Emerging IoT and Edge Computing Synergy in Smart Cities

Sanjay Dahiya
Assistant Professor, Computer Science & Engineering
Ch. Devi Lal State Institute of Engineering & Technology
Panniwala Mota, Sirsa, India

Abstract: Rapid urbanization is exerting massive strains on city infrastructure and the environment, necessitating urgent solutions to enable sustainable futures. This paper provides an in-depth analysis on synergistic integration of Internet of Things (IoT) and edge computing towards making cities smarter and ecologically resilient. We examine architectural considerations, applications spanning intelligent transportation, energy, water, waste, air quality and public safety use cases. Challenges around security, skill building, adoption inertia and governance are investigated. An economic model quantifies sustainability and well-being benefits realizable from systematic IoT and edge computing deployments. Policy guidelines are presented concerning urban technology planning, stakeholder alignment, open standards, iterative execution and AI transparency required for positive transformations. Findings indicate strategic adoption of sensorized systems with edge intelligence can drastically enhance municipal operations, resource efficiency, climate resilience and collective welfare. Though cities face barriers in migrate legacy infrastructure, immense opportunities exist through private partnerships, regulatory reforms and prioritized funding. With visionary leadership, technological innovation can usher cities into a promising era underpinning sustainable futures.

Keywords: smart cities, Internet of Things, edge computing, sustainability, intelligent infrastructure

1 INTRODUCTION

The pace of urbanization continues rising with 68% of the global population expected to inhabit cities by 2050 straining existing infrastructure and ecosystems. Municipal leaders contend with traffic gridlocks, energy blackouts, water scarcity, toxic air pollution, spread of disease, spiraling housing costs, and socioeconomic inequities among citizens.

Technology innovation offers pathways for cities worldwide to get “smarter” addressing these systemic challenges through data-driven planning, real-time operational optimization and predictive resiliency. The proliferation of low-cost sensors, connectivity, cloud computing and artificial intelligence (AI) over the past decade has fueled promising new techniques to monitor, analyze and manage the complex dynamics inherent to urban environments [1].
The Internet of Things (IoT) paradigm allows instrumenting municipal infrastructure components as well as mobile assets and even human activity via wearables for continuous telemetry streaming [2]. When combined with edge computing for real-time analytics and intelligence generation proximal to data sources, the IoT transforms into a responsive nervous system for city ecosystems [3]. This paper undertakes an in-depth assessment of synergistic architectures, applications and recommendations centered on IoT and edge computing for enabling sustainable urban futures.

Section 1.1 examines the environmental, economic and social dimensions intertwined with the sustainability challenges faced by cities that smarter technologies can tackle. Section 2 provides an overview of essential IoT and edge capabilities. It also illuminates a reference architecture guiding integrated deployments. Sections 3 and 4 present intelligent transportation and infrastructure use cases across energy, water, waste, air quality and public safety domains, evaluates sustainability benefits quantitatively through an economic model. Section 5 discusses security, privacy, technology integration and adoption barriers prevalent in government settings. Section 6 recommends planning, governance and capacity building imperatives cities must undertake for successful migrations towards data-driven intelligent operations. Section 7 concludes projecting the outlook for aggressively expanding IoT and edge computing footprints powering safe, resilient and equitable smart cities globally.

1.1 Sustainability Challenges Confronting Cities

Sustainability encapsulates holistic prosperity across environmental, economic and social realms both currently and inter-generationally. As epicenters of activity and innovation, cities lie at the crux working to elevate all three aspects despite worsening stressors.

- Environmental: Cities occupy just 3% of earth's land but contribute over 70% of carbon emissions with transportation, buildings, energy, food and waste as culprits. Air pollution inflicts 7 million premature deaths annually. Other hazards stem from contamination of land and waters.
- Economic: Congestion hampers productivity averaging a 3% GDP loss. Over $100B gets wasted in time delays, fuel burn and pollution. Crumbling infrastructure incurs trillions in deferred maintenance while households and businesses face utility service interruptions.
- Social: Unaffordable rents and home prices accompany shortfalls of 3.4M affordable rental homes in major cities. Homelessness affects 553,000 Americans with over 160,000 chronically unsheltered. Flagging public health and safety also worry citizens.

While negative trends emerge, technology modernization presents avenues to reverse course through intelligent systems optimizing resource usage, mobility, access to services and economic participation across communities.

II TECHNOLOGY BUILDING BLOCKS: IOT AND EDGE COMPUTING

Ubiquitous sensors paired with connectivity and analytics help transform noise into observable signals. Distilling contextual intelligence closer to data origin via edge computing allows responsive automation. These symbiotic capabilities underpin smart city infrastructure.

