Questions:

a) what is IoT and what makes a city smart?

b) What are the benefits of using IoT in cities?

c) what are the challenges that occur?

Internet of Things in Smart Cities: Comprehensive Review, Open Issues, and Challenges

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***Abstract*—Smart cities rely mainly on the Internet of Things (IoT) to make an urban area smart to offer its citizens a high quality of life with optimal use of resources and preservation of the environment. IoT is the key component that collects raw data on the surrounding environment to be analyzed to extract information that supports decision making. The widespread use of IoT results in the emergence of smart homes, smart energy, smart transportation, and smart healthcare, which build a smart city. On the other hand, challenges, such as heterogeneity, scalability, security, and privacy, hinder the efficient functioning of the IoT in the construction of smart cities. This article presents a comprehensive overview on the concept of IoT moving forward to the concept of smart city, highlighting key elements and characteristics, studying and reviewing state-of-the-art research on this theme. Future directions are discussed to guide researchers, who focus on interoperability between IoT platforms in smart cities and on IoT architectures based on micro-services. Case studies of successful smart cities are presented for gaining learned lessons. The impact of integrating wireless networks (5G and 6G) in the IoT is also clarified in the future direction. The significance of this research is found in its comprehensive examination of various aspects of the smart city instead of concentrating on a singular facet.**

***Index Terms*—Internet of Things (IoT), smart city, smart energy, smart healthcare, smart transportation.**

I. Introduction

The WORLD Bank's findings reveal that more than 50% of people worldwide live in cities. By 2045, the urban population is projected to grow 1.5 times, reaching 6 billion [1]. This population growth makes it imperative that governments prepare quickly for this expansion and supply the essential facilities, foundations, and low-cost housing requirements that are essential for their citizens. This population explosion will pose enormous challenges, due to the limited assets in various fundamental aspects, such as healthcare, community, education, and mobility. To maintain the sustainability of these resources, new administration methods must be applied [2]. Therefore, making cities smarter is the most popular strategy [3]. So, recent studies, such as [4], [5], [6], and [7], present significant contributions to understand this concept presenting a real applications and case studies.

Manuscript received 3 May 2024; revised 1 July 2024, 23 July 2024, and 24 July 2024; accepted 22 August 2024. Date of publication 26 August 2024; date of current version 24 October 2024. *(Corresponding author: Essam H. Houssein.)*

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Digital Object Identifier 10.1109/JIOT.2024.3449753

In 2020, the united nations development program (UNDP) [8] reported that cities were responsible for 70% of global greenhouse gas emissions (GHG) and were vulnerable to natural disasters caused by climate change, including flooding and heat stress. It also noted that cities are environments in which the effects of 1.5° Celsius above warming will converge, including heat-related strain, land and coastal inundation, the appearance of new disease carriers, air pollution, and limited water supply. Smart cities will provide remedies to address and adapt to the challenges posed by climate change [9]. For example, smart energy systems, as one of the key components of smart city infrastructure could reduce carbon emissions by reducing energy consumption [10]. Furthermore, the decentralized nature of smart energy systems increases resilience by providing local power generation during natural disasters, such as hurricanes and storms, when traditional centralized power plants are affected. Smart water systems are capable of identifying at-risk areas and providing early warning to citizens, such as identifying areas within a city at risk of stormwater flooding. Additionally, smart transportation systems often focus on reducing emissions by reducing driving time.

The Internet of Things (IoT) is a system that relies on merging various devices and technologies without the need for human intervention. IoT devices establish an online connection, transmitting data to the cloud, and receiving commands and instructions on how to proceed. In summary, IoT systems collect and analyze data to extract information to support decision making [11]. The smart city is an infrastructure that utilizes cutting-edge technology to facilitate efficient data management, resulting in improved citizen satisfaction, increased economic growth, and a more sustainable environment [12]. The IoT serves as a critical foundation in constructing smart cities that enable automated actions [13]; where it provides various services that require the utilization and use of various data collected from daily life [14]. The integration of IoT and artificial intelligence (AI) increases smartness in decision making to intelligently deal with critical events [15]. Such resulting services offer residents a sustainable and pleasant living setting, especially in essential sectors, such as health, education, energy, transportation, communications, etc.

In reality, several challenges arise when applying the idea of a smart city. Among these challenges, enhancing people's quality of life, privacy concerns, notably concerning personal and household data. Additionally, people may be apprehensive about implementing new technology or think it is too intrusive [16]. The integration of heterogeneous

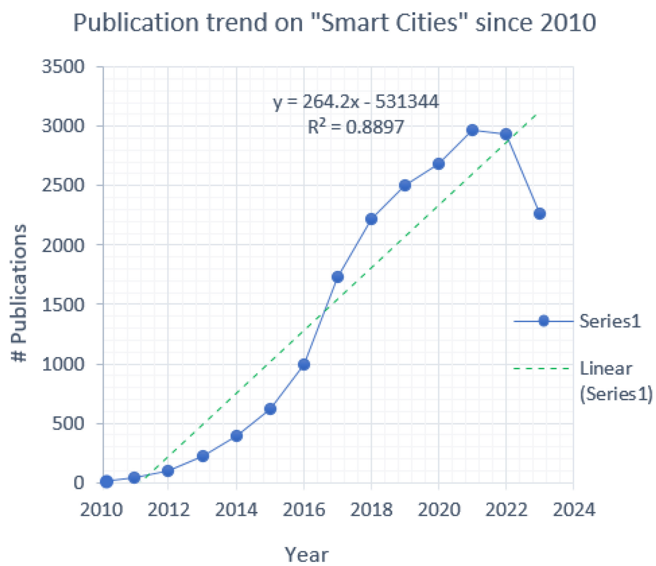

Fig. 1. Recent research trend on "smart cities" since 2010.

elements constitutes a significant challenge in the context of smart city architectures, as the smart city comprises many different vendors and types of sensors, devices, and appliances [17]. To realize the smart city concept, it must be possible to achieve seamless integration of these diverse components. Heterogeneity between elements hinders integration and interoperability between smart city components or applications, leading to incompatibility between platforms [17]. Furthermore, continuous generation, aggregation, handling, and retention of large-scale heterogeneous data derived from numerous intelligent city sensors present a unique set of difficulties [18].

