Smart Cities: Definitions, Architectures, Technologies, Life Cycle, Domains, Challenges, Opportunities, and the Case of Amman

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ABSTRACT

The concept of Smart Cities (SCs) has attracted significant global interest in recent years, as urban areas seek innovative ways to enhance residents' quality of life and promote environmental sustainability. The SC paradigm represents a forward-looking approach to urban development, leveraging advanced technologies to build more efficient, livable, and resilient cities. This growing interest is fueled by rapid advancements in Information and Communication Technologies (ICT), which have enabled everyday objects and systems to operate more intelligently, streamlining urban services and daily life. As cities evolve into next-generation SCs, it becomes crucial to examine their key components—ranging from definitions, architectures, and enabling technologies to application domains, implementation challenges, research opportunities, and real-world case studies. This article explores these dimensions comprehensively, offering a synthesis of existing SC definitions and presenting a new definition proposed by the author. It introduces a structured eight-phase Smart City Development Life Cycle (SCDLC), reviews current architectures and technologies, and categorizes the primary domains where smart solutions *are applied. Highlighting the leading smart cities of 2025, the paper also provides an in-depth case study of Amman, Jordan, and concludes with a discussion of key insights drawn from the overall study.*

Keywords: Smart Cities (SCs), Information and Communication Technologies (ICT), Smart City Technologies, Smart City Challenges, Smart City Development Life Cycle (SCDLC), Internet of Things (IoT), Artificial Intelligence (AI), Smart Buildings, Urban Sustainability, Amman City, Systematic Literature Review.

INTRODUCTION: SMART CITIES

Currently, a large portion of the world's population resides in urban areas, and this trend is expected to continue [1]. This increase is due to factors such as migration from rural areas and natural population growth [2]. People migrate to cities for better job opportunities, improved quality of life, and enhanced education and healthcare. Consequently, governments need to address the challenges posed by rapid and uncontrolled urban growth, including traffic congestion, air and water pollution, pressure on city services, and high living costs [3]. To tackle these issues, the concept of SC has emerged, aiming to provide sustainability and comfort through modern technology, addressing many problems faced by traditional cities [4] [5].

Along with the evolution of society, there has been a significant development of ICT. Technologies like the Internet of Things (IoT) and cloud computing have gained importance in recent times [6]. These technologies are becoming a main part of the evolution of cities. Therefore, urbanization and ICT have led to the emergence of the SC paradigm [1]. SCs have been greatly developed and have significantly extended their capabilities in recent years. In general, SC is an urban area that exploits ICT to improve the quality of life of its citizens (*i.e.,* the heart of a SC) as well as the sustainability and efficiency of its operations.

SCs are those modern cities that employ modern ICT facilities to satisfy their citizens [7]. According to recent research studies, by 2030, sixty percent of the country's population will be occupied in modern cities [8]. Therefore, living in modern cities poses a great challenge for governments, as it is not easy to manage these large cities using traditional methods, especially when the number of citizens increases significantly and thus the demand for services increases. Thus, modern SCs will be able to accommodate these large numbers of citizens and manage their various needs, as SCs are equipped with modern ICT facilities.

A SC represents a sustainable environment capable of providing all its services in an easy and comfortable way to its residents. Its goal is to facilitate the lives of its citizens, so that all or part of the services are done electronically. Therefore, the citizen can save time and effort instead of visiting the physical buildings of ministries and government departments in order to conduct some transactions. For example, instead of going to the Electricity Authority building to pay the bill in the traditional way, the citizen pays the bill electronically. On the other hand, modern technology plays a major role in building and thriving SCs, as technology is considered the backbone of any SC. The SC also exploits natural energy sources in order to provide its services, such as wind energy and solar energy. Moreover, citizens must have a good level of education and not be technology illiterate, because this helps in the acceptance and prosperity of SCs around the world.

Urban cities are characterized by their large populations, complex buildings, numerous transportation systems, high consumption of resources such as water, food, and energy, and large amounts of waste materials. These urban characteristics of cities result in numerous impacts on the city's environment. Therefore, it is necessary to maintain the sustainability of these urban areas [9] [10]. SCs are built by considering the economic, social, and environmental effects of current residents without affecting the ability of future generations to develop and maintain cities and practice all the acquired experiences of previous inhabitants [11]. Therefore, sustainable urban areas focus on how to achieve the well-being and comfort of their residents while ensuring that the requirements and aspirations of future generations are met by focusing on education, developing city infrastructure, changing citizens' habits and behaviors, and maintaining the environment and its resources.

IoT technology is centered on embedding sensors into everyday objects and utilizing connectivity to enable information exchange for various applications. There are more objects available than people in a city, so the amount of connectivity that IoT devices hold is vast. Unlike the internet, which is a grid of networks, IoT is a network of interconnected devices. IoT devices are crucial in people's daily lives in the city, managing large volumes of data. IoT devices can be viewed as a mesh of communicated devices that implies sending and operating devices that offer the capacity for information exchange among distinct platforms in a city [12]. IoT devices have lots of valuable applications when they appear in SCs [13]. A SC can be recognized as a city that is supplied with technology, like sensors and cameras that gather data; it is exploited to make critical decisions in the management of city operations [14].

This article covers the main topics relevant to SC paradigm; mainly, it covers the following topics: SC definitions, architectures, technologies, development life cycle, application domains, challenges, research opportunities, and case studies (*e.g.,* Amman city). Figure 1 summarizes the main topics of this article. This Figure employs a Feature Model (FM) to discover the topics covered in this study [15] [16] [17]. Interested readers can find more information about this FM in [18] and [19].

Fig. 1. Overview of the main topics covered in this study

Actually, there has been no international standardization of SCs until now; however, several features characterize SCs [20] [21] [22] [23]. These features include: smart economy (*e.g.,* smart tourism and advertising, and digital currency); smart governance (*e.g.,* electronic government services like e-payment); smart living (*e.g.,* quality of life, such as safety and security, citizen habits, and behavior); smart citizens (*e.g.,* creative and qualified citizens); smart mobility (*e.g.,* electric cars, car sharing, smart transportation); smart environment (*e.g.,* food, weather, green areas, energy, waste management, and water); smart infrastructure (*e.g.,* smart homes, buildings, streets, grids, and energy); smart education and healthcare (*e.g.,* electronic services like distance learning and e-learning); and smart transportation (*e.g.,* smart parking and traffic).

In this systematic literature survey, recent studies are reviewed to address various aspects of SCs, including definitions, common architectures, technologies, application domains, challenges, and research opportunities. The survey highlights several exemplary SCs to provide valuable insights for researchers. It covers key aspects of SCs, proposes a unique definition, introduces a development life cycle for SCs, and outlines several challenges of SCs. Based on the literature review, author suggests various research opportunities relevant to any well-planned SC. Additionally, the survey includes a detailed investigation of the densely populated city of Amman as a case study of a SC.

The systematic literature review was guided by a structured selection framework, as shown in Figure 2. Relevant articles were identified using predefined search keywords across major scientific databases, including IEEE Xplore, Scopus, and Web of Science. The selection process applied filters based on publication date and inclusion criteria related to various SC dimensions—such as definitions, architectures, technologies, application domains, challenges, research opportunities, and case studies—with a specific focus on the city of Amman. Articles meeting a threshold of at least one relevant criterion (threshold value: 0.12) were included; others were discarded.

This study aims to provide a comprehensive analysis of the current body of knowledge on SCs, focusing on their definitions, architectural models, enabling technologies, application domains, and the challenges associated with their implementation. It also presents selected global examples of cities that have adopted the SC paradigm, along with their respective rankings, offering practical

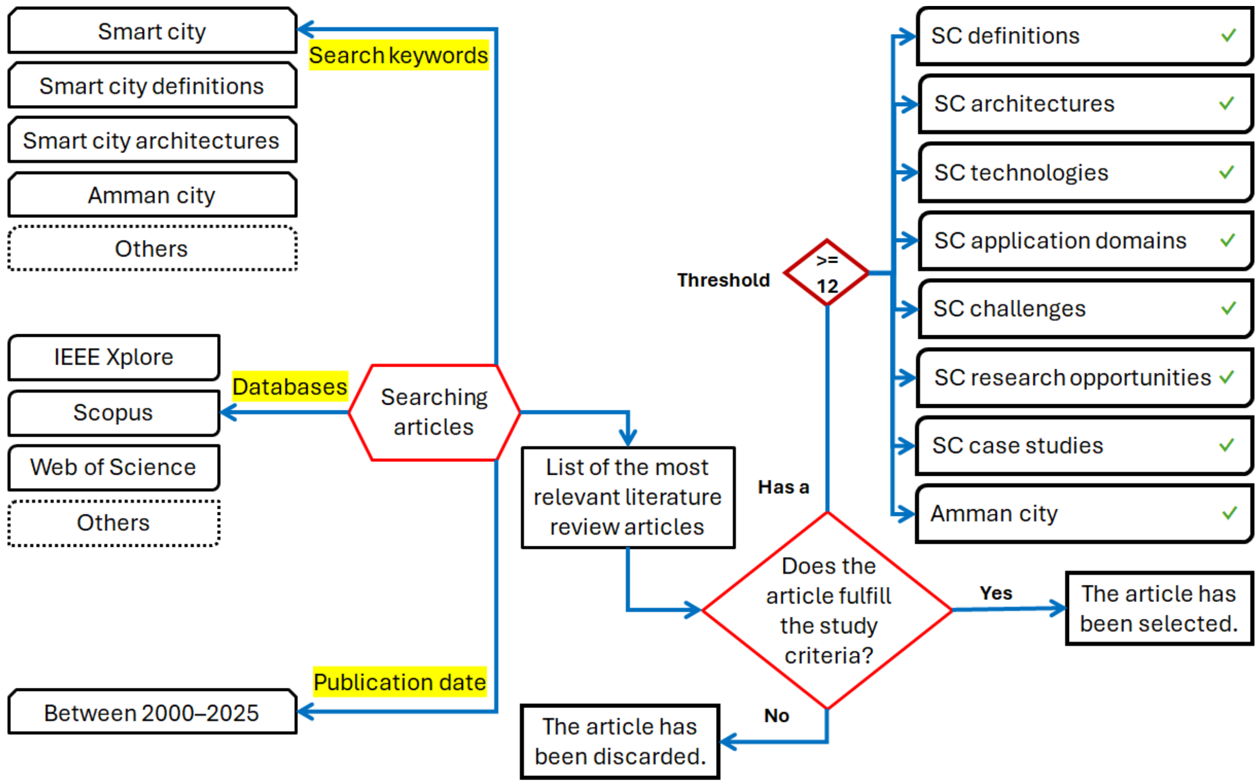

Fig. 2. Methodological flowchart for the systematic literature review process. Articles were identified using predefined search keywords across major scientific literature databases (IEEE Xplore, Scopus, and Web of Science), filtered by publication date, and assessed based on inclusion criteria related to SC dimensions such as definitions, architectures, technologies, application domains, challenges, research opportunities, case studies, and specific relevance to Amman. Articles meeting at least one criterion (a threshold value of 0.12) were selected for inclusion; others were discarded

insights into diverse implementation strategies. A key objective of this work is to examine the city of Amman, Jordan, as a case study of a developing urban environment transitioning toward sustainability and smart urbanism, highlighting its major projects and persistent challenges. Additionally, the study introduces a novel conceptual contribution to the field: the Smart City Development Life Cycle (SCDLC), which outlines eight distinct phases for developing SCs—whether initiated from the ground up or adapted from existing urban infrastructure. The work further proposes a refined definition of SCs and identifies a range of unresolved challenges that hinder effective implementation. Finally, the study proposes several research opportunities that may inform future academic investigations and practical advancements in the SC domain (*cf.* Figure 3).