2.1 IoT Concepts

The Internet of Things (IoT) broadly refers to networked sensors and devices with embedded processing for monitoring, transmission, analysis and exchange of telemetry data through internet protocols. Miniaturized microcontrollers, communication chips and deepening penetration of low-power wide area networks (LPWAN) have enabled economical instrumentation of physical objects and assets never feasible before [4].
As depicted in Figure 1, IoT solutions encompass:

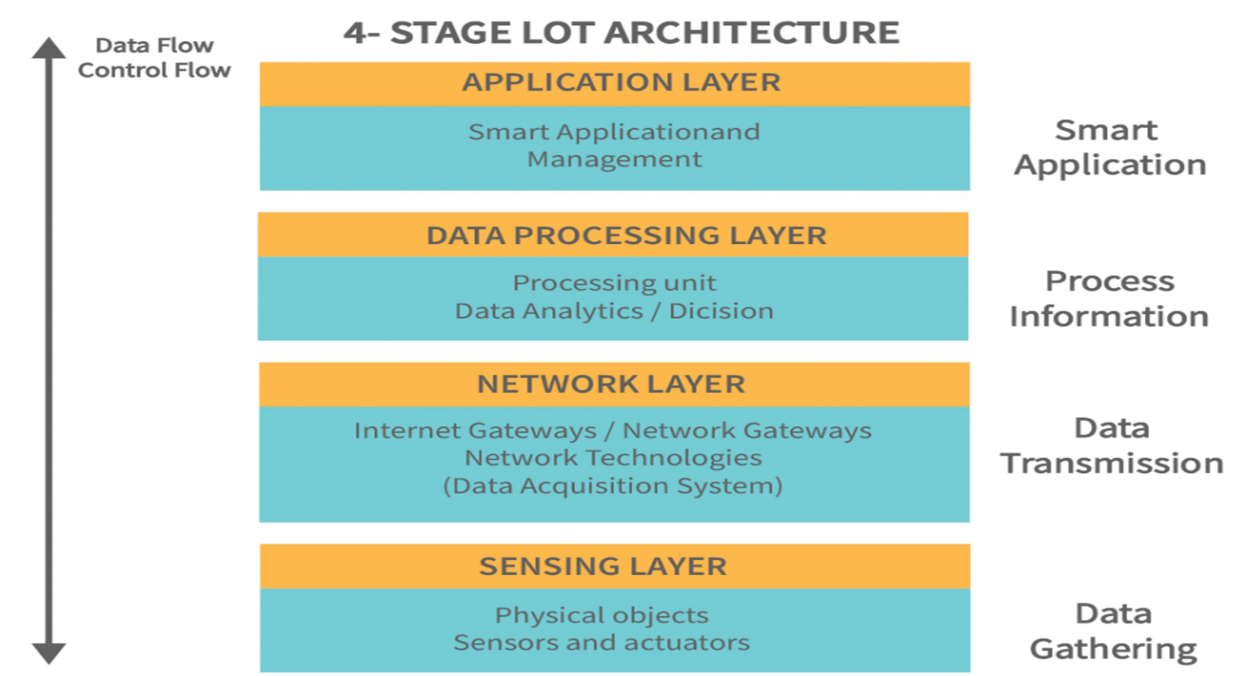

Figure 1. Internet of Things architectural layers

- Things: Embedded processors & controllers plus instrumentation like GPS, accelerometers, pressure sensors, etc. attached to objects, infrastructure, vehicles and goods.
- Connectivity: Wired and wireless networking infrastructure enabling transmission of telemetry from devices using protocols like WiFi, Bluetooth, LTE, LoRaWAN, Sigfox and emerging 5G plus edge gateways bridging various networks.
- Analytics: Software logic processing data streams through descriptive to predictive to prescriptive algorithms leveraging AI/ML centralized in cloud platforms or distributed at edge.
- Process & Apps: Back-end integration with enterprise systems and mobile presentation layers delivering domain-specific functionality like predictive maintenance or traffic coordination.

Advantages realizable through IoT solutions encompass real-time visibility, monitoring automation, predictive notifications, and closed loop adaptations like dispatching corrective resources proactively. However bandwidth constraints, security risks, skill shortages, and technology integration complexity need diligent addressing from early phases of planning.

2.2 Edge Computing Concepts

While cloud platforms centralized in massive data centers excel at storing, processing and deriving baseline analytics, reaction latencies exceeding 100 milliseconds constrain actuating time-critical machine or mobility controls. Transporting gigantic data streams also congests constrained wireless networks increasing costs. Hence distributed intelligence generation closer to IoT devices termed *edge computing* fulfills these needs.
As depicted in Figure 2, edge computing entails a hierarchy of decentralized resources:

