smart cities

Review

Unlocking the Future: Fostering Human–Machine Collaboration and Driving Intelligent Automation through Industry 5.0 in Smart Cities

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Abstract: In the quest to meet the escalating demands of citizens, future smart cities emerge as crucial entities. Their role becomes even more vital given the current challenges posed by rapid urbanization and the need for sustainable and inclusive living spaces. At the heart of these future smart cities are advancements in information and communication technologies, with Industry 5.0 playing an increasingly significant role. This paper endeavors to conduct an exhaustive survey to analyze future technologies, including the potential of Industry 5.0 and their implications for smart cities. The crux of the paper is an exploration of technological advancements across various domains that are set to shape the future of urban environments. The discussion spans diverse areas including but not limited to cyber–physical systems, fog computing, unmanned aerial vehicles, renewable energy, machine learning, deep learning, cybersecurity, and digital forensics. Additionally, the paper sheds light on the specific role of Industry 5.0 in the smart city context, illuminating its impact on enabling advanced cybersecurity measures, fostering human–machine collaboration, driving intelligent automation in urban services, and refining data management and decision making. The paper also offers an in-depth review of the existing frameworks that are shaping smart city applications, evaluating how Industry 5.0 technologies could augment these frameworks. In particular, the paper delves into the various technological challenges that smart cities face, bringing potential Industry 5.0-enabled solutions to the fore.

Keywords: smart cities; transportation; industry 5.0; sustainable development; big data; urban environments

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1. Introduction

The evolution of industrial paradigms has always been instrumental in shaping the trajectory of human progress. Industry 1.0 saw the mechanization of labor through water and steam power [1]. Industry 2.0 marked the dawn of mass production facilitated by electric power the digital era dawned with Industry 3.0 through the integration of computers and automation, which further evolved into the cyber–physical systems of Industry 4.0. Now, as we stand at the cusp of a new era, we are witnessing the emergence of Industry 5.0, a paradigm that seeks to harmoniously integrate human ingenuity with machine capabilities [2]. It revolves around the central tenet of collaboration rather than mere automation, emphasizing the symbiotic relationship between human intuition and machine precision. As urban landscapes become increasingly characterized by interconnectedness and real-time data, smart cities are ripe platforms for the deployment of Industry 5.0 concepts [3]. By facilitating human–machine collaboration at an unprecedented scale, Industry 5.0 has the potential to revolutionize urban infrastructure, service delivery, and civic engagement in smart cities [4]. This dynamic interplay promises to render urban spaces more adaptive, efficient, and responsive to the ever-evolving needs of their inhabitants.

The concept of smart cities has gained significant momentum in the past decade, becoming a prominent area of interest among researchers, urban planners, and policymakers worldwide [5]. At its core, a smart city utilizes Information and Communication

Technologies (ICT) to enhance the quality and performance of urban services, reduce costs and resource consumption, and improve the interaction between citizens and the government [6]. Early models of smart cities focused on using technology to improve infrastructure and services: namely automating waste collection, managing traffic flow, and optimizing energy use [7]. However, the vision for smart cities has expanded and evolved over the years, incorporating advanced technologies to provide sophisticated, integrated, and intelligent solutions for urban challenges [8].

The advent of technologies, such as the Internet of Things (IoT), Artificial Intelligence (AI), blockchain, and 5G, has dramatically altered the landscape for smart cities. These technologies promise a paradigm shift in urban management, with the potential to transform everything from traffic systems to energy grids, waste management, public safety, and citizen services [9]. For example, IoT devices enable real-time monitoring of city operations, AI can optimize service delivery and make predictive models for various urban systems, blockchain can provide secure and transparent transactions, and 5G networks ensure high-speed and reliable connectivity for all these digital interactions.

Figure 1 presents an illustrative depiction of a typical smart infrastructure interconnected through Information and Communication Technology (ICT). The figure serves as a clear visual aid, revealing how various elements of a smart city are networked to create a cohesive, efficient, and responsive urban environment. The figure represents various infrastructure components typical of a smart city, which might include transportation systems, energy grids, water supply networks, waste management systems, buildings, public spaces, and more. Each component is depicted as being connected through ICT, emphasizing the central role of technology in coordinating and optimizing the performance of these disparate elements. The network of connections signifies the data communication that occurs between these different infrastructure components. This might include data sharing, real-time analytics, remote control, automated responses, and other interactions enabled by IoT devices, sensors, and advanced data analytics platforms. The illustration thereby encapsulates the concept of 'smart' in smart cities, where ICT serves as the backbone supporting coordinated, efficient, and intelligent operations across the city. By interpreting this interconnected infrastructure within the broader context of a smart city, viewers can understand how such integration can lead to improved efficiency, enhanced service delivery, better resource management, and overall improved quality of life for citizens. The figure thus serves as a concise visual summary of a smart city's complex and integrated nature, emphasizing the crucial role of ICT in tying these components together.

However, the road to fully realizing the potential of smart cities is fraught with challenges. The implementation of advanced technologies raises significant concerns about data privacy, security, and the digital divide among citizens [10]. Moreover, the need for substantial investments in infrastructure, the creation of new regulatory frameworks, and the management of potential socio-economic and environmental impacts are hurdles that must be overcome [11]. These complexities necessitate a comprehensive exploration and understanding of the future of smart cities, delving into the technological advancements, their potential applications, and the multitude of challenges that they bring. As we stand on the cusp of a new era of urban development, this investigation is vital for creating sustainable, inclusive, and truly 'smart' cities of the future.

1.1. Motivation

The evolution of technology has been pivotal in streamlining human life, injecting convenience and ingenuity into daily routines. [12] offered a comprehensive description of smart cities, surveying their characteristics and composition and analyzing numerous research articles, to provide a generic overview of smart city architecture; furthermore, outlined the components of a smart city and highlighted real-world implementations. Therefore, the blueprint of a smart city is painted with strokes of Information and Communication Technologies (ICT) and the Internet of Things (IoT), with the objective of amplifying operational efficacy, elevating the standards of public services and citizen well-being, and establishing and implementing practices fostering sustainable growth, thereby catering to the escalating expectations of its inhabitants. Optimizing these technologies can metamorphose them into environmentally friendly, highly productive, and flexible tools. Advances in ICT significantly enhance the management of available resources. Additionally, research focused on nascent technologies is geared toward honing the efficacy of existing solutions.

Figure 1. ICT-Enabled Smart Infrastructure in Urban Environments.

The digital transformation has consistently demonstrated its prowess wherever deployed, primarily attributing to the simplicity and efficiency it brings to operations [13]. Equally crucial, is the role of data-driven decision making, which remains a critical determinant in any sphere, including the realm of smart cities [14]. Consequently, this necessitates an in-depth exploration of ways to augment forthcoming technologies to further enrich human life. Gazing into the future facets of smart cities via the present circumstances can unlock novel research pathways, equipping scholars with the ability to construct a completely fresh framework for understanding smart cities based on the interactive elements discussed in this paper.

This paper can be seen as a panoramic assessment of the technical ecosystem to determine the compatibility and performance of diverse technologies and their results in unison. To our understanding, this is the initial attempt at treating future smart cities as an interconnected network of systems and delving into the various interactive aspects of smart cities in a research-intensive manner. The classification suggested in this paper provides a comprehensive overview of future smart cities, attempting to encapsulate all major aspects or systems that interact to form the complex entity known as a smart city. Achieving true smart city status necessitates holistic technological coverage. Fortunately, the fourth industrial revolution, which is known as Industry 4.0, represents the fusion of advanced digital technologies with traditional industrial processes, enabling autonomous systems, enhanced connectivity, and real-time data analysis, thereby revolutionizing manufacturing and supply chain dynamics as defined by [15], who witnessed a steep decline in hardware costs in communication, computing, and storage sectors, making this technology amalgamation possible and affordable at the grassroots level. This paper provides a succinct discussion on the requirements, challenges, and execution strategies of comprehensive coverage, aiming to establish them as a foundational norm for future smart cities.

1.2. Contribution

This paper offers several key contributions that can guide future research and practical implementations of smart cities. The principal contributions, especially designed to elucidate the intricate relationship between emergent technologies and the core concept of smart cities, are as follows:

1. **Integration of Technologies with Smart Cities**: While presenting an in-depth exploration of future technologies like cyber–physical systems, fog computing, unmanned aerial vehicles, renewable energy, machine learning, deep learning, cybersecurity, and digital forensics, this paper emphasizes their direct relevance and application to the smart city paradigm. By bridging this gap, this paper provides a clearer understanding of how these technologies will shape the future of intelligent urban environments.
2. **Critical Analysis of Challenges**: The manuscript offers a detailed assessment of challenges that smart cities face, including issues related to privacy, security, ethical considerations, and urban inequality.
3. **Holistic View of Intelligent Urban Environments**: this paper presents a comprehensive perspective on the evolution of smart cities, harmonizing their technical, socio-economic, political, and environmental dimensions, while underscoring the interplay between novel technologies and urban planning.
4. **Insight into Stakeholders' Roles**: This paper goes beyond mere technological aspects and examines the roles of various stakeholders such as the government, private sector, academia, and citizens in the co-creation and sustainable evolution of smart cities.
5. **Proposal of a Taxonomy for Smart Cities**: To further enhance clarity, the paper introduces a taxonomy of smart cities, offering a structured way to discern the multilayered nature of intelligent urban ecosystems and how technology acts as a backbone to these structures.

By intertwining technology with the concept of smart cities, this contribution aims to provide better visibility and a clear roadmap for researchers, practitioners, and stakeholders in the domain of urban development.

The emergence of smart cities has paved the way for a new era of urban living, one where technology and urban infrastructure blend seamlessly to offer more efficient and sustainable urban environments. The manifold possibilities, along with the complex challenges presented by this development, are the focus of this paper. By offering a detailed examination of future technologies and their potential implications, a critical evaluation of the challenges, a comprehensive perspective of intelligent urban environments, and a thoughtful exploration of stakeholder roles, this manuscript paves the way for a deeper understanding of smart cities. Furthermore, the proposed taxonomy serves as a roadmap, guiding the way for future research and practice in this rapidly evolving field.

1.3. Structure of the Paper

The organization of the rest of the paper is as follows: Section 2 delves into current and previous research and studies relevant to smart cities. Section 3 focuses on outlining the prerequisites needed for the cities of the future. Section 4 showcases potential applications in these future-oriented and smart urban environments. Lastly, Section 5 addresses the unresolved research questions and provides insights into potential future research trajectories.

2. Related Studies

This section undertakes a review of contemporary studies, focusing on their most pertinent points. Additionally, a table comparing various taxonomies, juxtaposing the proposed future smart city framework with the currently prevalent studies, is presented towards the end of this section. It becomes apparent upon review that there are several under-explored areas in these studies. These areas prominently include cyber–physical systems, fog computing, unmanned aerial vehicle, renewable energy, machine learning, deep learning, cybersecurity, and digital forensics. Addressing these topics is vitally important for future smart cities to enable a sustainable and accessible lifestyle for all.

In the research paper "Cyber-Physical-Social Systems: A State-of-the-Art Survey, Challenges and Opportunities", an evaluation of ongoing research that contributes to the advancement of Cyber–Physical–Social Systems (CPSSs) is presented. They highlight various essential components of CPSSs, such as the transition from Cyber–Physical Systems (CPSs) to CPSSs, system architecture, practical applications, guiding principles, real-world case studies, enabling methodologies, and organizations for CPSSs. In a bid to construct a robust foundation for the evolving intelligent world, they propose a virtualization architecture along with an integrated framework for storage, computation, and networking within CPSSs. Performance enhancements resulting from the proposed idea are substantiated through simulations. Lastly, the paper surfaces several research challenges, potential solutions, and areas for future exploration, thus providing direction for researchers in this field.

"Fog Computing Approaches in Smart Cities: A State-of-the-Art Review" paper puts forth a systematic literature review (SLR) of fog computing (FC), focusing on optimal fog-based approaches employed in smart cities. In addition, based on the content analysis of the study, they introduce a classification that consists of three categories: service-oriented, resource-based, and application-driven. This SLR further delves into each category's evaluation criteria, tools used, evaluation methods, advantages, and shortcomings. It also sheds light on the types of algorithms proposed within each category. Above all, by taking diverse perspectives into account, they present comprehensive and specific open issues and challenges, classifying future trends and concerns into pertinent subcategories.

In their study, [16] put forth a methodology for forecasting the energy usage of electric vehicles (EV) within a smart city context. They explore the fundamental factors contributing to this energy consumption and project the outcomes following the application of their proposed approach. The model, based on real-world data, demonstrates a relatively low error rate of 8.44%. They conducted a thorough examination of AI-driven advancements in the Renewable Energy (RE) sector within the European Union (EU). Their principal focus lies in the analysis of energy consumption, the efficiency of conversion processes, and the outcomes of harnessing renewable energy from sources like solar, water, wind, and biomass. These technologies, as the study points out, are instrumental in domains such as health, energy, transportation, education, and public safety and are aimed at facilitating a superior, more straightforward, and smarter living experience.

From an Information Systems (IS) perspective, it becomes apparent that the data utilized in smart city applications is unstructured and originates from heterogeneous sources, including sensors and online platforms. Consequently, the collection, processing, analysis, management, and visualization of such data pose significant challenges. To address these tasks, recent advancements, such as the Internet of Things (IoT) and sensor networks, have been leveraged.

