Exploring Opportunities and Challenges in Sustainable and Smart Cities Through the Lens of Smart Technologies

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Abstract. This paper offers a tutorial based on a survey, focusing on the technologies that support and the potential applications within smart cities. It begins by providing a thorough definition of smart cities concepts from both industrial and academic viewpoints, then proceeds to investigate various applications within smart urban environments, spanning from the Internet of Everything to intelligent healthcare, cloud manufacturing, smart additive manufacturing, and geospatial intelligence. Emphasizing key-enabling technologies, the paper underscores the importance of achieving consistent harmony between human and machine efficiency. With the aid of emerging applications and supporting technologies, smart technologies have the potential to augment manufacturing output and enhance customer satisfaction. However, to fully realize the concept of smart cities in the foreseeable future, several challenges and open issues such as security, privacy, human-robot collaboration in industrial settings, scalability, and the skilled workforce need to be effectively addressed. This comprehensive approach aims to provide solutions to contemporary urban challenges while advancing the smart city concept.

Keywords: Smart city · Smart additive manufacturing · Geospatial intelligence · Internet of everything · Cloud manufacturing · Security and privacy

1 Introduction

Urbanization is a process fueled by population growth seen through the expansion of cities globally. By 2050 it is projected that 68% of the worlds population will be living in areas highlighting the trend, towards more interconnected city structures [28]. The 11th United Nations Sustainable Development Goal (SDG) focuses on establishing sustainable cities making it crucial for city planning to incorporate these objectives. The concept of technology driven cities aims to transform centers into high tech hubs with fully automated systems impacting not only the economy but also raising environmental concerns. Cities have

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become centers of resource consumption and regional dependence leading to challenges such as land use issues, strained infrastructure, transportation problems, environmental risks and improving residents quality of life [15]. Emphasizing the development of systems has been widely advocated as a solution to address these complex issues. Existing infrastructure endeavors to provide solutions for overcoming barriers, in constructing adaptable communities [16]. Cities are often described using a range of adjectives, such, as "intelligent" or "digital" [3]. A city is seen as a system with layers; technology forms the base layer, specific applications make up the second layer and user adoption is key, in the layer. Smart cities fundamentally rely on infrastructure [12].

The incorporation of information technology in governance, as highlighted by references [32,53], aims to enhance infrastructure management and optimize resource utilization, with cities adopting electronic technologies to elevate living standards and cultivate sustainable environments within their boundaries. This thinking urban system prioritizes resident services, sustainability, and innovation, leveraging technological systems such as communication networks, machine learning (ML), big data, and the Internet of Things (IoTs) to improve infrastructure efficiency and address environmental challenges [25].

Smart buildings, incorporating sensors, enhance disaster preparedness and maintenance, prioritizing residents' well-being. These sensors, interconnected and invaluable, improve warning systems and optimize traffic flow, focusing on quality of life rather than ICT [27]. Smart cities leverage data and human insights, exploring blockchain technology's challenges and opportunities to enhance service delivery [38]. Technological solutions support city managers in meeting resource demands effectively, driving technological progress and blurring boundaries between physical, virtual, and biological domains [8]. Cutting-edge technologies play pivotal roles in various smart city domains, including energy, transportation, healthcare, information analytics, and city mobility [31].

Geospatial technology has revolutionized the creation, analysis, and visualization of information, encompassing analytics, business intelligence, and data infrastructure. Advancements in sensing, GIS, GPS, radar, and LiDAR enable the capture, processing, and visualization of data, driving the integration of analytics into business operations and increasing government investments in the geospatial technology market, projected to reach USD 1.44 trillion by 2030 [55]. Global initiatives such as the UN Global Geospatial Information Management (UN GGIM) underscore the importance of geomatics, a multidisciplinary field crucial for collecting geospatial data through survey methods, satellite systems, and geographical information systems [11].

The integration of technologies with various disciplines has significantly bolstered the significance of geomatics. Starting from the early days of cartography, the field has evolved with the integration of satellite imagery, enabling a deeper understanding of dynamics within natural and human systems, facilitated by computational software for extensive spatial data processing. This research aims to explore the challenges and opportunities linked to integrating these enabling technologies into applications for smart cities.

2 Application in Smart City Environments

This section explores various potential applications of key enabling technologies within smart city environments, as illustrated in Fig. 1.

