smart cities

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Review

Exploring the Symbiotic Relationship between Digital Transformation, Infrastructure, Service Delivery, and Governance for Smart Sustainable Cities

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Abstract: Infrastructure, service delivery, governance, and digital transformation stand as indispensable cornerstones, playing pivotal roles in the establishment of intelligent and sustainable urban centers. While the extant literature has underscored the significance of each of these elements, their interconnected and symbiotic relationship demands a more profound exploration. Grounded in a systematic review of the existing literature and relevant case studies, this paper explored the intricate interplay between digital transformation, infrastructure development, service delivery, and governance in contemporary society, all in the pursuit of cultivating smart sustainable cities. It contends that by collaboratively working together, these four pillars possess the transformative potential to turn cities into smart and sustainable cities. Digital transformation emerges as the catalyst, propelling innovation and efficiency, while infrastructure forms the bedrock for the seamless delivery of services. Effective governance, in turn, ensures alignment with the evolving needs of citizens. In essence, this study underscores the transformative power of combined action, asserting that the interdependent elements within can transform cities beyond merely having smart or sustainable status to become smart sustainable cities. This paradigm shift harmonizes technological advancements with the foundational goals of sustainable development, steering towards a holistic and inclusive urban future.

Keywords: digital transformation; governance; infrastructure; service delivery; sustainable cities; smart cities; smart sustainable cities

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1. Introduction

The shift in discourse towards sustainable development has evolved from singular environmental concerns to a comprehensive focus on environmental, social, and economic development [1]. The notion of sustainable cities emerged as a response to growing concerns about environmental degradation, efficient use of scarce resources, and the imperative to create inclusive and resilient urban spaces [2]. This evolution led to the United Nations formally incorporating the development of sustainable cities and communities as one of its Sustainable Development Goals (SDG 11).

Sustainable cities, defined as inventive urban centers with a triple-bottom-line approach, prioritize social, economic, and environmental impact [3]. They aim to provide a sustainable and resilient habitat for the existing population while ensuring the potential for future generations to enjoy a similar quality of life [4–7]. The United Nations SDG 11 outlines these cities as dedicated to achieving environmental, social, and economic sustainability, with inclusivity, safety, and resilience.

In practical terms, sustainable cities commit to fortifying societies and economies, cultivating employment and entrepreneurial opportunities, and providing accessible and affordable housing. These cities focus on inclusivity and sustainable economic growth, minimizing resource consumption, waste, and emissions. Moreover, they prioritize investments in public transportation, the creation of green public spaces, and participatory governance, planning, and decision making [4–8].

Lately, running parallel to the sustainable cities movement is the emergence of smart cities, defined diversely based on attributes and contexts [9,10]. According to one perspective, smart cities employ technologies, pervasive computing, and digital tools to govern and manage information and resources, fostering real-time engagement with places, activities, and people [11]. They are characterized by economic efficiency, environmental sustainability, distinctive urban identity, favorable living conditions, and inclusive governance [8–10,12–17]. For example, smart cities prioritize intelligent infrastructure, energy conservation, enhanced mobility, and advanced waste management facilitated by smart technology [12–15]. Another perspective characterizes smart cities by six key attributes: a smart economy, smart people, smart mobility, smart environment, smart governance, and smart living [16,18–21]. This perspective focuses on smart humans, encompassing social innovation, smart citizenry, knowledge capital, and inter-organizational collaboration.

While the term 'sustainable city' has traditionally been favored, 'smart city' has gained momentum and is increasingly becoming the leading driver of urban sustainability and regeneration initiatives [22]. However, both models pose challenges and engender issues in alignment with the foundational goals of sustainable development [23]. The smart city concept, in particular, has faced criticism for being a technocentric approach to sustainability [24–27].

Numerous studies explored sustainable and smart cities separately, unveiling critical nuances for each type [8,24]. In response to the challenges of each concept, recent research focuses on integrating sustainability into smart city approaches and making sustainable city models smarter [4–7,23,24,26,28–30]. Beyond 'smart' and 'sustainable cities', the concept of 'smart sustainable cities' was introduced by the United Nations Economic Commission for Europe (UNECE). Scholars argue that these innovative urban centers leverage Information Communication Technologies (ICTs) to enhance the quality of life across economic, social, environmental, and cultural dimensions [4–8,27].

In recent years, research on the intersection of concepts of smart and sustainable cities known as smart sustainable cities has emerged. For example, Freeman (2017) probed into the origin and implementation of the smart sustainable city concept [23], while Bibri and Krogstie (2019) proposed a novel model for future smart sustainable cities [24]. Trindade et al. (2017) contributed a theoretical basis, emphasizing the relationship between sustainable urban development and smart cities [31]. Ahvenniemi et al. (2017) explored the difference between smart and sustainable cities, underlining that technologies in smart cities should enable sustainable development [32]. Martin et al. (2018) examined tensions in the visions and practices of smart sustainable cities, advocating for empowerment and inclusion [27]. Ibrahim et al. (2018) offer a roadmap for transforming a city into a smart sustainable entity [33].

However, three prominent challenges emerge concerning smart sustainable cities. Firstly, the impact of digital technology on environmental and social sustainability remains marginal [34–37]. Secondly, the fragmented approach to smart city development lacks inclusivity and consideration for local contexts [38–42]. Thirdly, existing research on smart sustainable cities primarily focuses on philosophies and conceptualization, neglecting to explore the models and relationships between foundational city elements—infrastructure, technology, service delivery, and governance [16,26,43,44]. While acknowledging the importance of the first two aspects, which have been explored to a certain extent both philosophically and empirically, this study focuses on addressing the third challenge. This is because there exists a significant research gap in understanding how the four vital city elements—infrastructure, digital technology, service delivery, and governance—synergize to transform a city into a smart sustainable entity. Consequently, this study explored the symbiotic relationship among these four key aspects to drive the development of smart sustainable cities, departing from the current trend in research in the field. In this context, the study initially conceptualizes the smart sustainable city, followed by delineating the roles of infrastructure, service delivery, governance, and digital transformation, along with their alignment. Furthermore, it analyzes the symbiotic linkages among these aspects,

unravelling how these relationships manifest within the context of smart sustainable cities. For this purpose, the key research questions explored are as follows:

- How is a smart sustainable city conceptualized in the wake of existing two categories such as smart city and sustainable city?
- What roles do infrastructure, serviced delivery, digital transformation, and governance play in 'smart cities' and 'sustainable cities'?
- What are the interconnectedness and symbiotic relationships between the four aspects—infrastructure, service delivery, governance, and digital transformation—in the context of smart sustainable cities?

The novelty of this paper lies in elucidating how digital transformation, serving as a catalyst for innovation, can enhance infrastructure efficiency to facilitate effective and seamless service delivery, as well as foster effective governance. It is thus theorized that these aspects collectively contribute to the transformation of cities into smart sustainable entities.

2. Materials and Methods

The research adopted a qualitative methodological approach, with an extensive exploration of the extant literature and case studies to unravel the complexities inherent in smart sustainable cities. Given the interdisciplinary nature of the field, the sources of the literature span a diverse range, encompassing scholarly journal articles, books, book chapters, conference proceedings, reports, news articles, web articles, etc. The imperative was to gather the most pertinent literature from these varied sources, tailored to the study's focus.

This investigation involved the formulation of a thorough search strategy, the curation of scholarly sources, the establishment of inclusion and exclusion criteria, the systematic organization of literature based on thematic elements, and the subsequent application of thematic analyses.

2.1. Search Strategy and Scholarly Sources

A comprehensive exploration of scholarly literature was undertaken to investigate published works centered on the primary domains of smart cities, sustainable cities, and smart sustainable cities, along with their associated elements. Given the study's specific focus on the interplay between infrastructure, service delivery, governance, and digital transformation, the search was extended to encompass these interconnected facets within the aforementioned primary domains.

While scholarly peer-reviewed journal articles constituted the primary sources, valuable insights were also derived from diverse sources such as conference proceedings, books, reports, and online articles. Multiple databases, including Elseveie (Science Direct, Scopus), Wiley Online, Taylor and Francis/Routledge, Sage, Springer, EbscoHost, Google Scholar, Research Gate, Academia.edu, etc., were meticulously explored. Scholarly articles from the above-mentioned sources were systematically gathered, categorized, and subjected to critical assessment.

The search employed a strategic use of keywords, such as sustainable cities, smart cities, smart sustainable cities, ICT use in cities, Artificial Intelligence (AI) application in cities, digital transformation, infrastructure, service delivery, city flow, smart governance, strategies for smart sustainable cities, and opportunities and challenges of smart sustainable cities, to ensure a comprehensive and targeted retrieval of the relevant literature. While compiling the articles, four criteria—authenticity, credibility, representation, and meaning [45]—were employed to assess the quality of the articles.

2.2. Inclusion and Exclusions

The inclusion and exclusion criteria were guided by the research questions posed in this study. The inclusion criteria encompassed diverse dimensions of smart cities, sustainable cities, and smart sustainable cities. Additionally, it considered elements such as ICT use, digital transformation, infrastructure, service delivery, city flow, smart governance,

dimensions, indicators, factors, challenges, opportunities, strategies, and other relevant aspects for the three city types—smart city, sustainable city, and smart sustainable cities.