"Potential of Augmented Reality and Virtual Reality Technologies to Promote Well-being in Older Adults" paper presents a comprehensive overview of unmanned aerial vehicle (UAV) networks from the perspective of Cyber–Physical Systems (CPS). They begin by providing an in-depth exploration of the fundamental principles and advancements in the three CPS components within UAV networks. Subsequently, they delve into an internal examination to understand how these components contribute to the overall system performance. They categorize UAV networks into three classifications: cell level, system level, and system-of-systems level, explicitly highlighting the interplay between these CPS components. This analysis sheds light on the challenges that arise from each individual aspect. The authors conclude their review by discussing new research directions and open issues, aiming to provide a fresh understanding of the latest advancements in UAV networks.

In their study, [17], emphasize the vital role of Information and Communication Technology (ICT) in the realization of smart cities. Within a smart city context, IoT sensors are deployed across various locations to gather data pertaining to traffic, waste management, resident mobility, and other relevant aspects. The insights derived from this data are then utilized to effectively manage resources and assets. Deep learning techniques have been extensively employed to analyze the vast amount of data generated by IoT sensors within smart cities. Furthermore, the article aims to provide an overview of the state-of-the-art applications of deep learning in the context of smart city data. The researchers conclude the article by suggesting several future research directions in this domain.

Evaluation" paper achieved significant advancements in the field of transportation with their cybersecurity (CS) research on a secure traffic police remote sensing approach using low-altitude unmanned aerial vehicles (UAVs) equipped with a deep learning-based vehicle speed detection system. The study focuses on addressing the need for accurate and real-time vehicle speed detection in IoT-based smart cities, particularly in situations where real-time detection is lacking. They propose a novel system that utilizes UAVs for remote sensing applications, aiming to enhance traffic safety and security. Through their experiments, they determined the optimal field of view (FOV) camera by adjusting the height and degree and embedded the Mobile Net-SSD deep learning model parameters in the PI4B processor of a physical car. The system is implemented in a real environment, specifically at the JXUST university intersection, showcasing the effectiveness of their intelligent speed control system without the need for physical police presence. The results demonstrate the superior performance of the proposed low-altitude UAV system in detecting and estimating vehicle speeds, particularly in highly dynamic situations and varying speeds. Their solution proves highly effective on crowded roads, such as junctions near schools and hospitals, where vehicle speeds are unsteady.

Ref [18], achieved significant contributions in the field of smart hospitality (SH) through their research. The study aims to explore recent developments, themes, and issues within the context of smart hospitality, synthesizing existing knowledge and contributing to the future development of this field. The authors conducted an examination of eight recent review articles on smart hospitality and tourism, analyzing a total of 145 peer-reviewed articles from the Web of Science focused on smart hospitality. This extensive analysis enabled the development of a conceptual framework and a comprehensive research agenda for smart hospitality innovations and agile hospitality ecosystems.

Table 1 presents a comprehensive comparison of some of the studies reviewed above. The analysis reveals that the current state-of-the-art studies exhibit certain limitations in incorporating the latest technologies across all domains of development. "√" Means the areas is covered and "X" means the area is not covered.

Table 1. Comparative Analysis of Reviewed Studies in Smart City Development.

Reference	CPSS	FC	UAV	RE	ML-DL	H-IoT	EC	IS	ICT	CS	DF	PT	SH	FL
[19]	√	X	X	X	√	√	X	X	√	X	X	X	X	X
[20]	X	√	X	X	√	X	X	X	√	X	X	X	X	X
[21]	√	X	√	X	X	X	X	X	√	X	X	X	X	X
[22]	X	X	X	√	√	X	X	X	√	X	X	X	X	X
[23]	X	X	X	X	√	√	X	√	√	X	X	X	X	X
[24]	X	X	X	X	X	√	X	X	√	√	X	X	X	X
[25]	X	√	X	X	X	X	X	X	√	√	X	X	X	X

Table 1. *Cont.*

Reference	CPSS	FC	UAV	RE	ML-DL	H-IoT	EC	IS	ICT	CS	DF	PT	SH	FL
[26]	X	X	X	X	√	X	X	√	√	√	X	X	X	X
[27]	X	X	X	X	X	X	√	√	√	√	X	X	X	X
[28]	X	X	X	X	X	X	X	√	√	√	√	X	X	X
[29]	X	X	X	X	√	X	X	X	√	X	X	X	X	X
[30]	X	X	X	X	X	X	X	√	√	√	√	X	X	√
[31]	X	X	√	X	√	√	√	X	√	√	√	X	X	X
[32]	X	X	X	X	√	X	X	X	√	√	X	√	√	X
[33]	X	X	X	X	X	X	X	X	X	X	X	X	√	X
[34]	X	X	X	X	X	X	X	X	X	X	√	X	X	X
This Study	√	√	√	√	√	**X**	**X**	**X**	√	√	√	**X**	**X**	**X**

3. Prerequisites for Future Cities: Setting the Foundations for Smart Urban Environments Based on Related Studies

In order to pave the way for the cities of the future and create smart urban environments, there are several key prerequisites that need to be addressed. These prerequisites serve as the foundational elements necessary for the successful implementation of smart city initiatives. They include Infrastructure Development and Connectivity, Data Integration and Management, and Collaboration and Stakeholder Engagement.

Figure 2 offers a visually intuitive and comprehensive representation of the critical prerequisites for the transformation into future smart urban environments, serving as a blueprint for smart city evolution. It incorporates three foundational pillars, each with its associated set of keywords, representing the varied aspects necessary for constructing an efficient, intelligent, and sustainable urban ecosystem.

The first pillar, 'Infrastructure Development and Connectivity', embodies the essence of robust physical and digital infrastructure required for the smooth functioning of a smart city. This segment delineates various elements like advanced communication networks, IoT, and smart grid systems, representing the city's veins and arteries ensuring efficient data flow and resource distribution.

The second pillar, 'Data Integration and Management', underscores the profound importance of managing the vast volumes of data generated in a smart city. Effective data processing, analytics, and governance are emphasized, illustrating the city's brain, which interprets data, derives insights, and informs decision making for better urban management.

Lastly, the 'Collaboration and Stakeholder Engagement' pillar emphasizes the human aspect of smart city development. It highlights the necessity of active stakeholder participation, collaborative efforts, and engaged citizenship in the planning, development, and governance of smart cities, representing the city's heart, where citizen needs, aspirations, and well-being are prioritized.

By incorporating these multifaceted elements into a single graphic, Figure 2 elucidates the interconnected and complex nature of smart city development, serving as an essential roadmap for researchers, urban planners, policymakers, and city administrators.

3.1. Infrastructure Development and Connectivity

One of the fundamental prerequisites for future cities is the development of robust infrastructure and connectivity [35]. This involves the establishment of advanced communication networks, including high-speed internet connectivity, wireless infrastructure, and IoT networks [36]. Additionally, smart grid systems for efficient energy management and distribution are crucial. These infrastructure components form the backbone of smart city operations, enabling seamless data exchange, communication, and interconnectivity among various devices, sensors, and systems within the city.

Figure 2. Foundational Prerequisites for Transitioning to Future Smart Urban Environments.

3.2. Data Integration and Management

Future cities generate vast amounts of data from diverse sources such as sensors, social media, and public services [37]. Effective data integration and management systems are essential for processing, analyzing, and extracting valuable insights from this data [38]. This prerequisite involves the implementation of advanced data analytics platforms, cloud computing infrastructure, and data governance mechanisms. By integrating and managing data efficiently, cities can derive actionable insights to optimize resource allocation, enhance service delivery, and improve overall urban efficiency.

3.3. Collaboration and Stakeholder Engagement

Collaboration and stakeholder engagement are critical prerequisites for future cities [39]. The successful transformation of cities into smart urban environments requires active participation and cooperation among various stakeholders, including government authorities, private sector organizations, academia, citizens, and community groups. Collaborative partnerships facilitate the sharing of knowledge, expertise, and resources to address challenges, co-create solutions, and ensure the alignment of smart city initiatives with the needs and aspirations of the community [40]. Engaging stakeholders through open dialogue, participatory decision-making processes, and citizen engagement initiatives fosters a sense of ownership and enables the development of inclusive and sustainable smart cities.

By addressing these prerequisites, cities can lay the foundations for smart urban environments. Infrastructure development and connectivity provide the necessary infrastructure backbone, while data integration and management enable the effective utilization of data for informed decision making. Collaboration and stakeholder engagement ensure that smart city initiatives are developed in a holistic and inclusive manner. These prerequisites collectively contribute to the creation of future cities that are sustainable, efficient, and responsive to the needs and well-being of their residents.

4. Analysis of Technological and Management Attributes for Future Smart Cities

Smart cities' applications and taxonomies encompass a rapidly evolving field at the intersection of urban development and technology. As urbanization intensifies and the need for efficient and sustainable urban environments grows, cities around the world are embracing the concept of "smart cities" to address the challenges of the modern era. This concept involves the integration of various technologies, such as the Internet of Things (IoT), big data analytics, and artificial intelligence, to optimize the functioning of urban systems and improve the quality of life for residents. Smart city applications span a wide range of sectors, including transportation, energy management, waste management, public safety, healthcare, and more. To better understand and categorize these applications, taxonomies have been developed, which provide a framework for classifying and organizing the diverse array of smart city initiatives. These taxonomies help policymakers, urban planners, and technology providers to identify and prioritize areas for implementation, fostering the development of innovative solutions and contributing to the creation of sustainable, connected, and livable cities for future generations.

4.1. Cyber–Physical Systems in Smart Cities

Cyber–Physical Systems (CPSs) represent the amalgamation of computational elements with physical processes. As a pioneering technological model, CPSs are contributing to the evolution of smart cities by facilitating advanced services, efficient resource management, and improved quality of life. Urban areas worldwide are increasingly leveraging the potential of CPSs to drive transformational change toward sustainable, resilient, and intelligent cities.

Emergence of CPSs in Urban Areas

The genesis of Cyber–physical Systems lies in their inherent ability to bridge the digital and physical worlds, thus catalyzing a paradigm shift in urban development. They integrate computing, networking, and physical processes through feedback loops where physical processes affect computations and vice versa. Since their inception, CPSs have seen increased adoption in diverse fields like healthcare, transportation, energy, and, significantly, in building smart cities.

Role of CPSs in Smart Cities

Smart cities represent an ecosystem that integrates information and communication technology (ICT) with physical components to enhance the quality, performance, and interactivity of urban services, reduce costs and resource consumption, and improve contact between citizens and government. Within this framework, CPSs play an indispensable role.

CPSs facilitate efficient energy management, optimizing energy consumption and reducing greenhouse gas emissions. They allow for predictive maintenance of infrastructure, enhancing the lifespan of utilities and ensuring sustainable resource management. CPSs also support improved traffic management, enabling real-time decision making to reduce congestion and improve mobility. Table 2 provides a meticulous summary of the existing literature on Cyber–physical Systems (CPSs), particularly pertaining to the context of smart cities. The table is neatly categorized into columns denoting the authors of the works, a detailed summary of each study, and the main findings that were derived from each piece of research. The 'Authors' column lists the researchers who have contributed to the field of CPSs in smart cities. It aids in identifying the leading scholars and institutions driving the research in this area. The 'Detailed Summary' column gives an in-depth overview of each study, encapsulating the scope, objectives, methodologies, and key aspects of the research. It allows readers to gain a quick understanding of what each study is about and its relevance to the broader field. The 'Main Findings' column encapsulates the primary conclusions or contributions of each study. This section highlights the significant advancements, insights, and understandings that have been contributed to the field of CPSs in smart cities through each piece of work.

Table 2. Summary of The CPS Literature.

Authors	Detailed Abstract Summary	Main Findings
[41]	This article proposes an dge cloud-assisted CPSS (cyber–physical–social system) framework for smart cities. This framework migrates some tasks from the cloud center to network edge devices so as to provide lower-latency, real-time, more effective, and proactive services.	• An edge cloud-assisted CPSS framework for smart cities is proposed, which migrates some tasks from the cloud center to network edge devices to provide lower-latency, real-time, more effective, and proactive services; • This framework enables the smart city to use knowledge or rules mined from Internet of Things sensor data to promote the development of the city; • The proposed framework provides new opportunities and challenges, such as low delay and real-time services.
[42]	This chapter discusses how cyber–physical systems can be used to support smart city development. It highlights social challenges of CPS-based smart city development that relate to aspects of acceptability, qualification, and adaptation. Finally, it explains how the process fields of CPS-enhanced smart city formation are embedded in wider economic contexts on a regional, national, and global scale and it also raises issues of social acceptability.	• Cyber–Physical Systems (CPS) can be used to enhance the efficiency of smart city developments; • Economic geography perspectives can be used to better understand CPS-supported smart city development; • Social challenges related to CPS-based smart city development include acceptability, qualification, and adaptation.
[43]	This paper discusses the development and challenges of IoT/CPS applications for smart buildings and cities. The authors study the development and challenges in five topics: middleware, computation model, fault tolerance, quality of data, and virtual run-time environment.	• Middleware, computation model, fault tolerance, quality of data, and virtual run-time environment are important topics for designing CPS/IoT applications for smart buildings and cities; • Smart buildings and smart cities are attractive application domains for IoT/CPS technologies; • Many challenges remain open in the development of CPS/IoT applications for smart buildings and cities.
[44]	Cyber–Physical–Social Systems (CPSS) include cyberspace, physical space, and social space. Smart cities are becoming a reality to achieve higher efficiency and optimum use of resources. This paper will discuss smart cities and the CPSS concept with some of its key technologies, challenges, and further development.	• Cyber–Physical–Social Systems (CPSS) are a new paradigm that alter human relationships with machinery and the physical world; • Smart cities are becoming a reality to achieve higher efficiency, optimum use of resources, and better management; • Key technologies, challenges, and further development of CPSS are discussed in the paper.