This article reviews current research on SCs. The survey is divided into the following sections: (1) the "*Smart city definitions*" section presents the different definitions of SC; (2) the "*Smart city*

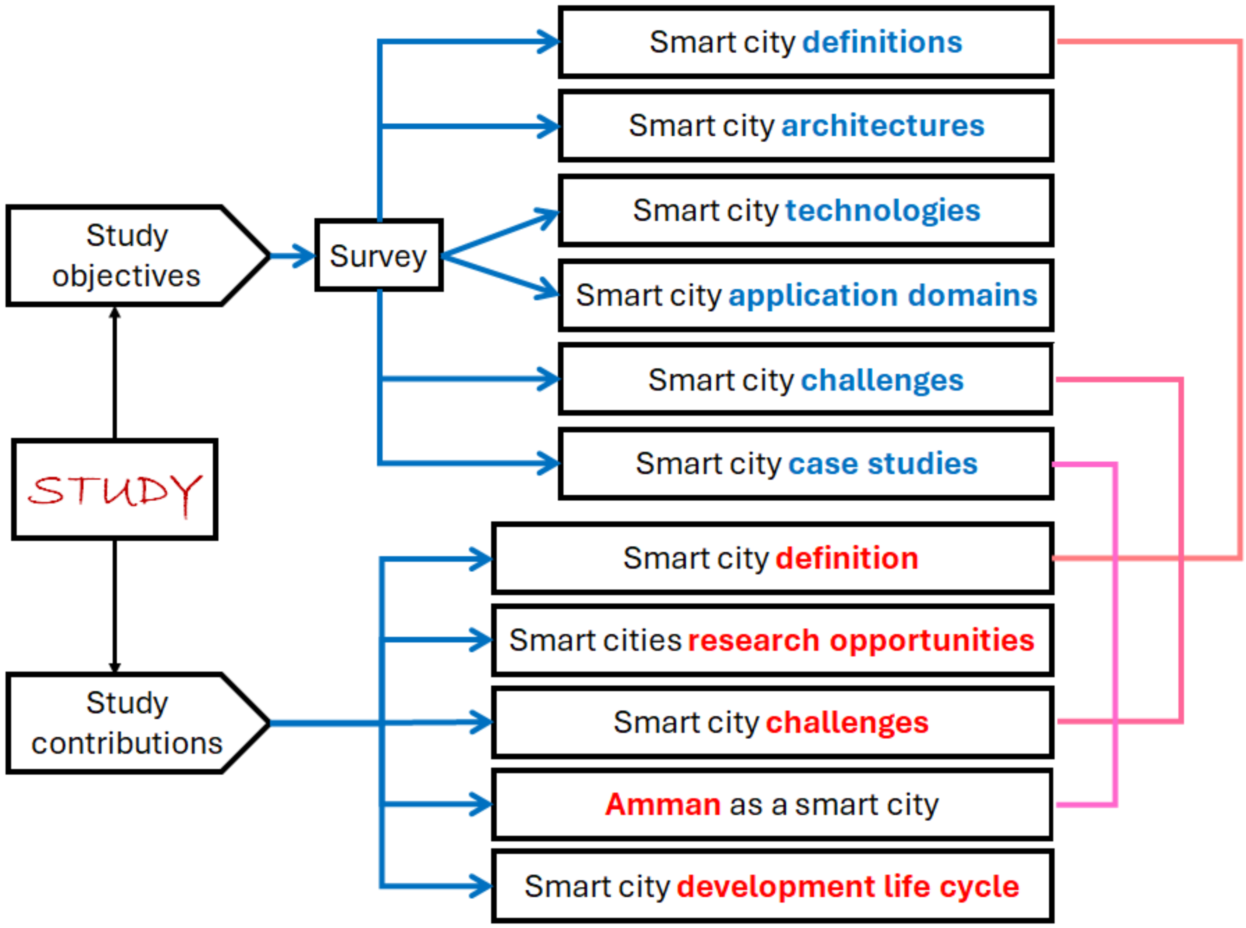

Fig. 3. Structure of the study's objectives and contributions. The diagram provides an overview of the key components explored in the study. The upper section outlines the study's objectives, while the lower section highlights the main contributions

architectures" section describes the most common architectures of SC; (3) the "*Smart city technologies*" section presents the SC technologies; (4) the "*Smart city development life cycle*" section shows the suggested development life cycle of SC; (5) the "*Smart city application domains*" section presents the classifications of the applications to specific domains of the city (such as healthcare, transport, and education); (6) the "*Smart city challenges*" section presents the challenges of SCs (*i.e.,* open and specific challenges); (7) the "*Smart cities research opportunities*" section presents the promising research opportunities relevant to the research area based on the knowledge acquired through literature; (8) the "*Smart city case studies*" section presents global examples of smart cities and highlights Amman as a case study; and, finally, (9) the "*Discussion, contributions and summary*" section discusses key insights from the study, highlights the main contributions, and provides a concise summary of the work.

SMART CITY DEFINITIONS

The aim of this section is to provide a taxonomy of SC definitions. The suggested taxonomy is closely related to the taxonomy proposed by Yin *et al.* [24] and Sánchez-Corcuera *et al.* [1]. The proposed taxonomy makes use of four categories: technology-based, domain-based, data-based, and integration-based definitions. Table 1 presents the suggested taxonomy and its categories. Also, it provides a short description of each category.

Table 1. Definitions of smart city: category taxonomy used to classify different smart city definitions

Category	**Description**	**References**
Technology-based definitions	In this category, the definitions are focused on the importance of technology. Therefore, some literature defines a SC based on its inclusion of ICT.	[25] [26] [27] [28]
Domain-based definitions	A city includes numerous domains, such as healthcare, education, transportation, and government. Some literature defines smart cities based on those domains.	[29] [30] [31]
Data-based definitions	In this category, the definitions are centered around the transmission or use of the data. Consequently, some literature defines a SC based on its transmission or use of the data.	[32] [33]
Integration-based definitions	A city includes several sectors that exploit ICT. In this category, literature defines a SC based on its ability to integrate all elements that compose a city into a single system.	[34] [35]

In the last two decades, the concept of SC has become more and more popular, but there is still confusion around what a SC is, specifically since many similar concepts are often utilized interchangeably [36]. Nowadays, SC paradigm is a promising and applicable approach. Every SC has characteristics, requirements, and infrastructure, and people expect a lot from this city so that it provides them with flexible, comfortable, and high-quality services. In this section, author reviews literature on the different definitions of the smartness of a city. Table 2 presents different samples of SC definitions from the literature (*resp.* author's definition).

Table 2: Definitions of smart city: samples of different definitions from literature

Reference	**Definition**	**Category**
Dashkevych and Portnov [37]	"Smart cities are cities that balance economic, environmental, and societal advances to improve the wellbeing of residents through a widespread introduction of ICT and other technological tools."	Technology-based definitions
Tahmasseby [38]	"One that employs ICT to fulfill market demand, *i.e.,* the citizens."; "An ultra-modern urban area that addresses the needs of businesses, institutions, and especially citizens."	Technology-based definitions
Dameri *et al.* [35]	"A SC is a well-defined geographical area where the co-operation between ICT, logistics, energy production and so on are able to provide benefits for the citizens such as well-being, inclusion, environmental quality and intelligent development, among others."	Integration-based definitions
Hader *et al.* [32]	"The smartness of a city is the ability to transmit and receive data using communication protocols."	Data-based definitions
Lazaroiu and Roscia [31]	"A city that performs well in some applied domains (*e.g.,* mobility, government, living and people)."	Domain-based definitions
Palmisano [25]	"A SC is defined by the use of ICT to sense, analyze, and integrate the key information of core systems in running cities."	Technology-based definitions
Harrison *et al.* [26]	"A SC is an urban area that exploits operational data, that is, data extracted from traffic, power consumption, and so forth, in order to optimize the operations."	Technology-based definitions

Odendaal [29]	"A SC is a region which capitalizes the opportunities presented by ICT in promoting its prosperity and influence."	Domain-based definitions
Yamamoto *et al.* [33]	"A city that gathers data first and then provides services using it."	Data-based definitions
Monzón [34]	"A SC is an integrated system where human and social capital are combined using the ICTs in order to achieve a sustainable and resilient development with a high quality of life."	Integration-based definitions
Su *et al.* [27]	"A SC is the product of a digital city combined with the IoT."	Technology-based definitions
Marsal-Llacuna *et al.* [39]	"SCs initiatives try to improve urban performance by using data, information and Information Technologies (IT) to provide more efficient services to citizens, to monitor and optimize existing infrastructure, to increase collaboration among different economic actors, and to encourage innovative business models in both the private and public sectors."	Technology-based definitions
Gracias *et al.* [40]	"Smart cities use digital technologies, communication technologies, and data analytics to create an efficient and effective service environment that improves urban quality of life and promotes sustainability."	Data-based definitions

Al-Msie'deen (author's definition)	A SC is a city that is prepared based on up-to-date traditional (streets, hospitals, and schools) and modern communication (ICT, AI, and IoT) infrastructure to improve the quality of life for its citizens (city services such as education, healthcare, traffic, and so on).	Technology-based definitions

Many definitions of SCs exist (the concept was first utilized in the 1990s) [36]. A SC, according to the author, is a city that is prepared based on up-to-date traditional (*e.g.,* streets, hospitals, and schools) and modern communication (*e.g.,* ICT, AI, and IoT) infrastructure to improve the quality of life for its citizens (*i.e.,* city services such as education, healthcare, traffic, and so on).

SMART CITY ARCHITECTURES

This section presents the common architecture of SCs. Since SC paradigm was created, several researchers have tried to present the most suitable architecture according to ICT solutions [1]. Because of the diverse requirements and everyday circumstances in cities that have executed SC architectures, these architecture executions have not been following a standard, and consequently, they have diverse characteristics [41]. In fact, there isn't an ideal architecture for SCs. Table 3 presents the most popular SC architectures. The architectures given in Table 3 are complementary and can be executed in the same city, where each architecture has its own characteristics [42].

Table 3: Smart city architectures

Architecture	**Description/Definition**	**Projects**

Cloud computing architecture	“Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (*e.g.,* networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction. This cloud model is composed of five essential characteristics, three service models, and four deployment models.” [43]	Smart car parking system [44], air quality prediction [45], healthcare framework [46] and New York city noise [47].
Fog computing architecture	“Fog computing is a layered model for enabling ubiquitous access to a shared continuum of scalable computing resources. The model facilitates the deployment of distributed, latency-aware applications and services, and consists of fog nodes (physical or virtual), residing between smart end-devices and centralized (cloud) services. The fog nodes are context aware and support a common data management and communication system. Fog computing minimizes the request-response time from/to supported applications, and provides, for the end-devices, local computing resources and, when needed, network connectivity to centralized services.” [48]	Smart dashboard [49], smart home application [50], smart waste management [51], smart parking system [52, 53], and urban surveillance video stream [54].

Edge computing architecture	"Edge computing is a new paradigm in which the resources of an edge server are placed at the edge of the Internet, in close proximity to mobile devices, sensors, end users, and the emerging IoT." [55]	Smart healthcare [56], secure healthcare system [57], renewable energy from agricultural waste [58], urban street cleanliness assessment system [59], and cyber-physical-social system [60].

Cloud computing architecture is split into numerous layers (*e.g.,* infrastructure-as-a-service). Each of the layers consumes the services offered by the other layers and also offers its own services to the other layers. Fog computing architecture is an extension of cloud computing architecture. This extension is achieved by enhancing the performance and duties of the network's end nodes. In this type of architecture, the data storage and processing devices are installed on the same local network. Thus, the fog computing architecture creates low-latency communication between its components. This architecture is utilized for applications where low latency is needed. Whereas edge computing follows the assumption that if the data is produced at the network's edge (*e.g.,* sensor), then it would be more effective to process that data at the same edge [1].