Conversely, aspects that did not directly contribute to the investigation of interconnectedness and symbiotic relationships, as outlined in the research questions, were excluded. This entailed excluding considerations of economic, environmental, social, and cultural aspects from the scope of the study.

2.3. Organisation of the Literature

The initial search, involving screening keywords and abstracts, yielded over 500 articles. Following a scrutiny of the articles based on inclusion and exclusion criteria, and their subsequent organization under themes and subthemes, 184 articles emerged as pertinent and were selected for the final review and analysis. These chosen articles comprise 65.82% peer-reviewed journal articles, 6.63% conference proceedings, 8.67% books, 5.61% book chapters, 12.76% reports, and 0.51% theses (Table 1).

Furthermore, the selected articles were categorized according to the type of cities such as smart, sustainable, and smart sustainable cities. In addition to this, articles were categorized under various aspects such as infrastructure, service delivery, governance, and digital transformation. However, it was observed that many of the articles investigated multiple and overlapping aspects. However, a breakdown of the articles was conducted on the seven aspects mentioned above irrespective of the fact that an article might have investigated overlapping or multiple aspects. Figure 1 presents the distribution of articles across different elements/aspects of smart sustainable cities. An aspect-wise breakdown reveals that articles belonging to aspects related to smart cities, sustainable cities, and smart sustainable cities are 16.84%, 10.20%, and 8.16%, respectively. Infrastructure and service delivery were covered in 30.61% and 27.04% of articles, while digital transformation and governance were examined in 27.04% and 11.73%, respectively. This indicates a reasonable distribution of articles from varied authentic sources; therefore, the results are suitable for review and further analyses.

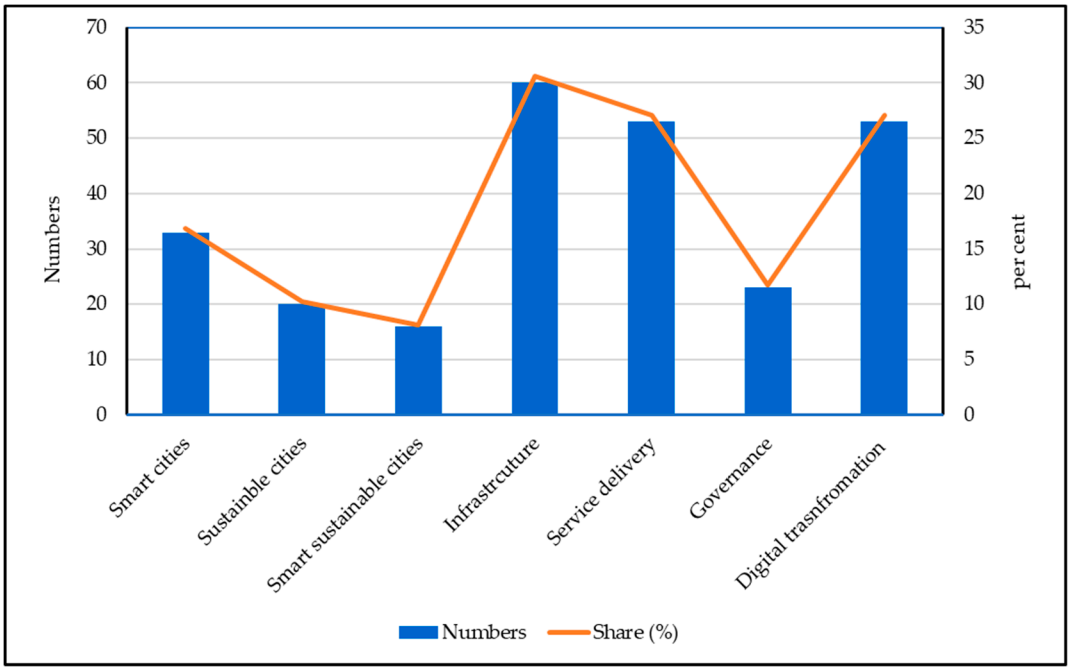

Figure 1. Articles under various elements/aspects of smart sustainable cities.

Table 1. Sources of the literature.

Literature Source	Numbers	Share (%)
Journal articles	130	65.82
Conference Proceedings	13	6.63
Books	17	8.67
Book chapters	11	5.61
Report	25	12.76
Thesis	1	0.51
Total	196	100.00

2.4. Analyses

The collected literature underwent systematic review and analysis, employing specific themes and subthemes within each theme. The analytical framework comprised the following themes and sub-themes.

- Defining smart sustainable cities.
  - Smart cities;
  - Sustainable cities;
  - Smart sustainable cities.
- Conceptual Framework for Smart Sustainable Cities.
- Role of infrastructure, serviced delivery, digital transformation and governance in 'smart cities' and 'sustainable cities'.
- Interconnectedness and symbiotic relationships between the four aspects-infrastructure, service delivery, governance and digital transformation.
  - Digital Transformation and Infrastructure;
  - Infrastructure and Service Delivery;
  - Digital transformation and service delivery;
  - Service Delivery and Governance;
  - Governance and Digital Transformation;
  - Case Studies of successful symbiotic relationships.

The subsequent sections offer in-depth discussions of the findings within each thematic category.

Moreover, the thematic analyses derived from the literature review were substantiated with evidence and examples drawn from case studies on symbiotic relationships observed in five countries: Singapore, Estonia, India, the UK, and Rwanda. Although no specific examples from individual cities were identified, the interdependent and symbiotic relationships observed across various sectors in the aforementioned countries demonstrated how their implementation at the city level could catalyze the transformation of cities into smart sustainable entities.

3. Conceptualizing a Smart Sustainable City

3.1. Smart Cities

The global discourse on smart cities lacks a universal consensus due to varying interpretations rooted in context and function. One perspective defines a smart city through the lens of ICT utilization, AI use, universal connectivity, extensive data use, social capital, business innovation, intelligent communities, and ecological sustainability [10,14,46]. Within this paradigm, a smart city is envisaged as an interconnected, instrumented, and intelligent urban space optimizing functionalities through ICT and advanced technologies such as AI [10,14,47–49]. Another viewpoint adopts a holistic approach, suggesting a city is smart if it excels in one or more of six key attributes: economy, mobility, people, environment, governance, and living conditions [16,18–20,50,51]. Cities in Europe and North America exemplify smartness by fostering entrepreneurship, innovation, ICT usage, connectivity, mobility, participatory governance, sustainability, and resident empowerment [33,52,53].

In the Global South, two distinct smart city models have emerged. One prioritizes specialized cities with ICT connectivity, sustainable infrastructure, and advanced transportation to foster entrepreneurship and economic activities [10,16,48,54]. The second model focuses on improving existing cities by enhancing infrastructure, services, transportation, environmental sustainability, and overall quality of life, emphasizing ICT connectivity, energy efficiency, an entrepreneurial ecosystem, aesthetic urban environments, and participatory governance [9,10,48,55].

Essentially, smart cities might have six characteristics that include smart governance, smart people, smart mobility, smart economy, smart environment, and smart living. However, the overarching and catalytic role of shaping these characteristics in a city is performed through the ubiquitous use of ICT. Thus, a smart city seamlessly integrates technologies, ubiquitous computing, and digital instruments into urban life [11,25,56]. This integration enables real-time precision in managing functions, processes, and engagements, resulting in enhanced economic efficiency, improved environmental sustainability, enhanced quality of life, effective service delivery, and distinctive urban images [32,56–58]. Moreover, smart cities are governed by participatory and inclusive governance models [9,14,16–18,33,55,59].

3.2. Sustainable Cities

The conceptualization of a sustainable city is diverse, with varying definitions [44,60]. The sustainable development of a city has been a primary focus in the last decades. Rogers (1998) defines a sustainable city as an urban area where an enhanced quality of life coexists with policies effectively curbing demands on external resources [61]. It evolves into a self-sufficient economic, social, and environmental system. Brugmann (1997) [62] and Meadows (1999) emphasize environmental performance, prioritizing measurement, and reduction in pollution, greenhouse gas emissions, energy, water consumption, and land loss, while improving water quality, recycling rates, green-space ratios, and forest preservation [63].

Contrastingly, Rode and Burdett (2011) advocate for socio-economic aspects, emphasizing social equity and a greener living environment for sustainable city development [64]. They argue for proximity, density, and variety to foster productivity and innovation. In essence, a sustainable city is environmentally safe, socially inclusive, and economically productive, enabling citizens to meet their needs without degrading the natural world [65,66]. The sustainable city advocates a systematic approach, recognizing vital relationships between people, socio-economic activities, and the environment [32,67]. Thus, a sustainable city has to achieve a dynamic balance among economic, environmental, and socio-cultural development goals, framed within a local governance system characterized by greater citizen involvement and inclusiveness [68]. Consequently, the sustainable city can be conceptualized in terms of four dimensions: environment, economy sociocultural, and governance. These dimensions given their interdependence, synergy, and equal importance should work in tandem to enable the attainment of sustainable city goals. This holistic perspective underscores the interconnectedness of ecological, social, and economic factors in sustainable urban development.