Table 2. *Cont.*

Authors	Detailed Abstract Summary	Main Findings
[45]	This paper discusses smart cities as cyber–physical systems. It outlines some key defining characteristics of a Smart City and fundamental research issues that remain largely open.	• Smart cities are Cyber–Physical Systems (CPSs) that require new software platforms and strict requirements for mobility, security, safety, privacy, and the processing of massive amounts of information; • Key defining characteristics of a Smart City include innovative services for transportation, energy distribution, healthcare, environmental monitoring, business, commerce, emergency response, and social activities; • Fundamental research issues remain largely open, such as how to ensure the security, safety, and privacy of Smart Cities.
[46]	This paper discusses the integration of computing and communication capabilities into physical systems, with a focus on smart cities. It argues that smart cities are a system of cyber–physical and social systems and explores new challenges in the field.	• Cyber–Physical Systems (CPSs) are related to the integration of computing and communication capabilities into physical systems; • Smart cities are an example of CPSs that must include the presence of people in the loop of producing, collecting and consuming data, information, and services; • CPSS 2019 aims to present innovative research trends and explore new challenges in the field of smart cities as a system of cyber–physical and social systems.
[47]	This paper discusses cyber physical systems and their role in smart cities development. It describes the concepts of CPS, Smart Cities, and the various challenges posed by CPS in implementing in smart cities.	• Cyber Physical Systems (CPS) are essential for the development of smart cities; • CPS can support day-to-day activities in smart cities; • There are various challenges posed by CPS in implementing in smart cities and research directions for CPS should be explored.
[48]	This paper discusses the role of Cyber–Physical Systems (CPS) in smart cities. It reviews smart city requirements, components, and applications and discusses smart transportation and smart construction.	• Cyber–Physical Systems (CPS) are being implemented to make cities more instrumented, interconnected, and intelligent; • Smart city components and applications include smart transportation and smart construction; • Global warming and climate change have a crucial impact on urban life, through events such as frequent urban floods.
[49]	The paper discusses Cyber–Physical Systems (CPSs) and social networking facilities used to implement a ubiquitous city platform. It adopts a semantic web approach that models data by a suitable ontology specifically designed to support the main user scenarios in smart cities.	• Cyber–Physical-Systems (CPSs) and social networking facilities can be used to implement a ubiquitous city platform called Wi-City-Plus; • A semantic web approach can be used to model data by a suitable ontology to support user scenarios in smart cities; • This approach allows for technical interoperability and service integration envisaged by the CPS ideal model.

Table 2. *Cont.*

Authors	Detailed Abstract Summary	Main Findings
[50]	The aim of this proposal is to develop a model of secure transportation system using efficient CPS which not only reduce the unnecessary accident rates but also increase the safety system that enhances the livability of smart cities and Industry 4.0.	• Development of a secure transportation system using efficient CPS to reduce accident rates and increase safety; • Dynamic and intelligent security solutions to detect evolving threats and cyberattacks during data or signal transmission; • Improved livability of smart cities and Industry 4.0 through secure transportation systems.
[51]	This paper provides a literature review for CPSC and identifies future research opportunities. Specifically, it defines the concepts with typical CPSC applications, presents the main characteristics of CPSC, and highlights the research issues.	• Crowd-Powered Smart City (CPSC) is an emerging trend to leverage the power of crowds (e.g., citizens, mobile devices, and smart things) to monitor what is happening in a city, understand how the city is evolving, and further take actions to enable better quality of life; • The paper presents the main characteristics of CPSC and highlights the research issues; • Existing limitations are identified to inform and guide future research directions.
[52]	This paper discusses Smart City approaches and provides a strategic overview of a SC's range of services.	• Smart City approaches use data from sensors, citizens, and archives to provide public services that improve quality of life, optimize mobility, and enhance flexibility and the responsiveness of public authorities; • This article provides an integrative and strategic overview of a Smart City's range of services by compiling the public service portfolios of Vienna, Singapore, and San Francisco; • This approach helps to create a scientific basis for the evaluation of Smart City services and to provide a strategic modular toolkit for public managers to plan and design Smart Cities.

Figure 3 delineates the sophisticated architecture of an Industrial Control System (ICS) as an instance of a Cyber–Physical System (CPS) implemented within a smart city framework. The diagram distinctly showcases the interconnected layers and components of an ICS, underscoring its integral role in a smart city's infrastructure.

The bottom layer of the diagram represents the physical process, which could be any industrial process such as manufacturing, water treatment, or power generation. This is where the physical machinery and operational elements lie.

The second layer represents the control loop, where devices such as sensors and actuators are employed. Sensors monitor the physical processes and send data to the upper layers, while actuators execute the commands received from the upper layers to act on the physical processes.

The middle layer represents the control network, which serves as a conduit for the data flow between the lower and upper layers. It integrates field-level devices with a broader control system, enabling real-time communication and data exchange.

The top layer, known as the supervisory control, comprises elements such as Human–machine Interfaces (HMIs), servers, and engineering workstations. Here, data from sensors are received, processed, and visualized for human operators. Decisions made by operators or automated systems are sent back down to the control loop and the physical process, closing the loop.

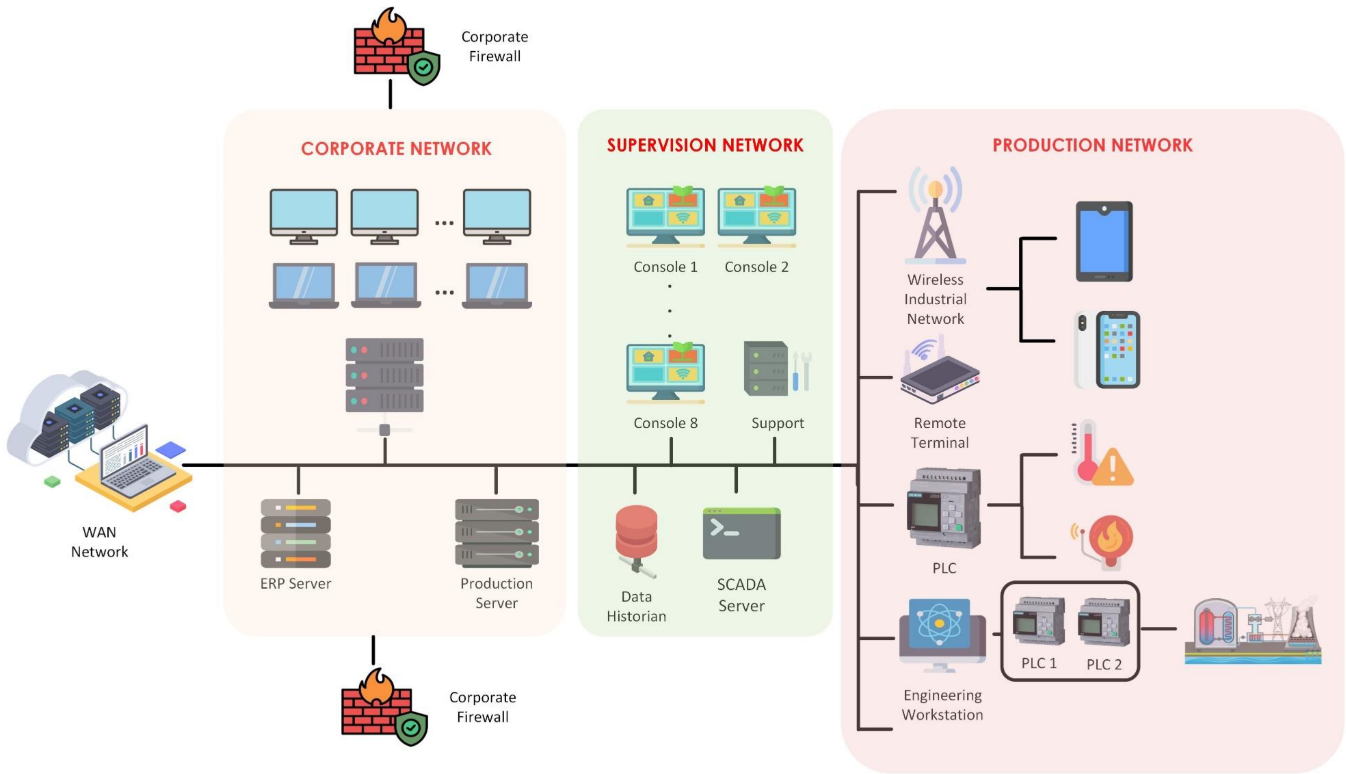

Figure 3. Industrial Control System Architecture.

Figure 3 effectively captures the bidirectional feedback loop existing between the physical and cyber components, indicative of the essence of a CPS. By illustrating how data flows between these components to monitor, control, and optimize industrial processes, the figure elucidates the crucial role of CPS like ICS in the operational efficiency, resource optimization, and safety of smart cities.

4.2. Fog Computing in Smart Cities

As the urban landscape increasingly embraces the concept of smart cities, a concurrent rise in data-driven operations and services is taking place. This digital transformation demands robust and efficient computing resources to ensure seamless operation. Fog computing, a decentralized computing infrastructure, has emerged as a pivotal solution in managing, processing, and storing the data generated within smart cities [53].

A typical example can be seen in smart traffic management, where fog computing allows for real-time processing and analytics of data from IoT devices, leading to immediate decision making to alleviate traffic congestion. Similarly, in public safety and emergency services, fog computing can facilitate real-time surveillance, threat detection, and quick responses to emergencies.

Challenges and Opportunities

While fog computing presents an enticing prospect for smart cities, it also introduces unique challenges. The deployment of fog nodes raises issues of scalability and resource management, while the distributed nature of the architecture brings about cybersecurity concerns. Additionally, ensuring interoperability among various devices and systems can prove to be complex.

However, these challenges also bring opportunities for innovation. For instance, implementing advanced AI algorithms and machine learning models can improve resource allocation and enhance system performance. Blockchain technology could be used to bolster security, data integrity, and user privacy in a fog computing environment.

Future Perspectives

The adoption of fog computing in smart cities is set to rise with the continued proliferation of IoT devices and increasing demand for real-time, reliable, and secure data processing. Technological advancements, such as 5G and beyond, are expected to further amplify the role of fog computing in smart cities, enabling ultra-low latency and high-reliability applications.

Figure 4 presents a comprehensive view of the fog computing architecture deployed in smart cities, meticulously illustrating the hierarchical and dual-model structure (top-down and bottom-up) of the system. At the foundation of architecture, we find 'things', which are internet-connectable objects in the physical world. This level also embodies the concept of edge computing, where tasks are handled locally by these 'things', or among horizontally connected entities, thus adhering to the bottom-up model. Next in hierarchy comes the 'near-edge', representing the fog nodes. These nodes act as intermediate gateways between 'things and the cloud, offering crucial services such as acceleration, cache/storage, computation, control, and networking. In addition, we see 'cloudlets' at this level, representing computational resources that are directly accessible by 'things' in proximity. Fog nodes, in certain scenarios, can also serve as 'cloudlets', handling task offloads from 'things', a concept known as 'cloudlet edge computing'. When a cloudlet is located at the fog and co-located with the gateway, it transitions into a fog node, thus providing all five services of a fog node. At the uppermost tier of the architecture, we have the cloud, providing extensive storage and computing capabilities and aligning with the top-down model. Here, the data and tasks flow from the 'things' through the fog nodes up to the cloud for further processing and analysis. In special cases, the concept of 'mist computing' comes into play. It denotes situations where two 'things can interact directly to perform tasks and make decisions without needing assistance from the fog or the cloud. Their ad hoc network forms the 'mist'. This architecture, as illustrated in Figure 4, demonstrates how fog computing addresses the BLURS (Bandwidth, Latency, Uninterrupted, Resource constraint, and Security) challenges of traditional cloud centric IoT systems in a smart city setting, ensuring efficient and seamless city operations.

However, the widespread adoption of fog computing not only requires technological advancements but also regulatory adaptations, stakeholder collaboration, and an understanding of the societal implications of this transition. Future research and development should focus on these dimensions to fully exploit the potential of fog computing in the smart cities landscape. Table 3 presents a meticulously curated summary of the existing literature on fog computing, specifically in relation to its application and relevance in the sphere of smart cities. This tabular presentation is neatly compartmentalized into columns denoting authors of the studies, a detailed summary of each piece of the literature, and the principal findings that were drawn from each work.

4.3. Unmanned Aerial Vehicles in Smart Cities

The role of UAVs in smart cities extends across various sectors, significantly transforming service delivery and urban planning. In transportation, drones can aid in real-time traffic monitoring and management, significantly reducing congestion and improving mobility. Similarly, UAVs can assist in infrastructure inspection and maintenance, identifying potential faults and damage that can be addressed proactively, thereby enhancing the city's resilience.

In public safety, drones can be employed for surveillance, disaster management, and emergency response, providing valuable real-time information and increasing the effectiveness of these services. For environmental management, UAVs offer a novel platform for air quality monitoring, wildlife conservation, and mapping urban green spaces.

