the analysis conducted, the recommendations are the following:

- Centralized Data Analytics: Establish a centralized data repository for real-time analytics to enhance resource allocation and improve public services, inspired by Seoul's traffic systems and Dublin's waste management solutions.
- Sustainable Mobility Solutions: Introduce real-time traffic management systems and expand cycling and walking infrastructure to reduce congestion. Implement integrated ticketing systems for public transport to increase accessibility and efficiency.
- Citizen Engagement Platforms: Develop mobile applications and platforms like Dublin's open data initiatives and Seoul's mVoting app to empower residents and encourage participation in governance and urban development.
- Digital Inclusion Initiatives: Address the digital divide through subsidized internet access, public Wi-Fi hotspots, and digital literacy programs tailored for underserved and elderly populations.
- Environmental Sustainability: Transition to renewable energy sources and adopt IoT-enabled waste management systems modeled after Tallinn's innovations. Implement air quality monitoring systems for real-time updates and improved public health.
- Cybersecurity and Privacy: Prioritize cybersecurity measures and establish transparent data governance policies to protect citizens and maintain trust in digital infrastructure.
- Public-Private Partnerships: Foster collaborations with private entities to drive innovation and share costs, following successful examples like Dublin's innovation hubs and Seoul's integration of private technology solutions.
- Clear Timelines and KPIs: Develop detailed timelines and measurable goals for smart city initiatives to ensure accountability, aligning with the objectives of the Digital Transformation Strategic Plan for 2024–2028.

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