3.3. Smart Sustainable Cities

The term ‘smart sustainable city’ gained prominence in urban development around 2015 [26,44,69]. Despite the abundance of discourse on ‘smart’ and ‘sustainable cities’, specific studies on ‘smart sustainable cities’ are relatively scarce in academic journals. However, notable contributions from Scandinavian countries, especially Sweden and Norway, have emerged [26,43,44].

Investigations in this field, notably the scholarly contributions of Bibri and Krogstie (2017), have primarily focused on formulating precise definitions and enhancing the conceptual framework, specifically probing the intricate landscape of the smart sustainable cities field [44]. Höjer and Wangel (2015) envisage smart sustainable cities as an aggregate concept, asserting that smartness, sustainability, and urbanity must coexist for a city to qualify as smart sustainable [26]. This implies that cities can be sustainable or incorporate

smart technologies independently, emphasizing the necessity for their amalgamation to define a smart sustainable city. Another approach combines sustainable development with ICT infrastructure and smartness in an urban environment, giving rise to the idea of a smart sustainable city [26,67,69]. Consequently, the dimensions of a smart sustainable city include the dimensions of a sustainable city performed and managed by digital technologies.

In the context of sustainability of smart cities, the focus of smart cities is on utilizing clean, climate-friendly technology to mitigate carbon emissions, a significant contributor to climate change and environmental degradation [34–36]. However, this emphasis on carbon reduction often overshadows other ecological concerns such as habitat loss, water scarcity, and ecosystem disruptions [36]. Despite technological advancements and reduced carbon emissions, the overall environmental impact of smart cities remains marginal. Additionally, challenges related to the supply chain influence the environmental sustainability of smart cities. For example, the development of smart devices needs the extraction of a wide range of resources (such as raw materials, minerals, metals, etc.) and the use of large amounts of oil and gas for energy production to power processes of production and distribution. The impact of such processes on the environment is enormous; moreover, it destabilizes the ecosystem.

While smart city initiatives prioritize economic and partially environmental factors, they often neglect social aspects [36]. Critics argue that smart cities and ICTs fail to address environmental and social challenges; instead, they contribute to them [37]. Moreover, it was argued that the sustainability of cities adopting smart technologies may be contingent upon the exploitation of resources and livelihoods elsewhere [37].

Furthermore, smart city initiatives typically adhere to a homogenous, systematic approach in theory but exhibit heterogeneity and fragmentation in practice, particularly in the Global South [38,39]. Many projects are implemented on a small scale, resulting in isolated urban bubbles that exacerbate socio-spatial struggles [40]. This fragmented development often lacks coordination and comprehensive planning, leading to a lack of inclusivity and consideration for local contexts [39,41,42].

Also, administrative geography significantly influences the deployment of smart city technologies, resulting in disparities in service accessibility among people [41]. In other words, local contexts and demands play a crucial role in shaping smart sustainable cities. Moreover, the integration of smart technologies with neoliberal urbanism presents sustainability challenges, as it prioritizes monetizable activities over holistic development [39]. Achieving sustainability in smart cities requires addressing economic, social, and environmental factors while considering local contexts and challenges. Thus, an effective high-level overview roadmap is crucial for planning this transformation process [67].

Nevertheless, a joint definition by the United Nations Economic Commission for Europe (UNECE) and the International Telecommunication Union (ITU) describes a smart sustainable city as an innovative urban center using ICTs to enhance the quality of life, improve urban operations and services, and boost competitiveness across economic, social, environmental, and cultural dimensions [23]. Transforming cities into smart sustainable cities requires an efficient process, considering city context, local interests, citizen well-being, readiness for change, and delivery of smart and sustainable solutions at all levels [33].

3.4. A General Conceptual Framework for Smart Sustainable Cities

Figure 2 presents a conceptual framework for a smart sustainable city. The major considered determinants of a sustainable city are economy, environment, socio-cultural aspects, and governance. On the other hand, infrastructure, service delivery, and governance all enabled and managed by digital technology are pivotal for smart cities. Despite the environmental and social sustainability challenges of smart cities [37–39], infrastructure, service delivery, governance, and digital technology contribute to both the sustainability and smartness of the cities [9,10,16,32,48,54,55,67,68]. Therefore, in this framework, it was considered that city infrastructure serves as the backbone, influencing socio-economic functions and impacting the environment. Efficient service delivery is essential for urban

life's smooth flow. Effective governance manages the economy, society, city dynamics, and service delivery. Digital transformation acting as a catalyst becomes a vital factor in enhancing the efficiency of these dimensions to benefit society. Thus, the study theorized that a symbiotic relationship exists between infrastructure, service delivery, governance, and digital transformation in crafting a smart sustainable city. However, since the focus is on infrastructure, service delivery, and governance enabled by digital technologies, the conceptualization of smart sustainable cities was kept within the context of the four above-mentioned aspects and detailed discussion on the environmental and social sustainability and impact of fragmented approach was kept out of the scope of the study.

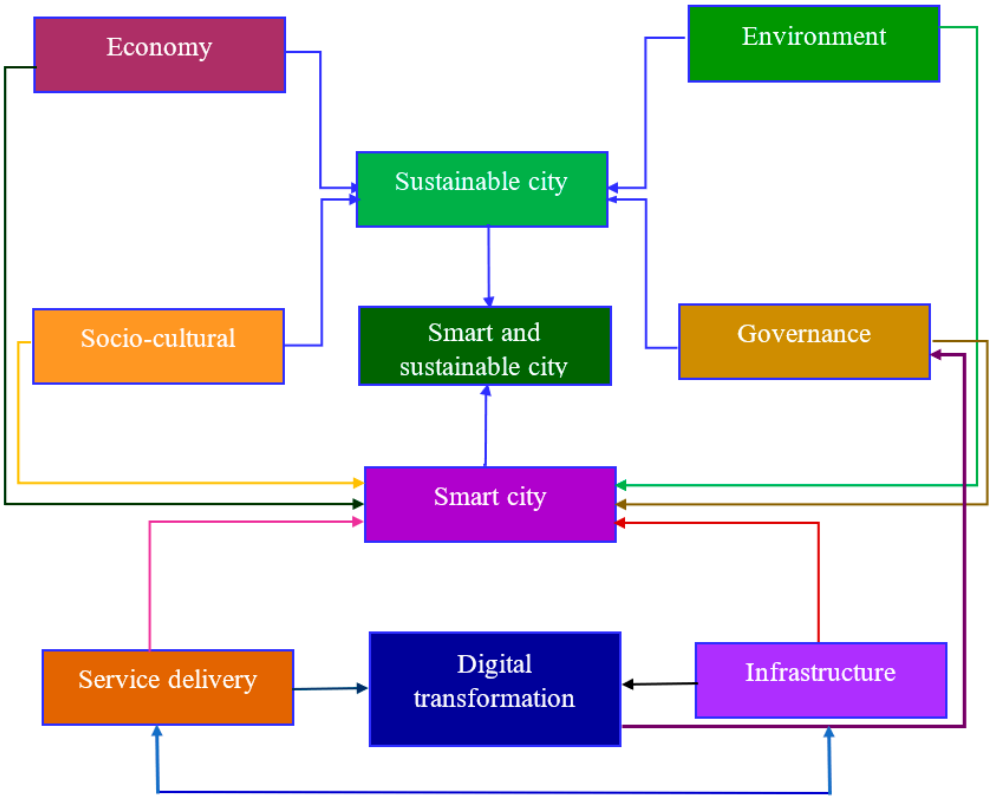

Figure 2. Conceptual framework of a smart sustainable city.

4. Role of Infrastructure, Serviced Delivery, Governance, and Digital Transformation in 'Smart Cities' and 'Sustainable Cities'

The scholarly literature emphasizes the pivotal roles of infrastructure, service delivery, governance, and digital transformation, in shaping 'sustainable' and 'smart cities' [70,71]. The United Nations (2018) [72] underscores infrastructure as crucial for economic growth and improved urban quality of life, emphasizing its role in minimizing environmental impact and enhancing resilience against climate change [73].

Given the importance of efficient service delivery, emphasizing its impact on citizen satisfaction and social equity within urban areas has been highlighted [74–76]. Governance plays a critical role in sustainable urban development [77–80] with stakeholder engagement, adaptive management, and collaborative decision-making contributing to resilient and sustainable cities [81].

The realm of digital transformation is increasingly acknowledged as a catalyst for sustainability in cities [81–84]. Meng et al. (2023) emphasize digitalization competitiveness and enhanced productivity [85]. Nam and Pardo (2011) highlighted how digital transformation optimizes resource utilization, enhances connectivity, and augments the overall efficiency of urban systems [86]. The holistic integration of these elements proves indispensable in the pursuit of sustainable urban development [12].

Similarly, the literature consistently affirms that infrastructure, service delivery, governance, and digital transformation collaboratively shape smart cities, fostering innovation and efficiency [70–80]. Infrastructure is a linchpin, facilitating advanced technology deployment [70,71,83], while well-designed infrastructure is integral for seamless connectivity and smart solutions integration [50]. Service delivery optimization through technology is highlighted in smart cities [87] enhancing the experience of city inhabitants [86]. Effective governance is pivotal for smart cities' success [9,88], with collaboration and data-driven decision-making playing a crucial role in realizing smart city initiatives [89,90]. Digital transformation, which leverages technology, is at the core of smart cities [83,90], transforming cities into dynamic and responsive environments [19]. These interconnected elements substantiate the multifaceted approach essential for the development and sustenance of smart cities.