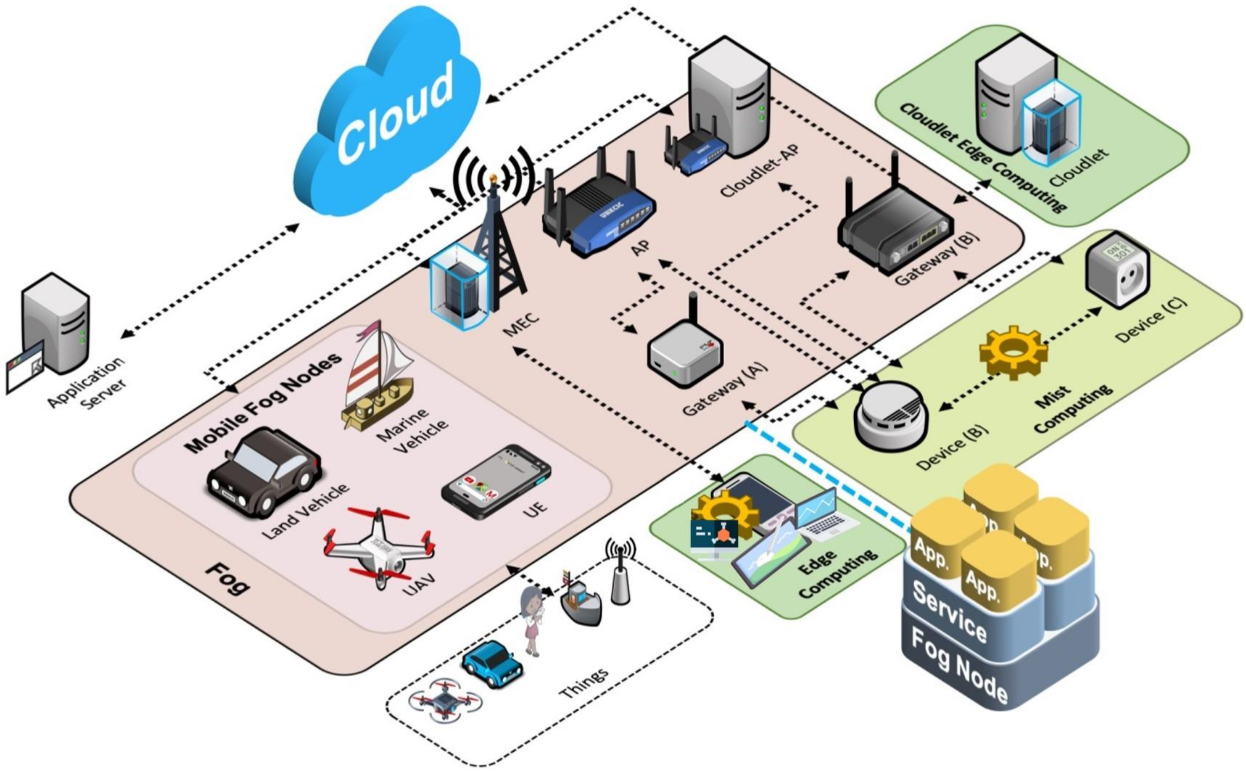

Figure 4. Architectural Design of Fog Computing in Smart Cities.

Table 3. Summary of The Fog Computing Literature.

Authors	Detailed Abstract	Main Findings
[54]	This paper discusses the use of a patial data warehouse to manage the voluminous data generated by IoT devices in smart cities. It proposes an architecture that integrates a cloud layer with a fog computing layer and provides guidelines to managers on how to implement the architecture. The architecture is validated with a case study that uses real data from a smart city.	• We proposed an architecture that integrates a cloud layer with a fog computing layer to support spatial analytics in smart cities; • We introduced a set of guidelines to aid smart city managers in implementing the proposed architecture; • We validated our architecture with a case study that demonstrated its efficacy and effectiveness.
[55]	This paper discusses fog computing for smart cities' big data management and analytics. It describes how fog computing can address the issues of latency and network bandwidth required by time-sensitive smart city applications.	• Smart cities are increasingly relying on utility-supplied IT delivered over the Internet to manage the vast amounts of data generated by their various systems; • Edge and fog computing paradigms offer potential solutions to address big data storage and analysis in the field of smart cities; • A fog-based data pipeline can be designed to address the issues of latency and network bandwidth required by time-sensitive smart city applications.

Table 3. *Cont.*

Authors	Detailed Abstract	Main Findings
[56]	This paper discusses the potential applications of fog computing in sustainable smart cities. It describes how fog computing can be used to reduce delays and enhance energy efficiency. The paper also discusses different caching techniques and the use of Unmanned Aerial Vehicles (UAVs) and various Artificial Intelligence (AI) and Machine Learning (ML) techniques in caching data for fog-based IoT systems.	• Fog computing can be used to reduce delays and enhance energy efficiency in sustainable smart cities in the IoT era; • Different caching techniques and the use of Unmanned Aerial Vehicles (UAVs) and various Artificial Intelligence (AI) and Machine Learning (ML) techniques can be used to improve the performance of fog-based IoT systems; • Potential and challenges of such systems should be considered when implementing fog computing for sustainable smart cities.
[57]	This paper discusses how fog computing and Internet of Things technology can be used to build smart cities. It proposes an IoT architecture based on fog computing, which effectively solves the problems of big data processing and network scalability.	• Fog computing and Internet of Things technology are essential for the construction of smart cities; • An IoT architecture based on fog computing is proposed to solve the problems of big data processing and network scalability; • A layered fog computing network architecture is proposed to make the city's operation more coordinated, efficient, and harmonious.
[58]	This paper presents a secured architecture called the Blockchain and Fog-based Architecture Network (BFAN) for IoE applications in the smart cities. The proposed architecture uses encryption, authentication, and blockchain to secure data. It is designed to reduce the latency and energy and ensure improved security features.	• Proposed BFAN architecture for IoE applications in smart cities, which reduces latency and energy consumption and ensures improved security features through blockchain technology; • Simulation results demonstrate that the proposed architecture performs better than existing frameworks for smart cities; • BFAN architecture assists system developers and architects to deploy applications in the smart city paradigm.
[59]	This paper presents a systematic mapping study of the use of the Fog Computing paradigm in smart cities platforms. It provides an overview of the current state of research on this topic and identifies important gaps in the existing approaches and promising research directions.	• Fog Computing is a promising approach to support emerging IoT applications with stringent requirements on latency and data processing; • A systematic mapping study was performed to provide a comprehensive understanding of the use of the Fog Computing paradigm in smart cities platforms; • Important gaps in the existing approaches and promising research directions were identified.
[60]	This paper discusses the role of fog computing and IoT in smart city development. It describes how fog computing can help with time-sensitive data processing and quick decision making.	• Fog computing is a distributed technology which performs computations at the edge of the network, making it a smart choice for smoother processing and execution of smart city applications; • IoT devices are generating large amounts of heterogeneous data, making it important to have reliable applications for day-to-day activities; • Multi-dimensional abstractions can extend technological contributions in current epidemic situations.

Challenges and Opportunities

However, the widespread adoption of UAVs in smart cities is not without challenges. Privacy concerns and potential noise pollution associated with drones need to be adequately addressed. Regulations governing drone operations, including flight paths, altitude limits, and no-fly zones, need to be established and strictly enforced to ensure public safety.

Despite these challenges, UAVs bring immense opportunities for innovation and development. Advancements in drone technology, such as enhanced battery life, improved sensors, and autonomous operation, will further expand their potential applications in smart cities.

Future Perspectives

The future of UAVs in smart cities is promising, with rapid advancements in technology and an increasing recognition of their potential. Integration of drones with emerging technologies like Artificial Intelligence (AI), Internet of Things (IoT), 5G, and beyond is expected to augment their capabilities, driving a new era of urban development.

However, achieving this potential requires a balanced approach that addresses the associated challenges. Robust regulatory frameworks, comprehensive privacy and security measures, and active stakeholder engagement are needed to ensure the safe and ethical deployment of UAVs in smart cities. Future research should focus on these aspects, contributing to the realization of smart cities that are not only technologically advanced but also socially inclusive and responsible.

Table 4 delivers a comprehensive summary of the body of the literature that revolves around Unmanned Aerial Vehicles (UAVs), with a specific focus on their significance and applications in the field of smart cities. The table is methodically divided into columns signifying the authors of the studies, a detailed summary of each research work, and the cardinal findings derived from each individual study.

Table 4. Summary of The Unmanned Aerial Vehicles Literature.

Author	Detailed Abstract	Main Findings
[61]	This paper overviews the beneficial applications that UAVs can offer to smart cities and particularly to ITS while highlighting the main challenges that can be encountered.	• UAVs can offer a variety of applications to smart cities, particularly in the field of ITS; • Challenges exist in organizing the operation of UAV swarms, particularly due to their battery-limited capacity; • Open research areas should be undertaken to strengthen the case for UAVs to become part of the smart infrastructure for futuristic cities.
[62]	This paper explores the involvement of surveillance drones in smart cities. It looks at the application status, application areas, proposed models, and characteristics of drones. The paper finds that surveillance drones can be used in a variety of ways and can offer efficient and sustainable solutions compared to conventional surveillance methods.	• Surveillance drones are used in seven distinct research fields, with air pollution and traffic monitoring being the dominant application areas; • Most models are based on the application of rotary-wing single-drones with the camera as the aerial sensor; • UAVs can offer efficient and sustainable solutions compared to conventional surveillance methods when integrated with other technologies.
[63]	This paper surveys the scientific contributions in the application of unmanned aerial vehicles (UAVs) for civil engineering, especially those related to traffic monitoring. It is concluded that this is still a field in its infancy but that progress in advanced image processing techniques and technologies used in the construction of UAVs will lead to an explosion in the number of applications.	• UAVs are gaining considerable interest in transportation engineering for traffic monitoring and analysis; • Advanced image processing techniques and technologies used in the construction of UAVs will lead to an increase in applications and benefits for society; • This field is still in its infancy and further research is needed.

Table 4. *Cont.*

Author	Detailed Abstract	Main Findings
[64]	This paper develops UAV-aided intelligent transportation systems to enhance the usage of vehicular networks and support low latency vehicular services. The performance of UAV-aided intelligent transportation systems is analyzed in terms of the average age-of-information (AoI). The deployment of multiple UAVs is optimized to minimize the average peak AoI.	• UAVs can be deployed as data collectors to receive data packets from vehicles due to their advantages of high mobility and low operating cost; • The concept of age-of-information (AoI) is adopted to measure the freshness of data packets of vehicles; • The deployment of multiple UAVs can be optimized to minimize the average peak AoI according to the traffic intensity of vehicles under seamless coverage, finite queue, and coverage probability constraints.
[65]	This paper discusses the use of drones for intelligent city management, especially in the context of security. It explains the drone security management flow and discusses how emerging technology such as blockchain can help improve the management of smart cities.	• AI, blockchain, and Drone technologies are playing an important role in the concept of smart cities; • Drones can be used to support intelligent city management with their advantages in regional monitoring; • Emerging technologies such as blockchain can help improve the management of smart cities.
[66]	This paper proposes the use of drones to deploy and manage IoT devices in the context of smart cities. It argues that this would be more efficient and cost-effective than current methods.	• We propose a drone-based IoT as a service (IoTaaS) framework that enables the dynamic provisioning or deployment of IoT devices using drones; • IoTaaS allows IoT devices and gateways to be mounted on drones and provides a distributed cloud service by placing the IoT devices in an area according to the requirements specified by a user; • A proof-of-concept implementation of IoTaaS for smart agriculture and air pollution monitoring applications shows that IoTaaS can reduce setup costs and increase the usage of IoT devices.
[67]	This paper establishes an intelligent multi-attribute service response framework in smart city based on the request of users and the response of AVs. In the first phase of the framework, each central server decides the minimum service execution cost (SEC) to respond to the user's service. In the second phase, based on the SEC of each central server, an auction game is developed to model the competition among the central servers to help the user select the optimal one to execute the service with the lowest service transaction price (STP).	• An intelligent multi-attribute service response framework in smart city is established based on the request of users and the response of Avs; • Optimal AV selection algorithms are designed for services with one attribute and services with multiple attributes; • An auction game is developed to model the competition among the central servers to help the user select the optimal one to execute the service with the lowest service transaction price.

Figure 5 provides a visual exploration of various applications of unmanned aerial vehicles (UAVs), also known as drones, in the context of smart cities. It encompasses a range of scenarios where these autonomous systems significantly contribute to the functioning and efficiency of urban environments. The figure showcases several real-world applications such as environmental monitoring where UAVs are employed to collect data on pollution levels, weather conditions, or wildlife populations.

Emergency response is another critical area, with drones providing rapid assistance during natural disasters, fires, or medical emergencies, greatly reducing response times and improving safety. In transportation and logistics, UAVs facilitate speedy and efficient delivery of goods, alleviating traffic congestion and improving supply chain operations.

Figure 5. Applications of UAV in Smart Cities [68].

The utility extends to infrastructure inspection as well, where drones are used for monitoring and maintenance tasks in inaccessible or hazardous areas, such as power lines, bridges, or tall buildings. The figure also highlights the use of UAVs in urban planning and management, where aerial imagery and data collected by drones assist in better decision making and strategic development. Furthermore, UAVs also have a role in surveillance and security, providing a cost-effective and versatile solution for public safety monitoring.