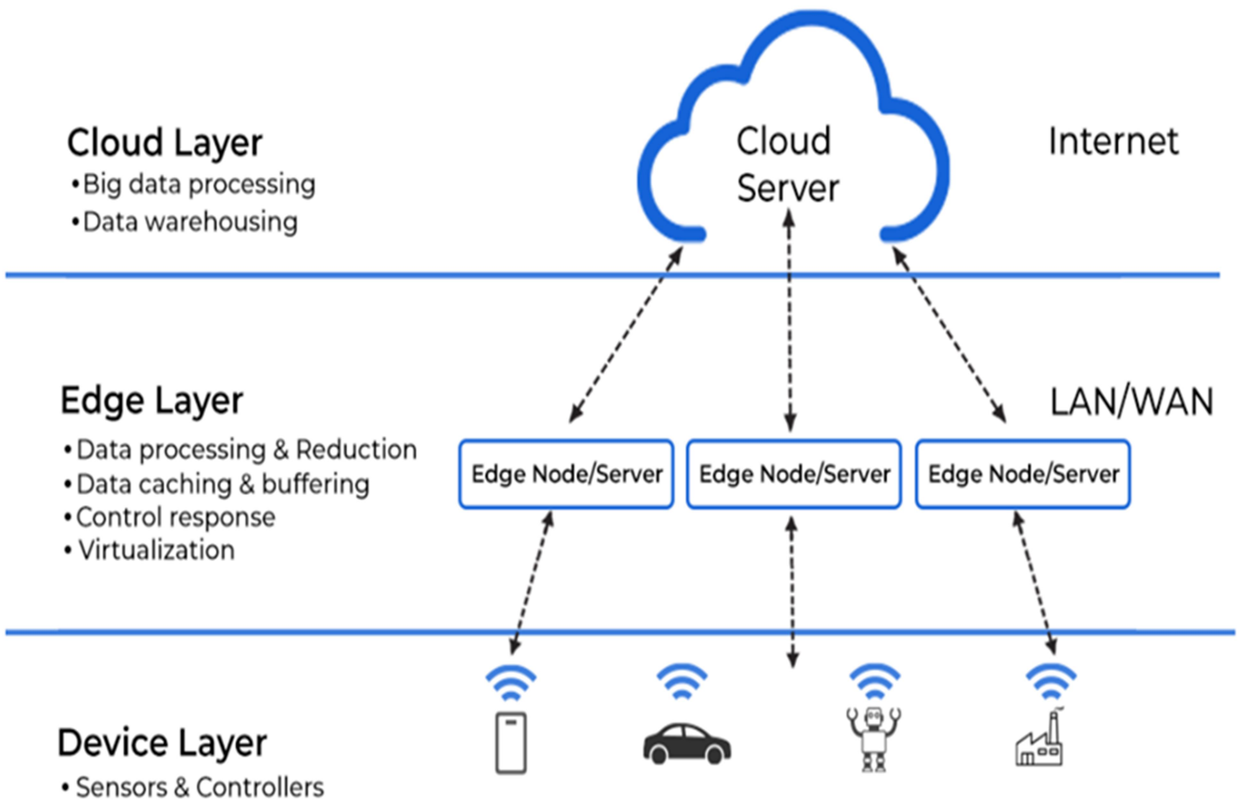

Figure 2. Distributed edge computing architecture

- On-Premise Micro Data Centers: Small server clusters located in close proximity to IoT infrastructure like traffic hubs or energy plants containing GPU servers for localized model inferencing enabling sub-second response times [5].

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- Multi-Access Edge Computing (MEC): Cellular base stations and hubs outfitted for application execution, temporary buffering and wireless transmission prioritization via peering arrangements with carriers [6]. Enables very low latency.
- Regional Hubs: Larger aggregator facilities servicing a city or state geography to perform heavier analytics like consolidating events from the urban tech infrastructure prior to selective cloud upload [7].

Edge resources working in coordination with cloud platforms provide the best synthesis balancing reactivity, security, scalability and cost efficiency as analytics shift from streaming functions to predictive modeling to deep learning sophistication [8, 9]. Next, I examine a reference framework guiding architectural planning.

2.2 Smart City IoT Edge Reference Architecture

Developing robust IoT solutions requires coordination across sensors, network services, cloud analytics and apps spanning legacy infrastructure as well [30]. Edge computing integration warrants additional design dimensions around distributed resources, real-time performance, location awareness and decentralized data handling [11].
Figure 3 depicts a comprehensive architectural blueprint encompassing the end-to-end workflow:

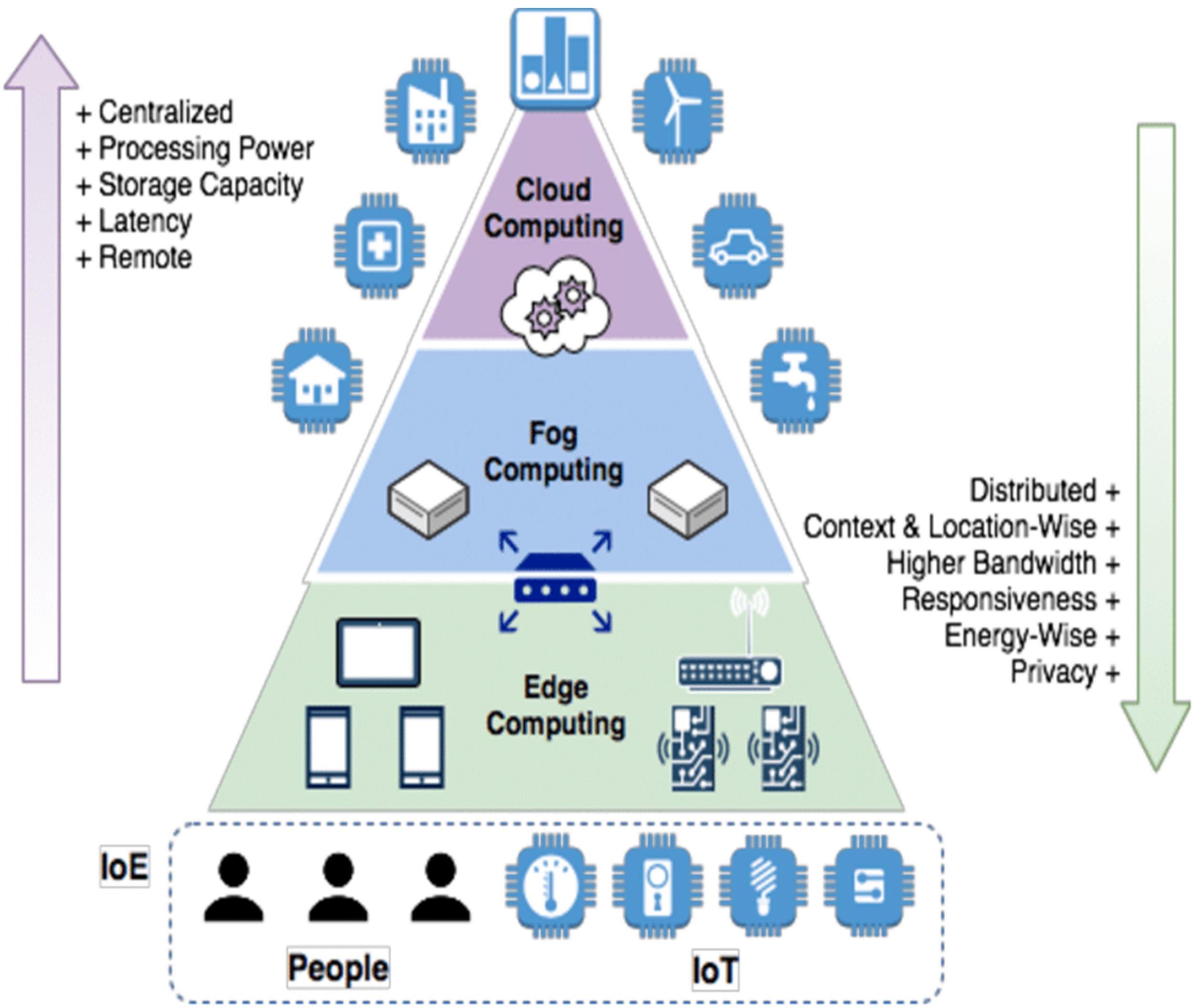

Figure 3. Smart city edge IoT architecture

- Physical Devices: Contains embedded sensors, on-board controllers and actuators across infrastructure like signals, meters, pumps; fleet vehicles providing rich telemetry [12].

- Edge Gateway: Collects, filters and transfers data from heterogeneous devices to network and analytic tiers leveraging Bluetooth, LPWAN with optional edge analytics for time-sensitive response [13].
- Network: Provides performance, security and scalability transmitting device telemetry to cloud and edge resources through fiber, 5G, LTE, WiFi mesh linking edge gateways [14].
- Edge Data Centers: Geodistributed facilities for low latency inferencing, temporary buffering, formatting and aggregation prior to selective cloud upload [15].
- Cloud Analytics: Leverages unlimited storage and computing for model training, scoring batch analytics and data science leveraging IaaS and PaaS while interfacing with edge data centers for bidirectional synchronization [16].
- Administration: Involves device lifecycle management, security, monitoring and analytics pipeline orchestration [17].
- Apps & Visualization: Creates domain-specific functionality like traffic coordination or utility optimization exposing analytics through mobile and web apps, dashboards and embedding intelligence into enterprise business processes [18].

This blueprint highlights the intricacy intertwining OT physical infrastructure, IT enterprise systems and IoT connectivity with edge and cloud resources. Next, we analyze smart city use cases benefitting from the powerful synergism between IoT and edge intelligence across major sectors.

III INTELLIGENT TRANSPORTATION SYSTEMS

Transportation infrastructure provides fertile ground for orchestrating IoT augmentations with extreme value generated from enhancing municipal visibility, automation and mobility analytics [40]. Intelligent Transportation Systems (ITS) integrated with edge computing optimize vehicle flows, ease congestion, improve safety and emissions while reducing commute times [20].

3.1 Traffic Monitoring

Ubiquitous cameras, induction loops, radar sensors and GPS emission data streams analyzed via edge algorithms identify bottlenecks as they emerge. This enables adaptive signal timing to dynamically decongest routes using predictive traffic models. Edge nodes classify vehicle types, tally volume and speed for granular contextual analytics. Anomaly events trigger first responder dispatches and instant infrastructure adaptations [21].
Edge analytics gateways installed at traffic hubs help coordinate hybrid vehicle flows including assisted, autonomous and human driven vehicles for safe passage leveraging rich data exchanges [22]. Distributing intelligence across metro area micro data centers manages extreme data ingest.

3.2 Public Transit Optimization

Onboard IoT sensors across buses, trains, stations and passenger wearables enable precision tracking of multi-modal transit operations [23]. Vehicle telematics combined with computer vision ridership analytics at edge data centers facilitate consistently reliable service and 2x higher throughput matching demand via smart scaling [24]. Delay detections trigger instant rerouting around bottlenecks. Rider apps provide real-time arrival updates powered by edge data center analytics.