SMART CITY TECHNOLOGIES

Nowadays, technologies are the backbone of several SCs around the world. The use of the latest technologies (*e.g.,* IoT, big data, or cloud computing) inside the city aims at solving city-critical problems and improving a variety of public services and functions within the city. This section presents the major technologies that define the smartness of a city. Table 4 presents the most important technologies for SC.

Table 4: Smart city technologies: major technologies that define the smartness of a city

Technology	Definition / Description	Reference
Internet of Things (IoT)	"The network of devices that contain the hardware, software, firmware, and actuators which allow the devices to connect, interact, and freely exchange data and information."	[61]
	"As used in this publication, user or industrial devices that are connected to the internet. IoT devices include sensors, controllers, and household appliances."	[62]
ICT	"Includes all categories of ubiquitous technology used for gathering, storing, transmitting, retrieving, or processing information (*e.g.,* microelectronics, printed circuit boards, computing systems, software, signal processors, mobile telephony, satellite communications, networks). ICT is not limited to information technology but reflects the merging of information technology and communications."	[63]
	"ICT encompasses all technologies for the capture, storage, retrieval, processing, display, representation, organization, management, security, transfer, and interchange of data and information."	[64]
Blockchain	"Blockchains are distributed digital ledgers of cryptographically signed transactions that are grouped into blocks. Each block is cryptographically linked to the previous one (making it tamper evident) after validation and undergoing a consensus decision. As new blocks are added, older blocks become more difficult to modify (creating tamper resistance). New blocks are replicated across copies of the ledger within the network, and any conflicts are resolved automatically using established rules."	[65]

Artificial Intelligence (AI)	AI is a technology that assists computers and other smart devices (*e.g.,* mobile devices, smart sensors, and wearable devices) to simulate human intelligence in addition to problem-solving capabilities. The two most common sub-disciplines of AI are Machine Learning (ML) and Deep Learning (DL).	[66]
Sensors	"A device that produces a voltage or current output that is representative of some physical property being measured (*e.g.,* speed, temperature, and flow)." "A portion of an IoT device capable of providing an observation of an aspect of the physical world in the form of measurement data."	[67] [68]
Geospatial technology	"The geospatial technology is an emerging technique to study real earth geographic information using Geographical Information System (GIS), Remote Sensing (RS) and other ground information from various devices and instruments."	[69]
Big data analytics	"Big data analytics refers to those advanced technologies that are involved in analyzing large-scale heterogeneous datasets, big data mining, and statistical analysis." "Big data analytics is a phenomenon that analyses large volumes of data using sophisticated tools and techniques to extract valuable insights and to solve business use-cases."	[70] [71]
Cloud Computing (CC)	"Cloud computing is a new type of distributed computing technology that combines traditional computer technology with modern network technology. It is based on advanced virtualization technology and allows network application infrastructure to be expanded at low cost."	[72]

5G networks	"The term 5G stands for the fifth generation of network technology. The 5G network was deployed worldwide in 2019 instead of the 4G network that was introduced in 2009. Inside SCs, the 5G network connects approximately everyone and everything, involving machines, objects, and tools. The main features of 5G networks are large bandwidth, high speeds, lower latency times, and minor energy consumption."	[73], [74]
Software-Defined Network (SDN)	SDN is the physical division of the network control plane from other planes (*i.e.,* data and application planes), where a control plane manages numerous machines. Thus, SDN turns the network from conventional individual machines into a centralized control system. SDN identifies three distinct planes, which are the control, data, and application planes. Division of network planes allows the network controller to have a universal view, enable the management of the network during run time, handle less data traffic, and improve network flexibility.	[20] [75]
Network Function Virtualization (NFV)	NFV combines the network's hardware resources and embedded software systems into one cohesive logical unit, which is called a virtual network. To allow network functions to run on a processing-based platform, NFV separates software functions from hardware resources. NFV uses two common schemes of virtualization, which are internal and external virtualization. Internal virtualization uses a single server-based software container to deliver network functions. While external virtualization offers several physical resources as one cohesive virtual unit.	[20] [76] [77]

SC leverages modern technologies such as IoT, smart sensors, 5G networks, smart traffic lights, autonomous vehicles, Global Positioning System (GPS), and Electric Vehicle (EV) charging stations to improve transportation. Also, SC employs smart meters, smart grids, and renewable energy sources for effective energy management. Moreover, the environmental monitoring of SC is improved through air quality sensors and smart waste bins. Furthermore, the public safety sector in SC benefits from smart surveillance cameras and emergency response systems.

Numerous sectors inside SC benefit from modern technologies. The healthcare sector exploits telemedicine platforms and wearable health devices to improve its services. Furthermore, citizen engagement is facilitated through mobile apps and online participation platforms. Additionally, smart buildings use building management systems and smart security systems. Finally, data analytics and AI underpin these technologies for constructing more effective, sustainable, and livable urban environments.

Furthermore, context-aware applications play a crucial role in a SC. The primary function of these applications is to gather and utilize information about the state of citizens and their devices to provide the most suitable services within the city [78]. Today, context awareness is essential and is commonly referred to as ubiquitous computing, meaning omnipresent or universal [79]. Therefore, the ability of an application to collect information about its environment (or context) at any time and adapt its behavior accordingly through appropriate functions or services is known as context awareness [80]. For example, when a citizen enters a restaurant, they receive an alert on their smartphone with the food and drink menu. Similarly, when a traveler arrives at the airport, a welcome message is sent to their phone.

SMART CITY DEVELOPMENT LIFE CYCLE

This section uniquely presents the concept of the Smart City Development Life Cycle (SCDLC). Often, existing cities (*i.e.,* traditional cities) are transformed into SCs through the use of modern ICT tools. Seldom is a SC built entirely from scratch. In both scenarios, a series of phases must be followed to systematically convert ordinary cities into SCs. In brief, these phases can be summarized as follows: planning, analysis, design, development and implementation, operation and management, evaluation and optimization, sustainability and scaling, and finally, review and innovation (*cf.* Figure 4).

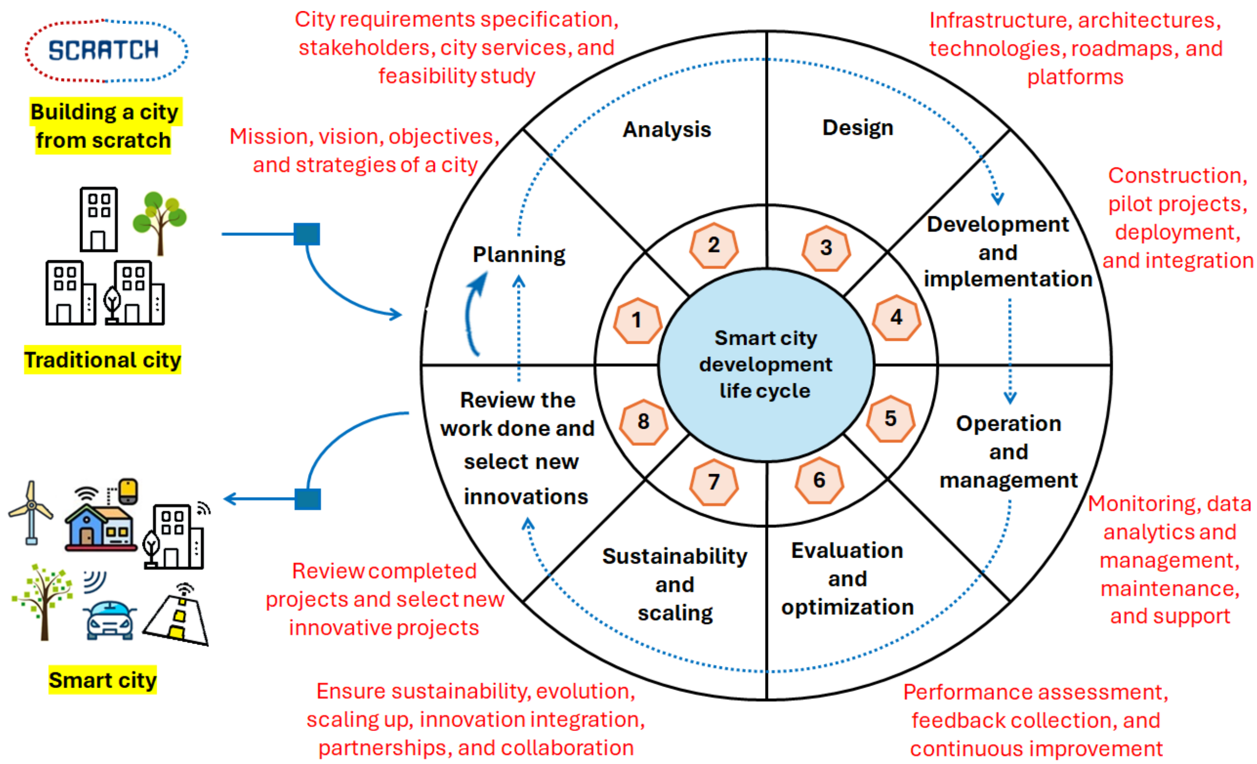

Fig. 4. Smart City Development Life Cycle (SCDLC) — Life cycle phases

SCDLC proposed by Al-Msie'deen in this article outlines a comprehensive approach to SC initiatives (*cf.* Figure 4). It begins with planning, which establishes the city's mission, vision, objectives, and strategies. Next, the analysis phase involves identifying city requirements, stakeholder needs, city services, and conducting a feasibility study. In the design phase, the city's infrastructure, architecture, technologies, roadmaps, and platforms are developed and specified. The development and implementation phase focuses on deploying and integrating smart solutions. The operation and management phase ensures ongoing monitoring, data analytics, maintenance, and support. The evaluation and optimization phase assesses performance, drives continuous improvement, and collects citizen feedback. The sustainability and scaling phase emphasizes ensuring project sustainability, scaling successful initiatives, integrating innovations, and leveraging partnerships and collaboration. Finally, the review and innovation phase involves evaluating completed projects and selecting new initiatives for future development, ensuring the city's continuous evolution.

At each phase of SC development, a specific set of activities is followed. For example, in the analysis phase, city requirements, services, stakeholders, and the feasibility of proposed projects are determined (*cf.* Figure 4). Current studies do not include a term called SCDLC, which is introduced in this article. The purpose of this concept is to propose initial phases (along with corresponding activities for each phase) for developing SCs or innovative projects within a city. This term can be adopted by researchers and scientists as a starting point for further developing the concept into a standardized form.

SMART CITY APPLICATION DOMAINS

This section presents the application domain taxonomy of different SC approaches. A SC encompasses numerous domains where the advent of ICT leads to pivotal transformation and change. In this work, author decided to adopt Yin's taxonomy [24] for application domains and divide domains into four categories (*i.e.,* business, citizen, environment, and government-related categories) with a broader extension (*cf.* Figure 5). Table 5 presents the application domain taxonomy utilized to categorize various SC approaches.