Gracias et al. [19] presented that the implementation of smart city initiatives challenges can be addressed through three main strategies: 1) policy and governance; 2) partnerships and collaboration; and 3) technology and infrastructure. Four key elements; technology, telecommunication, talent, and tolerance are suggested to be aligned with the infrastructure layer for building a smart city [6]. These strategies aim to improve quality of life, efficiency, sustainability, and economic development. Future smart city projects can benefit by employing a comprehensive, adaptive approach, fostering citizen engagement and public-private collaboration, and leveraging innovative technologies to achieve their goals. Resulting paradigm is know as social smart city (SSC), and in general it is knows as social IoT (SIoT) [5]. This holistic approach ensures diverse stakeholder needs and perspectives are considered, leading to the successful implementation of smart city initiatives and enhanced lives for citizens.

According to the Scopus [20] database, Fig. 1 illustrates the analysis report on smart cities, spanning 2010 to 2023. It aims to clarify the evolution of research in this domain and the level of interest among researchers.

We have meticulously examined +200 recent studies on smart cities and IoT published in high-impact journals indexed by Web of Science and Scopus. From this pool, we have selected and highlighted most relevant and noteworthy research articles that serve the following major contributions of this article: 1) presenting a comprehensive overview on the concept of IoT and smart city; 2) highlighting key elements and characteristics of IoT and smart cities; 3) study and review state-of-the-art research on IoT and smart cities; 4) summarizing the main challenges of smart cities; 5) presenting successful case studies on smart cities; and 6) shading the light on future directions.

The remaining sections of this article are organized as follows. Section II presents related work on smart cities and the IoT. Section III delves into the definition and common architecture of the IoT. Section IV delves deep into the notion of a smart city, including its components and characteristics, followed by the common challenges of smart cities in Section V. Section VI lists three case studies of smart cities. Section VII discusses future directions; finally, the conclusion is presented in Section VIII.

II. Related Work

A numerous literature reviews concerning our subject matter are available. Researchers spot their light on different aspects in this theme. Some related work focus on studying case studies, such as Sejong [7], Zurich [21], Amsterdam [22], Masdar City [23], and Cagliari (Italy) [5]. Other studies focus on enhancing smart cities by integrating recent Information and Communications Technologies (ICT) [15].

Stübinger and Schneider [24] employed data-driven techniques from natural language processing and time series forecasting to examine the top 200 Google Scholar publications concerning smart cities. This approach enabled the identification of major themes, including smart {*infrastructure, economy, policy, technology, sustainability, and health*}. Their analysis suggested an impending rise in the significance of smart sustainability in the future, based on the identified trends. Singh et al. [25] conducted a comprehensive review in this theme to study several key aspects: origin and emergence, primary pillars, typical architecture, components, challenges, opportunities, and future trends. Zhao et al. [26] conducted a review on 191 publications sourced from respected journals and influential literature from 2000 to 2019. They identified four primary challenges within smart city research: 1) fragmentation and overemphasis on technology dominate smart city research; 2) focus on exploring the advantages of smart cities, neglecting the examination of technological drawbacks and unsuccessful projects; 3) crucial need for the formulation of new theories designed explicitly for smart city research; and 4) existing conceptual frameworks in smart city research are deficient in empirical testing (i.e., gap in practical validation).

Al Sharif and Pokharel [27] provided a review that delves into identifying dimensions, evaluating assessment tools, examining available technologies, and addressing technical and non-technical risk parameters involved in their implementation. Laufs et al. [28] focused on emerging security technologies within 'smart cities', aiming to assess their alignment with conventional security interventions. They introduced three distinct categories to classify these security interventions: 1) leveraging new sensor technologies but employing traditional actuators for security purposes;

2) upgrading existing systems within smart cities to imbibe 'smart' capabilities in terms of security; and 3) introducing entirely new security functionalities within the framework of smart cities, diverging from traditional approaches.

Winkowska et al. [29] carried out a bibliometric analysis encompassing publications indexed in the Scopus and Web of Science databases between 2009 and 2019 to uncover primary research focal points evident in the worldwide body of literature concerning smart cities. Their findings emphasize that achieving a "smart" city status is not solely achievable through technological advancements. To truly embody "smartness," a city must integrate various essential elements. These encompass the facets of a smart economy, smart populace, smart living conditions, smart environmental management, smart governance practices, and smart mobility solutions. Furthermore, Tan and Taeihagh [30] conducted an examination of smart city development, specifically within developing countries. Their study aimed to comprehend the conceptualizations, motivations, distinctive drivers, and obstacles influencing smart city development in these regions. They gathered insights from 56 studies detected through a comprehensive literature review. They concluded that it is imperative to embed simultaneous socioeconomic, human, regulatory, and legal reforms within the long-term developmental paths of these nations.