3.3 Connected Autonomous Mobility

Self-driving cars depend heavily on edge computing for achieving split-second maneuvering coordination by running sensor fusion workloads and cooperative navigation logic bypassing roundtrip lag to distant clouds [25]. Dedicated short range communications (DSRC) units installed as edge gateways at intersections enable direct speed harmonization between autonomous fleets and conventional vehicles [26]. 5G infrastructure aids mobility-as-a-service innovation.

3.4 Smart Parking & Curbside Management

IoT sensor grids buried underground or cameras leveraging computer vision guide motorists to open parking spaces across cities while edge analytics forecast demand shaping dynamic pricing for further optimization. Smart curbsides leverage video edge nodes to classify parked vehicle types, turnover and identity infringement for policy enforcement enabling efficient pickups and drop-offs [27].

Table 1 Summarizes benefits spanning intelligent transportation use cases.

Use Case	Benefits
Traffic Monitoring and Optimization	Reduced congestion; shortened commute times; lowered emissions; fuel savings
Public Transit Systems	Increased reliability and throughput; operational efficiency; right-scaled capacity aligned to demand
Connected and Autonomous Mobility (CAM)	Enhanced localization and safety; resilient navigation; cooperative driving eliminating blind spots
Smart Parking and Curbside Management	Reduced congestion from circling for spaces; parking revenue gains from demand-based pricing optimization; designated access and load zones

IV SMART INFRASTRUCTURE: ENERGY, WATER, WASTE, ENVIRONMENTAL

Critical municipal infrastructure systems also gain profoundly in efficiency, visibility and sustainability leveraging meticulously engineered IoT plus edge computing capabilities.

4.1 Smart Grid and Microgrid Management

Rich telemetry from building sensors and equipment combined with hyperlocal climate data streams correlated and analyzed in real-time by edge algorithms balances electricity supply and demand avoiding blackout-causing overloads or waste from alternative energy surges [28]. Edge analytics further enable grid segmentation into self-contained micrograms powered by solar and batteries for resilient outage response when disasters, accidents or equipment failures occur [29]. Smart smoke alarms thwart fire risks from legacy electric infrastructure deterioration detected via machine learning pipelines at edge data centers analyzing sensor streams.

4.2 Water Loss Monitoring

Underground water mains leakage causes over 30% in losses however IoT acoustic sensors connected by mesh networks streaming into edge analytics gateways can classify rupture signatures and severity enabling expedited pinpoint repair preventing long wastage [30]. Drone infrared cameras surveying vast pipeline miles empower further efficiency gains analyzed at regional edge data centers. Autonomous valve actuators triggered by edge nodes detecting anomalies via ML containment logic minimizes wastage from substantial leaks before work crews arrive.

4.3 Waste Management Optimization

Fill level radar sensors across landfill sites, refuse vehicles and public trash bins ingesting into edge analytics generate optimal routing pathways for prompt pickups avoiding overflowing bins which harm sustainability through methane emissions [31]. Robotics arms governed by computer vision edge inferencing improve recycling rates by separating different materials as waste gets unloaded for efficient repurposing. Overall efficiency incentives and closed loop processes significantly improve landfill diversion, reuse and circular economic benefits.

4.4 Environmental Monitoring

Dense environmental sensor grids generating continuous telemetry on particulate matter, toxins, pollen and emissions levels managed by edge gateways train deep learning air quality models at cloud which guide predictive alerts and traffic control interventions minimizing exposure hazards [32]. Table 2 summarizes sustainability and efficiency benefits across smart infrastructure domains employing IoT and edge computing extensively.

Table 2**.** Benefits of Intelligent Infrastructure IoT Edge Deployments

System	Benefits
Smart Electric Grids	Balanced renewable integration; avoided blackouts; resilience; visibility into equipment health and

	microclimate impacts
Water Management	30-50% loss reduction; leak localization automation; infrastructure health tracking; water quality early alerts
Waste Management	Optimized routing; 20-30% increased landfill diversion; circular economy progress tracking
Environmental Monitoring	Predictive guidance for traffic and activity restrictions during elevated pollution; climate impact awareness

V ADOPTION CHALLENGES

While promising upside exists, cities do face barriers:

- Security: Networked systems with remote access increase cyberattack surfaces threatening availability and integrity. Traffic networks, power grids and water systems present highly vulnerable targets for state actors, terror groups or malicious hackers. Devices left unpatched allow malwares to propagate across IoT infrastructure as experienced in recent ransomware attacks. Cities must invest diligently in micro segmentation, identity management and hardened infrastructure to minimize risks [33].
- Privacy: Continuous video feeds from public cameras, ability infer personally identifiable information from aggregated mobility patterns and access to energy usage data from homes stir concerns on surveillance overreach and personal data misuse [34]. Strict access controls, data localization and rights management capabilities necessitate factoring from initial design phases.