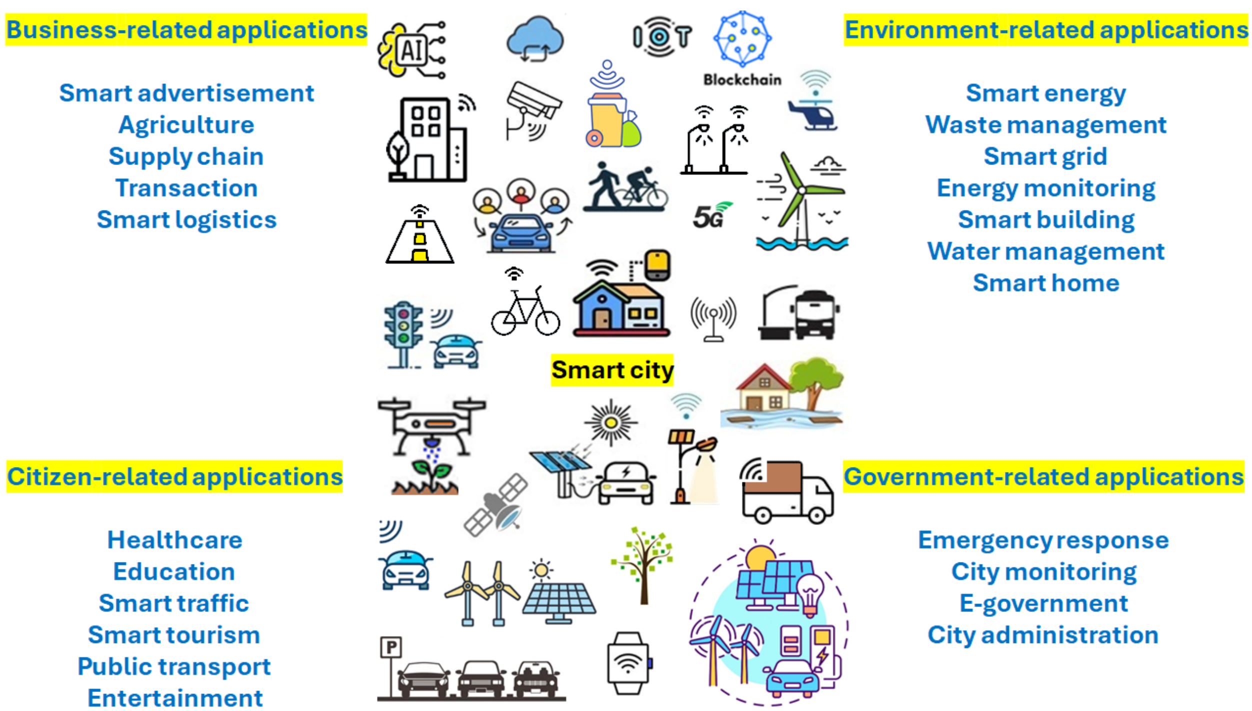

Fig. 5. Key categories of smart city applications

Table 5. Application domain taxonomy of various smart city approaches

Domain	Description	Subdomain	References
Business	Domains related to business conducted in the city and aimed at improving the efficiency and quality of business activities in a city (*i.e.,* making the business more prosperous).	Advertisement	[81], [82]
		Agriculture	[83], [84], [85]
		Entrepreneurship	[86], [87], [88]
		Enterprise management	[89], [90]
		Transaction	[91], [92], [93]
		Logistics	[94], [95], [96]
Environment	Domains related to city environment resources and aimed at improving the efficiency and quality of services that are derived from the local environment of the city, such as renewable energy (*i.e.,* providing a more sustainable environment in the city).	Renewable energy	[97], [98], [99], [100]
		Pollution control	[101], [102], [103]
		Waste management	[104], [105], [106]
		Housing	[107], [108], [109]
		Smart grid	[110], [111], [112], [113]
		Public space	[114], [115], [116]
		Water management	[117], [118], [119], [120]
		Building	[121], [122], [123], [124]
Government	Domains that are related to government and aim at improving the internal and external efficiency of the government (*i.e.,* making the government more efficient).	Emergency response	[125], [126], [127]
		Public service	[128], [129]
		Public safety	[130], [131], [132]
		Transparent government	[133], [134]
		E-government	[135], [136], [137]
		City monitoring	[138], [139], [140], [141]
Citizen	Domains that are related to citizens of a city and aim at improving the essential services provided to citizens, such as sport, education, and healthcare (*i.e.,* making the citizens of a city happier and more comfortable).	Healthcare	[142], [143], [144]
		Tourism	[145], [146], [147]
		Education	[148], [149], [150]
		Smart traffic	[151], [152], [153]
		Public transport	[154], [155], [156]
		Entertainment	[157], [158], [159]

SC applications have expanded rapidly due to advances in sensor technology and improvements in wireless networking [20] [160]. Figure 5 illustrates the key categories of SC applications, based on the application taxonomy proposed by author (*cf.* Table 5).

SMART CITY CHALLENGES

The multidisciplinary nature of SCs creates multiple research challenges. This section presents the open and specific domain challenges of SCs. Table 6 presents the open challenges of SC. When a city decides to become a SC, it must meet the needs of its residents and provide them with basic services. It must also employ modern technology to provide its main functions and services to its citizens. The use of ICT tools may be accompanied by many challenges in some cities, the most important of which is technological illiteracy. If technological illiteracy is widespread within the city, introducing modern technology to the city will be an obstacle rather than a useful and important tool. Technological illiteracy is usually high in underdeveloped and poor countries, and perhaps the biggest reason for this illiteracy in some countries is the large number of elderly people who are not proficient in using technology. Thus, it is necessary to change the behaviors and habits of citizens in some cities to enable the best use of technology in those cities.

Table 6: Open challenges for smart cities

Reference	**Challenges**
Singh *et al.* [23]	Design and operational costs; heterogeneity; security; privacy; data collection and analysis; waste management; big data and connectivity; and failure management.
Chourabi *et al.* [161]	Managerial and organizational challenges (*e.g.,* project size and resistance to change); technological challenges (*e.g.,* lack of IT staff with integration skills); government challenges (*e.g.,* leadership and transparency); policy context challenges (*e.g.,* integration of the ICT with political and institutional components); people and communities challenges (*e.g.,* education and quality of life); economic challenges (*e.g.,* innovation and entrepreneurship); built infrastructure challenges (*e.g.,* IT infrastructure like security and privacy); natural environment challenges (*i.e.,* challenges relevant to the sustainability of the introduction of ICT).
Yin *et al.* [24]	Challenges of city traffic, citizen behavior, and city planning.

Bergh and Viaene [162]	Expert team; coordination mechanism; relation between IT and business; motivated workers; real implementation; and ecosystem.
Pierce and Andersson [163]	Collaboration (*e.g.,* weak collaboration with stakeholders); financial (*e.g.,* limited funds); governance (*e.g.,* outdated regulations); awareness (*e.g.,* lack of experience in SC technologies); interoperability (*i.e.,* SC integration); and privacy (*e.g.,* big data).
Anand and Anand [164]	Water sector (*e.g.,* lack of drinkable water and rainwater collection systems); energy sector (*e.g.,* lack of electricity in some urban areas); waste sector (*e.g.,* lack of waste collection system); mobility sector (*e.g.,* road infrastructure, congestion, and an inadequate public transport system); built environment sector (*e.g.,* high house prices); education sector (*e.g.,* literacy rate and quality of education); healthcare sector (*e.g.,* health insurance rate and lack of public/private services).
Silva *et al.* [165]	Waste management; performance; sustainability; heterogeneity (*i.e.,* interoperability); cost operation (*i.e.,* cost of deploying the city and maintenance cost); information security; connectivity; system failures; big data; and carbon footprints.
Monzón [166]	Governance (*e.g.,* government instability and high levels of violence/corruption), economy (*e.g.,* economic crises and downturns), mobility (*e.g.,* reduce private car numbers in the city center), environment (*e.g.,* urban sprawl and pollution), people and living (*e.g.,* scarcity of resources and technology illiteracy).
Paes *et al.* [167]	Environmental (*e.g.,* waste reduction and adoption of alternative energies); economic (*e.g.,* infrastructure of cities and cooperation between government, industry, and academia); technological (*e.g.,* big data and electronic devices and sensors); and social (*e.g.,* citizen participation and culture/habits of citizens) challenges.

Ali *et al.* [20]	Cost of operation, massive connected devices, scalability, big data, security, infrastructure, and connectivity.
Al-Msie'deen (author's opinion)	City's infrastructure (*i.e.,* traditional, ICT, and IoT infrastructure); data security, safety, and privacy; interoperability; governance and policy issues; coordination and collaboration between private and public sectors; investment and funding; mobility; technological integration; connectivity; public awareness and acceptance; and sustainable energy.

As some researchers center their study on a specific domain of SCs, Table 7 presents the challenges of specific domains inside SCs, such as agriculture, healthcare, and so forth.

Table 7: Domain specific challenges for SCs

Domain	**Challenge(s)**	**Refs.**
Innovation	Strategic vision (*e.g.,* the ambiguity of being a SC); organizational capabilities and agility (*e.g.,* administrative constraints and human resources); technology domestication (*e.g.,* technological determinism); ecosystem development (*e.g.,* governance models and business models); and transboundary innovation (*e.g.,* scalable boundary-spanning collaborations).	[168]
IoT	Technical challenges (*e.g.,* interoperability, standardization, data privacy/security, and network/device compatibility); social challenges (*e.g.,* accessibility, inclusiveness, user acceptance/adoption, and ethical/legal considerations); and economic challenges (*e.g.,* return on investment, implementation/deployment processes, and cost/funding).	[169]
	Challenges related to wearable and autonomous computing systems.	[170]
	Challenges related to security and privacy, smart sensors, networking, and big data analytics.	[171]

Artificial intelligence (AI)	Challenges related to security/surveillance; energy consumption/distribution; operationalizing new technologies; predicting future needs; AI's ethical use; and measuring the environmental effects of AI infrastructure.	[172]
Agriculture	Challenges related to the smart farm, such as the high cost of technology, constructing farms inside cities, the energy outlay, the high real estate cost, the need for IT skills, and a lack of awareness.	[173]
Waste management	Lack of strict government regulatory policies, proper financial planning, and benchmarking processes. Electronic waste (e-waste) and the identification of waste materials before the separation process (an expensive job).	[174] [175]
Traffic	Traffic congestion, heterogeneous traffic flow, capacity of the roads, vehicle-to-vehicle communication, and berth scheduling.	[176]
Energy	Implementation challenges (*e.g.,* technical complexity, resistance to change, privacy and security concerns, high implementation costs, and limited data access); variability (*resp.* intermittency) of renewable energy sources; and managing energy consumption in cities (*i.e.,* mismatch between energy supply and demand). Challenges related to achieving lower energy consumption.	[177] [178]
Healthcare	Technological challenges (*e.g.,* costs, poor data quality, and data governance/ethical concerns); organizational challenges (*e.g.,* poor planning, poor leadership, and change culture); environment challenges (*e.g.,* poor computer skills and end user behavior). Challenges related to health monitoring.	[179] [180]
Privacy and security	Challenges related to data privacy and protection. Challenges related to data storage-related privacy.	[181] [182]

	Challenges related to cybersecurity threats.	[183]
Citizen	Challenges related to the digital divide and literacy, people with disabilities, and encouraging citizens as ICT users.	[184]

SMART CITIES RESEARCH OPPORTUNITIES

Based on the knowledge acquired through literature review, this section presents the research opportunities that are promising and related to SC paradigm. Several studies have been done in the fields of water and food management inside SCs. These fields have not been very well explored yet; thus, it is possible to advance these fields in several areas, such as crop management, transgenic research, water management, water storage, and so on (*cf.* Table 8).