Therefore, well-planned, designed, and efficient infrastructure, as well as optimized service delivery, proficient governance, and innovative digital solutions are indispensable for developing both 'smart' and 'sustainable' cities [12] and consequently smart sustainable cities.

The diverse elements related to infrastructure, service delivery, governance, and digital transformation influencing smart sustainable cities as adapted from the United for Smart Sustainable Cities (U4SSC) Key Performance Indicators (KPIs) project [91] are presented in Table 2. The amalgamation of these elements collectively propels environmental sustainability, economic prosperity, and an improved quality of life in urban areas. Therefore, in this study, a synergistic integration, emphasizing a harmonious approach to creating smart sustainable cities, is theorized.

Table 2. Diverse elements of infrastructure, service delivery, governance, and digital transformation.

Infrastructure	Service Delivery	Governance	Digital Transformation
Basic water supply system	Drinking water quality	Citizen participation in decision-making and implementation	Household internet access, fixed broadband subscriptions
Potable water supply system	Water consumption	Responsiveness	Wireless broadband subscriptions
Wastewater collection system	Freshwater consumption	Emergency service response time	Wireless broadband coverage
Household sanitation system	Wastewater treatment solid Waste treatment	Police service	Availability of WIFI in public areas
Electricity including renewable energy infrastructure	Electricity consumption, electricity system outage time, electricity system outage frequency, renewable energy consumption, residential thermal energy consumption	Fire service, crime prevention, traffic facilities childcare availability, natural disaster-related activities, disaster-related economic plans, resilience plans	Household internet access, fixed broadband subscriptions, student ICT access, electronic health records, digital financing/banking/payment system
Public transport network	EMF exposure, noise exposure		
Bicycle network	Bicycling		
Transportation mode share	Efficient transportation		
Shared bicycles	Bicycling		
Shared vehicles	Ride share		
Low-carbon emission passenger vehicles	Low air pollution		
Public transport network convenience	Travel time index		
Pedestrian infrastructure	Public building sustainability		
Public buildings	Public building energy consumption		
Integrated building management systems in public buildings	Sustainable and efficient buildings		
Cultural infrastructure	Cultural activities		

Table 2. *Cont.*

Infrastructure	Service Delivery	Governance	Digital Transformation
Informal settlements	Residential facilities for bioadvected groups		
Open green spaces/green areas	Green area accessibility		
Protected natural areas	Environmental sustainability		
Recreational facilities	Outdoor recreation		

5. Interconnectedness and Symbiotic Relationships between the Four Aspects—Infrastructure, Service Delivery, Governance, and Digital Transformation

The linkage and symbiotic relationship among the four pivotal aspects are explored in the following sections. Figure 3 presents the conceptualized symbiotic relationship among the four facets of smart sustainable cities with digital transformation serving as a catalyst. Each of these dimensions engages in reciprocal cause-and-effect or feedback relationships, fostering mutual enhancement and higher efficiency. Furthermore, the synergy of digital transformation and the optimized utilization of ICT serves as a dynamic catalyst, propelling the augmentation of the three aspects—infrastructure, service delivery, and governance. The symbiotic relationships among these aspects are presented in the following subsections.

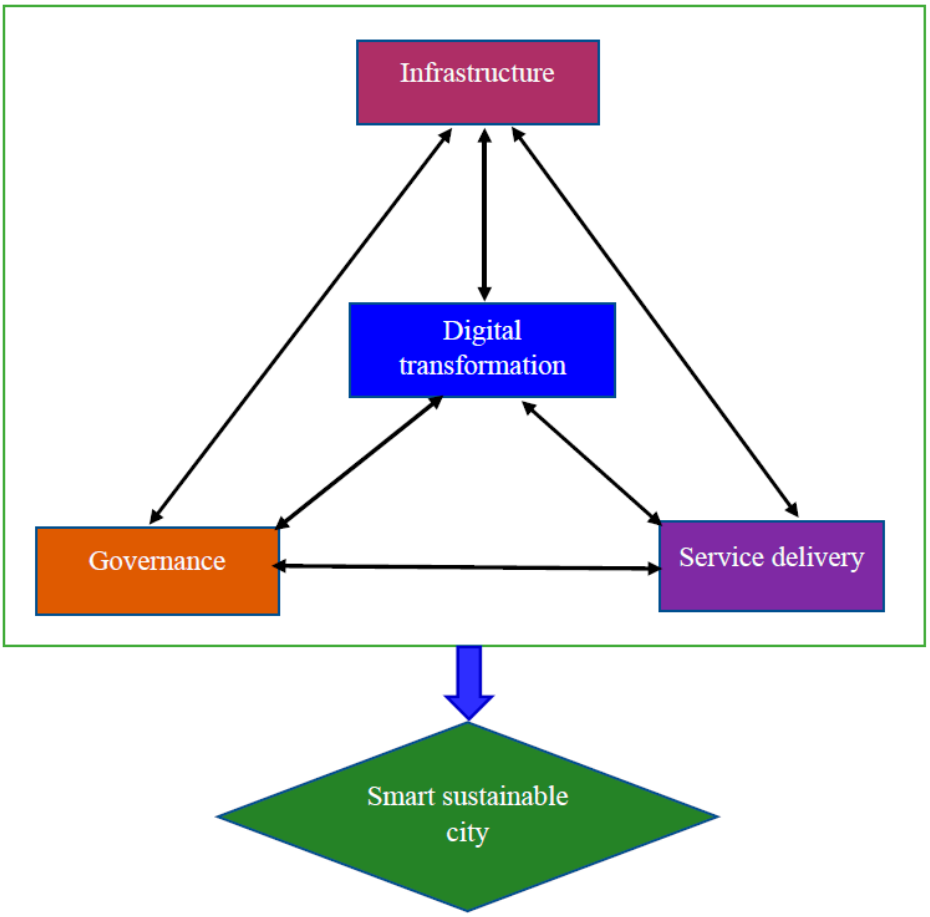

Figure 3. A conceptual framework for the linkage and symbiotic relationships between infrastructure, service delivery, governance, and digital transformation.

5.1. Digital Transformation and Infrastructure

5.1.1. Defining Digital Transformation and Its Significance

Digital transformation encompasses the seamless integration of digital technologies, primarily ICT, Internet of Things (IoT), and AI, into an organization's operational framework. This integration fundamentally transforms how the organization delivers value to its stakeholders, customers, and employees [92,93]. While ICT and IoT have been extensively employed in city functions with evident success, the adoption of AI has been more recent. The advancements in AI are ushering in autonomous technologies for city management, heralding the advent of autonomous cities. These spaces, born out of years of experimentation with eco and smart-city concepts, witness diverse artificial intelligence, ranging from service robots to digital platforms, orchestrating urban activities traditionally performed by humans.

Evidence suggests that AI-enabled smart cities offer various benefits, including enhanced efficiency and performance, better risk identification and monitoring, improved economic prospects, streamlined data and information processing, enhanced service delivery, more informed decision-making, increased engagement and interaction, and greater sustainability. However, alongside these benefits come challenges related to data management, organizational and managerial adaptation, skill acquisition, interpretation of AI outputs, ethical considerations, legitimacy concerns, political dynamics, legal frameworks, policy formulation, social and societal implications, and economic ramifications [94].

Despite the challenges, the transformative process utilizes technology to optimize internal processes, enhance decision-making capabilities, improve customer experiences, and drive innovation [95–97]. The impact of digital transformation is particularly evident in many spheres of society and infrastructure. For example, in the government sector, the adoption of digital tools and online platforms enhances service delivery, streamlining processes and improving accessibility. Data analytics play a crucial role in informed decision-making, performance monitoring, and resource allocation, contributing to enhanced policy development and implementation [98,99]. Initiatives like e-government and open data platforms further reinforce transparency and accountability in governmental processes, transforming organizational culture [100,101].

Similarly, in healthcare, digital transformation revolutionizes patient care through technologies such as electronic health records, telemedicine, and remote patient monitoring [92–94]. This not only improves the coordination of care but also enables timely interventions, ultimately enhancing patient outcomes. Operational efficiency is achieved through streamlined data management and the implementation of data analytics, leading to cost reduction and optimized resource allocation. Additionally, the integration of AI and machine learning (ML) supports research, diagnostics, and personalized treatment plans, fostering innovation [102–104].

In the education sector, digital tools including AI and online platforms create personalized learning experiences, enhancing engagement and accessibility [105–107]. Administrative processes, ranging from enrolment to grading, are streamlined, enabling educational institutions to allocate resources effectively and focus on improving educational outcomes. Digital transformation in education also facilitates global collaboration and connectivity, allowing students to engage with international peers, access educational resources worldwide, and participate in collaborative projects [106–108].

Thus, the overarching impact of digital transformation is manifested in its ability to enhance efficiency, improve services, foster innovation, and increase connectivity across diverse sectors. Embracing digital technologies is imperative for organizations and consequently, the cities to remain competitive, respond to evolving demands, and better serve their stakeholders and society.