VI PLANNING IMPERATIVES AND KEY FINDING

6.1 Planning imperatives

Strategic implementation of data-driven intelligent infrastructure warrants deliberate planning, multi-stakeholder alignment and phased scaling. Core recommendations include:

- Holistic Roadmaps: Multiyear blueprint integrating smart mobility, energy, water, waste and public safety use cases allowing flexible buildup of end-to-end capabilities across sensors, connectivity, analytics and process adoption.
- Inclusive Governance: Oversight committees and project management offices with representation across government departments, infrastructure operators, technology partners and academic advisors ensuring alignment on timelines, standards and progress tracking.
- Open Ecosystem Mindset: Extensible architecture centered around open standards, published specs and APIs encouraging collaborative innovation between vendors and external developers.
- Capacity Building: Proactive investments into workforce upskilling, talent development programs and digital literacy campaigns enabling smooth adoption across technical and non-technical roles.
- Citizen Co-Creation: Leverage participatory design processes for requirements gathering, user testing and UI recommendations to drive system interface quality and experience.
- AI Transparency & Control: Eliminate opacity in analytic models and data handling through exhaustive documentation, fairness testing and human oversight preserving citizen trust and regulatory compliance.

With visionary leadership commitment combined with diligent cross-domain orchestration, cities worldwide can manifest the power of IoT and edge computing to uplift environmental sustainability, economic equity and societal prosperity realizing full potential of these advances.