Table 8: Smart city research opportunities

Domain/Sector	**Research opportunities**
Water	Water management, water storage, water meter reading system, rainwater harvesting systems, water quality monitoring, wastewater management, controlling flood, *etc.*
Food	Crop management, food safety and quality, food distribution and logistics, smart farming, transgenic research, food waste reduction, *etc.*
Computer Vision (CV)	City monitoring, face recognition, Traffic Management Systems (TMS), smart waste collection, crowd management, fire detection, intelligent surveillance systems, *etc.*
Healthcare	E-Services, Human Computer Interaction (HCI), disease detection and monitoring, medical/health crisis, telemedicine, wearable devices, biometric sensors, Electronic Health Records (EHR), bioinformatics and biomedical image analysis, *etc.*
Education	Digital and distance learning, e-learning, smart learning hubs, learning analytics, metaverse, virtual reality, smart classrooms, *etc.*

AI	Cybersecurity, controlling pollution, parking systems, public transportation, waste management, traffic management, energy tracking, security, encryption, big data, intelligent drainage systems, *etc.*
Blockchain	Finance, privacy, data management, supply chain, logistics, emergency response systems, smart contracts for public services, transparent voting systems, *etc.*
Waste	Smart waste collection, recycling and waste sorting, waste to energy technologies, smart waste monitoring and analytics, *etc.*
Agriculture	Drones for crop monitoring, aquaponics systems, rooftop and balcony gardens, greenhouse, vertical farming systems, automated smart irrigation systems, raising chickens and beekeeping, *etc.*
Energy	Renewable energy, energy storage systems, electric vehicles, smart meters, data privacy and security, energy data analytics, energy consumption, *etc.*
IoT	Smart street lighting, smart parking systems, air/water quality monitoring, emergency response systems, smart surveillance, smart meters/grids, smart waste bins, remote health monitoring, participatory sensing, fire detection, agriculture, noise pollution, *etc.*

Computer Vision (CV) is a multidiscipline field including engineering, biology, mathematics, psychology, and physics disciplines. It aims to address how computers obtain useful interpretations of digital images and videos. Thus, it improves a computer's ability to obtain, process, analyze, and interpret digital media. CV involves vast subdomains, such as object tracking, motion estimation, virtual reality, and face recognition [185]. CV studies are quite important to SCs, especially in the healthcare domain. Also, it can be utilized in other domains, like city monitoring, advertisement, traffic management systems, and logistics [1]. Pushing this field forward and utilizing modern techniques inside SCs might be a key advancement.

In the upcoming years, SC paradigm in healthcare is expected to become more significant due to the growing urban population and rising healthcare demands. This will present new opportunities for both healthcare providers and patients [186]. Recently, the most research effort has been done in the healthcare area inside SCs. Several improvements were made regarding this domain in bioinformatics, biomedical image analysis, and so on. In fact, more studies are needed to improve this domain in order to be totally accepted by patients in the city. Also, more research is needed to improve electronic services for both clinics and hospitals.

Regarding the education sector, there are numerous studies that have been done in literature [149] [187] [188]. Smart education is the main component of SC development. SCs always include new education services and applications for citizens to exploit. Educating the city's citizens is considered a foundational step in the development of SCs. Thus, education must be the primary focus of a SC in order for its residents to thrive. Education inside SCs has not been very well studied yet; therefore, it is possible to advance this sector in numerous areas, such as e-learning, smart dashboards, smart campuses [189], interactive multimedia [190], the metaverse [191], virtual reality [192], smart classrooms [193], and so on (*cf.* Table 8).

Furthermore, there is some research done in the area of AI techniques in numerous domains of SC [194] [195]. SCs are continuously including new services and applications for citizens to use based on AI. AI aims at improving the performance of the city in some domains, such as traffic management and city monitoring. Actually, more studies should be done on AI techniques. AI has not been very well exploited yet, so it is possible to utilize it in several areas of SC, such as cybersecurity, controlling pollution, parking systems, public transportation, waste management, traffic management, energy tracking, security, encryption, and so on.

Moreover, blockchain is a technology for resolving privacy and data management concerns in the context of SCs. Thus, there are some studies to be done on blockchain techniques. Nowadays, blockchain is widely seen as the gold standard for transparency — often referred to as ”the king of transparency”. Several research opportunities for SCs need further study. Table 8 presents research opportunities for SCs based on the author's perspective.

SMART CITY CASE STUDIES

This section presents real-world case studies that illustrate how the SC concept has been implemented in various urban contexts around the world. Through the last decade, several cities around the world have attempted to change from a conventional city to a SC. But, in several cases, those endeavors have been unsuccessful, even though there have been considerable investments from the public and private sectors. This section presents those modern cities where SC concept has been appropriately implemented. Table 9 presents the top 10 smart cities in 2025 [196].

Table 9. The top smart cities in 2025 [196]

City	Country	SC rank 2025	SC rank 2024	Change
Zurich	Switzerland	1	1	—
Oslo	Norway	2	2	—
Geneva	Switzerland	3	4	+1 △
Dubai	United Arab Emirates	4	12	+8 △
Abu Dhabi	United Arab Emirates	5	10	+5 △
London	United Kingdom	6	8	+2 △
Copenhagen	Denmark	7	6	-1 ▽
Canberra	Australia	8	3	-5 ▽
Singapore	Singapore	9	5	-4 ▽
Lausanne	Switzerland	10	7	-3 ▽

Rankings out of 146 cities. △ ▽ Change from previous year. — No arrow indicates no change.

The information presented in Table 9 is taken from the IMD smart city index for 2025. This index ranks 146 smart cities worldwide according to the data analyzed by scholars as well as the survey answers of 120 citizens in each city. Also, it provides an overview of how a city's infrastructure and technology influence its overall performance and the quality of life for its residents.

There are many indexes specializing in classifying and ranking SCs around the world. Each index usually issues an annual report containing the ranking of SCs around the world and what changes and improvements have been made for each city during that year. Most of these indexes use different surveys distributed to the residents of these cities, and these surveys are analyzed and studied well. Cities are also evaluated based on many different criteria, such as the technology used and the infrastructure of these cities. Among these indexes, the following can be highlighted: the IMD Smart City Index [196], the IMD World Digital Competitiveness Ranking [197], the WIPO Global Innovation Index [198], the Roland Berger Digital Inclusion Index [199], and the UN E-Government Development Index [200].

In the IMD Smart City Index for 2025, as in the previous year, Zurich ranked first, followed by Oslo and Geneva (*cf.* Table 9). In a SC, ideas are developed and implemented with innovation at the core. Zurich exemplifies this through its forward-thinking approach to city management. By examining, adopting, and supporting innovative ideas, the city leverages digital transformation as an opportunity for improvement. Its aim is to maintain and further enhance the high quality of life for its residents, promote sustainable growth, and solidify Zurich's position as a hub of innovation and business [201].

Oslo, the capital of Norway, is ranked 2nd in the IMD Smart Cities Index 2025 [202]. The city aims to enhance the quality of life for its citizens by being both sustainable and innovative. It considers the use of modern technology across all sectors essential to improving citizens' daily lives. Oslo employs a wide range of modern technological solutions safely to develop and manage key urban domains. The most important areas where technology is applied include water management (along with energy and waste management), mobility, education, and healthcare. The city collaborates with relevant stakeholders, both internally and externally, to promote smart development across these critical domains. Several smart initiatives are underway in Oslo, such as electric buses and green energy systems. The needs of residents serve as the guiding philosophy for development [203]. Additionally, Oslo is prepared to digitize any emerging service where digital transformation is feasible.

Dubai ranks 4th worldwide in the IMD Smart City Index 2025 [202], leading the Gulf Cooperation Council (GCC), and, respectively, the Arab world and Asia [204]. The city has emerged as a global leader in SC development, driven by its ambitious digital Dubai strategy [205]. Dubai has launched over 130 initiatives (*e.g.,* Dubai data initiative, Dubai blockchain strategy, Dubai AI roadmap, and Dubai paperless strategy) aimed at improving government services, fostering innovation, and enhancing residents' quality of life [206]. In the 2025 IMD Smart City Index, Dubai ranked 4th globally, outperforming cities such as Zurich and Oslo in key transport indicators [204]. Key projects include the Dubai AI accelerator [207], the Dubai Pulse platform [208] — which integrates IoT and big data — and the development of autonomous transport systems [209]. Furthermore, the Dubai 2040 urban master plan emphasizes sustainability, aiming to reduce carbon emissions and expand public spaces [210]. These initiatives position Dubai at the forefront of SC innovation, establishing a benchmark for urban development in the Middle East and beyond.

Canberra, the capital city of Australia, is ranked the world's eighth smartest city in the IMD Smart City Index for 2025 [202]. It is a unique and distinctive city, offering a high quality of life that many other cities around the world aspire to achieve. Canberra hosts the largest public Wi-Fi network in Australia, and the government envisions the city as sustainable, green, and inclusive. The city is committed to using technology to improve the quality of life for all residents [211]. The key principles guiding Canberra's development include: people, by placing citizens at the center of all initiatives; data, through focused efforts on collection, protection, sharing, and informed decision-making; design, as a method for managing change and ensuring intended outcomes are achieved; and strategies, by fostering open relationships with industry groups. Several innovative projects and initiatives are underway in Canberra, such as the 3D Canberra planning tool, a digital health record for the Australian Capital Territory (ACT), community hubs, a child and youth information system, digital education programs, an integrated court management system, and the Transport Canberra journey planner.

According to the IMD Smart City Index 2025 [196], Copenhagen (Denmark) was ranked as one of the world's leading Smart Cities in both 2025 and 2024 (*cf.* Table 9). The city aims to become the world's first carbon-neutral capital by 2025. To achieve this goal, Copenhagen is implementing a wide range of projects related to waste management, transportation, and water systems. A key contributor to this progress is the Copenhagen Solutions Lab [212], which plays a central role in driving innovation. The city applies SC paradigm across several domains, including digital services, environmental sustainability, and climate action.

According to the IMD Index [202], Singapore is one of the smartest cities in Asia, with 99% of government services fully digitized from end to end [213]. The government's vision for Singapore is to create a digital government, economy, and society that leverage technology to drive transformation across urban living, transportation, healthcare, public services, and business. The Ministry of Digital Development and Information introduced the term Smart Nation. This initiative aims to seamlessly integrate technology across all city domains to transform how citizens live, work, and play.

Amman as a smart city

This section presents Amman as a SC and outlines the methodology for analyzing the city under study. Amman ranks 127$^{\text{th}}$ in the IMD SC Index 2025 (*i.e.,* 127 out of 146) [196]. Also, Amman ranks 128$^{\text{th}}$ in the IMD SC Index 2024 (*i.e.,* 128 out of 142) [214], while the city is ranked 135$^{\text{th}}$ in the same index in 2023 (*cf.* Table 10). Amman is the capital of Jordan. It is located in the northwest of Jordan [9]. Amman has an area of about 7,579 km^2. The population of Amman is expected to reach six million in 2025 [3].

Table 10. Summary of Amman, analyzing if Amman has smart city vision, platform, a roadmap designed, and a particular department customized entirely to the evolution of Amman as smart city

SC rank 2025	SC rank 2024	Change	Vision	SC platform	Roadmap designed	SC department
127 / 146	128 / 142	+1 △	✓	✓	Yes	No

Figure 6 presents an overview of Amman's performance in the SC Index from 2023 to 2025 [215], showing a gradual improvement in its global ranking. It also provides key background indicators, including the city's population, area [216], and Human Development Index (HDI), along with national indicators such as life expectancy, income, and education levels [215]. These indicators offer important context for evaluating Amman's SC development progress.