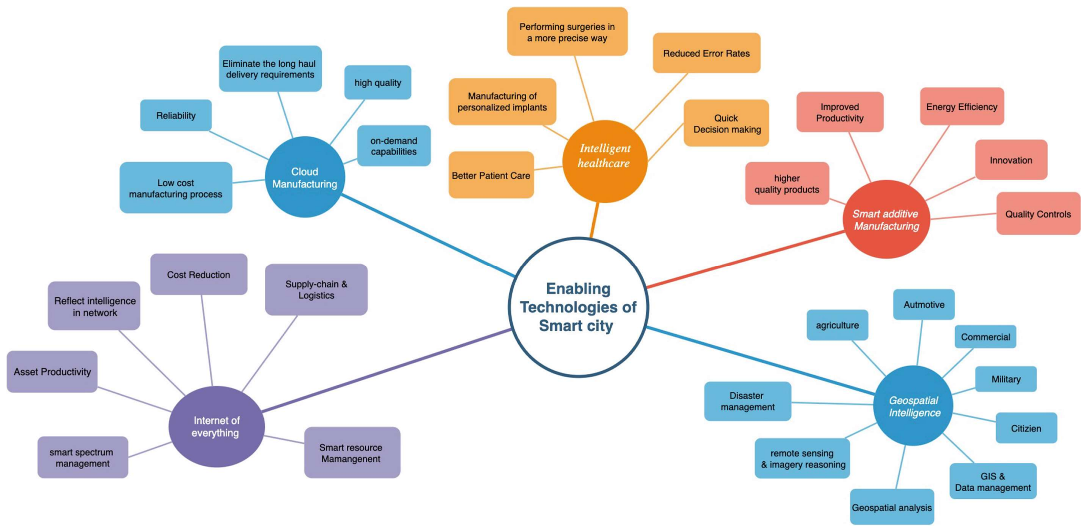

Fig. 1. Key enabling technologies of smart city environments.

Furthermore, the Economist Intelligence Unit, supported by NEC, has seized an opportune moment to introduce technology solutions aimed at enhancing city safety. This initiative involves evaluating 31 segments of industries and economy across 162 indicators, grouped into six pillars, including high tech, intelligent, smart transport, safe cities—digital security, smartest cities, innovative cities, and sustainable cities [10,37,46,48]. Statistical analysis of city performance across various indices in Table 1 reveals that top-ranking cities are predominantly located in Europe, the United States, Southeast Asia, and Australia. Tokyo consistently leads among these cities, with London, New York, and Singapore maintaining their positions in the top five across multiple indices, underscoring the importance of technology in city rankings.

Table 1. Top five cities ranking smart city

Ranking cities	High tech cities	Intelligent cities	Smart transport cities	Safe cities (digital security)	Smartest cities	Innovative cities	Sustainable cities
1	Tokyo	New York City	Singapore	Sydney	London	Tokyo	Oslo
2	London	London	Amsterdam	Singapore	Zurich	London	Stockholm
3	San Francisco	Paris	London	Copenhagen	Taipei City	New York	Tokyo
4	New York	Tokyo	Shanghai	Los Angeles	New York	Paris	Copenhagen
5	Los Angeles	San Francisco	New York	San Francisco	Barcelona	Singapore	Berlin

2.1 Internet of Everything

The Internet of Everything (IoE) acts as a vital link between individuals, processes, data, and objects, offering immense potential for smart city applications [23]. Within industries, IoE advancements can enhance user experiences and provide benefits for businesses and countries, particularly in boosting customer satisfaction and streamlining processes [51]. Despite its potential, IoE faces challenges in optimizing supply chain and logistics efficiency, though it simplifies wireless information exchange among individuals through sensors, such as those used in the Internet of Medical Things (IoMT) for patient monitoring [14].

The effectiveness of IoE hinges on the volume of data collected by sensors and devices, which is analysed through cloud-based applications, as envisioned by initiatives like the UN GGIM [56]. IoE's role in improving efficiency, cost-effectiveness, and security measures is anticipated, with demonstrated successes in wireless sensing technology applied to homes and intelligent building systems [9]. Additionally, the incorporation of IoE has shown promise in significantly enhancing power efficiency [50].

2.2 Cloud Manufacturing

Cloud manufacturing modernizes production by integrating cutting-edge technologies like cloud computing, IoT, and virtualization for efficient and cost-effective collaboration among partners, ensuring reliability, quality, and demand responsiveness while minimizing environmental impact [2]. Control systems oversee operations, IoT sensors gather production data, and studies support the effectiveness of cloud manufacturing as a service-oriented model [43]. Business strategies such as the pay-as-you-go model are explored, anticipating cloud manufacturing's evolution to meet complex demands across engineering, production, and logistics sectors, driven by advancements in intelligence, ML, edge computing (EC), and green communication networks [54].