4.4. Renewable Energy in Smart Cities

The quest for sustainability has ushered in a new era of urban development, with renewable energy emerging as a central pillar of smart city initiatives worldwide. Smart cities, characterized by the integration of digital technology into urban infrastructure, are embracing renewable energy sources to not only reduce their environmental footprint but also enhance the efficiency, reliability, and quality of urban energy systems.

Emergence of Renewable Energy in Urban Landscapes

The discourse around renewable energy in urban settings has evolved in tandem with the global urgency to mitigate climate change and achieve sustainable development. With increasing urbanization and its consequent energy demand, cities have become critical players in the transition towards cleaner energy alternatives. This transition forms the cornerstone of smart cities, seeking to harmonize urban progress with environmental stewardship [69].

Role of Renewable Energy in Smart Cities

Renewable energy plays a multifaceted role in smart cities, influencing various aspects of urban life. Primarily, renewable energy sources, such as solar, wind, hydro, and bioenergy, provide a sustainable alternative to fossil fuels, significantly reducing greenhouse gas emissions. This shift not only mitigates environmental impact but also enhances public health by improving air quality.

Beyond environmental benefits, renewable energy contributes to energy security, resilience, and economic development in smart cities. The integration of renewable energy reduces dependence on external energy sources, offering greater energy autonomy. It also bolsters urban resilience by diversifying the energy mix and reducing vulnerability to fossil fuel price volatility. Additionally, the renewable energy sector can stimulate local economies by creating jobs and fostering innovation.

Challenges and Opportunities

However, the adoption of renewable energy in smart cities also presents challenges. Technical hurdles such as intermittent energy supply, infrastructure requirements, and energy storage need to be addressed. Economic challenges, including the high initial investment for renewable energy infrastructure, and regulatory challenges, such as policy support for renewable energy adoption, also need attention.

Despite these challenges, the renewable energy transition opens doors for numerous opportunities. Technological advancements like smart grids, energy storage solutions, and energy-efficient buildings can facilitate the integration of renewable energy in urban systems. Moreover, strategies like public–private partnerships can mobilize the necessary capital for renewable energy projects.

Future Perspectives

The future of renewable energy in smart cities looks promising. With advancements in technology, evolving regulatory frameworks, and increasing public awareness about climate change, renewable energy is set to play an increasingly significant role in shaping sustainable and resilient urban landscapes.

Nevertheless, realizing this potential requires a concerted effort from various stakeholders, including policymakers, urban planners, businesses, and citizens. Future research and policy initiatives should aim to tackle the existing challenges and capitalize on the opportunities presented by the intersection of renewable energy and smart cities. Table 5 provides an all-encompassing summary of the existing literature on renewable energy, particularly emphasizing its role and implications in the realm of smart cities. The table is systematically structured into columns representing the authors of the studies, a detailed summary of each piece of research, and the crucial findings that have emerged from each study.

Table 5. Summary of The Renewable Energy Literature.

Authors	Detailed Abstract Summary	Main Findings
[70]	This paper discusses the role of renewable energy resources in smart cities. It describes how they can be integdonerated into the energy systems of smart cities and the benefits of doing so. Finally, it discusses some of the challenges of integrating renewable energy into smart city energy systems.	• Renewable energy sources (such as solar, wind, geothermal, hydropower, ocean, and biofuels) can play a vital role in the transition towards a sustainable urban life; • Integrating renewable sources into energy systems of smart cities is a sagacious strategy towards clean and sustainable process; • Optimization issues of the energy system for integrating renewable components, ensuring good stability, maximizing the operating range, and minimizing the investment costs should be critically evaluated in future works.
[71]	This paper explores the role of application programming interfaces (APIs) for managing real-time, online, and historical energy data in the context of residential buildings and electric vehicles. A layered architecture that employs APIs in big data is developed for district energy management towards providing energy information intelligence and support decision making on energy sustainability in facilitating prosumption operations.	• Application programming interfaces (APIs) can be used to manage real-time, online, and historical energy data in the context of residential buildings and electric vehicles; • A layered architecture was developed to collect energy data and provide data to prosumers for better energy prosumption in smart grids; • APIs can be used to facilitate decision making on energy sustainability and support prosumption operations.

Table 5. *Cont.*

Authors	Detailed Abstract Summary	Main Findings
[72]	This paper discusses the DC4Cities approach to integrating renewable energy sources into the local power grid for data centres in smart cities. It describes how the project offers a solution for optimizing the share of local renewable power sources when operating data centres in smart cities.	• DC4Cities offers a technical and business related solution for optimizing the share of local renewable power sources when operating data centers in smart cities; • Power management options between the data center and the smart city together with internal adaptation strategies for data centers are introduced; • An implementation of the suggested approach is presented and evaluated in a simulation.
[73]	This paper discusses how the development of microgrids can help to make a city smart. It describes how an energy management system is used to determine the optimum solution for renewable energy resources and transfer it to the microgrid.	• Microgrids are an effective way to reduce energy losses, minimize energy imbalance, and improve the reliability of a power system; • An energy management system (EMS) is used to optimize the use of renewable energy resources (RES) and transfer it to the microgrid; • A variety of strategies and approaches are employed in the development of an efficient energy management system to address the drawbacks of renewable energy sources, such as variability and load fluctuations.
[74]	This paper discusses MOVESMART, a holistic approach for the provision of renewable personal mobility services. It focuses on the cloud-based (backend) services of the MOVESMART platform.	• MOVESMART is a holistic approach for providing renewable personal mobility services and leveraging crowd-sourcing data, tools for collecting real-time information by multimodal travelers, and traffic prediction mechanisms; • MOVESMART guarantees real-time responses to renewable (on-demand) mobility queries for efficient multi-modal route planning that are time-dependent as well as sensitive to aperiodic incidents and traffic prediction forecasts; • The MOVESMART platform is cloud-based, providing a backend service for efficient and sustainable mobility services in urban environments.
[75]	This paper investigates the problems of extending the sensors network lifetime in smart cities. It proposes a model for data collection based on energy harvesting (EH) with the cluster head rotation feature. The results show that the network lifetime increases when EH technology is used.	• Energy harvesting (EH) technology can be used to extend the lifetime of sensors networks in smart cities; • The proposed model combining EH with cluster head rotation feature results in flexible and sustainable networks; • Simulation results show that the network lifetime increases when EH technology is used.

Figure 6 depicts the diverse range of applications for renewable energy within the context of smart cities. At the heart of the diagram is the grid—the central point of interconnection and energy distribution in the city. The grid is further classified as a 'Smart Grid' due to its bidirectional communication and energy flow which allows for efficient energy management and enhanced resilience.

Several renewable energy sources feed into the smart grid, each with their unique applications. These include solar, wind, geothermal, hydro, and bioenergy sources. Each energy source is visually represented and connected to the corresponding applications within the city's context.

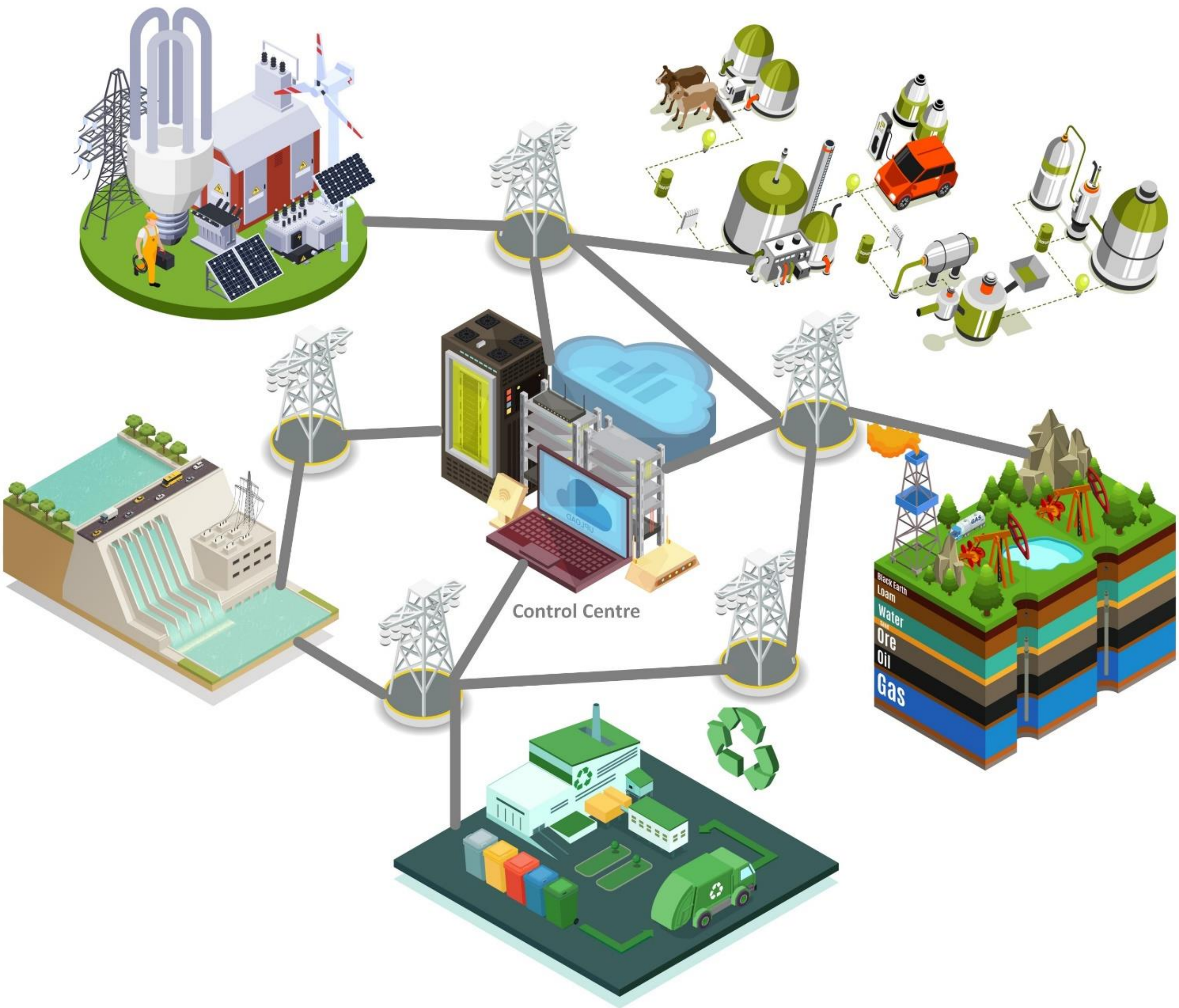

Figure 6. Renewable Energy Connectivity in Smart Cities.

Solar energy, for instance, is prominently used in powering streetlights, buildings, and charging stations for electric vehicles. Wind energy, on the other hand, finds its applications in power generation for buildings and public spaces, while geothermal energy is often used for heating or cooling buildings. Hydro and tidal energy sources are primarily harnessed for generating electricity. Bioenergy, derived from organic waste materials, is used for power and heat production, significantly reducing waste that would typically go to landfills.

4.5. Machine Learning and Deep Learning in Smart Cities

As the digital revolution permeates urban development, the role of advanced technologies such as Machine Learning (ML) and Deep Learning (DL) in shaping smart cities has become increasingly prominent. By leveraging the potential of these intelligent algorithms, smart cities are exploring innovative ways to enhance urban life's efficiency, sustainability, and quality.

Emergence and Significance of Machine Learning and Deep Learning

Machine learning, a subfield of Artificial Intelligence (AI), enables computers to learn from and make decisions based on data. Deep Learning, a subset of ML, mimics the human brain's functioning using artificial neural networks to process large amounts of data and recognize complex patterns [76].

The significance of ML and DL in the smart city context is rooted in their ability to handle and extract meaningful insights from the vast amounts of data generated by urban systems. The integration of Information and Communication Technologies (ICT) and Internet of Things (IoT) devices in smart cities leads to the generation of big data, making ML and DL critical for effective data management and decision making.

While the large-scale and agent-based microsimulation presented by [77] showcases the potential for a comprehensive analysis of various transport modes in the city of Bologna, certain aspects warrant further consideration. One significant concern arises from the usage of "big data" sources from different years, which inherently introduces uncertainties and assumptions, potentially compromising the reliability of the simulation outcomes. Although it is acknowledged that updating data to the year 2018 involves many assumptions, the validity and real-world application of such an approach remain questionable. While the use of SUMO as the microsimulator offers advantages, especially in terms of accessibility and analysis tools, it would be prudent to assess its relative effectiveness and accuracy against other state-of-the-art microsimulators. The mentioned potential improvements, such as more recent data availability and sophisticated data fusion methods, highlight that this work is in its nascent stages and requires continuous refinement. Lastly, while scenario-building provides a platform for interdisciplinary collaboration, a more standardized and reproducible method would greatly enhance its applicability across different urban settings.

Role of Machine Learning and Deep Learning in Smart Cities

The application of ML and DL in smart cities spans various sectors. In transportation, these technologies are used for real-time traffic management, predicting congestion, and optimizing routes. In the energy sector, ML and DL enable predictive maintenance of infrastructure, optimization of energy consumption, and integration of renewable energy sources. In public safety, ML and DL algorithms enhance surveillance systems, anomaly detection, and emergency response. In the realm of healthcare, these technologies contribute to remote health monitoring, predictive diagnostics, and personalized medicine.