Figure 7 illustrates the methodology used for selecting the case study city. This approach is flexible and applicable to any SC worldwide. It combines key criteria and analysis steps to systematically identify cities that meet SC characteristics. While Amman serves as the specific example in this study, the methodology provides a generalizable framework suitable for evaluating

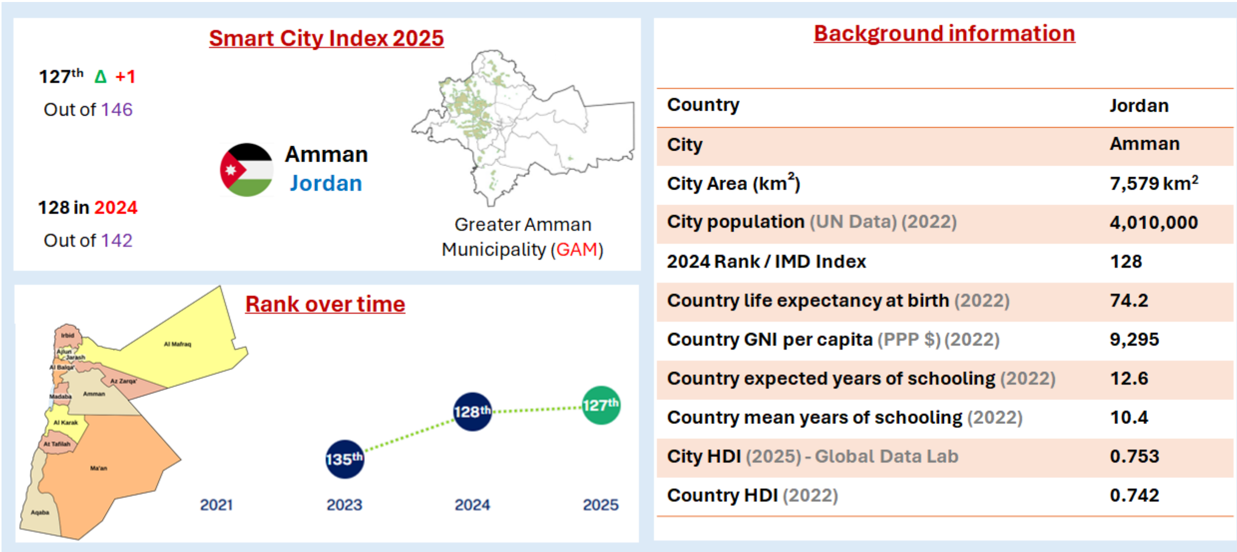

Fig. 6. Smart City Profile of Amman, Jordan (2025). The figure presents Amman's position in the SC Index 2025 [215], showing an improvement from 128th in 2024 to 127th out of 146 ranked cities. The map highlights the Greater Amman Municipality (GAM), and a timeline illustrates Amman's ranking progression from 2023 to 2025. The background table provides key demographic and development indicators, including city area (7,579 km^2), population (4,010,000 in 2022), and Human Development Index (HDI) for the city (0.753) and country (0.742). Additional national indicators such as life expectancy, GNI per capita, and education statistics are also included for contextual comparison

or selecting other cities in diverse contexts.

Amman's vision is to improve the quality of life for Amman's citizens with the utilization of practical technology and achieve resilient and sustainable development [217]. The basic elements of the approach toward SC are automation using new technology, business process re-engineering, and the private sector. The city approach aims at identifying the essential resources to achieve the SC vision, assessing stakeholder concerns and user needs, and defining the potential projects to be included in the city roadmap (*cf.* Table 11).

Amman was built as a traditional city with basic infrastructure (*i.e.,* buildings, streets, hospitals, universities, schools, and so on). Currently, the city adopts modern technology infrastructure, such as 4G/5G networks, high-speed communication lines, machines and computers with high specifications, high-speed internal networks, data centers of high standards, disaster recovery methodologies, secure firewalls, blockchain, cybersecurity, AI, and more (*cf.* Figure 8).

The digital transformation in Amman led to several improvements in various domains of the city. Some of these improvements include: 100% of e-services completed; 134 services available

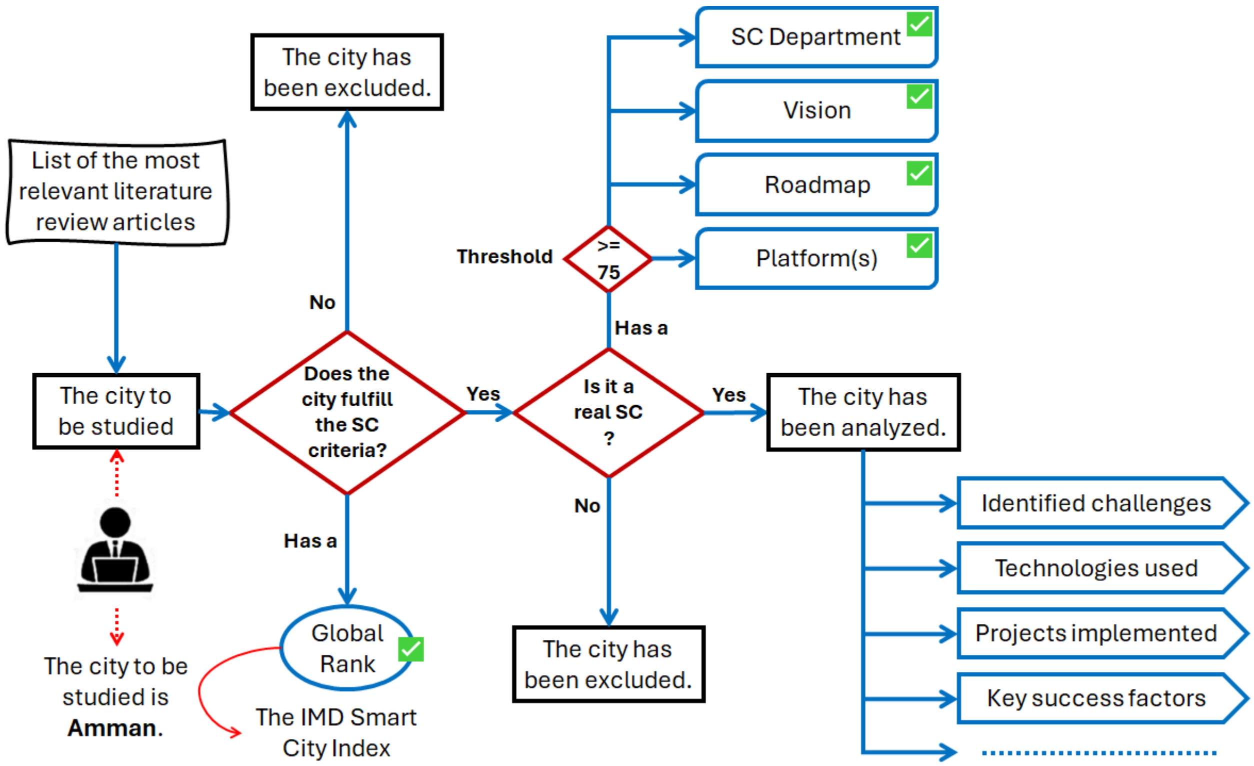

Fig. 7. Smart city selection and analysis methodology. The flowchart illustrates the decision-making process used to evaluate whether a city qualifies as a SC based on predefined criteria. A city that meets the initial criterion—its presence in the global rank—is then assessed against additional criteria, including the existence of an SC department, a defined vision, a roadmap, and supporting platforms. To qualify for further study and analysis, the city must fulfill at least three of these criteria (threshold ≥ 0.75). The analysis then identifies key challenges, deployed technologies, implemented projects, and success factors

online; paperless procedures at Greater Amman Municipality (GAM); the GAM app; the Unified Inspection System (UIS); QR code apps; and a decrease in the number of visitors to city government facilities by 98%.

In 2019, GAM developed a SC roadmap for Amman [218]. This roadmap exploits the latest improvements in technologies (AI and big data) to resolve the city's urban planning requests (*cf.* Table 12). Moreover, this roadmap tries to increase the use of e-services and automate procedures in several ministries to attain transparency and increase the efficiency of government services and functions. Also, the roadmap intends to improve city services and reduce traffic congestion inside Amman.

Many benefits have been achieved in the city of Amman after applying SC paradigm. Some of these benefits include e-payments (*e.g.,* eFAWATEERcom), end-to-end services, efficiency of city

Table 11. Summary of projects executed in the city of Amman

Projects	**Domains**			
	Business	Citizen	Environment	Government
E-payments	✓			
Smart traffic control system		✓		
Smart home system			✓	
Traffic monitoring platform				✓
Flood Early Warning System (FEWS)				✓
Smart streetlight project			✓	
Expanding ride-sharing services		✓		
Parking and curbside management		✓		
Transportation electrification project		✓		
Smart road asset management project				✓
Dedicated walking and biking paths		✓		
The Bus Rapid Transit (BRT) project		✓		✓
Expanded BRT feeder services by neighborhood		✓		✓
Areas guide (Amman explorer)		✓		
Digital marketing and e-commerce	✓			
Smart energy meters for smart grids			✓	
Waste management (waste sorting and recycling)			✓	
Amman is listening		✓		

Table 12. Technologies used in the city of Amman

Technologies									
IoT	**ICT**	**Blockchain**	**AI**	**CC**	**BDA**	**Geospatial**	**Sensors**	**Cameras**	**5G networks**
×	×	×	×	×	×	×	×	×	×

functions and services (cost, quality, and speed), simple procedures (*i.e.,* e-transactions), traffic congestion management, paperless procedures (*i.e.,* eco-friendly), employee training, *etc.*

Amman, a highly urbanized capital, faces several open challenges. Some of those challenges are rapidly growing population and traffic congestion, large number of refugees in Jordan, human resources capabilities for smart solutions, economic challenges globally and regionally, citizen

Fig. 8. Amman: Smart and sustainable city

behavior and habits, and so on (*cf.* Table 13).

Table 13. Challenges facing Amman as a smart city

Challenges	
Number of refugees	Number of citizens
Infrastructure	Traffic congestion
Heterogeneity	Connectivity
Big data	Human resource capabilities
Scalability	Economic challenges
Security, safety, and privacy	Citizen behavior and habits
Cost of operation	Limited funding and aging infrastructure

ICT sector evolves rapidly in Jordan, especially in Amman. ICT sector plays an important role in Gross Domestic Product (GDP), where it is considered the third biggest contributor to GDP.

Thus, one of the main drivers of Amman's sustainable growth is ICT sector. This sector can assist in modernizing the public sector and providing smart infrastructure, such as smart building and transport, e-services, and data collection and analytics. Finally, this sector can also offer support for evidence-based policymaking.

The ”Amman is listening” project is one of the unique initiatives currently in the city of Amman. This platform is designed to better understand the needs of citizens and provide useful information about services or activities that they inquire about. The primary goal of the ”Amman is listening” project is to improve trust between the government and citizens. The platform also allows residents to suggest ideas to the government to enhance service delivery. It plays a crucial role during critical times and crises by continuing to provide services to residents in need. Key outputs of the project include providing data transparency for all city residents, enabling any resident to send their feedback through the application, and notifying residents of important information during times of crisis [219]. As shown in Table 14, Amman has implemented various SC initiatives, including a Bus Rapid Transit system and solar-powered infrastructure.

In Jordan, the urban challenges of Amman city continue to expand as more people move from rural communities [220], [221], [222] to the city for a better life, economic chances, and protection. Consequently, the significant increase in the number of residents of Amman adds more challenges to the government. For example, there is a major challenge in collecting, storing, updating, maintaining the security of urban data, and sharing it transparently with residents [9].

In fact, a survey—even a simple one—should be conducted to identify which urban indicators are most important to the citizens of Amman. Based on the survey results, the municipality and decision-makers can give greater attention to the indicators selected by the majority of participants, prioritizing them for implementation or resolution. In this study, from a list of 25 urban indicators, survey respondents (n = 20 citizens) were asked to select the 10 they perceived as most urgent for their city. The higher the percentage of responses for a given indicator, the higher its priority for the city. The survey results (*cf.* Figure 9) showed that road congestion, unemployment, affordable housing, fulfilling employment, and cost of living received the highest percentage of responses, indicating that these urban indicators are considered more critical than others and

Table 14. Summary of key features and statistics highlighting Amman's progress and initiatives as a developing smart city

Category	**Details/Statistics**
Population	$\sim$ 4.5 million (2024 $est.$)
Smart Infrastructure	Fiber-optic network expansion; 85% urban internet coverage
Digital Infrastructure	4G/5G coverage, fiber-optic networks
Transportation	Amman Bus Rapid Transit (BRT); 135 buses, 3 main lines, GPS-enabled
Digital Services	Over 134 e-government services available "Sanad" platform
Startups & Innovation	King Hussein Business Park hosts 100+ tech startups and incubators
Smart Mobility & Traffic	Smart traffic lights, parking e-payment, ride-share pilots, BRT expansion Traffic remains top resident concern
Green Buildings	50% of new municipal buildings powered by solar; LED streetlights
Digital Literacy Gap	Over 35% of Jordanians lack basic digital skills Examples of digital skills: using apps, e-services, *etc.* Ratios significantly higher among older adults and rural migrants
Smart Waste & Energy	Smart streetlights, smart meters in buildings, biowaste-to-biogas initiatives
Education Tech	95% of public schools equipped with digital learning tools
Global Smart Ranking	Ranked 127th in 2025, up from 128th in 2024 — progress underway
Challenges	Traffic congestion, limited funding, and aging infrastructure *etc.*

should be prioritized for resolution in Amman (see [223] for full survey details).