Furthermore, cognitive computing addresses flexibility challenges in the cognitive Internet of Things (CIoT) by integrating diverse sensory devices, as seen in [5]. Additionally, the anticipated AI-based semantic Internet of Everything (AI-SIoE) hybrid service architecture is expected to cater to various device types across different scenarios [13].

2.3 Smart Additive Manufacturing

Sustainable manufacturing, recognised as a cost-effective approach in today's industries, prioritises efficient production, pollution reduction, and optimal resource utilisation throughout product life-cycles [41]. Additive manufacturing, building product components layer by layer, offers lighter and more durable parts, with smart additive manufacturing (SAM) utilising AI and computer vision to enhance precision and visual representation in 3D printing. Businesses and researchers are increasingly embracing manufacturing solutions, leveraging technologies like AI, IoT, cloud computing, Big Data, and CPS to achieve sustainability, profitability, and productivity [34]. The SAM has emerged as a pivotal technology in the manufacturing sector, enhancing sustainability and customer satisfaction through integrated product features and services [30]. By integrating SAM with automated functions, supply chain processes can minimise product delivery times, maximising benefits in smart city environments.

Moreover, in [1], practical insights into smart system realization and productivity impact were provided, highlighting enabling technologies like networked sensor data interoperability and machine cognition. Additionally, [17] identified key indicators for smart industry in manufacturing, emphasizing its potential to enhance company value and customer satisfaction. Furthermore, the application of smart industry in the textile sector was explored, suggesting its adoption in fibre computing solutions in the near future [36].

2.4 Intelligent Healthcare

Doctors are increasingly using ML models for disease diagnosis, improving accuracy and benefiting patients by saving time and resources [6]. However, there is a growing demand for personalised technology to monitor health indicators such as blood pressure and blood sugar levels [47]. Wearable devices like smartwatches and sensors, supported by cities, offer real-time health data monitoring, stored in the cloud for ML analysis to detect conditions and notify healthcare providers when intervention is required. Collaborative robots (cobots) can aid surgeons by facilitating communication and automating routine tasks, transforming healthcare in smart city environments [4].

The authors in reference [33] propose expanding the use of technology, such as 3D printing and 4D imaging scans, to enhance the capabilities and accessibility of wearable devices. Furthermore, technologies like digital twins (DT) can assist doctors in offering personalised drug prescriptions to patients [35]. Subsequent sections explore recent research on the potential applications of smart healthcare.

2.5 Geospatial Intelligence (GEOINT)

The term GEOINT, coined by Clapper at the National Geospatial-Intelligence Agency, involves extracting geospatial information within a space-time framework, integrating imagery, imagery intelligence, and geospatial data for comprehensive analysis, including crime pattern analysis using methods like hotspot mapping [7]. Satellite data is crucial for monitoring infrastructure, resources, disasters, and health, while geophysical phenomena studies are conducted using various methodologies [22]. A common intelligence framework incorporating data analytics, sensor fusion, augmented reality, and predictive modeling enhances situational awareness in megacities, with the IoT, AI, Cloud, and Big Data playing significant roles in the geospatial ecosystem, enabling technology-based solutions for sustainable transport and demand forecasting [26]. GEOINT significantly contributes to technology connectivity, locational data, and intelligence solutions for smart city development.

2.6 Other Enabling Technologies

Cutting-edge technologies such as Network Slicing (NS), eXtended Reality (XR), and Private Mobile Networks (PMNs) are pivotal in advancing technology-based development and supporting its applications. NS enables the creation of tailored networks on a single physical infrastructure, addressing the diverse needs of smart cities efficiently [52]. XR technologies, encompassing augmented and virtual reality, are already being applied in various smart city projects, including health education, remote healthcare services, and maintenance tasks [19].

Future developments in XR technologies will rely on advancements in networking, EC, virtual communication technologies, and computational capabilities. Additionally, upcoming cognitive networks are expected to align with the requirements of a connected society, offering fast data speeds, minimal delays, high reliability, energy efficiency, and sufficient traffic capacity.

3 Future Research Challenges

Insights from cutting-edge sources reveal that the concept of smart cities is already being implemented across various sectors, including healthcare, cloud manufacturing, advanced AM and GEOINT, integrating technologies such as AI, IoT, EC, and advanced connectivity like 6G and beyond. Challenges in city development include handling diverse data types, effective resource allocation, managing vast data volumes efficiently, and addressing delays, requiring attention for its complete realization. Moreover, discussions have centred on leveraging smart city concepts to address challenges posed by the COVID-19 crisis, employing advanced technologies like holography systems, 4D scans, humanoid robotic assistants, telemedicine, and smart inhaler devices to provide tailor-made treatments and diagnoses, optimize supply chains, digitalize medical services, improve pharmaceutical production methods, raise public awareness about health concerns, and enhance crowd surveillance measures.