Lim et al. [31] present a comprehensive review of 55 articles to discern the outcomes stemming from smart city development. They identified 12 positive outcomes, including heightened citizen involvement, environmental protection, and facilitation of social development. In contrast, they also highlighted four negative results, such as privacy and security concerns, as well as potential impacts on freedom of speech and democracy. Kim et al. [32] conducted a detailed quantitative and qualitative review to reveal the obstacles that prevent smart homes from moving toward sustainable smart cities. Specifically, they proposed innovative solutions tailored for the advancement of energy-saving systems within sustainable smart cities. These solutions include infrastructure development for advanced energy conservation systems and the implementation of a new energy trading strategy for distributed energy systems. Sharifi et al. [33] conducted a review encompassing 147 studies that examined the utilization of intelligent solutions and technologies during the coronavirus pandemic which offered a range of advantages. These included improving a city's ability to foretell pandemic patterns, facilitating integrated and prompt responses, reducing virus transmission, supporting overstretched sectors, mitigating supply chain disruptions, ensuring the continuity of essential services, and optimizing city operations.

Siddiqui et al. [34] introduced a security architecture for services during collaborative activities within software defined networking (SDN) and smart contract-enabled urban environments in smart cities, focusing on authentication and authorization. Shah et al. [35] presented an innovative reference architecture and approach for a disaster-resilient smart city (DRSC), achieved by combining IoT and big data technologies. Rathore et al. [36] introduced a transport control model leveraging cyber–physical systems (CPSs) and sensor technology to constantly monitor and analyze vast urban data, facilitating informed decision making for smart city management.

Almost of recent studies survey different aspects for smart cities. For instance, Pandya et al. [37] concentrated on federated learning, it is applications and challenges in smart city, while Monios et al. [38] surveyed IoT platforms and commercial and open-source tools, focusing on key aspects and characteristics for building smart city applications. Kasznar et al. [39] designed a classification framework to provide insights into new initiatives concerning smart city infrastructure by addressing key dimensions, themes, and deficiencies in current methodologies. Ullah et al. [40] explored the potential of IoT and machine learning technologies in creating smart cities focusing on challenges like data privacy, security, and ethical considerations. Fadhel et al. [41], focused on information fusion methods highlighting advantages, quality, challenges, and critical issues. On the other hand, Olaniyi et al. [42] highlighted strategies for addressing big data challenges. Ahmed et al. [43] presented a review on smart homes and smart cities discussing barriers and future trends.

To sum up, in contrast of these studies that focus on specific aspects of the smart city, such as big data analytics, federated learning [37], information fusion [41], etc., this study provides a comprehensive overview of various aspects of the smart city for guiding researchers starting with the concept of the smart city and its fundamentals components, the role of IoT, challenges, the future directions, and learned lessons from studied case studies. Table I presents a concise summary of recent top-10 distinct comprehensive literature reviews discussed in this section.

III. Internet of Things

A. Definition of IoT

The concept of the IoT is originated in 1982 when an adapted Coca-Cola vending machine connected to the Internet [44]. Weiser [45] introduced a contemporary concept of IoT in 1991, rooted in the idea of ubiquitous computing. Simultaneously, Kevin Ashton [46] coined the phrase "IoT" to describe a network of interconnected devices.

There is no singular definition for the IoT that is accepted by the global user community. Madakam et al. [47] proposed that the most comprehensive definition of the IoT is "A network of intelligent entities, openly interconnected, capable of self-organization, exchanging information, data, resources, and reacting and adapting to environmental conditions and alterations." According to Gubbi et al. [48], the IoT is the integration of sensors and actuator devices that allow the exchange of information through multiple platforms within a single framework, creating a unified operational picture to facilitate novel applications. This can be accomplished by employing pervasive sensing, data analysis, and representation of information to be organized through the overarching platform of the cloud. Patel et al. [49] defined the IoT as a

TABLE I
CONCISE OVERVIEW OF THE RECENT TOP-10 DISTINCT AND PERTINENT COMPREHENSIVE LITERATURE REVIEWS PRESENTED IN THE RELATED WORK

Ref	Year	Main Contributions	Main Goal	Key Elements / Case Study	Recommendations
[38]	2024	Compare platforms and open-source tools in terms of scalability, security, interoperability, and cost-effectiveness to highlight their capabilities	Assist city planners and developers in selecting the most appropriate platform	IoT platforms: e.g., Oracle IoT, SAP IoT, Akenza, Hitachi Lumada, etc. List smart cities that implement tools and projects **(e.g., Pamplona and Treno implement STARDUST project)**	Open-source IoT platforms are required to be enhanced to facilitate smart city building
[40]	2024	Explore the potential of IoT and ML in creating smart cities applications.	Emphasizes the integration of the IoT and ML.	Key components, challenges, knowledge discovery. **(No specific city use case)**	Recommend integration of such technologies with focus on raising challenges concerning security and privacy issues
[41]	2024	Survey information fusion methods highlighting advantages, quality, challenges, and critical issues in implementation.	Assist developers insights into information fusion technologies and algorithms	challenges, information fusion limitations, components, datasets. Blockchain and AI integration. **(No specific city use case)**	Integration of advanced ICT technologies in smart city applications.
[42]	2023	Survey strategies for addressing big data challenges in smart cities.	Enhancing decision-making using big data analytics.	Survey techniques and challenges related to big data. **(No specific city use case)**	Enhance integration of data analytics techniques focusing on critical aspects such as security and privacy.
[37]	2023	Survey federated learning (FL), it's applications and challenges in smart city.	Highlight the role and potential of FL in smart city	Smart city components (transportation, healthcare, etc.) **No specific city use case, but study Projects (e.g., IoT-NGIN)**.	enhance privacy and security for FL-based applications in the light of learned lessons, open issues, and challenges
[25]	2022	Survey primary pillars, typical architecture, components, issues, opportunities, and future directions	gain comprehensive knowledge and best practices	Paradigms, characteristics, challenges, supporting technologies and opportunities **(case study: Masdar city)**	Emphasizing sustainable development and integrating advanced ICT technologies such as AI, IoT, and big data.
[27]	2022	Survey various aspects: assessment tools, available technologies, and risk factors.	gain technical analysis on variety of risks	Smart city components (e.g., smart economy, governance, etc.), technologies, and risks. **(No specific city use case)**	Highlight risks concern security and privacy issues.
[33]	2021	Survey key technologies e.g., IoT, big data analytics, and AI during the COVID-19 pandemic	Highlights effectiveness of smart cities to face pandemic like COVID-19	Focus on broader lessons and insights.**(No specific city use case)**	Focus on legal barriers, technological feasibility, privacy and security issues.
[32]	2021	Survey barriers hindering the evolution of smart homes into sustainable smart cities	Moving toward sustainable smart cities	key challenges technologies, and opportunities concerning smart energy integration. **(No specific city use case)**	Integration of advanced ICT technologies such as AI and Blockchain focusing on scalability and interoperability
[24]	2020	reviews the top 200 Google Scholar publications focus on listed key elements studying their relationship	Provide a data-driven methodology to the concept of smart city	Smart infrastructure, economy and policy, technology, sustainability, and health. **(No specific city use case)**	Smart sustainability: minimizing the required input of energy, water, food, waste, heat output and air pollution is becoming increasingly important