The survey results indicated that citizen engagement, bike-friendliness, energy efficiency and renewable energy, social mobility and inclusiveness, security, and walkability received the lowest proportion of responses. This may suggest that these urban indicators are perceived as less critical than others, are not considered priorities by residents of Amman, or are already sufficiently available within the city.

As shown in Table 15, Amman, Oslo, and Dubai exhibit distinct levels of SC readiness, reflecting differences in governance, ICT development, technological adoption, and sustainable infrastructure. This comparison provides a critical benchmark for evaluating the institutional and technical readiness of each city.

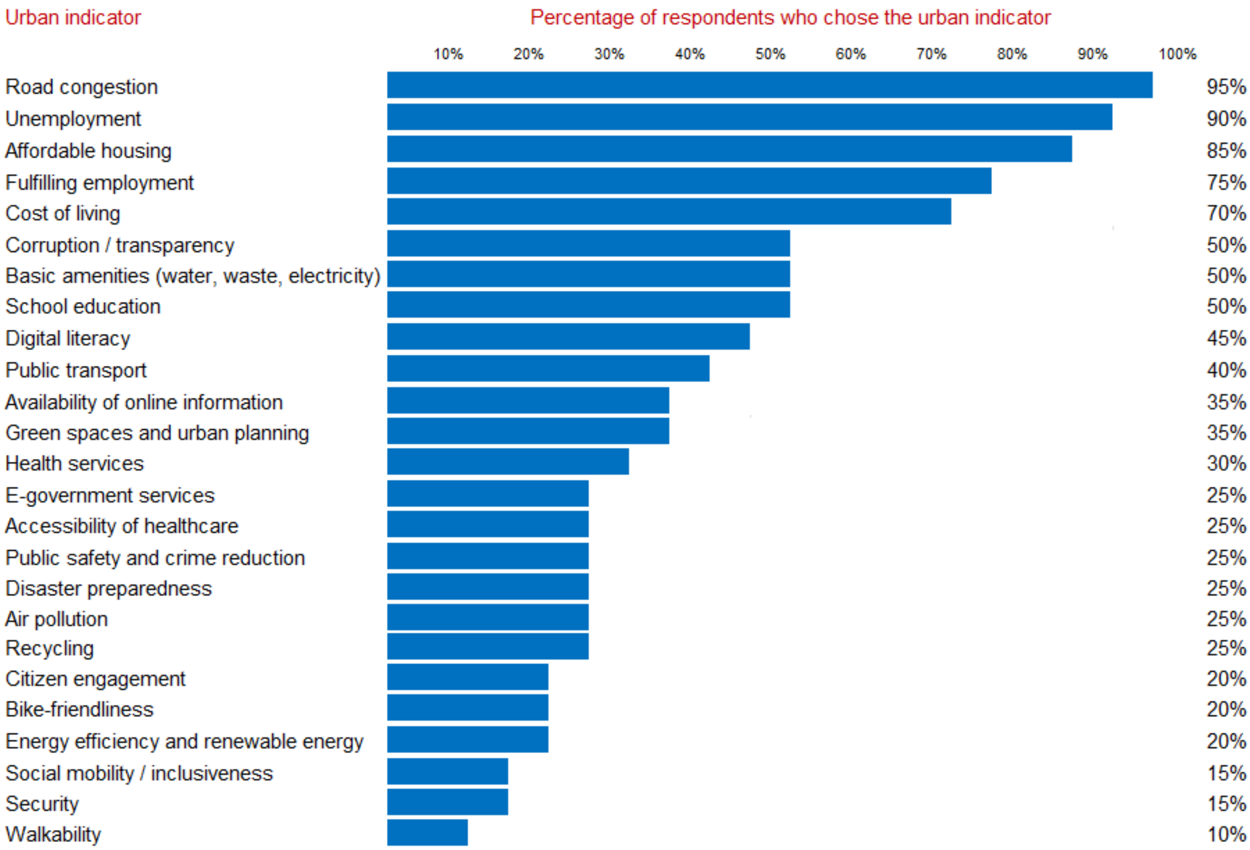

Fig. 9. Citizen prioritization of urban indicators for smart city development. This figure illustrates the percentage of survey respondents (n = 20) who selected each urban indicator as one of the ten most urgent for their city, from a predefined list of 25 indicators. A higher percentage indicates a greater perceived priority among participants. The results provide insight into which urban challenges are considered most pressing by citizens and can support data-driven planning and decision-making in the smart city context

Table 15: Amman, Oslo & Dubai: Smart City Comparison

Aspect	**Amman (Jordan)**	**Oslo (Norway)**	**Dubai (UAE)**
IMD SC Rank 2025	127 / 146	2 / 146	4 / 146
Change from 2024	+1 (128 → 127)	No change	+8 (12 → 4)

Vision	Exists – improve quality of life via technology, resilient & sustainable growth.	Strong – sustainability & innovation as core values.	Very strong – part of Smart Dubai 2021 / Digital Dubai strategy.
Roadmap	Yes – Launched in 2019 by GAM.	Comprehensive, with cross-sector stakeholder collaboration.	Detailed, funded, and backed by dedicated Smart Dubai Office.
SC Department	No dedicated SC department.	Yes – integrated within municipal governance.	Yes – Smart Dubai Office.
Smart City Platform	Yes – GAM app, Sanad, and traffic monitoring platform.	Multiple integrated systems for mobility, energy, healthcare, education.	Unified government service platform; blockchain integration.
Governance	Fragmented, limited funding, weak interagency integration.	Strong political stability, transparency, policy integration.	Centralized, proactive policymaking, strong public-private partnerships.
Citizen Engagement	”Amman is Listening” platform; adoption hindered by ∼35% digital literacy gap.	High, participatory approaches, strong trust in institutions.	Strong e-service uptake, digital inclusiveness programs.
ICT Infrastructure	4G/5G, fiber optics, smart meters, AI pilots.	Advanced 5G, IoT integration, smart grids, renewable-heavy energy.	State-of-the-art 5G, city-wide IoT, AI-based analytics, blockchain governance.

Smart Mobility	BRT, traffic control systems, limited EV adoption.	Electric buses, bike lanes, integrated transport apps.	Autonomous vehicle trials, EV charging network, AI traffic control.
Smart Services	134+ e-services; partial IoT, blockchain, AI deployment.	Fully digitized municipal services, advanced water/waste management.	Near-total automation in public services, AI chatbots, predictive maintenance.
Strengths	Growing ICT sector (3^{rd} largest GDP contributor), clear vision, early adoption of AI & blockchain.	Strong governance, advanced green infrastructure, citizen-focused innovation.	High investment, advanced AI/blockchain integration, strong central leadership.
Tech. Challenges	Aging infrastructure, funding limits, heterogeneous systems.	High cost of continuous innovation, climate adaptation.	Data privacy, high energy demand for tech operations.

In conclusion, several factors are behind the success story of Amman as a SC. Some of those factors are using the right policies and regulations, applying the correct administrative conditions, obtaining the right funds for SC initiatives across different sectors in the city, *etc.*

DISCUSSION, CONTRIBUTIONS, AND SUMMARY

This section discusses key insights from the study, highlights its contributions, and provides a brief summary of the overall work.

Discussion

In order to create smart, green, digital, and human-centric cities of the future, there is a need to give more care to education, investments, strategies, and the sharing of experiences. In that scenario, integrating inclusion with digital transformation will still be a big challenge for all types of cities around the world.

Currently, there are many existing definitions of the SC in the literature, and this in itself constitutes a major challenge for research. Each definition focuses on specific aspects of SC and is not comprehensive in all aspects. Therefore, great progress will be achieved in the field of SCs by finding a single definition of SC and applying this unified definition to every research project to proceed in the same direction (*i.e.,* standard definition of SC).

Moreover, we cannot consider a city that exploits ICT tools to be a SC. There are many benefits of technology, but only employing this modern technology and introducing it into cities does not make them SCs. Technology alone doesn't make the city secure, doesn't provide basic needs (*e.g.,* food, energy, water, and others), and does not protect the city's environment. For example, a city can monitor the entire traffic system and share information with its citizens, but the city doesn't solve traffic congestion problems. Can such a city be considered smart?

The main point is that modern technology is a key tool to create smarter cities, but it does not build a SC in itself. Though it does help to improve services like traffic, logistics, and so forth, it also helps to connect the city and its citizens. Consequently, a SC must meet the primitive needs of citizens (water, food, and so forth) and introduce modern technology to accomplish considerable enhancement in all domains of the city. The incorporation of modern technology and meeting the main needs and services of the inhabitants as a whole, without partition, establishes the basis for a SC.

On the other hand, cities must define a roadmap for SC so that the future steps of the city are clearly planned and designed. This roadmap helps maintain the city in the future and allows cooperation between the different groups working on its development (*e.g.,* the ministry of electricity, water, agriculture, and so on). Without a roadmap, many cities will face the problem of connecting different and diverse initiatives to each other. To summarize, cities that aim to transform into SC paradigm must prepare a clear roadmap in advance and form a specific department to manage the phases of city development, services, and maintenance.

According to *Al-Msie'deen*, SCs should be built from scratch with comprehensive preplanning, as he believes this approach can help circumvent the complex challenges typically encountered when converting traditional cities into smart ones (*cf.* Figure 10).

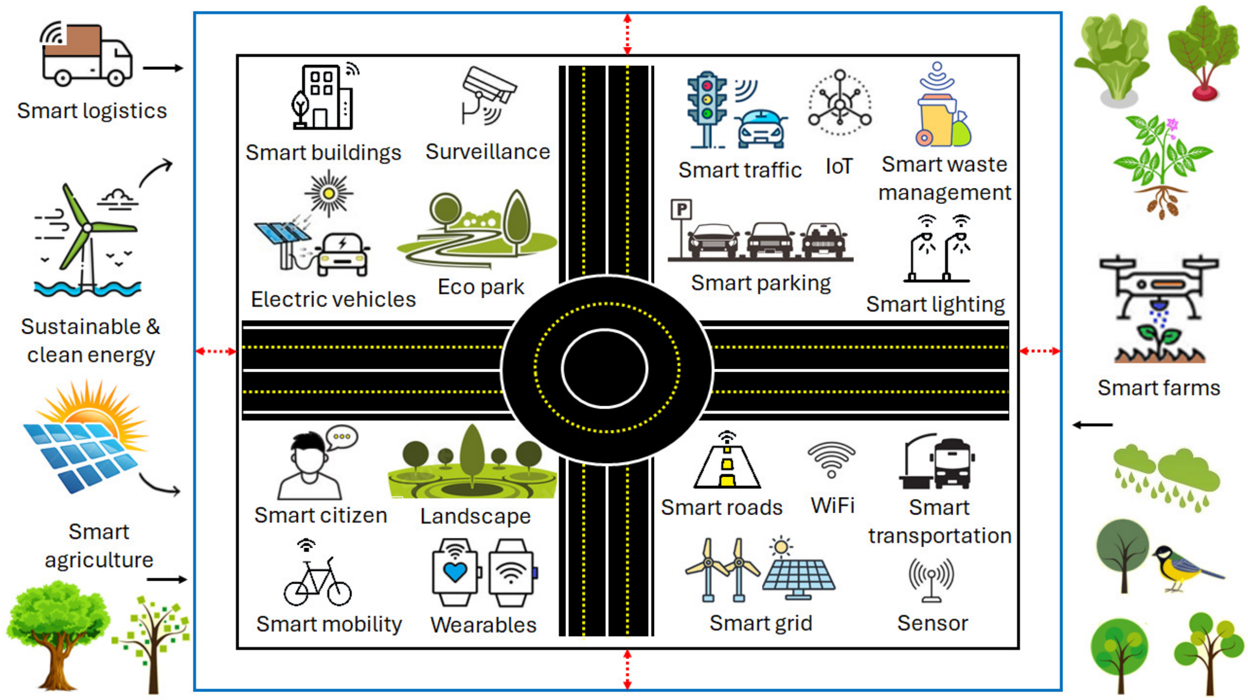

Fig. 10. Building smart cities from scratch

Currently, SC paradigm can be applied to traditional cities (already built), or new cities can be built from scratch to be smart from the beginning. It is preferable that SCs be planned, designed, and developed from scratch. Applying the concept of SCs to existing cities in their usual, pre-built form—without considering numerous factors—may hinder their sustainability. When SCs are prepared from scratch, there is room to provide all means of sustainability for the city. For example, many green spaces and parks can be provided in different areas of the city, and roads can be designed to accommodate future growth, with multiple lanes on each street and dedicated paths for bicycles, walkers, and the disabled. Furthermore, agricultural lands can be designated around the city to ensure that future population and building growth can be accommodated (*cf.* Figure 10).