Table 6 provides an exhaustive summary of the existing literature pertaining to Machine Learning (ML) and Deep Learning (DL), specifically their role, application, and implications in the context of smart cities. The table is systematically divided into sections denoting the authors of the studies, a detailed summary of each research work, and the essential findings that were derived from each respective study.

Figure 7 offers a comprehensive depiction of the various applications of machine learning and deep learning within smart cities. The image illustrates the broad spectrum of uses these technologies have in the urban landscape, underscoring their integral role in creating efficient, sustainable, and intelligent cities. Starting with transportation, the diagram highlights the application of machine learning in predicting traffic patterns, facilitating dynamic traffic management, and enabling autonomous vehicles. In terms of infrastructure, machine learning aids in predictive maintenance, thereby ensuring the efficiency and longevity of city assets. In the realm of environment and energy management, machine learning and deep learning technologies contribute significantly to optimizing energy consumption, predicting energy demand, and managing renewable energy resources. They also enable more accurate environmental monitoring, facilitating pollution control and sustainability initiatives. Furthermore, these technologies play a pivotal role in enhancing public safety and security. Predictive policing, real-time surveillance, and anomaly detection are some of the applications that leverage machine learning and deep learning for creating safer urban environments.

Table 6. Summary of The Machine Learning and Deep Learning Literature.

Authors	Detailed Abstract	Main Findings
[69]	This paper discusses how to use big data and machine learning to create an ntelligent system for managing energy efficiency of public sector buildings. The most accurate model was produced by the Random Forest method. The system could be used by public administration to plan reconstruction measures of public buildings, to reduce energy consumption and cost, and to connect such smart public buildings as part of smart cities.	• Machine learning and big data can be used to create an intelligent system for managing the energy efficiency of public sector buildings as part of the smart city concept; • Deep neural networks, Rpart regression trees, and Random forests with variable reduction procedures were used to create prediction models of specific energy consumption of Croatian public sector buildings; • The most accurate model was produced by the random forest method and a comparison of important predictors extracted by all three methods was conducted.
[78]	This paper discusses the use of machine learning methods for WSN-IoT nodes deployed in smart city applications. It finds that supervised learning algorithms have been most widely used for these applications.	• Machine learning techniques have great potential to efficiently manage the automated operation of IoT nodes in smart cities; • Supervised learning algorithms have been the most widely used (61%) for smart city applications, followed by reinforcement learning (27%) and unsupervised learning (12%); • This is the first in-depth literature survey of all ML techniques in the field of low power consumption WSN-IoT for smart cities.
[79]	This paper discusses the concept of Industrial IoT (IIoT) and its applications for smart cities. It surveys currently available deep learning (DL) techniques for IIoT in smart cities and presents insights, open issues, and future trends applying DL techniques to enhance IIoT security.	• The significant evolution of the Internet of Things (IoT) enabled the development of numerous devices able to improve many aspects in various fields in the industry for smart cities; • Deep learning (DL) techniques for IIoT in smart cities, mainly deep reinforcement learning, recurrent neural networks, and convolutional neural networks, can be used to enhance security; • Insights, open issues, and future trends applying DL techniques to enhance IIoT security are presented.
[80]	This paper is a comprehensive and systematic literature review of machine learning methods in the emerging applications of smart city. It looks at the state-of-the-art, taxonomy, evaluation and model performance. The study concludes that the hybrid models and ensembles are the best performers.	• Hybrid models and ensembles are the best performers for smart city applications due to their high accuracy and low complexity; • Deep learning techniques have higher accuracy than hybrid models and ensembles but require more computation power; • Support vector machines and decision trees generally outperform artificial neural networks for accuracy and other metrics.
[81]	This paper discusses a deep reinforcement learning concept used to learn the features of smart cities. The system successfully predicts the unwanted activity in intelligent cities by dividing the collected data into a smaller subset.	• Deep reinforcement learning with a modular neural network is used to predict the quality of services in smart cities; • The system successfully predicts the unwanted activity in intelligent cities by dividing the collected data into a smaller subset; • Experimental analysis shows that the system is efficient in maintaining security in smart cities.

Table 6. *Cont.*

Authors	Detailed Abstract	Main Findings
[82]	This paper provides an overview of data analytics in smart cities with a focus on smart mobility. It discusses the challenges and potential solutions to these challenges, including a framework for universal smart city decision making.	• Smart cities' decision-making process can be optimized using data analytics; • A framework of solutions, called universal smart cities decision making, was proposed to address current challenges in smart cities; • Big data, machine learning, and deep learning algorithms have been applied to smart cities and can play a role in decision making for smart mobility.
[83]	This paper investigates open data-based machine learning applications in the six different areas of smart cities. It finds that machine learning applications using open data came out in all the SC areas and specific ML techniques are discovered for each area, with deep learning and supervised learning being the first choices.	• Machine learning applications using open data are present in all areas of smart cities, with deep learning and supervised learning being the most popular techniques; • Open data platforms are the most used source of data; • Challenges associated with open data utilization include quality, frequency, consistency, and data format.

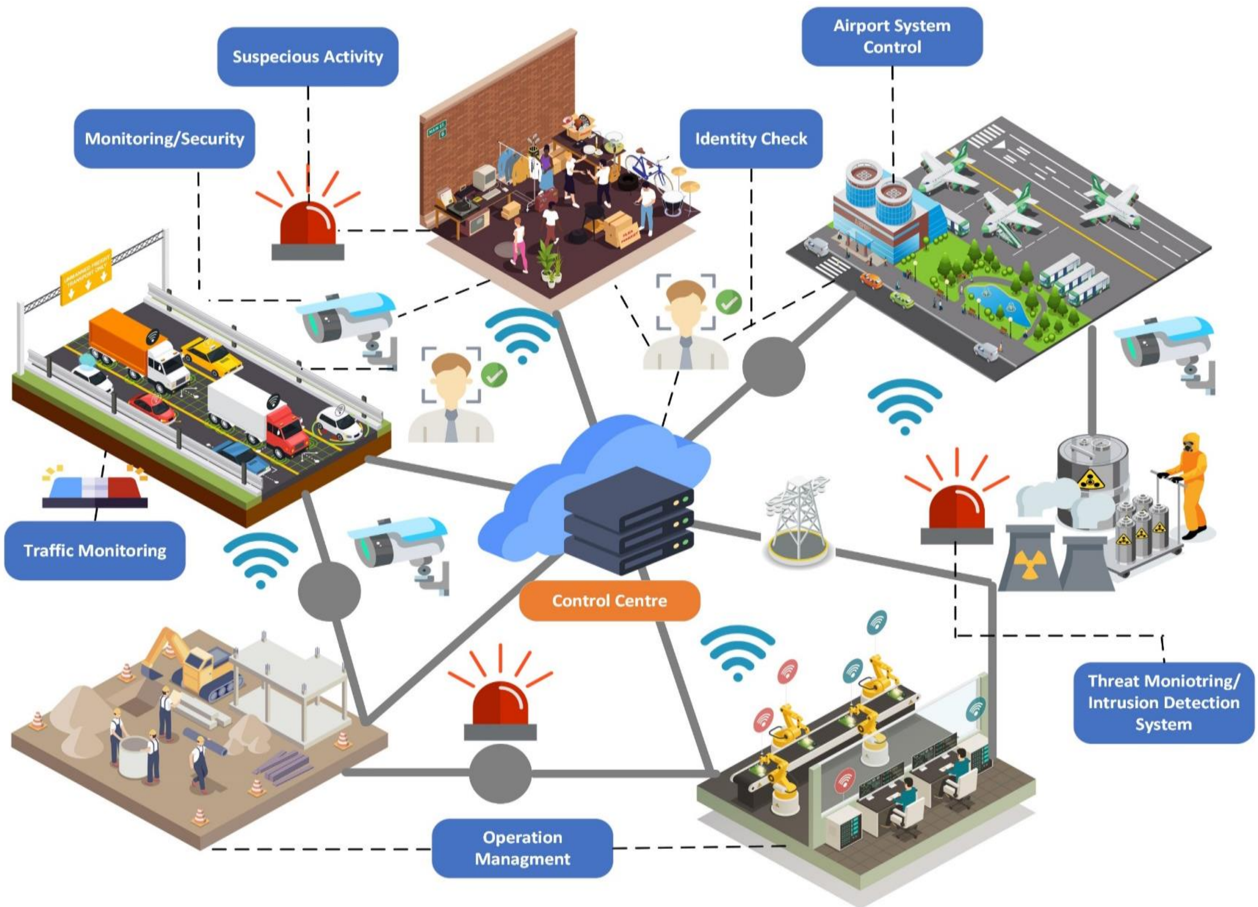

Figure 7. ML/DL Centralized Administration in Smart Cities.

4.6. Cybersecurity in Smart Cities

The progressive evolution of smart cities, characterized by the pervasive integration of Information and Communication Technologies (ICT) into urban infrastructure, has inevitably amplified the significance of cybersecurity. As cities continue to embrace digital transformation, enhancing cybersecurity measures becomes paramount to protect the urban digital ecosystem, uphold public trust, and ensure the sustainable progression of smart cities.

The Emergence of Cybersecurity in the Urban Context

The narrative around cybersecurity in the urban context has been influenced by the increasing reliance on digital technologies for delivering public services and managing city operations. The smart city paradigm, which is inherently data-driven, and network based, has opened new avenues for potential cybersecurity threats, making it an indispensable component of the smart city architecture.

Role of Cybersecurity in Smart Cities

The function of cybersecurity in smart cities extends across various sectors and operations, acting as a protective shield against potential digital threats. From safeguarding the privacy of citizen data to protecting the integrity of critical city infrastructure, cybersecurity measures form the backbone of resilient urban digital ecosystems.

In the context of public services, ensuring the security of digital platforms used for service delivery is crucial to protect user data and maintain public trust. In infrastructure management, cybersecurity mechanisms are required to prevent potential attacks that can disrupt city operations and services. In data management, robust cybersecurity measures ensure the integrity and confidentiality of the vast amounts of data generated and used by smart cities.

Challenges and Opportunities

The integration of cybersecurity in smart cities also presents its unique set of challenges. The sheer complexity of smart city ecosystems, characterized by numerous interconnected devices and systems, makes it a challenging task to secure against potential threats. Furthermore, the dynamic nature of cyber threats, continuously evolving in response to new defenses, adds to this challenge.

Despite these challenges, there are also opportunities for innovation and improvement. Technological advancements, such as Artificial Intelligence (AI) and blockchain, can be leveraged to enhance cybersecurity measures. AI can be used for real-time threat detection and response, while blockchain can ensure the integrity and traceability of data.

Future Perspectives

The future of cybersecurity in smart cities is intertwined with the future of urban development itself. As smart cities continue to evolve, so will the role of cybersecurity, requiring continuous adaptation and innovation. The integration of emerging technologies and the development of new cybersecurity strategies will be key to addressing future challenges. Table 7 presents a meticulous summary of the existing literature focused on cybersecurity, particularly highlighting its implications and applications within the realm of smart cities. The table is organized into columns that denote the authors of the studies, a detailed summary of each research piece, and the key findings that have emerged from each respective study.

Table 7. Summary of Cybersecurity Literature.

Authors	Detailed Abstract Summary	Main Findings
[84]	This paper discusses cybersecurity challenges in smart cities. It describes how security and privacy are intertwined challenges and how they can be addressed with technology.	• Smart cities pose challenges to security and privacy due to the increased interconnectedness of systems; • Security challenges include illegal access to information and attacks causing physical disruptions in service availability; • Privacy challenges include protecting data and triggering an emergency response when needed.

Table 7. *Cont.*

Authors	Detailed Abstract Summary	Main Findings
[85]	This paper provides an overview of smart cities, discussing the privacy and security issues in current smart applications along with the corresponding requirements for building a stable and secure smart city. It then summarizes the existing protection technologies and presents open research challenges and future research directions.	• Smart cities are expected to improve the quality of daily life, promote sustainable development, and improve the functionality of urban systems; • Security and privacy issues have become a major challenge that requires effective countermeasures; • Existing protection technologies and open research challenges have been identified to pave the way for further exploration.
[86]	This paper discusses the security vulnerabilities and privacy issues within the context of smart cities and the various privacy and security solutions, recommendations, and standards for smart cities and their services.	• Smart cities are increasingly incorporating ICT into their infrastructure, which opens up various security and privacy issues; • Security vulnerabilities and privacy issues must be addressed in order to ensure the safety of citizens; • Various privacy and security solutions, recommendations, and standards exist to protect citizens in smart cities.
[87]	This paper discusses cybersecurity in smart cities. It reviews deep learning models and cybersecurity applications and use cases based on deep learning technology in smart cities. Finally, it describes the future development trend of smart city cybersecurity.	• Smart cities bring great convenience to people's lives but also pose hidden dangers of cybersecurity; • Deep learning models, such as Boltzmann machines, restricted Boltzmann machines, deep belief networks, recurrent neural networks, convolutional neural networks, and generative adversarial networks, can be used to protect smart city cybersecurity; • Cybersecurity applications and use cases based on deep learning technology in smart cities are being developed and the future development trend of smart city cybersecurity is promising.
[88]	This paper provides an overview of security-related problems in the context of smart cities. It discusses specific data-security requirements and solutions in a four-layer framework. As urban management should pay close attention to security and privacy protection, the paper will serve them as a start point for better decisions in security design and management.	• Smart cities are complex environments in which existing security analysis are not useful anymore; • Data security in smart cities requires specific solutions in four layers: smart things, smart spaces, smart systems, and smart citizens; • Urban management should pay close attention to security and privacy protection, network protocols, identity management, standardization, trusted architecture, etc.
[89]	This paper discusses cybersecurity issues and challenges for smart cities. It presents a brief overview of the core concepts of security and privacy issues concerning smart cities and reveals recent cyber-attacks targeting smart cities. It also identifies numerous security weaknesses and privacy challenges pertaining to various cybersecurity issues and provides recommendations for future directions.	• The implementation of ICTs in urban infrastructure has led to greater attention in smart cities; • Smart cities are vulnerable to cyber-attacks, which can lead to privacy and security issues; • This paper has identified numerous security weaknesses and privacy challenges, as well as providing recommendations for future directions.
[90]	This paper discusses cybersecurity for smart cities. It explains the importance of cybersecurity for smart cities and how to develop intelligent strategies against cyber-attacks.	• Smart cities have eight categories of intelligent systems, which need to be secured against cyber-attacks; • Cybersecurity is a set of methods, policies, concepts, and guidelines used to protect information assets; • Smart city rulers should develop strategies to protect against cyber-attacks to ensure the safety of citizens.