network composed of three distinct components: 1) human to human; 2) human to machine/things; and 3) things/machine to things/machine, all interconnected via the Internet. For constructing IoT key elements (i.e., SThs), things have to be attached with sensors and actuators to be identifiable, capable of communication and interactive [50], [51].

Abdul-Qawy et al. [52] argued that the actual essence of the IoT lies in its ability to link a wide range of diverse devices, including commonplace objects, intelligent sensors embedded in devices, context-aware computing, conventional computing networks, and smart objects with varying designs, systems, protocols, intelligence levels, applications, vendors, and size. These entities interact and communicate with each other to gather, create, process and share data through applications and management systems hosted on data centers/network clouds.

To sum up, the IoT paradigm denotes the pervasive presence of various things and objects in the environment, connected through wireless or wired communication networks using distinct addressing methods. These objects possess the capability to communicate and cooperate among themselves creating smart applications and services to cover every facet of human life, society, industry, and the environment. Smart energy, smart healthcare, smart community, and smart transportation are some of the most well-known IoT applications, which fall under the umbrella of smart city elements as well. These applications will be discussed next in details in "The Smart City" section.

B. IoT Architecture

IoT architecture is the foundation; if the architecture is not resilient and adaptable, deployment and utilization of the IoT may be delayed and require reengineering [53]. Numerous IoT architectures have been suggested in the academic literature [54], [55], [56] and [57]. As shown in Fig. 2, most common IoT architectures may include three, four, five or six layers. In six-layer architecture, coding layer is added for enabling smart things (SThs) identification [58], however it could be combined with the perception layer and enhanced by integrating recent technologies such blockchain [59]. Thus, the five-layer architecture is most balanced one; where it combines the most essential characteristics for enabling data security and privacy [58]. These layers are perception, network, processing (cloud), application, and business. A brief summary of each layer is presented below.

1) *The Perception Layer* is the most basic tier within the IoT architecture; here sensors (i.e., SThs) collect data about their state to perceive environmental features.
2) *The Network Layer* receive sensory data obtained from the perception Layer and transmit it to the cloud/fog

III Internet of Things

A. Definition of IoT

There are a lot of different definitions of IoT. The essential characteristics of IoT are the composition of various distinct devices (things) that communicate with each other and share and analyze data through the Internet. In order to share data, the devices are equipped of sensors and actuators. A network of intertwined "things" that exchange information is forming a smart application

B. IoT Architecture

5-layered architecture covers the most important aspects:

1. Perception Layer: collection of data through sensors
2. Network Layer: sends the received sensory data the cloud application
3. Processing Layer: process and analyze data
4. Application Layer: ?
5. Business Layer: ?

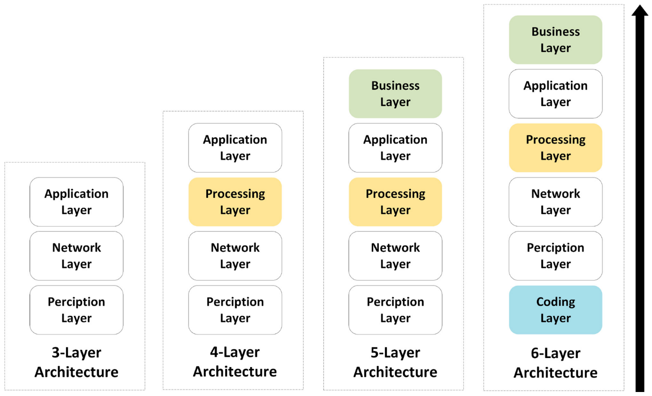

Fig. 2. Most common IoT architectures.

layer. This layer may include a network management center or an information processing center [60].

3) *The Processing Layer (Cloud Layer)* houses highly resource-intensive algorithms to mine and process received data to make more intelligent decisions [15].
4) *The Application Layer* realize various IoT applications that depend on the processing of data and information, e.g., smart homes, cities, cars, healthcare, etc. [58].
5) *The Business Layer* facilitates the administration of IoT applications and services that handle all IoT-related research. It also develops various business models to influence business operations [61].

IV. SMART CITY

A. Concept of Smart City

In the 1990s, the term "smart city" was coined to reflect the shift in urban development toward technological development, innovation, and globalization [62]. Smart cities have received much attention since IBM started their Smarter Planet initiative in 2008 [63]. Multiple reports and articles have been published on smart cities, but there is no consensus on the exact definition. Most definitions refer to the utilization of ICT as a critical factor in the development of services and improving decision support systems to present comfortable life [64]. For instance, Su et al. [65] defined smart city as the utilization of ICT to detect, evaluate and incorporate the essential data from the core systems to provision intelligent responses to various types of daily life services and automated operations. So, in [11], the application of various ICTs to improve the quality of life of city residents is what makes a city a "smart city."