5.1.2. Influence of Digitalization on the Development of Physical and Virtual Infrastructure

Öhman (2010) [109] and Ablyazov (2021) [110] underscore the societal and material facets of infrastructure, highlighting its role in shaping spatial localizations and influ-

encing various socioeconomic factors, which was also supported by several other scholars [111–114]. Digital technology has broken the physical barrier and become a pervasive presence across space and time. Ablyazov (2021) [110] suggests using Internet of Things (IoT) technology to overcome barriers to digital transformation, enabling the intricate integration of physical and digital urban infrastructure.

In the context of physical infrastructure, digitalization integrates smart technologies with infrastructure to make them smart and efficient. For example, it assists in creating smart grids for optimizing energy distribution and efficient traffic management systems [115]. Similarly, IoT plays a crucial role by providing real-time data through embedded sensors for predictive maintenance and lifespan extension of the physical infrastructure. The concept of digital twins has also emerged, creating virtual replicas for real-time monitoring and simulation, enhancing decision-making and proactive maintenance [111–114,116].

In the virtual infrastructure domain, digitalization drives the widespread adoption of cloud computing, creating a flexible and scalable virtual environment [117]. Massive data centers, a product of digitalization's growth, serve as the backbone of virtual infrastructure, supporting the global-scale deployment of applications and services. Digitalization also leads to the development of software-defined infrastructure and AI, abstracting hardware functionalities into software for enhanced adaptability and scalability. The rise of digitalization facilitates the development of virtual networks, exemplified by the expansion of 5G networks, which provide high-speed and low-latency connectivity for various applications [117,118]. However, the increasing reliance on virtual infrastructure necessitates robust cybersecurity measures to protect virtual assets, sensitive data, and critical systems.

The integration of digital technologies including AI transforms both physical and virtual infrastructure, enhancing efficiency, resilience, and adaptability, aligning with the demands of modern society and the dynamic forces embedded in economic structures. This transformative evolution shapes the interconnected and intelligent world in which the systems are built, operated, and interact with infrastructure [109–111].

5.1.3. Digital Technologies for Optimizing Infrastructure Planning, Construction, and Maintenance

Digital technologies play a crucial role in enhancing infrastructure planning, construction, and maintenance, yielding efficiencies, cost reductions, and improved decision-making throughout the project lifecycle [12,83]. In the planning phase, data analytics tools, such as Geographic Information Systems (GIS), Augmented/Virtual Reality, etc., aid informed decision-making for optimal project location and design [115,116]. Predictive analytics forecasts future infrastructure needs, valuable in urban planning for accommodating evolving demands. Simulation and modelling tools empower planners to conduct simulations on various aspects such as traffic movement, environmental impact assessments, structural analyses, and more. These tools help in identifying challenges and optimizing designs for enhanced efficiency and effectiveness. Public engagement is enhanced through digital technologies such as virtual reality (VR) and augmented reality (AR), allowing stakeholders to visualize projects, provide feedback, and participate in decision-making [115,119,120]. In construction, Building Information Modelling (BIM) aids collaboration, coordination, and error reduction [115]. Drones and Unmanned Aerial Vehicles (UAVs) assist in optimizing resource allocation, provide real-time aerial surveys and monitoring sites and enhance safety [121].

Furthermore, digital technologies, including IoT and data analytics, enable monitoring infrastructure conditions in real-time, identifying potential issues before they become critical and extending asset lifespan [122]. Remote monitoring and control enable maintenance teams to detect faults and perform diagnostics without physical inspection. Asset management systems provide a centralized platform for tracking and managing infrastructure assets, including maintenance history, replacement schedules, and overall health. Augmented Reality (AR) applications assist maintenance teams by overlaying digital in-

formation onto the physical environment, enabling visualization of repair instructions, schematics, and data during tasks [122–125].

Similarly, AI holds significant potential for enhancing infrastructure across various sectors including energy, water, wastewater, transport, and telecommunications. It can not only facilitate but also bring agility and efficiency in forecasting, routing, maintenance, security, network quality management, etc. [111]. With its data-driven approach and inherent flexibility, AI can effectively address challenges across different network sizes and geographical scales.

Thus, digital transformation contributes to a more efficient, sustainable, and resilient infrastructure development and management, empowering people and decision-makers to meet societal demands.

5.2. Infrastructure and Service Delivery

5.2.1. Relationship between Robust Infrastructure and Effective Service Delivery

The nexus between robust infrastructure and effective service delivery is crucial for societal and organizational advancement [126]. It forms the foundation for reliable provision across various services for example electricity, education, healthcare, water supply, etc. [126,127]. However, the challenges in public services provisions, which stem from governance and management issues related to infrastructure, underscore the necessity of addressing institutional structures, internal organizational processes, financial management, and personnel economics [128,129].

In addition to physical infrastructure, information plays a critical role in public service provision, which assists in effective monitoring, feedback mechanisms, and citizen coordination [130,131]. For example, information constraints affect citizens' awareness of service location, eligibility, and quality, influencing service efficiency [131]. In this context, digital technology enhances the efficiency and quality of infrastructure and transforms public service provision by automating tasks, enhancing monitoring, and overcoming information barriers [12,115,116,131].

5.2.2. The Influence of Well-Designed Infrastructure on Service Accessibility and Quality

Well-designed infrastructure significantly enhances service accessibility and quality across various sectors [132–134]. For example, High-speed Rail (HSR) networks in transportation reduce travel time, increase mobility, and improve environmental sustainability, enhancing service quality for passengers [135,136]. Fiber-optic broadband networks in digital infrastructure contribute to economic opportunities, employment, and online activities, providing faster internet speeds and improved reliability [137–139]. Educational infrastructure, represented by well-designed e-learning platforms, enhances accessibility and service quality through interactive content and personalized learning experiences [138]. In healthcare, telemedicine platforms connect patients with healthcare professionals, particularly benefiting those in remote areas, improving access, and elevating service quality [140,141]. Similarly, effective urban planning and public spaces, incorporating well-designed public transportation and pedestrian-friendly infrastructure, enhance city accessibility, reduce congestion, and improve residents' quality of life [142,143].

In each instance, careful and optimal infrastructure planning not only enhances accessibility but also enhances overall service quality, emphasizing the critical role it plays in the cities.

5.2.3. Aligning Infrastructure Development with Evolving Service Demands

Aligning infrastructure with evolving service demands creates challenges and opportunities [144,145]. Among the critical challenges, rapid technological advancements risk project obsolescence [145] and budget constraints may impede necessary investments [146]. Coordinating diverse stakeholders in infrastructure development is complex, and meeting service demands may strain resources, contributing to environmental degradation if not managed sustainably.

However, data-driven decision-making, adaptive designs, and collaborations with the private sector through Public–Private Partnerships (PPPs) offer opportunities [147,148]. Exploring financing models like green bonds and community crowdfunding provides alternatives [149–151]. Community involvement ensures local alignment, and integrating AI and IoT enhances service efficiency [152–154]. Resilient infrastructure ensures continuous service delivery despite challenges. Addressing these dynamics requires a strategic, collaborative, and adaptive approach, emphasizing flexibility, sustainability, and technological innovation [152–154].

5.3. Digital Transformation and Service Delivery

5.3.1. Relationship between Service Delivery and Digital Transformation

Digital transformation strategically integrates technologies, streamlining processes, and enhancing organizational efficiency through the adoption of tools, data analytics, and optimized workflows [94]. This integration leads to improved customer experiences via online platforms, mobile apps, and self-service options, fostering stronger interactions. The data-driven nature of digital transformation facilitates informed decision-making in service delivery [155], providing insights into customer preferences, anticipating needs, and refining services [156–158]. This transformative impact underscores the intrinsic connection between digital transformation and enhanced service delivery.

5.3.2. Influence of Digital Transformation on Service Delivery

Digital transformation significantly impacts service delivery as mentioned previously by optimizing processes and enhancing efficiency [154,159,160]. In addition to streamlining operations, it assists in improving service quality [160,161]. The shift to online platforms, mobile apps, and self-service options, driven by digital transformation, enhances customer experiences [151,152]. The integration of AI into public services also holds promise for enhancing service efficiency and quality for citizens [162]. Specifically, it can improve decision-making processes in public healthcare and educational culture, while also offering practical tools for streamlining different management processes, for example, online motor vehicle registration, driver's license renewal, passport renewal, obtaining copies of birth/marriage certificates, etc. [163]. Nevertheless, the data-driven decision-making power of digital technology empowers organizations to understand preferences, predict demands, and enhance services [156–158]. This amalgamation significantly boosts operational efficiency and people's and stakeholders' satisfaction [154,159,160,164].