Table 7. *Cont.*

Authors	Detailed Abstract Summary	Main Findings
[91]	This paper discusses cybersecurity challenges in smart cities. It reviews the most critical challenges and concludes that cybersecurity is essential for smart cities.	• Smart cities are being established around the world to promote economic development and improve the quality of life of citizens; • Cybersecurity is a critical challenge in preserving smart cities from hacking operations; • There is a relationship between cybersecurity and smart cities as such cities cannot be established without providing an appropriate electronic and physical security environment.
[92]	This paper discusses cybersecurity risks and strategies related to smart cities. It argues that cybersecurity is a protection factor in the development of smart cities.	• Cybersecurity is essential for the development of Smart Cities as it protects data and information from theft and loss; • Smart cities must take advantage of the opportunities of new technologies while addressing the challenges they present; • Strategies and approaches must be implemented to ensure the security of information and communications.

Figure 8 illustrates the multifaceted challenges of cybersecurity in smart cities, emphasizing the interconnected roles of Confidentiality, Integrity, and Availability (CIA). The image visually depicts the way these principles intersect and interact within the context of a smart city's digital infrastructure. At its core, the diagram includes a representation of a ransomware attack scenario, demonstrating how it simultaneously breaches all three principles of the CIA triad:

- Confidentiality is compromised when unauthorized access is gained to a smart city's system.
- Integrity is impacted when vital data are encrypted and made unusable.
- Availability is affected when the system or data become inaccessible until a ransom is paid.

The image encapsulates these intersections to illustrate the intrinsic connectivity of the CIA principles and underscores their importance in maintaining the overall security of smart city infrastructure. Furthermore, the figure showcases the need for a balanced and comprehensive cybersecurity approach that protects these principles simultaneously to ensure the smooth and secure operation of smart city initiatives. The diagram, in essence, emphasizes the complex and multidimensional nature of cybersecurity challenges in the context of smart cities.

4.7. Digital Forensics in Smart Cities

As urban environments continue to digitalize and adopt the smart city paradigm, the need for robust cybersecurity measures becomes ever more critical. One essential aspect of these measures is digital forensics, an area that has become increasingly important in identifying and understanding cyber threats, thereby helping to mitigate and prevent future attacks.

Emergence of Digital Forensics in the Urban Landscape

The concept of digital forensics has evolved in alignment with the advent and proliferation of digital technologies. Initially centered around computer crime investigations, digital forensics has expanded its scope in tandem with the ever-growing complexity of the cyber landscape. Today, with the digitalization of cities, digital forensics is being adopted in smart city contexts to safeguard urban digital infrastructure and services.

Figure 8. Cybersecurity Challenges in Smart Cities.

Role of Digital Forensics in Smart Cities

Digital forensics plays a crucial role in smart cities, enabling the identification, preservation, analysis, and presentation of electronic evidence related to cybercrime or misuse. It facilitates incident response by providing insights into the how, when, where, and who of cyberattacks. This functionality is key for several urban sectors, including public administration, transportation, energy, healthcare, and public safety. In smart cities, where data is continuously generated and transmitted, digital forensics aids in investigating security incidents involving a variety of devices and platforms. In public administration, it helps maintain the integrity of e-governance platforms. In transportation and energy sectors, it plays a pivotal role in investigating attacks on smart grids, autonomous vehicles, and traffic management systems. In the healthcare sector, digital forensics can be crucial in investigating breaches of health information systems.

Challenges and Opportunities

The application of digital forensics in smart cities poses several challenges. The sheer volume of data, the complexity of interconnected systems, and the diversity of devices can complicate forensic investigations. Legal and ethical challenges, including privacy concerns and jurisdiction issues, also need to be addressed. However, these challenges also present opportunities for innovation and research. Technological advancements can improve digital forensic tools and methodologies, enhancing their scalability and efficiency. Cross-disciplinary research, involving law, ethics, and technology, can help address the legal and ethical concerns associated with digital forensics.

Future Perspectives

The future of digital forensics in smart cities is intertwined with advancements in technology and changes in the cyber threat landscape. As technology evolves and cyber threats become more sophisticated, digital forensics will need to adapt, requiring continuous research, development, and training. Furthermore, a collaborative approach involving various stakeholders—including city administrators, law enforcement agencies, cybersecurity professionals, and the community—will be crucial. Policies and frameworks that support the adoption and integration of digital forensics in the smart city ecosystem should also be developed. Table 8 offers a comprehensive summary of the existing literature focused on Digital Forensics, particularly with a lens on its role and relevance in the context of smart cities. The table is systematically divided into columns representing the authors of the studies; it provides a detailed summary of each piece of research and the key findings that have surfaced from each respective study. Figure 9 illustrates a comprehensive guideline for implementing digital forensics in smart cities. The figure is divided into key stages, representing the systematic approach adopted during a digital forensic investigation. These stages encompass the initial identification of potential cyber incidents, followed by the careful preservation and collection of digital evidence from various sources, such as IoT devices, cloud systems, and network traffic. Subsequently, the gathered evidence is meticulously analyzed to determine the nature of the incident, identify the perpetrators, and evaluate the impact. The final stage of the process entails documenting the findings, which may serve as invaluable input for legal proceedings or enhancing cyber incident response strategies. The figure underscores the importance of each step in the digital forensic process, highlighting its significance in maintaining the integrity, security, and resilience of smart city ecosystems.

Table 8. Summary of Digital Forensics Literature.

Paper Title	Authors	Detailed Abstract Summary	Main Findings
Future challenges for smart cities: Cybersecurity and digital forensics	[93]	This paper discusses the security landscape of a smart city, identifying security threats and providing deep insight into digital investigation in the context of the smart city.	• Smart cities comprise interconnected components that are vulnerable to cybersecurity threats; • Digital forensics is necessary to identify and enumerate evidence in the event of a cyber incident; • Forensic preparedness and lessons learned from past forensic analysis can help protect the smart city against future incidents.
Digital forensics trends and future	[94]	This paper looks into trends of applications of digital forensics and security at hand in various aspects and provides some estimations about future research trends in this area.	• Rapid evolution of computers and mobile phones has caused these devices to be used in criminal activities, making digital forensics an important tool for investigating cyber crimes; • Research in digital forensics has been conducted to help forensic investigation to resolve existing challenges; • Future research trends in digital forensics and security will focus on providing appropriate and sufficient security measures to protect against cyber crimes.

Table 8. *Cont.*

Paper Title	Authors	Detailed Abstract Summary	Main Findings
Digital Forensics to Intelligent Forensics	[95]	This paper argues that current investigative techniques are becoming unsuitable for most types of crime investigation, particularly as deployed by law enforcement. It suggests that more intelligent techniques are necessary and should be used proactively and that by applying new techniques to digital investigations there is the opportunity to address the challenges of the larger and more complex domains in which cybercrimes are taking place.	• Current investigative techniques are becoming unsuitable for most types of crime investigation due to the growth in cybercrime and the complexities of the types of the cybercrime; • There is a need to enhance the use of the resources available and move beyond the capabilities and constraints of the forensic tools that are in current use; • Applying principles and procedures of artificial intelligence to digital forensics intelligence and to intelligent forensics can help address the challenges of the larger and more complex domains in which cybercrimes are taking place.
The Internet of Things and the Smart City: Legal challenges with digital forensics, privacy, and security	[96]	This paper examines the interaction between digital forensics, privacy, and security in the context of the Internet of Things and the Smart City. It discusses how this interaction can inform public policy as to privacy and personal autonomy.	• The growth of ICTs in smart cities and the IoT has created more computable data with both benefits and risks; • Digital/computational forensics and analytics are used to combat crime and bring evidence to policymakers, police investigators, and judges; • The interaction between technology and public policy as to privacy and personal autonomy must be carefully considered to ensure the safety and rights of citizens.
A Survey on Digital Forensics in Internet of Things	[97]	This paper surveys the field of digital forensics in the Internet of Things. It looks at the impact of IoT on digital forensics and systematizes the research efforts made by previous researchers. It also highlights open issues and outlines suggestions for future study.	• Digital forensics in the context of IoT requires a 3D framework consisting of a temporal dimension, a spatial dimension, and a technical dimension; • The temporal dimension walks through the standard digital forensic process while the spatial dimension explores where to identify sources of evidence in IoT environment; • The technical dimension guides a way to the exploration of tools and techniques to ensure the enforcement of digital forensics in the ever-evolving IoT environment.
A New Digital Forensics Model of Smart City Automated Vehicles	[98]	This paper discusses a new digital forensics model for smart city automated vehicles. The model is designed to investigate cases of cybercrime.	• A novel Digital Forensics Model was developed to investigate AAV cases; • The model is designed to protect PII against Cyberstalking and other cybercrime challenges; • The model is compliant with GDPR (General Data Protection Regulation).

Table 8. *Cont.*

Paper Title	Authors	Detailed Abstract Summary	Main Findings
Forensic readiness of smart buildings: preconditions for subsequent cybersecurity tests	[99]	This paper discusses the importance of forensic readiness, digital evidence preservation and interpretation, and knowledge management in a smart world.	• Smart buildings have many advantages but also come with cybersecurity risks; • Cybersecurity and forensic readiness are essential for protecting smart buildings from cyber-attacks; • Knowledge Management (KM) is needed to better understand and handle cybersecurity issues of smart sensors and other configurable devices.
Security in smart cities: A brief review of digital forensic schemes for biometric data	[100]	This paper reviews state-of-the-art digital forensic schemes for audio–visual biometric data. These schemes can be used to validate the integrity of biometric data in smart city applications.	• Smart cities rely on biometric authentication for user verification, which can be digitally manipulated or tampered with; • Digital forensic schemes for audio–visual biometric data can be used to validate the integrity of biometric data; • Social media applications necessitate the validation of biometric data integrity.
Digital forensics model of smart city automated vehicles challenges	[101]	This paper discusses the development of a digital forensics model for smart city automated vehicles.	• The Digital Forensics Model is in progress to protect privacy data, including PII, against Cyberstalking and other cybercrimes in Smart City Automated Vehicles; • Mass surveillance from smart phone to PC and from automated car to smart television; any online device can be used as a privacy breach toolkit; • The proposed development is still ongoing and requires further research and development.
Autonomous Vehicles' Forensics in Smart Cities	[102]	This paper discusses autonomous vehicles' forensics in smart cities. It describes a non-invasive mechanism for the collection and storage of forensic data from AVs that is efficient, secure, and preserves the privacy of data generated by the AV.	• A non-invasive mechanism for the collection and storage of forensic data from AVs within smart cities was designed and implemented; • This mechanism is efficient, secure, and preserves the privacy of data generated by the AV; • The mechanism aids the relevant authorities in informed decision making.
Identifying Threats, Cybercrime, and Digital Forensic Opportunities in Smart City Infrastructure via Threat Modeling	[103]	This paper discusses the challenges faced by investigators in responding to cybercrime on smart city infrastructure. It proposes a common definition of smart city infrastructure and uses the STRIDE threat modeling methodology to identify threats. It also maps offences, possible evidence sources, and types of threats to help investigators understand what crimes could have been committed and what evidence would be required in their investigation work.	• A common definition of Smart City Infrastructure was proposed and the STRIDE threat modeling methodology and Microsoft Threat Modeling Tool were used to identify threats present in the infrastructure; • Offences, possible evidence sources, and types of threats were mapped to help investigators understand what crimes could have been committed and what evidence would be required in their investigation work; • Technical and legal opportunities in digital forensics on Smart City Infrastructure were discussed.

Table 8. *Cont.*

Paper Title	Authors	Detailed Abstract Summary	Main Findings
Application of an Intrusion Detection System in Smart Cities: A Review	[104]	This paper discusses the various threats that a smart city faces and types of Intrusion Detection Systems (IDS). It provides machine learning-based techniques for IDS in detail and concludes with challenges that are faced during the execution of security mechanisms in a smart city.	• Smart cities face various threats at different layers of their architecture; • Intrusion Detection Systems (IDS) are well-suited for a smart city environment due to their ability to detect abnormalities in the system; • Machine learning-based techniques can be used to improve the effectiveness of IDS in smart cities.