To make the city smart, it is necessary to combine, communicate and integrate all systems that focus on various aspects of the city [66]. The smart city makes investments to promote sustainable economic growth and high standards of living in addition to managing natural resources in an environmentally responsible manner through the implementation of participatory governance [67].

In summary, it is clear that the concept of a "smart city" has been divided into two broad categories. The first focusses on the empowerment and optimization of infrastructure through ICTs, energy consumption, environmental and waste management, mobility, etc. The second focusses on citizens, education, social integration, governance, and creativity at the core of the definition. Therefore, it is evident that a consensus is needed on the definition of a smart city [68].

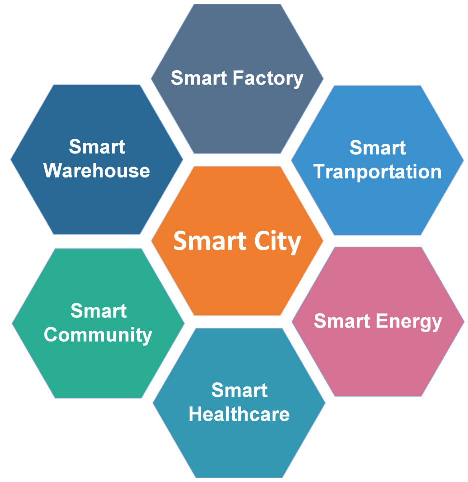

Fig. 3. Common key elements of a smart city.

B. Components of Smart City

Fig. 3 shows some key elements of a smart city, such as smart community, smart energy, smart transportation, and smart healthcare. The composition of smart cities varies depending on the focus areas, with elements, such as disaster management systems in one city's smart community and waste management in another [17]. The following sections will explore key elements commonly present in most smart cities.

1) Intelligent Transportation System: Intelligent transportation system is a set of tools that allows for a unified, interconnected, and automated means of transportation that is highly data-driven to better meet user needs and address those of both passengers and system operators [69]. Data and information on traffic jams, road conditions, passengers, and other topics will be collected from IoT connected devices to be analyzed with the aide of super-computing and cloud computing. Subsequently, computer algorithms will maximize user experience, safety, user routing, and transportation infrastructure [70].

Smart transportation is composed of two components: 1) smart traffic control management (CTC) and 2) autonomous vehicles (AVs) [71]. The ultimate goal of the CTC system is to have a distributed system in which all vehicles, control bases, and traffic signs can exchange data between themselves to make an informed decision in a secure and optimal environment. In this context, we should be very aware of electric vehicles. In the future, transportation will be heavily relying on driverless or AVs that do not require the intervention of humans to make decisions on their behalf [71]. In the cloud-based system, all components of Intelligent Transportation System (ITS) will exchange all required data between themselves and then conduct appropriate analysis to make the best decisions.

2) Smart Energy: Smart grids affect primarily the electricity industry, and enable the identification of more practical and economical solutions for the transition to renewable and

IV Smart City

A. Concept of Smart City

There is no universal definition of a "smart city", however, there are 2 categories in which the concept of a smart city falls:

1. Improving decision making by collecting and processing data through ICTs which leads to a greater standard of living

2. government investments to achieve a "sustainable economic growth and high standards of living"

B. Components of Smart Cities

1) Smart Transportation: This component can be divided into 2 parts: (1) smart traffic control management which means that all devices (e.g. vehicles) exchange information to make better decision like taking another road for example.
(2) autonomous vehicles

2) Smart Energy: Optimization of energy usage to shift towards sustainable and renewable energy.

sustainable energy by integrating multiple sectors (including industrial, buildings, transportation, and heating, cooling, and electricity) [72]. Thus, a Smart Energy System is a system of integrating and coordinating Smart Energy, including electricity, thermal, and gas, to identify and optimize the performance of each sector and the energy system as a whole [73].

Mosannenzadeh et al. [74] defined smart energy city as a crucial component of site-specific smart city development, aiming to ensure a sustainable, self-sustaining, and resilient transformation of energy systems by optimizing their integration into energy conservation and energy efficiency, as well as regional renewable energy resources. It is distinguished by a blend of ICT and technology that allows for integrating several areas and encourages multistakeholder cooperation while ensuring the sustainability of its actions.

3) Smart Healthcare: Smart healthcare is a smart system that includes IoT components (wearable devices, the mobile Internet) to obtain information and connect people, materials, and institutions in real time addressing the requirements of the medical ecosystem [75]. Smart healthcare facilitates remote health monitoring and helps alleviate the burden on hospital resources, such as physicians and hospital beds. Additionally, it may be utilized to improve healthcare accessibility for individuals living in remote regions or to help older people maintain their independence at home for an extended period [76]. A wide range of smart healthcare systems have been implemented. For example, IBM Watson [77], which uses guidelines derived from the literature on medical issues to respond to health-related inquiries. Additionally, Yin and Jha [78] proposed a Health Decision Support System (HDSS) to enable disease detection in many settings, including both in-clinic and out-of-clinic scenarios through the integration of data from wearable medical sensors (WMSs) with computer-based clinical decision support systems (CDSSs).

4) Smart Community: is an integrated human-centric system in which technology provides citizens with data and services that enable them to make informed decisions [79]. The U.S. National Science Foundation (NSF) [80] defines a smart community as a combination of advanced technologies and physical surroundings, such as infrastructure, that seek to improve the overall quality of life for individuals residing, working, or traveling within the community, focussing on social, economic, and environmental well-being. The performance of a smart community cannot be achieved through the implementation of individual components alone, so smart communities are integrated with a broad spectrum of other components to maximize the benefits associated with a smart city.