5.3.3. Aligning Digital Transformation with Service Delivery Demands

Aligning digital transformation with service delivery entails navigating a landscape rife with challenges and opportunities. Some major challenges include the integration of digital technologies seamlessly into existing processes poses a significant hurdle. For example, implementing unified systems like Customer Relationship Management (CRM) across diverse departments could be very complex [158,165]. Similarly, ensuring the security of customer data, especially in sectors like healthcare, is paramount during digital transformations [159]. Also, overcoming organizational resistance to change is another challenge, as employees may hesitate to adopt new tools or workflows, potentially impeding successful digital implementation [154]. Furthermore, while certain services provided by AI are preferred, there are still specific services that remain exclusively within the domain of human capabilities [163]. Despite these challenges, digital transformation opens avenues for enhanced people/stakeholder engagement. Real-time and personalized interactions can be facilitated. For example, service delivery organizations can be accessed by e-platform using chatbots for instant support and addressing the challenges faced by the people. Digitizing processes also enhances efficiency and reduces service delivery times. For instance, a logistics company can provide real-time visibility of the freight through a digital tracking system. Furthermore, organizations can make informed decisions and optimize service delivery strategies based on predictive data analytics and simulated scenarios [155]. Thus,

despite the challenges, digital transformation offers significant opportunities to enhance service delivery.

5.4. Service Delivery and Governance

5.4.1. Linkage between Efficient Service Delivery and Good Governance

The nexus between effective service delivery and good governance is a cornerstone for the functionality of public institutions and societal well-being. Good governance, embodying principles such as transparency, accountability, responsiveness, and the rule of law, significantly shapes the efficacy, equity, and quality of public services. Transparency and accountability are also two important pillars of good governance [166–168]. Public participation is integral to good governance, considers community needs in decision-making, and enhances service solutions [9]. The rule of law provides a stable environment for service delivery, ensuring fairness, rights protection, and dispute resolution. Elements like strategic vision, planning, institutional capacity, and performance monitoring, inherent to good governance, collectively enhance service delivery efficiency and adaptability [169]. This commitment to principles establishes a governance framework, where effective governance practices optimize service delivery, creating a reinforcing relationship that, in turn, upholds the principles of good governance, promoting citizens' well-being through responsive service delivery.

5.4.2. Importance of Transparent Accountable Governance Practices for Improved Service Provision

Transparent and accountable governance practices are pivotal for enhancing service provision, fostering trust, and aligning public services with citizens' needs [167]. Transparency, involving the disclosure of information and decision-making processes, cultivates citizen trust by providing insight into resource allocation and decision-making [9,55,166,168]. Accountability mechanisms reinforce confidence in governance integrity, emphasizing that public services prioritize peoples' interests [9,55].

This governance approach facilitates responsive decision-making, incorporating public input for decisions that better reflect peoples' needs [9,55,156]. This commitment leads to enhanced service quality, enabling individuals to evaluate standards with the assurance of accountability mechanisms ensuring compliance. Inclusive citizen participation is facilitated, allowing citizens to engage in decision-making. Additionally, transparent communication about policy objectives, combined with accountability mechanisms, encourages officials to implement policies efficiently. Moreover, they have deterrent effects on corruption, as transparency and accountability make illegal activities difficult to cover. For instance, transparent budgetary processes enable people to track public fund allocation, identify inefficiencies, and prevent corruption, with audits ensuring officials are accountable for resource use [170,171]. Overall, transparent and accountable governance practices create an environment conducive to improved service provision, trust, people participation, effective resource allocation, and a resilient, people-centric service delivery system.

5.4.3. People/Stakeholder Engagement and Data-Driven Decision-Making in Enhancing Governance

People/stakeholder engagement and data-driven decision-making play pivotal roles in advancing governance, emphasizing transparency, accountability, and responsiveness. People/stakeholder engagement, involving active public participation in decision-making, ensures well-informed choices by incorporating diverse community perspectives, needs, and preferences [172]. This engagement while enhancing transparency and responsiveness, makes governance activities understandable and accessible, fostering trust and accountability [55,167]. Responsive governance soliciting public input enables governance structures to effectively address citizen needs, aligning policies and services with community expectations [55,172–174].

Simultaneously, data-driven decision-making involves leveraging data and analytics to inform policies and strategies [175]. This evidence-based approach reduces reliance

on intuition, ensuring well-informed and impactful policies. Data analytics enhances the efficiency of resource allocation by identifying trends, patterns, and areas of need, directing efforts to maximize impact [155,161,165,175–177]. Consequently, predictive planning becomes possible, anticipating future challenges and trends, and enhancing the resilience and adaptability of governance structures [155,176].

The dynamic collaboration between citizen engagement and data-driven approaches ensures a comprehensive consideration of both quantitative data and qualitative insights. Technological advancements, particularly digital platforms, facilitate people/stakeholder engagement and enable real-time feedback, thereby contributing to more responsive governance. A significant outcome of this collaboration is the empowerment of people, as engagement instils a sense of ownership, while data-driven decision-making supports community-led initiatives with objective information [153,178]. This cooperative approach promotes continuous improvement in policy evaluation and iteration. Such collaboration supports adaptive governance structures that can effectively respond to changing needs and challenges. In essence, this transformative synergy equips governance structures to address complex challenges with efficacy, enhancing overall governance effectiveness, fostering a sense of community ownership, and building trust in the decision-making process.

5.5. Governance and Digital Transformation

5.5.1. The Influence of Digital Tools and Platforms on Governance Structures and Processes

Digital tools and platforms exert a significant impact on governance structures and processes, catalyzing transformative changes in government operations, people engagement, and service delivery [179,180]. The integration of digital technologies facilitates enhanced communication between governments, people, and stakeholders through platforms like social media, websites, messaging apps, chatbots (AI-powered), etc. [178,181]. Real-time updates and feedback mechanisms promote transparency and responsiveness, dismantling traditional communication barriers and fostering a more informed and engaged community [178]. Moreover, digital platforms play a crucial role in championing open government and transparency. Initiatives such as open data and online portals provide easy access to government information, including budgets, policies, and performance data [155,164]. This digital transparency builds public trust by allowing people to scrutinize government actions and hold officials accountable for their decisions.

Data analytics and decision-making are currently undergoing a revolution with the advent of digital tools such as AI, including big data analytics and machine learning. These tools have the capacity to process vast amounts of data, providing invaluable insights for evidence-based decision-making. For instance, by leveraging AI, government institutions can reap numerous benefits from access to real-time information, enabling informed policy decisions and regulatory control. The timely processing of data enhances decision-making efficiency and facilitates more effective management practices. Furthermore, it promotes better dissemination of regulatory norms, resulting in improved outcomes in regulatory mechanisms such as taxation [163]. Essentially, governance structures now can enhance policy formulation, allocate resources more efficiently, and implement programs effectively by identifying trends, measuring policy impact, and adapting strategies based on real-time information, ultimately contributing to smart sustainable urban development [165,182,183].

Furthermore, remote collaboration tools, such as collaboration platforms, video conferencing, and cloud-based services, facilitate effective remote work and collaboration among various stakeholders. These tools promote flexibility and resilience, ensuring service continuity during emergencies and fostering an adaptable and efficient workforce.

Thus, digital tools and platforms have become integral to governance, fostering transparency, efficiency, and citizen engagement. Their integration into governance structures enhances public administration effectiveness, improves service delivery, and promotes a more responsive and accountable government.

5.5.2. The Potential of E-Governance and Digital Platforms in Enhancing Citizen Participation and Accountability

E-governance and digital platforms have the potential to significantly enhance citizen participation and accountability within governance structures [9,150]. Additionally, access to current and real-time information enabled by AI contributes to higher performance across social sectors like health, education, and social welfare, ultimately cultivating a positive perception of a modern and dynamic government among the public [163]. The rise of e-government services streamlines service delivery by enabling people to access government services, submit applications, and conduct transactions digitally. Simultaneously, digital platforms, including social media, online forums, and participatory platforms, facilitate people/stakeholder's engagement and participation. These tools empower people to voice opinions, participate in consultations, and engage with policymakers, fostering inclusive decision-making and contributing to a sense of ownership and accountability among the public. This digital transformation not only reduces bureaucratic hurdles but also enhances efficiency, improving the overall user experience and providing people with faster and more convenient access to essential services [177,182]. Transparency in governance is augmented through e-governance initiatives, including open data initiatives and online access to government information. Open data initiatives involve the publication of government datasets and budgets, allowing citizens to scrutinize government actions and monitor public service performance, building trust [183]. Accountability mechanisms, such as online grievance redressal, performance dashboards, and digital audits, enhance accountability by providing people with avenues to report problems and track the performance of governance agencies. Real-time reporting of governance activities on digital platforms keeps citizens informed and promotes transparency, enabling rapid responses to emerging issues [161,183].

5.5.3. Addressing the Challenges Related to Data Privacy, Cybersecurity, and Inclusivity in Digital Governance

Digital governance, while providing numerous benefits, grapples with significant challenges in various domains, including data privacy, cybersecurity, inclusivity, interoperability, ethical technology use, and trust and transparency [159,161,184].

Concerns regarding data privacy stem from invasive practices leading to the collection, storage, and potential misuse of personal information. Integrating privacy by design principles, which involve anonymizing data, obtaining informed consent, and limiting personally identifiable information collection, is a crucial consideration. User empowerment through clear consent mechanisms and transparent privacy policies further helps build trust and respect user rights [159,160].

Cybersecurity challenges involve the vulnerability of digital governance systems to cyber threats like hacking, data breaches, and ransomware attacks. Robust cybersecurity measures, including encryption, regular security audits, and incident response plans, are essential for protection. Addressing insider threats requires continuous user training on cybersecurity best practices and implementing monitoring systems to detect unusual activities.