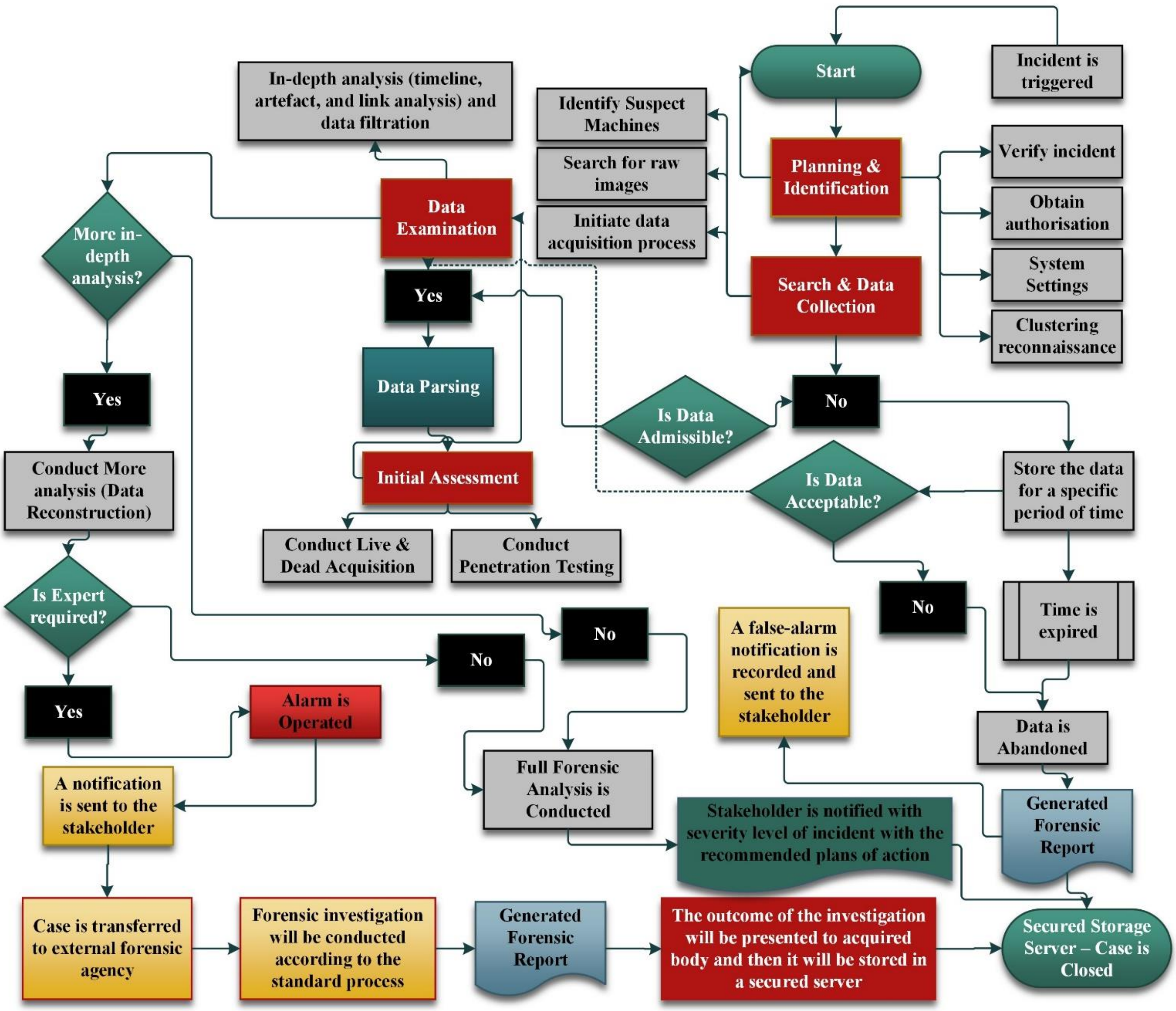

Figure 9. Digital Forensic Guideline for Smart Cities.

5. Unresolved Concerns Identified through the Literature Review

In this section, key challenges and open-ended issues recognized in the current literature are delved into. Scrutinizing these unresolved matters is crucial as they can provide guidance for future research and exploration. Ranging from methodological constraints in existing studies to gaps in theoretical frameworks or inconsistencies in findings, these issues might be varied. Unexplored areas or topics that have not received adequate attention could also be included. By having these concerns identified and addressed, contributions to the enrichment and progression of the field are aimed to be made.

Data Privacy

As smart cities harness the power of data to optimize urban life, significant privacy concerns are raised. Smart cities are typically characterized by the widespread collection, storage, and use of personal data, from travel patterns to energy consumption. This data-driven approach enables more efficient and personalized urban services, but it also risks infringing on citizens' privacy rights. The challenge lies in how to protect this data, safeguard individual privacy, and ensure its ethical use while still deriving valuable insights to improve city services. Currently, comprehensive and universally accepted solutions to these data privacy concerns are lacking, making this a critical area for future research and policy development.

Cybersecurity

The burgeoning connectivity in smart cities, while offering a myriad of benefits, also increases the potential for cyber threats. As urban infrastructure becomes more digitized and interconnected, it also becomes more vulnerable to cyber-attacks that could disrupt critical services, from power grids to transport systems. The issue of how to robustly safeguard smart city infrastructure and services from a diverse array of ever-evolving cyber threats remains an unresolved concern. Despite advancements in cybersecurity measures, ensuring the security of smart cities continues to pose significant challenges, necessitating continuous innovation and vigilance.

Interoperability

A smart city framework often involves a wide variety of different information technologies and systems. The integration and seamless communication of these disparate systems within a unified city-wide framework is a complex task. Achieving standardization and interoperability between different systems and devices is a fundamental need to ensure the efficient functioning of smart cities. However, this is easier said than done due to technological, vendor-specific, and regulatory barriers. Thus, the development of common standards and interoperable solutions remains a prominent issue in smart city literature.

Data Management

Smart cities produce vast volumes of data, spanning multiple domains and sources. Managing this data effectively, from collection and storage to analysis and transfer, is crucial for enabling data-driven decision making and service delivery. Yet, it is a significant challenge due to the sheer volume and complexity of data, as well as issues related to privacy, security, and interoperability. Efficient and effective data management strategies are still being developed and their implementation on a city-wide scale remains an open question.

Reliability

Smart cities rely heavily on information technologies to deliver services and function effectively. Ensuring the reliability and continuous availability of these IT services is crucial, especially for critical services like energy, water, and transportation. This involves safeguarding against various potential disruptions, from system failures to cyber-attacks. Despite advances in technology and system design, achieving high reliability in the face of such diverse potential disruptions remains an unresolved concern.

Digital Divide

The advent of smart cities has brought the issue of the digital divide into sharper focus. As cities become smarter and more reliant on digital technologies, there is a risk that those without access to these technologies—due to economic constraints, lack of skills, or other factors—will be left behind. This can exacerbate existing socio-economic inequalities and create new ones. Addressing the digital divide in the context of smart cities is a complex and ongoing issue that requires a combination of technological, policy, and social solutions.

Legal and Regulatory Frameworks

The rapid evolution of digital technologies in smart cities often outpaces the development of legal and regulatory frameworks. Existing laws and regulations may not fully accommodate the novel situations and challenges presented by smart cities, from data privacy issues to the use of autonomous systems. Consequently, the development of updated, applicable, and effective legal and regulatory frameworks that can keep up with the pace of technological change is a significant and unresolved challenge.

Sustainability of IT Infrastructure

Alongside the benefits of digitization, the sustainability of large-scale IT infrastructure in smart cities is a pressing concern. The environmental impact of maintaining such infrastructure, including energy consumption and electronic waste, can be significant. Despite advancements in green IT solutions, the development of truly sustainable IT infrastructure that balances performance with environmental impact remains a significant challenge. This issue represents a key area of ongoing research, with the need for novel and sustainable solutions continuing to grow.

6. Future Direction of Research

Industry 5.0 presents a variety of compelling opportunities for future research directions in the realm of smart cities. Below, are several ways Industry 5.0 could shape this exploration.

Human-centric Smart Cities: Industry 5.0 emphasizes the collaboration between humans and machines. This presents an opportunity to research how to build more human-centric smart cities that balance efficiency and automation with the needs and preferences of their human inhabitants.

Advanced Cybersecurity: With the increasingly sophisticated digital infrastructure of smart cities, cybersecurity becomes more complex. Researching new Industry 5.0-informed approaches to cybersecurity, such as advanced AI-driven threat detection and response systems, will be crucial.

Intelligent Automation in Urban Services: The potential of integrating intelligent automation in urban services is vast, including areas like transportation, healthcare, waste management, and energy. Future research could explore these applications, the benefits they could bring, and how they might be implemented effectively.

Data Management and Decision Making: Industry 5.0's advanced machine learning and AI algorithms could revolutionize data management and decision making in smart cities. Exploring the potential of these technologies for improving urban analytics, predictive modeling, and data-driven decision making is a promising research direction.

Sustainability and Resource Efficiency: Industry 5.0 could enhance sustainability in smart cities, for instance, through improved resource efficiency and waste reduction. Research could investigate how Industry 5.0 technologies can contribute to achieving these goals.

Ethical, Legal, and Social Aspects: As Industry 5.0 shapes smart cities, there will be an array of ethical, legal, and social implications. Research will be needed to understand these impacts and develop appropriate guidelines and regulatory measures.

Interoperability Standards: The creation of new interoperability standards that take advantage of Industry 5.0 technologies could be a critical area of research. This could help ensure that diverse systems within smart cities can work together effectively.

Digital Inclusion: As smart cities become more technologically advanced, ensuring digital inclusion is crucial. Research could focus on how to use Industry 5.0 technologies to close the digital divide and ensure all citizens can benefit from smart city developments.

These potential research directions reflect the breadth and depth of changes that Industry 5.0 could bring to smart cities. Each area offers exciting possibilities for creating more efficient, sustainable, inclusive, and livable urban environments.

7. Conclusions

As urbanization continues at an unprecedented pace, cities worldwide are grappling with the myriad of challenges that require innovative solutions. The central theme emanating from this research is the transformative potential of advancements in information and communication technologies, particularly as epitomized by Industry 5.0, to reshape the blueprint of future smart cities.

The exploration is based on a thorough survey, highlighting that the essence of Industry 5.0—centering on intelligent automation and fostering deeper human–machine symbiosis—is poised to radically alter the technological bedrock of urban regions. Multiple domains stand to benefit from these advancements and it is imperative to shed light on some key areas.

1. **Technological Pioneering**: From the integration of cyber–physical systems that allow for more dynamic interaction between digital and physical entities to fog computing which decentralizes data processing and storage, the landscape of smart cities is evolving. Furthermore, the role of unmanned aerial vehicles, renewable energy sources, and state-of-the-art machine learning and deep learning algorithms are all indicators of the progressive transformation on the horizon.
2. **Enhancing Urban Services and Security**: A city's ability to serve its inhabitants is arguably its most essential function. With Industry 5.0, the automation of urban services and the ability to tailor these services to individual needs becomes increasingly feasible. Concurrently, as digital infrastructures become ubiquitous, the necessity for cutting-edge cybersecurity solutions becomes paramount. Digital forensics, powered by Industry 5.0, stands as a beacon of hope in safeguarding citizens from potential cyber threats.
3. **Data Management and Decision Making**: The sheer volume of data generated by smart cities necessitates intelligent data management. Industry 5.0 facilitates the creation of more efficient data management systems, empowering city officials to make well-informed decisions swiftly.
4. **Reassessing Smart City Frameworks**: As underscored in this paper, resting on existing laurels is not an option. With the advent of new technologies, current smart city frameworks require regular reevaluation and potential overhauls to integrate the latest that Industry 5.0 has to offer.

However, it would be myopic to focus solely on the technological aspects. This paper, while emphasizing the technological prowess of Industry 5.0, also brings to the fore the ethical, legal, and societal facets that accompany such advancements. In a world where technology and society are deeply intertwined, it is imperative to strike a harmonious balance. Achieving sustainable and inclusive development is non-negotiable.

In summation, the future of smart cities is not just a race to adopt the newest technologies. It is a holistic vision that aspires to employ technologies, such as those stemming from Industry 5.0, to foster urban environments that are not only intelligent but also sustainable, resilient, and citizen centric. As we tread the path to this future, the insights and revelations from this paper should serve as essential beacons, lighting the way toward a harmonious, efficient, and technologically augmented urban realm.

The future of smart cities is intricately connected with the advancements in information and communication technologies, particularly the advent of Industry 5.0. The findings of this paper suggest that Industry 5.0, with its emphasis on intelligent automation and human–machine collaboration, is set to revolutionize the technological landscape of urban environments.

The application of Industry 5.0 technologies, spanning across diverse areas like cyber–physical systems, fog computing, renewable energy, machine learning, deep learning, and digital forensics, has demonstrated potential to address some of the most pressing challenges faced by smart cities. Moreover, the transformative capabilities of Industry 5.0 promise to foster a more effective data management and decision-making process, robust cybersecurity measures, and enhanced urban services, all of which are fundamental components of the smart city framework.

The paper underscores the imperative of continuously reevaluating and updating existing smart city frameworks to integrate Industry 5.0 advancements. While technological solutions are a critical piece of the puzzle, the paper also emphasizes the importance of considering ethical, legal, and social implications and the need to ensure inclusive and sustainable development.

Finally, the exploration presented in this paper highlights that the smart city vision of the future is not just about implementing cutting-edge technologies. It is about leveraging these technologies, like those offered by Industry 5.0, to create more sustainable, intelligent, and citizen-centric urban environments.

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