C. Characteristics of Smart City

The combination of several attributes contributes to the development of a smart city. According to [81], a smart city is defined by six characteristics: 1) smart people; 2) smart economy; 3) smart governance; 4) smart mobility; 5) smart environment; and 6) smart living. In [82], Smart cities are characterized by their sustainability, high standard of living, urban development, and intelligent features as shown in Fig. 4.

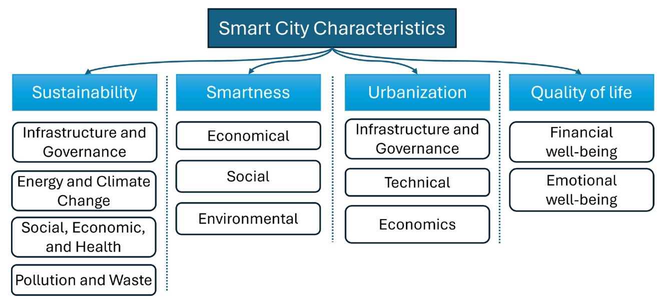

Fig. 4. Smart city characteristics.

Sustainability encompasses the aspects of a city's infrastructure, governance, energy, climate change, pollution, and waste management. Quality of life is an assessment of an individual's emotional and financial well-being. Urbanization encompasses a variety of factors and indicators, from technology to infrastructure, governance, and economics. Smartness refers to the aspiration to enhance the economic, social, and environmental conditions of a city and its citizens [82].

V. Common Challenges of Smart Cities

A. Security and Privacy

The consensus among researchers and experts is that the security of the IoT ecosystem is a fundamental hurdle to the effective implementation of IoT devices. Maple [83] identifies physical restrictions on devices communication, heterogeneity, scalability, and ad-hoc nature as security issues in the IoT, besides authentication and identity, authorization, and access control. The development and implementation of effective, interoperable, and scalable security measures are further complicated by the complexity of IoT; where several heterogeneous devices located in various contexts may communicate information with each other [84].

Syed et al. [11] offered an overview of the security and privacy challenges within IoT framework for smart cities, along with potential strategies to address them. Ahmed [85] discussed available solutions and highlighted research challenges for achieving a secure smart city. Younan et al. [59] presented a new paradigm entitled Quantum Chain of Things (QCoT) for securing IoT applications by integrating quantum computing and blockchain. Chentouf and Bouchkaren [86] concentrated their efforts on utilizing blockchain technology to bolster security and privacy within smart city services. They proposed a decentralized, secure, and transparent electronic voting system. Privacy and security measures, such as anonymization, access control, and encryption, can be implemented to safeguard sensitive data from cyber-attacks [87].

B. Heterogeneity

As is known, the IoT is a network of numerous interconnected objects and devices linked to the Internet. These devices are diverse in terms of their standards and technologies, which communicate through various protocols. Due to heterogeneity challenges, getting the IoT up and running on a large scale is difficult. Noaman et al. [88] conducted a systematic review of 81 primary sources to

3) Smart Healthcare: Sharing knowledge from various hospitals and other institutions improving the remote accessibility of those information.

4) Smart Community: Defines to help individuals in the decision making of certain areas like: social, economy and enviroment. This help improves the quality of life

C. Smart City Characteristics

1) Sustainability: climate change, waste etc.

2) Smartness: ESG

3) Urbanization: tech, infrastructure etc.

4) Quality of Life: Emotionally and financially

V Common Challenges of Smart Cities

A Security: information is being exchanged over the Internet which can be prone to cyber attacks

B Heterogeneity: All of the devices used to collect and share data have are based on different technologies which complicates the interconnection of them.

C Scalability: The raising demand for IoT devices affects the performance of the IoT network identify 14 heterogeneous IoT challenges, focusing on device heterogeneity, data format variations, communication, and interoperability issues, and identified 81 solutions to these difficulties. Hong and Shi [89] proposed an effective framework to manage heterogeneous sensor systems across different domains to improve quick disaster responses in smart cities. Phuttharak and Loke [90] introduced an event-driven architecture for smart city platforms, focusing on scalability, flexibility, and heterogeneity in event processing.

C. Scalability

Scalability for IoT is the ability to support more systems/components, such as connected devices/users and new application features/capabilities, without impacting performance [91]. By 2050, the number of connected devices on the Internet will exceed 100 billion [92], which highlights scalability as a critical issue for the IoT [93]. The management of IoT scalability could be described in two key points [94]: the first point is that IoT devices are growing, as a result existing management protocols are not sufficiently adaptable to accommodate the demands of IoT devices. The second point is that addressing social interactions among individuals, since IoT devices serve as portable companions for people.

A variety of potential solutions have been proposed. For example, in [95] a peer-to-peer (P2P)-based architecture was proposed; This architecture possesses the ability to expand and adapt itself to accommodate extensive IoT networks. Furthermore, a new scheduling algorithm is introduced in [96] to optimize energy consumption for large-scale IoT networks, this algorithm could reduce the hops between sensor nodes, which consequently reduces packet loss. Javed et al. [97] unveiled an open and scalable IoT platform by embracing the modular features of edge computing.

VI. Case Studies

This section highlights the most brilliant and successful case studies of real smart cities according to [21], [22], and [23]. First, Zurich is highlighted as the world's smartest city based on the IMD Smart City Index [21]. Second, Amsterdam is discussed as Europe's first smart city. Finally, we draw attention to Masdar city in the Middle East, a meticulously planned city from scratch aimed at reducing emissions and improving citizens' quality of life. In each case study, we will outline the challenges faced and the solutions implemented. At the end of the section, we will summarize the learned lessons.