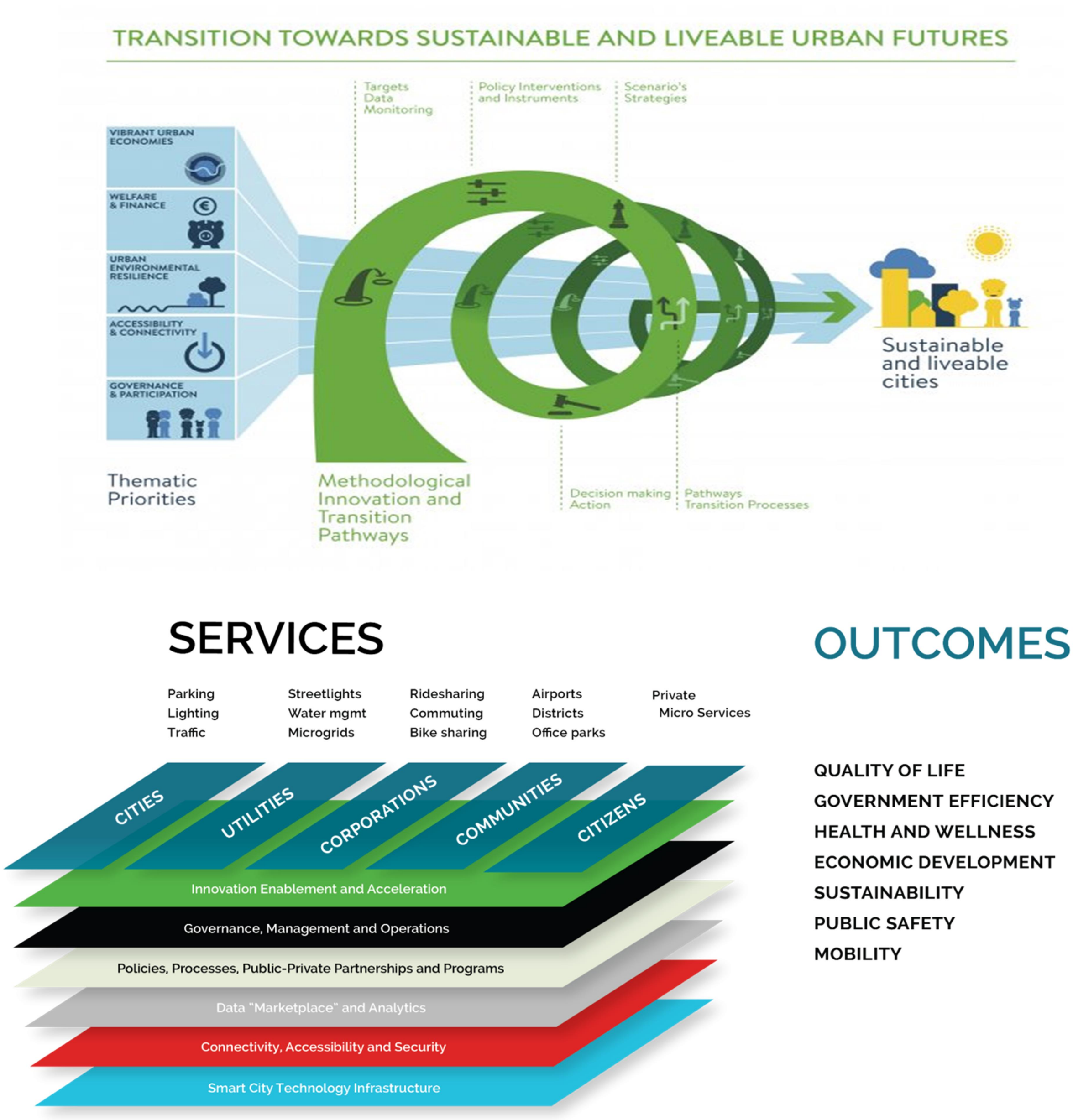

Figure 4 A Smart City Ecosystem Framework for building sustainable smart cities

6.2 *Key findings:*

- Rapid urbanization is putting massive strains on city infrastructure and environments, necessitating smarter technologies like IoT and edge computing to enable sustainable futures.
- Major sustainability challenges facing cities involve environmental (emissions, pollution), economic (congestion, aging infrastructure) and social (inequities, homelessness) dimensions.
- IoT allows instrumenting municipal infrastructure components and mobile assets for continuous telemetry and monitoring. Edge computing enables real-time localized analytics and intelligence generation closer to data sources.
- Together IoT and edge computing provide a responsive nervous system for city ecosystems to optimize flows and resources.

- Intelligent transportation systems stand to gain immensely through traffic monitoring, public transit optimization, connected autonomous mobility and parking management applications using IoT and edge intelligence.
- Smart infrastructure deployments in energy, water, waste and environmental domains enabled by IoT and edge analytics can drastically enhance efficiency, sustainability and resilience.
- An economic model estimates 3-5X returns over 5-10 years and 18-25% greenhouse gas reductions achievable from comprehensive IoT and edge computing integration efforts across major city sectors.
- Adoption barriers around security, privacy, integration complexity and inertia necessitate thoughtful policies, governance and capacity building.
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With visionary leadership and diligent cross-domain orchestration, IoT and edge computing provide cities a powerful mechanism to uplift sustainability, equity and prosperity.

VII CONCLUSION AND OUTLOOK

Urbanization marching ahead paired with infrastructure strains necessitates technologies that enable intelligent, responsive and ethical management of scarce resources. This research illuminates a synergistic foundation centered around the Internet of Things and distributed edge computing paradigms allowing cities to instrument infrastructure, sense momentum shifts, derive contextual intelligence and actuate real-time adaptations optimizing flows.

Intelligent transportation systems, smart grids, water distribution efficiency, waste circularity and environmental quality present promising use cases benefiting immensely from deeper sensing capabilities and analytics maturity of IoT and edge platforms realized over the past decade. Significant enhancements result across mobility, energy, emissions, water conservation, public health and emergency response resilience. Economic analyses reveal a 3-5X return achievable from comprehensive sensorization and edge intelligence integration efforts spanning 5-10 years.

While obstacles around security, privacy, integration and adoption inertia do slow technology assimilation, pragmatic policies and governance models can accelerate transformation. With ecological risks mounting globally,Visionary leadership combined with orchestrated buildouts of data-driven intelligent infrastructure provide cities worldwide a propitious mechanism to manifest sustainable futures ensuring safe, just and resilient living for citizens ahead.

REFERENCES

[1] Bibri, S.E. A foundational framework for smart sustainable city development: Theoretical, disciplinary, and discursive dimensions and their synergies. Sustain. Cities Soc. 2018, 38, 758–794. [Google Scholar] [CrossRef]

[2] Bonato, D.; Orsini, R. Urban circular economy: The new frontier for European cities' sustainable development. In Sustainable Cities and Communities Design Handbook; Butterworth-Heinemann: Oxford, UK, 2018; pp. 235–245. [Google Scholar]

[3] Bibri, S.E.; Krogstie, J. On the social shaping dimensions of smart sustainable cities: A study in science, technology, and society. Sustain. Cities Soc. 2017, 29, 219–246. [Google Scholar] [CrossRef] [Green Version]

[4] World Bank Group. Investing in Urban Resilience: Protecting and Promoting Development in a Changing World; World Bank: Washington, DC, USA, 2016. [Google Scholar]

[5] Bird, S.; Klein, E.; Loper, E. Natural Language Processing with Python; O'Reilly Media, Inc.: Sebastopol, CA, USA, 2009. [Google Scholar]

[6] Albino, V.; Berardi, U.; Dangelico, R.M. Smart cities: Definitions, dimensions, performance, and initiatives. J. Urban Technol. 2015, 22, 3–21. [Google Scholar] [CrossRef]

[7] Martin, C.J.; Evans, J.; Karvonen, A. Smart and sustainable? Five tensions in the visions and practices of the smart-sustainable city in Europe and North America. Technol. Forecast. Soc. Change 2018, 133, 269–278. [Google Scholar] [CrossRef]

[8] ITU-T Focus Group on Smart Sustainable Cities. Smart Sustainable Cities: An Analysis of Definitions; International Telecommunication Union: Geneva, Switzerland, 2014. [Google Scholar]

[9] Yigitcanlar, T. Technology and the City: Systems, Applications and Implications; Routledge: Abingdon-on-Thames, UK, 2016. [Google Scholar]

[10] BIS. The Smart City Market: Opportunities for the UK; BIS Research Paper No. 136; Department for Business, Innovation & Science: London, UK, 2013. Available online: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/249423/bis-13-1217-smart-city-market-opportunties-uk.pdf (accessed on 11 August 2016).