Inclusivity challenges encompass the digital divide, where unequal access to digital platforms may exclude certain citizens, particularly vulnerable groups. Bridging the digital divide necessitates strategies such as internet infrastructure development, digital literacy programs, and ensuring access to affordable devices. Designing digital platforms with a user-centric approach, focusing on accessibility features, is crucial for overcoming challenges related to the exclusion of vulnerable groups.

Ethical use of technology challenges involves biased algorithms in decision-making processes and surveillance concerns. Ethical AI practices, including guidelines implementation and regular audits, help mitigate biases in algorithms [164,176]. Legal safeguards, oversight mechanisms, and clear frameworks are crucial for addressing concerns related to widespread surveillance.

Trust and transparency challenges manifest in citizens' hesitancy to engage with digital governance platforms due to concerns about data privacy, security, and opaque decision-making processes [159,176,185]. Transparent communication about data practices, security measures, and the purpose of digital initiatives is essential for building trust. Striving for algorithmic transparency in decision-making processes ensures that citizens understand how decisions are reached, promoting accountability and trust.

Addressing challenges related to data privacy, cybersecurity, inclusivity, interoperability, ethical technology use, and trust and transparency requires a comprehensive and proactive approach. Despite these challenges, e-governance and digital platforms offer substantial benefits in transforming governance by increasing citizen participation, promoting transparency, and fostering accountability.

5.6. Case Studies of Successful Symbiotic Relationships

5.6.1. Singapore

Singapore's Smart Nation Initiative stands as a testament to the city-state's commitment to comprehensive digital transformation [186]. The key pillars are digital society, digital economy, and digital governance. Focused on leveraging technology across sectors, the initiative has seen substantial investments in smart infrastructure, incorporating sensors, IoT devices, and a nationwide broadband network [187]. This smart infrastructure has significantly improved public services. For example, traffic flow in the city is optimized through traffic management systems.

Moreover, the government harnesses data analytics for evidence-based policymaking and citizen engagement, contributing to efficient and responsive governance. One of the major smart service delivery efforts, Singapore implemented a digital health passport, 'HealthCerts,' during the COVID-19 pandemic. Built upon the nation's advanced digital infrastructure, including secure databases and a national digital identity system, HealthCerts allowed individuals to securely prove their health status, facilitating entry to public spaces and events [188]. This proactive approach underscores the synergy between technology and effective governance, adaptability and innovation for effective service delivery.

5.6.2. Estonia

Estonia has undergone a significant digital transformation, marked by a commitment to e-governance initiatives aimed at enhancing the efficiency of public services [189]. The country has created a robust digital infrastructure, featuring secure digital IDs and a national e-governance platform. This infrastructure enables Estonian citizens to conveniently access a diverse array of public services online, spanning healthcare and voting. The government's dedication to digital governance has not only increased transparency but also fostered peoples' participation and facilitated effective decision-making through data-driven insights. Central to Estonia's digital prowess is the X-Road, a secure data exchange platform connecting various government databases and systems. This innovation ensures the secure and interoperable exchange of data, significantly improving governance efficiency by reducing bureaucracy, minimizing data duplication, and enhancing the overall responsiveness of public services. The integration of X-Road has reinforced Estonia's reputation as a pioneer in the realm of e-governance leading to a smart sustainable society.

5.6.3. India

India's digital landscape has been reshaped by the Aadhaar system, despite its challenges and criticisms. A biometric-based digital identity initiative that has revolutionized peoples' access to services and identity authentication in the country. Supported by a robust digital infrastructure, Aadhaar facilitates secure identity verification, streamlining service delivery in critical areas such as financial services and government subsidies [190]. Further, the introduction of digital payment systems, particularly the Unified Payments Interface (UPI), has furthered financial inclusion, providing people with convenient and efficient tools for transactions, specifically in urban areas. This digital transformation

has not only enhanced governance efficiency but has also contributed to transparency by reducing fraud and ensuring targeted service delivery [191]. In tandem with Aadhaar, India has experienced a significant digital payment revolution, spurred by initiatives like demonetization and the widespread adoption of digital wallets and UPI. The development of a comprehensive digital payments infrastructure, including mobile banking apps and secure transaction gateways, has supported the surge in digital transactions. This shift in payment methods has transformed financial transactions, making it easier for people to pay bills, make purchases, and receive government subsidies. Beyond the convenience factor, the transition to digital payments is argued to play a pivotal role in improving governance, reducing corruption, increasing financial inclusion, and furnishing the government with valuable transaction data for informed policymaking. This offers an example of the influence of the transformation of digital infrastructure towards creating a smart sustainable society.

5.6.4. United Kingdom

The United Kingdom's Gov.uk stands as a cornerstone in the country's digital transformation, serving as a centralized platform that consolidates government information and services, fostering a unified digital experience for citizens [192]. Supported by a robust digital infrastructure ensuring reliability, accessibility, and security, Gov.uk provides a diverse range of online services, encompassing tax filing and healthcare information. This centralized and user-friendly portal simplifies peoples' access to government services, offering a streamlined digital interface [193]. Beyond enhancing service delivery, Gov.uk plays a vital role in governance by promoting transparency, simplifying interactions between citizens and the government, and facilitating data-driven decision-making. The integration of digital services through Gov.uk not only reduces administrative burden but also contributes to a more transparent and efficient governance framework in the United Kingdom that would contribute to forming a smart sustainable society.

5.6.5. Rwanda

Rwanda has undergone a significant digital transformation with the implementation of a digital land registry, aimed at modernizing and securing land ownership records [194]. This initiative is supported by a robust digital infrastructure designed to store, manage, and update land-related information efficiently. The digital land registry simplifies land transactions, mitigates fraud, and enhances the accuracy of land records, contributing to a more efficient and transparent real estate sector. The adoption of digital technology in land management has not only streamlined processes but also had positive implications for governance [194,195]. It has played a crucial role in reducing corruption, fostering increased accountability, and facilitating informed decision-making in urban planning. Rwanda's embrace of digital innovation in land registry reflects a commitment to leveraging technology for improved governance and efficiency in the management of vital public records and land infrastructure.

6. Discussion and Implications

6.1. Discussions

The symbiotic linkage between infrastructure, service delivery, governance, and digital transformation is a complex interplay that shapes the modern landscape of public administration and societal progress. An example of such interplay is presented in Figure 4. The interplay suggests that there are two-way relationships between infrastructure, service delivery, and governance, and that digital transformation plays a catalytic role.

Digital transformation, marked by the integration of advanced technologies including AI into organizational processes, plays a pivotal role in reshaping service delivery across sectors such as government, healthcare, education, etc. [92,93]. The adoption of digital tools and platforms enhances transparency, efficiency, and decision-making, creating a foundation for responsive governance. This transformative impact is particularly evident in

the optimization of internal processes, improvement in peoples'/stakeholders' experiences, and innovation in service provision [97,163,196].