A. Zurich City

For the fourth consecutive year, Zurich has been recognized as the world's smartest city according to the IMD Smart City Index (2023) [21]. Zurich excelled in various categories, securing the highest scores in healthcare and safety, activities, work and school, and governance. The only exceptions were air pollution and the affordability of rental housing. The city's focus on technology received lower-than-average rankings. Zurich's commitment to digital transformation aims to sustain its high standard of living, drive sustainable growth, and strengthen its position as an innovation and business hub. The city actively promotes innovative projects within its administration, such as innovation credits, city box, innovation fellowships, and the Smart City Lab, fostering collaboration, creativity, and the implementation of smart solutions for current challenges [98].

To tackle the climate-neutral city challenge, Zurich implements the "Urban Space and Mobility 2040" [99] strategy as a solution, promoting walking, cycling, and public transport, enhancing green spaces, and addressing environmental issues. additionally, Zurich addresses the challenge of efficient energy utilization by implementing the Altstetten network [100], a sustainable energy grid utilizing treated wastewater and waste heat from sewage sludge recycling. It aims to supply approximately 30 000 homes with thermal energy that is 75% or more CO2-neutral. This initiative is aligned with the 2k-watt objectives and supports urban planning goals. The city also introduces the "My Account" [101] portal for online services, aligning with the Digital City strategy to streamline information exchange, automate processes, and improve accessibility for residents and businesses, thus addressing the challenge of service efficiency.

B. Amsterdam City

The notion of a digital city was initially suggested in Amsterdam in 1994 as a citizen-driven initiative. In 2009, the Amsterdam Municipality launched a new initiative called "smart," with the Amsterdam Economic Board taking a leading role in addressing the challenge of economic viability. This board, representing government agencies, research institutions, and the business community, emphasizes the economic aspect of the smart plan, learning from the challenges faced by the earlier digital city project [22]. Furthermore, Amsterdam launched the West Orange project, a citizen-led initiative, uses smart technologies like smart meters and energy displays to address the challenges of energy consumption and carbon footprint reduction [23].

The Amsterdam Smart Program is a pioneering initiative in Europe [22], distinguished by its collaborative approach involving businesses, public authorities, research institutes, and citizens (over 70 partners, including CISCO and IBM). The initiative aims to transform the Amsterdam metropolitan region into a smart city, primarily focusing on reducing carbon emissions. Through a smart city platform, Amsterdam facilitates collaboration among stakeholders, fostering the creation and implementation of shared concepts and solutions [102]. This collaboration is a pivotal factor in the development of Amsterdam as an intelligent urban center.

C. Masdar City

Masdar City, established by the United Arab Emirates in 2006, is part of the country's economic vision to become an international hub for renewable energy and sustainable technologies. The city aims to diversify from the hydrocarbon sector, balancing hydrocarbon and renewable energy sources to address climate change and ensure energy resilience [23]. It is anticipated to host around 40k residents, 50k commuters, and over 1.5k businesses, the construction cost is estimated at $22 billion, primarily funded by the UAE government and independent investors [103].

The city will use smart design and smart urban planning to tackle the energy consumption challenge by around 70% compared to what's needed for a typical city in Abu Dhabi right now. By adjusting buildings' orientation and shape, the amount of energy needed to cool them can be reduced. A harmony between sunlight and shade may be attained in the streets and open areas, allowing for natural airflow and taking advantage of the principles of bio-climatic design [104]. To address the challenges of smooth and environmentally friendly mobility, the city is encouraging the utilization of electric vehicles, shuttles, pedestrian travel, and other eco-friendly means of transportation. Following the initial concept of a personal rapid transit (PRT) system, Masdar City launched the Navya Autonomous Shuttle in 2018, a self-driving, shared, and electric mobility solution [105].

Table II provides a concise overview of the case studies in terms of: city, start date, characteristics, application areas, projects, and future plans.

The lessons learned from the above case studies underscore the shared objectives of smart cities, emphasizing sustainability, efficient energy use, technological integration, improved quality of life, and environmental preservation. Amsterdam highlights the critical role of economic factors in shaping smart city strategies. Zurich exemplifies the importance of partnerships between the public and private sectors, which not only provide financial backing but also aid in implementing robust concepts and fostering innovative solutions. Masdar City showcases the necessity of establishing a modern infrastructure, including upgraded transportation systems, energy-efficient structures, and advanced communication networks, as the cornerstone for a successful smart city initiative.

VII. Discussion and Future Directions

In the upcoming subsections, we'll delve into interoperability, micro-services, and promising technologies highlighting their significance for future smart city.

A. Interoperability Between IoT Platforms in Smart Cities

IoT systems implement heterogeneous standards, including the constrained application protocol (CoAP) [121], message queuing telemetry transport (MQTT) [122], FIWARE [123], or OneM2M [124], which can lead to problems when it comes to interoperability. It can also make it difficult for businesses to get their products across different platforms, especially if they are small and innovative. Researchers suggest that 40% of the advantages can be achieved through the achievement of interoperability between devices [125]. Noura et al. [126] presented IoT interoperability taxonomy as Device Interoperability, Networking Interoperability, Syntactic Interoperability, Semantic Interoperability, and Platform Interoperability, as shown in Fig. 5. Koo and Kim [127] discussed interoperability requirements according to several types, such as semantic, syntactic, network, and middleware.

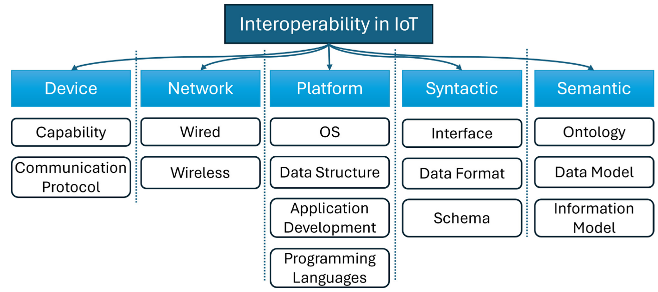

Fig. 5. Interoperability taxonomy in IoT.