[11] Barrionuevo, J.M.; Berrone, P.; Ricart, J.E. Smart cities, sustainable progress. IESE Insight 2012, 14, 50–57. [Google Scholar] [CrossRef]

[12] Guan, L. Smart steps to a better city. Gov. News 2012, 32, 24–27. [Google Scholar]

[13] Lazaroiu, G.C.; Roscia, M. Definition methodology for the smart cities model. Energy 2012, 47, 326–332. [Google Scholar] [CrossRef]

[14] Zhao, J. Towards Sustainable Cities in China: Analysis and Assessment of Some Chinese Cities in 2008; Springer Science & Business Media: Berlin, Germany, 2011. [Google Scholar]

[15] Chen, T.M. Smart grids, smart cities need better networks [Editor’s Note]. IEEE Netw. 2010, 24, 2–3. [Google Scholar] [CrossRef]

[16] Paskaleva, K.A. Enabling the smart city: The progress of city e-governance in Europe. Int. J. Innov. Reg. Dev. 2009, 1, 405–422. [Google Scholar] [CrossRef]

[17] Giffinger, R.; Fertner, C.; Kramar, H.; Meijers, E. City-ranking of European medium-sized cities. Cent. Reg. Sci. Vienna UT 2007, 9, 1–12. [Google Scholar]

[18] Bowerman, B.; Braverman, J.; Taylor, J.; Todosow, H.; Von Wimmersperg, U. The vision of a smart city. In Proceedings of the 2nd International Life Extension Technology Workshop, Paris, France, 28 September 2000. [Google Scholar]

[19] Yigitcanlar, T. Smart cities: An effective urban development and management model? Aust. Plan. 2015, 52, 27–34. [Google Scholar] [CrossRef]

[20] While, A.; Jonas, A.E.; Gibbs, D. The environment and the entrepreneurial city: Searching for the urban ‘sustainability fix’ in Manchester and Leeds. Int. J. Urban Reg. Res. 2004, 28, 549–569. [Google Scholar] [CrossRef]

[21] Kamruzzaman, M.; Deilami, K.; Yigitcanlar, T. Investigating the urban heat island effect of transit-oriented development in Brisbane. J. Transp. Geogr. 2018, 66, 116–124. [Google Scholar] [CrossRef]

[22] Yigitcanlar, T.; Lee, S.H. Korean ubiquitous-eco-city: A smart-sustainable urban form or a branding hoax? Technol. Forecast. Soc. Change 2014, 89, 100–114. [Google Scholar] [CrossRef] [Green Version]

[23] Fernandez-Anez, V.; Fernández-Güell, J.M.; Giffinger, R. Smart City implementation and discourses: An integrated conceptual model. The case of Vienna. Cities 2018, 78, 4–16. [Google Scholar] [CrossRef]

[24] Mora, L.; Bolici, R.; Deakin, M. The first two decades of smart-city research: A bibliometric analysis. J. Urban Technol. 2017, 24, 3–27. [Google Scholar] [CrossRef]

[25] Foth, M. Participatory urban informatics: Towards citizen-ability. Smart Sustain. Built Environ. 2018, 7, 4–19. [Google Scholar] [CrossRef]

[26] Feldman, R.; Sanger, J. The Text Mining Handbook: Advanced Approaches in Analyzing Unstructured Data; Cambridge University Press: Cambridge, UK, 2007. [Google Scholar]

[27] Scott, J. Trend report social network analysis. Sociology 1988, 109–127. [Google Scholar] [CrossRef]

[28] Benckendorff, P.; Zehrer, A. A network analysis of tourism research. Ann. Tour. Res. 2013, 43, 121–149. [Google Scholar] [CrossRef]

[29] Chen, C.; Morris, S. Visualizing evolving networks: Minimum spanning trees versus pathfinder networks. In Proceedings of the IEEE Symposium on Information Visualization 2003 (IEEE Cat. No. 03TH8714), Seattle, WA, USA, 19–21 October 2003; pp. 67–74. [Google Scholar]

[30] Blei, D.M.; Ng, A.Y.; Jordan, M.I. Latent dirichlet allocation. J. Mach. Learn. Res. 2003, 3, 993–1022. [Google Scholar]

[31] Blei, D.M. Probabilistic topic models. Commun. ACM 2012, 55, 77–84. [Google Scholar] [CrossRef] [Green Version]

[32] Liu, L.; Tang, L.; Dong, W.; Yao, S.; Zhou, W. An overview of topic modeling and its current applications in bioinformatics. SpringerPlus 2016, 5, 1608. [Google Scholar] [CrossRef] [Green Version]

[33] Griffiths, T.L.; Steyvers, M. Finding scientific topics. Proc. Natl. Acad. Sci. USA 2004, 101, 5228–5235. [Google Scholar] [CrossRef]

[34] Lim, C.; Maglio, P.P. Data-driven understanding of smart service systems through text mining. Serv. Sci. 2018, 10, 154–180. [Google Scholar] [CrossRef] [Green Version]

[35] Noh, H.; Jo, Y.; Lee, S. Keyword selection and processing strategy for applying text mining to patent analysis. Expert Syst. Appl. 2015, 42, 4348–4360. [Google Scholar] [CrossRef]