Following COVID-19, advanced technologies like cobots, CHIPBOT microchips for COVID patients, and currency-less CURBOT systems may revolutionise touchless transactions, healthcare, and security surveillance. Smart city projects offer potential for emerging sectors, integrating human-machine collaboration and tackling ethical issues, while smart industry developments enable customisable production and sustainable practices, though addressing security, privacy, and ethical concerns is crucial for successful deployment [20].

3.1 Security and Privacy

Security concerns in smart cities mirror those in traditional Cyber-Physical Systems (CPSs), requiring scalable authentication mechanisms to accommodate numerous stakeholders, while integrity and access control mechanisms are essential to secure data transfers and restrict resource access [44]. Transparency through log management systems is crucial for assessing service conformity and resolving conflicts, particularly with the incorporation of AI and automation, necessitating trusted execution and data integrity safeguards [45].

Privacy concerns in smart cities necessitate robust safeguards to protect sensitive data and promote trust within cloud manufacturing environments, while addressing ethical considerations in AI integration is crucial for fostering seamless collaboration between humans and cobots in industrial processes [39]. Despite the potential of blockchain to address security issues, its resource-intensive nature and scalability challenges highlight the need for lightweight frameworks and exploration of alternative security measures like quantum computing for securing Cyber-Physical Production Systems (CPPS) without downtime [49].

3.2 Scalability

Scalability in smart city technologies is vital for adapting to changing workloads, particularly in integrating robots and humans across factories, and can be monitored through service level indicators and agreements given the unpredictable growth of data and human involvement [18]. Technology providers must offer flexible services capable of handling increasing workloads and delivering low-latency responses, while AI-based cobots need to process queries efficiently from dynamic cloud and edge servers without delays.

The scalability of AM poses challenges in integrating its outcomes into production, navigating market trends, and refining industry standards [29]. Solutions may involve leveraging advanced printing capabilities and integrating EC with AI to reduce processing delays and improve predictive capabilities at the network edge.

3.3 Skilled Workforce

Addressing challenges in technology, society, and management demands skilled workers, underscoring the necessity for standardised policies guiding workforce development and training initiatives [21]. Overcoming obstacles like trainer shortages and financial limitations necessitates comprehensive training programmes and public-private partnerships to prepare the workforce for evolving technological demands. Furthermore, successful smart city transition mandates management comprehension of technologies, infrastructure upgrades, and business culture openness to support workforce training and human-cobot collaboration.

Smart manufacturing seeks to integrate workers with cobots and intelligent machines, necessitating regulations to ensure workplace safety and productivity, covering aspects such as defining cobots and guiding AI usage [24]. Establishing standards, laws, and guidelines can expedite and effectively manage the adoption of smart city technologies. Leveraging blockchain and quantum computing for transactions and data preservation, alongside integrating cognitive EC for efficient data processing, is crucial for establishing the foundation of smart systems. Despite advancements, scaling AM still poses challenges, as highlighted in Table 2 regarding the role of enabling technologies in smart city applications.

Table 2. Role of enabling technologies in smart city applications

Enabling technologies	Smart factory	Innovation ecosystem	Intelligent healthcare	Cloud manufacturing	Smart additive manufacturing	Geospatial intelligence
Edge computing	High utilization (H)	H	H	H	H	H
Digital twins	H	Medium utilization (M)	M	H	H	M
Collaborative robots	H	H	Low utilization (L)	H	H	M
Internet of everything	H	H	H	H	H	H
AI	H	H	H	H	H	H
Big data	H	H	H	H	H	H
Blockchain	H	H	H	H	H	H
Network slicing	H	L	H	H	H	M
Extended reality	H	H	H	H	H	M
Private mobile networks	H	L	M	M	H	M
6G and beyond	H	H	H	H	H	M

4 Conclusion

In conclusion, smart technologies offer significant opportunities for creating sustainable and intelligent urban environments through diverse applications such as the Internet of Everything, intelligent healthcare, cloud and smart manufacturing, and geospatial intelligence. However, realizing the full potential of the smart city paradigm faces key challenges, including security, privacy, human-robot collaboration, scalability, and skilled workforce development. Overcoming these hurdles requires collaborative, interdisciplinary efforts from stakeholders, supported by sustainable practices balancing economic, environmental, and social factors. Addressing the risks and challenges of smart technologies is crucial for cities to unlock their transformative potential, leading to an era of innovation, prosperity, and resilience in addressing urbanization issues.

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