Establishing energy farms around the city and in the right place and using them to operate the city is a great gain for those SCs built from scratch. It is possible to benefit from renewable and clean energy sources, such as solar and wind energy (*cf.* Figure 10). In traditional cities, there may not be enough space to establish such farms to harvest energy and use it to operate the city. The only solution for traditional and old cities may be to use the roofs of buildings and houses to harvest this energy.

In many crowded urban cities, citizens face difficulty finding suitable places to park their cars. Due to the high population density and the large number of buildings, constructing adequate free parking spaces is impossible. However, when designing SCs in new geographical areas from scratch, incorporating solutions for such problems can be a significant achievement (*cf.* Figure 10). For instance, in the Jordanian capital, Amman, there is a notable scarcity of free parking spaces available to the public. Additionally, government facilities and restaurants provide only a limited number of parking spaces, which are frequently reserved for their employees. This situation leads to substantial congestion and increases the likelihood of accidents, especially since most restaurants are situated along main streets.

Figure 10 illustrates that planning SCs in advance can address the issues currently faced by crowded urban areas. By providing traditional infrastructure, such as streets and buildings, according to the latest international standards and preparing the infrastructure for modern technology with all dimensions considered, many problems can be mitigated. Furthermore, farms are placed outside the city's future borders, and special industrial zones can be established beyond its regulatory boundaries. Additionally, energy-harvesting farms can be located outside the city limits. However, even with meticulous planning and preparation, the sustainability and success of a SC are not guaranteed. The most critical factor for the success of SCs is their citizens. Therefore, it is essential to focus on education, developing environmentally friendly habits and behaviors, and making excellent use of ICT tools. Moreover, SC paradigm can also be applied to existing cities if it is well planned and implemented.

Education plays a crucial role in the prosperity of SCs, as these cities continuously introduce new services for citizens through specialized applications. To ensure that citizens can use these applications effectively, it is essential to provide appropriate training or guidance. Typically, instructions for using an application are provided through software documentation, commonly referred to as a user manual [190] [224] [225]. During the software lifecycle, numerous documents, collectively known as software artifacts [226] [227], are produced. Examples of these documents include user tutorials, software requirements [228], bug reports [229], and design documents [230]. Furthermore, simulation can be employed to demonstrate specific procedures within SCs, where scenarios are recreated using specialized simulation software (*e.g.,* Arena [231]). For example, public safety protocols can be modeled for events such as a fire in a particular building or a car accident within the city.

Software systems are essential for managing SC operations and services. Data visualization is critical for interpreting massive datasets from sensors and IoT devices. Software visualization [232] [233] tools convert this information into interactive dashboards, maps, and models, allowing policymakers, developers, and citizens to identify trends, monitor performance, and make informed decisions. By simplifying complex urban data, visualization enhances transparency, communication, and the overall efficiency of SC systems.

After completing the planning and design process to make a city smart, an important question arises: What is the appropriate architecture for this city? This survey presents the most common architectures used in implementing SCs based on IoT. It's important to note that a single architecture can be selected to fit a specific city, or multiple architectures can be employed within the same city. Depending on the city's unique needs and requirements, the chosen architecture can be adapted accordingly. Thus, selecting the right architecture for SCs before beginning development and implementation can help reduce future problems and costs. There is an urgent need to establish a committee with the mission of standardizing the architecture of SCs. The committee's tasks include developing best practices for implementing technical infrastructure in SCs, providing ICT tools to collect and analyze data from various IoT devices, and ensuring that data collected from different devices (such as sensors and actuators) is represented in a unified format.

After analyzing several SCs, it is clear that most are limited to offering free WiFi and smartphone applications to facilitate electronic transactions and gather resident feedback. However, these features alone do not qualify a city as smart. To truly be considered smart, cities must effectively utilize the city-specific data they collect to provide innovative services. All city data should be collected on a single platform and presented in a manner that is useful to decision-makers, as valuable insights and future projections can be drawn from current data. SCs need to leverage data and technology to drive sustainability and efficiency, and they should continuously seek innovative solutions to enhance the quality of life for their citizens.

To clarify the conceptual contributions of this study, Table 16 summarizes each key element—such as the proposed SC definition, development life cycle, and the Amman case study—and explicitly maps them to corresponding gaps in the existing literature. This structured overview highlights how the work advances theoretical understanding and provides a foundation for future empirical research in the SC domain.

Table 16: Summary of conceptual contributions and addressed literature gaps

Contribution	**Description**	**Literature gap addressed**
Proposed SC definition	Introduces an inclusive SC definition that integrates traditional infrastructure (*e.g.,* streets, schools) with advanced ICT (*e.g.,* AI, IoT) to enhance quality of life.	Lack of unified, multidimensional SC definitions incorporating both foundational and emerging technologies.
SC development life cycle	Presents a novel eight-phase model (planning to innovation) to systematically guide SC transformation efforts.	No existing standardized lifecycle framework guiding SC development phases from inception to review.
Domain taxonomy (extended Yin model)	Adopts and expands Yin's taxonomy to four comprehensive categories (business, citizen, environment, government) with detailed subdomains.	Existing domain classifications are often narrow, fragmented, or lack real-world alignment.

Case study of Amman, Jordan	Provides a qualitative analysis of Amman's SC transformation, including its status, technologies, implemented projects, and strategic vision within a developing city context.	Scarcity of detailed and region-specific case studies on SC implementation in the Levant region.
SC challenges (open + domain-specific)	Summarizes extensive open and domain-specific challenges from literature and adds author's contextual insights.	Lack of comprehensive challenge mapping integrating technical, social, and infrastructural barriers.
SCs research opportunities	Identifies emerging research areas (AI, blockchain, smart education, CV, *etc.*) based on literature trends and author analysis.	Few studies synthesize emerging trends into an actionable research agenda for SC domains.
Conceptual position on greenfield SCs	Advocates for building SCs as greenfield projects, emphasizing the role of preplanning in avoiding the constraints of legacy infrastructure.	There is limited research discussing the strategic benefits of building SCs from the ground up compared to upgrading existing urban areas.

Furthermore, this study examined the strategic and operational elements underlying Amman's transformation into a SC. It assessed whether the city has articulated a clear SC vision, established a centralized platform, developed a structured roadmap, and formed a dedicated department to oversee SC initiatives. In addition, the analysis identified the key SC domains currently addressed in Amman, reviewed the range of projects implemented, and evaluated the core technologies being leveraged to support these efforts. This comprehensive evaluation provides insights into both the progress made and the areas that require further development to advance Amman's SC agenda.

This study focuses exclusively on the ICT-related and conceptual dimensions of SCs, such as technologies, architectures, challenges, and research opportunities, without addressing the actual implementation of SCs. Only published literature was reviewed; no primary data collection, such as interviews or fieldwork, was conducted. Additionally, no empirical validation was performed as part of this study. Several SCs were selected and briefly presented based on their global rankings, all positioned within the top ten SCs worldwide. Amman was chosen as a detailed case study due to the presence of essential SC features and its status as the leading city in the Levant region.

Statement of contributions to the study

This work presents a comprehensive review of SC paradigm, enriched with original contributions by the author to advance both theoretical understanding and practical application. The key contributions are as follows:

1. Proposed Definition: A novel and inclusive definition of SCs is introduced by the author, incorporating both traditional infrastructure (*e.g.,* streets, schools, hospitals) and modern technological components (*e.g.,* ICT, AI, IoT) to enhance the quality of life for citizens (*cf.* Table 2).
2. Smart City Development Life Cycle (SCDLC): The author proposes an 8-phase life cycle framework for transforming traditional cities into SCs. This structured model—comprising planning, analysis, design, development, operation, evaluation, sustainability, and innovation—is not yet formalized in existing literature and serves as a foundation for further research and standardization (*cf.* Figure 4).
3. Case Study on Amman: A detailed analysis of Amman as a SC is presented, including its vision, roadmap, platform readiness, implemented projects, and technological infrastructure. This case study contributes region-specific insight into SC transformation in developing urban contexts (see Tables 10-15).
4. Application Domain Taxonomy: The author extends existing taxonomies by adopting and broadening Yin's model to cover business, citizen, environment, and government domains, supported by detailed subdomain classifications and real-world examples (*cf.* Table 5).
5. Smart City Challenges: A thorough summary of open and domain-specific challenges is pre-

sented. Notably, Table 6 includes challenges based not only on the literature but also based on the author's own insights and observations, drawn from practical analysis and experience.

6. Research Opportunities: The article highlights promising research directions across various domains (*e.g.,* AI, healthcare, energy, education). These were identified through a comprehensive literature review as well as the author's independent evaluation of emerging trends and unmet needs (*cf.* Table 8).
7. Author's position on SC design: advocating for SCs to be built from scratch with comprehensive preplanning (*cf.* Figure 10) — an original viewpoint intended to provoke further discussion in future studies.

Together, these contributions aim to provide a well-structured foundation for researchers, policymakers, and city planners seeking to understand, implement, and advance SC initiatives.

While the conceptual models and frameworks proposed in this study—such as the SCDLC and the domain taxonomy—offer structured insights for understanding and developing SCs, they have not yet undergone empirical validation. Future work should focus on applying these models in real-world urban contexts to evaluate their practical utility, effectiveness, and adaptability across different city types and regions.

Summary

The concept of SCs has garnered global attention as urban areas seek innovative strategies to enhance the quality of life for their residents and promote environmental sustainability. SCs signify a forward-thinking model of urban development that capitalizes on advanced technologies to improve city efficiency, livability, and resilience. The rise of this paradigm is driven by rapid progress in ICTs, which have transformed everyday systems and infrastructure into intelligent, interconnected networks that streamline services and urban life.

This article provides a comprehensive overview of the SC ecosystem, delving into foundational elements such as definitions, architectural models, enabling technologies, application domains, implementation challenges, future research directions, and case studies. A key contribution of the study is the author's own definition of a SC and the introduction of an eight-phase Smart City

Development Life Cycle (SCDLC) designed to guide the transformation of traditional cities into smart ones.

The paper also presents an in-depth analysis of existing SC architectures and technological frameworks, along with a classification of key urban domains where smart solutions are applied. Furthermore, the study includes a focused case study of Amman, Jordan, assessing its current progress and strategic direction in adopting SC model.

Through a systematic literature review, this research highlights the current challenges facing SC development, such as technological, organizational, and socio-political barriers, and identifies opportunities for future innovation. Ultimately, this article serves as a valuable resource for researchers, city planners, and policymakers aiming to navigate and contribute to the evolving landscape of smart urbanism.

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