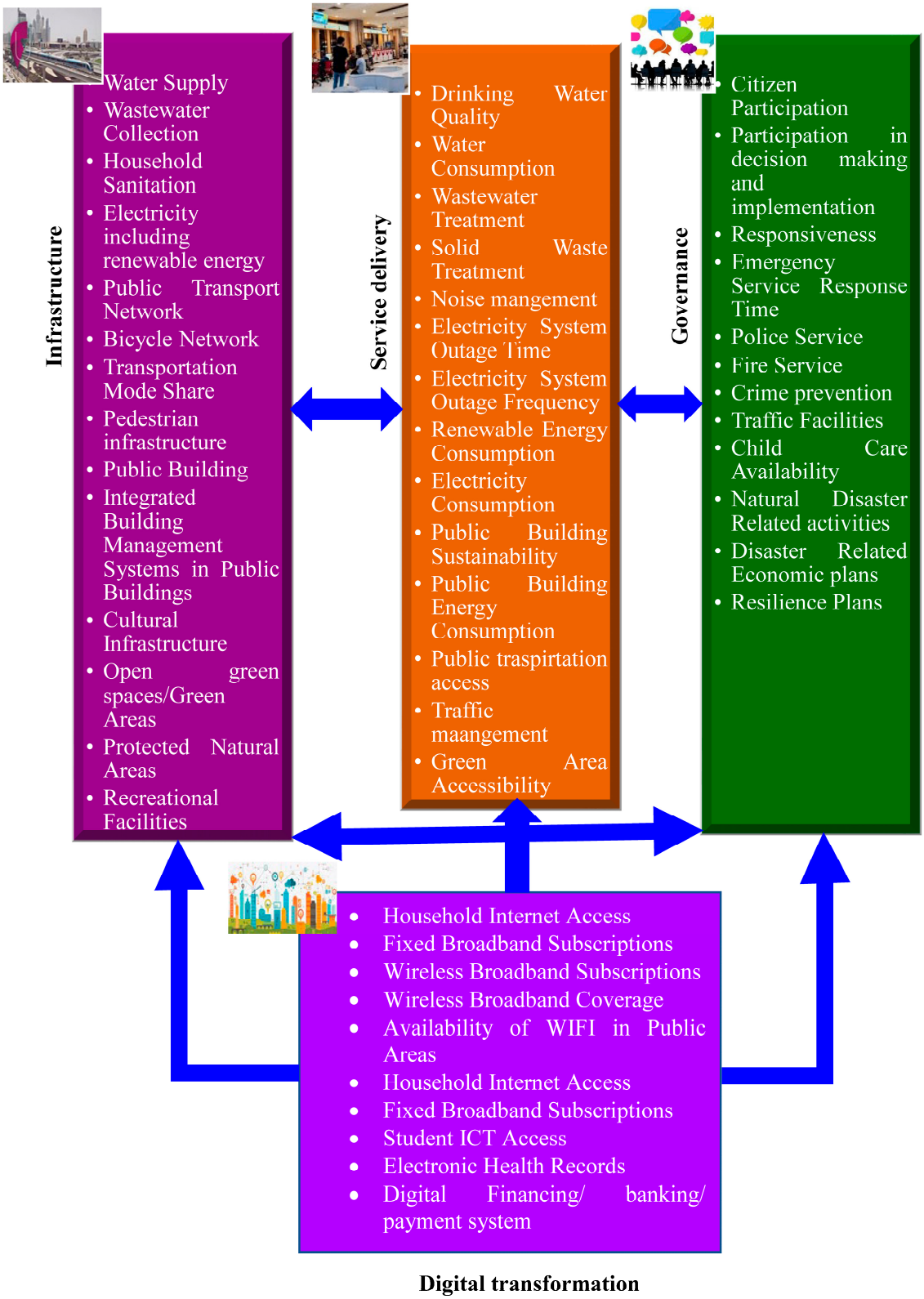

Figure 4. Example of a symbiotic relationships.

In parallel, the material and societal facets of infrastructure, as emphasized by Öhman (2010) [109] and Ablyazov (2021) [110], play a crucial role in shaping spatial development and socioeconomic factors. The integration of digital technologies into physical and virtual infrastructure, for example, by the use of IoTs and smart technologies, enhances efficiency, resilience, and adaptability [115,117]. This interconnected and intelligent world breaks physical barriers over space and time [112,114].

The impact of digital transformation on infrastructure planning, construction, and maintenance is substantial. Leveraging data analytics, GIS data analysis, and modelling tools in the planning phase facilitates informed decision-making and optimal project design [12,115]. Technologies such as BIM, drones, and UAVs enhance collaboration, coordination, and safety in construction [121]. Real-time monitoring through IoT and data analytics enables proactive maintenance, extending asset lifespan and optimizing resource allocation [123]. Augmented Reality applications assist maintenance teams by overlaying digital information onto the physical environment [124]. This integration of digital technologies contributes to more efficient, sustainable, and resilient infrastructure development and management.

The nexus between infrastructure and effective service delivery is fundamental for societal advancement. Well-designed infrastructure significantly enhances service accessibility and quality across various sectors, including transportation, digital networks, education, healthcare, etc. [127,136,138]. Challenges in public service provision, often rooted in political and governance issues, necessitate addressing internal organizational workings and economic factors [129,130]. Digital technologies, in this context, play a critical role in overcoming information constraints, enhancing monitoring, and automating tasks [12,116].

The connection between infrastructure and service delivery extends to the principles of good governance, which embody transparency, accountability, responsiveness, and the rule of law. Transparent and accountable governance practices are crucial for fostering trust, enhancing public service provision, and aligning policies with peoples' demands [166,168]. The integration of digital tools and platforms into governance structures amplifies transparency, efficiency, citizen engagement, and public trust [164,179,180].

The synergy between effective service delivery and good governance underscores the transformative impact of people/stakeholder engagement and data-driven decision-making. People/stakeholder engagement ensures well-informed choices, incorporating diverse perspectives and preferences, while data-driven approaches reduce reliance on intuition for evidence-based decision-making [172,175]. Moreover, the collaboration between people's engagement and data-driven approaches reinforces transparency, responsiveness, and accountability, contributing to a more effective and adaptive governance structure. Despite the benefits, the integration of digital technologies into governance structures faces challenges related to data privacy, cybersecurity, inclusivity, interoperability, ethical technology use, and trust and transparency. Overcoming these challenges requires a comprehensive and proactive approach [159,161,184].

Thus, the symbiotic linkage between infrastructure, service delivery, governance, and digital transformation is a multifaceted relationship that shapes the contemporary landscape of cities. Embracing digital technologies in infrastructure development, service delivery, and governance is imperative for organizations and governments in the cities to remain competitive, responsive to people/stakeholder demands, and adaptable to evolving challenges. The combined effect of the symbiotic relationship is likely to transform the cities into smart sustainable cities. However, it is acknowledged that addressing concerns regarding the impact of digital technology [34–37], as well as the non-homogeneity and fragmented approach of smart cities [38–42], is crucial for ensuring the environmental and social sustainability of smart sustainable cities.

6.2. Implications

The implications drawn from the symbiotic linkage between infrastructure, service delivery, governance, and digital transformation underscore the transformative impact of technology on contemporary cities. Several key implications emerge from this complex interplay:

- Digital Transformation as a Catalyst for Change: Digital transformation, characterized by the integration of advanced technologies including AI, is pivotal in reshaping service delivery across government, healthcare, and education sectors. The adoption of digital tools would enhance transparency, efficiency, and decision-making, laying the foundation for responsive governance, which is pivotal for smart sustainable cities;
- Interconnected and Intelligent Infrastructure: The integration of digital technologies into physical and virtual infrastructure, such as IoT and smart technologies including AI, leads to an interconnected and intelligent world. This evolution breaks physical barriers and enhances the efficiency, resilience, and adaptability of infrastructure in cities;
- Impact on Infrastructure Planning and Construction: Digital transformation significantly impacts infrastructure planning, construction, and maintenance. Technologies like data analytics, GIS analysis, and BIM contribute to informed decision making, collaboration, and safety. Real-time monitoring through IoT and AR applications contribute to more efficient, sustainable, and resilient infrastructure development in cities;
- Infrastructure's Role in Effective Service Delivery: Well-designed infrastructure plays a fundamental role in enhancing service accessibility and quality across various sectors. Challenges in public service provision, rooted in governance issues, can be addressed through digital technologies, overcoming information constraints and enhancing monitoring in smart sustainable cities;
- Contribution to Good Governance Principles: The nexus between infrastructure and effective service delivery aligns with principles of good governance, including transparency, accountability, responsiveness, and the rule of law. Digital tools and platforms amplify transparency, efficiency, and citizen engagement within governance structures, fostering public trust;
- Transformative Synergy of People's Engagement and Data-Driven Decision-Making: The collaboration between people engagement and data-driven decision-making enhances transparency, responsiveness, and accountability in governance structures. This transformative synergy empowers people/stakeholders, promotes continuous improvement in policy evaluation, and supports adaptive governance structures.

Thus, the symbiotic linkage between infrastructure, service delivery, governance, and digital transformation highlights the dynamic nature of contemporary urban society. Recognizing the multifaceted relationship among these elements is essential for fostering innovation, enhancing public services, and building a resilient and adaptive governance framework in the digital age and consequently transforming cities into smart sustainable cities.

7. Conclusions

The trajectory from the early focus on singular environmental concerns to the comprehensive embrace of environmental, social, and economic development reflects a paradigm shift in sustainable cities discourse culminating in the formal incorporation of sustainable cities and communities as a key component of the United Nations SDG (SDG 11). Defined by a triple-bottom-line approach, sustainable cities prioritize social, economic, and environmental impact, aiming to provide resilient habitats for current and future generations. The commitment to inclusivity, safety, resilience, and sustainability translates into tangible initiatives such as accessible housing, investments in public transportation, and participatory urban planning.

Parallel to the sustainable cities movement is the emergence of smart cities, characterized by advanced digital technologies and a focus on intelligent infrastructure, and their application to deliver services and perform socioeconomic activities. The term 'smart city'

has gained momentum and is seen as a leading driver of urban sustainability, although it has faced criticism for its perceived technocentric approach. This criticism has prompted recent research efforts to integrate sustainability more effectively into smart city approaches and make sustainable city models smarter.

The convergence of smart and sustainable cities gives rise to the concept of smart sustainable cities, which leverage digital technology to enhance the quality of life, optimize urban functions, infrastructure and services, and fulfil the needs of current and future generations across economic, social, environmental, and cultural dimensions. Several studies have explored these concepts separately and in intersection, exploring their nuances, challenges, and potential. However, a noticeable gap exists in understanding how the vital elements of city development—infrastructure, service delivery, governance, and digital technology—synergize to transform a city into a smart sustainable city.

This study addressed this gap by exploring the symbiotic relationship among infrastructure, service delivery, governance, and digital transformation—the key aspects of city development. It emphasizes that digital transformation serves as a catalyst for innovation and efficiency, infrastructure provides the foundation for seamless service delivery, and effective governance ensures alignment with the needs of citizens. By working together, it is thus theorized that these four pillars can transform cities into thriving places of sustainability and livability, thereby fostering the emergence of smart and consequently smart sustainable cities. However, a significant limitation of the study is that the specific impact of digital technologies, including AI, and the fragmented approach to smart city development on the social and environmental sustainability of smart sustainable cities has been kept out of this paper's scope. Recognizing the importance of these aspects for establishing smart sustainable cities, this will be considered in the scope of future research.

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