The effective deployment of smart cities hinges on addressing market fragmentation and establishing interoperability among existing smart city silos through global standards. Noura et al. [126] categorized interoperability management methods into gateways, virtual networks, networking technologies, open API, service-oriented architecture (SOA), semantic Web technologies, and open standards. Every category contains numerous interoperability proposals. A proxy-based was presented in [128] as a way to facilitate the connecting of M2M-compatible and FIWARE-compatible devices, ensuring semantic-level compatibility. In [129], a semantic-level interoperability architecture for integrating pervasive computing and the IoT was developed. This architecture emphasizes dividing the global IoT into smaller, more manageable smart areas.

B. Micro-Services Suite for Smart City Applications

The concept of micro-services allows the creation of IoT applications using a set of intricate, independent, and reusable components. These elements can be easily modified or adjusted to improve the scalability, extensibility, and reusability of the application [130]. Therefore, developing a framework centred on micro-services for managing DL services can greatly support and elevate IoT big data analytics. Such a framework enables an integrated architecture capable of efficiently handling and analyzing vast amounts of data, offering robust services applicable in various IoT applications [130], [131].

In fact, micro-services are essential to manage the diverse landscape of IoT devices and applications. They bolster scalability and availability within IoT frameworks, simplifying the complexities inherent in traditional SOAs [132]. In IoT solutions, achieving higher scalability allows efficient aggregation and processing of substantial data volumes. This often translates to improved precision in data analysis and facilitates processing in real-time.

C. Promising Technologies for Future Smart City

The billions of devices connected to IoT infrastructure will increase in the coming years, relying on their speed of communication for successful connection. 5G and 6G wireless networks are crucial for future smart cities, integrating software capabilities for improved sensing, speed, connectivity, instantaneous data handling, and intelligent decisions. In brief, these technologies enhance IoT potential and fostering the evolution of smart cities [130], [133]. Several key directions

TABLE II
BRIEF SUMMARY FOR THE CASE STUDIES CITIES

City	Start	City Characteristics	Application Area	Projects	Future Plan
Zurich	2016	- Sustainability - Innovation - Integrated Systems - Public Services	- Transportation - Energy - Urban Planning - Digital Connectivity - Sustainable Living - Smart Economy	- Altstetten energy network [100] - My Account [101] - Innovation Credits [106] - City Box [107] - Innovation Fellowships [108] - Smart City Lab [109] - LoRa Network [110] - Digital Twin [111]	- Zurich Strategies 2035 [112] - Urban Space & Mobility 2040 [99]
Amsterdam	2009	- Sustainability - Innovative Solutions - Partnerships - Mobility - Community Engagement - Citizen-Centric - Smart Governance	- Sustainable Energy - Smart Mobility - Circular Economy - Waste Management - Smart Buildings - Community Engagement - Healthcare	- Flexpower Amsterdam [113] - Energy Lab Zuidoost [114] - Ship to Grid project [115] - West Orange project [23]	- Structural Vision Amsterdam 2040 [116] - Amsterdam Green Infrastructure Vision 2050 [117]
Masdar	2006	- Renewable Energy - Sustainability - Smart Infrastructure - Green Spaces - Innovation Hub - Transportation	- Renewable Energy - Urban Planning - Sustainable Solutions - Research - Education - Business	- Personal Rapid Transit [118] - NAYVA Autonomous Shuttle [118] - ECO Bus [118] - ASPIRE [119] - Technology Innovation Institute [119]	- Net Zero By 2050 [120]

are emerging as focal points for the evolution of smart cities: 1) sensor-cloud model, combining wireless sensor networks (WSNs) with mobile cloud, is a promising technology for enhancing the sustainability of smart cities by promoting IoT greening [134]; 2) transfer learning paradigm that facilitates real-time data analytics holds immense potential for enhancing service performance across various domains [130]; 3) integrating ICT, such as big data analytics and blockchain, enables more effective decision making and security to leverage the wealth of data available in urban environments [15], [135]; and 4) drones offer a promising solution for IoT, reducing power consumption and device recharging, facilitating real-time traffic monitoring and management, and making IoT more environmentally friendly in smart cities [134].

VIII. Conclusion

Converting metropolitan areas into smart cities is a viable strategy that can ensure the sustainability of resources, enhance the quality of life and efficiency of services offered to inhabitants. Thus, it could provide promising solutions to adapt and mitigate risks of the climate change. Smart city is a combination of smart healthcare systems, smart transportation systems, smart communities, and smart energy systems that improve the city's economic, social, and living conditions. The IoT is an essential component of the smart city ecosystem, as it provides the necessary technology to enable the collection, storage, analysis, and extraction of data that facilitate intelligent decision making. However, several barriers prevent the IoT ecosystem from achieving optimal efficiency, including but not limited to heterogeneity, scalability, security, and privacy. So, for developing intelligent cities, it is necessary to consider characteristics, such as sustainability, energy efficiency, technology integration, quality of life, and environment protection.

The presence of multiple platforms within the smart city has led to a lack of interoperability and difficulty in communicating between different systems, resulting in a decrease in overall efficiency. As there is a lack of standards and advanced technologies, further research is necessary to ensure that semantic interoperability platforms are available across different IoT domains. The design of smart city applications based on micro-services leads to enhancing non-functional requirements (NFRs) and Quality of Service (QoS) aspects, including aspects like availability, reliability, interoperability, latency, and delay in IoT systems.

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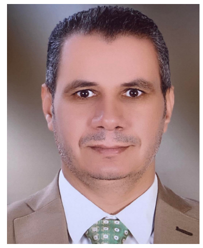

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